NIST Handbook 160

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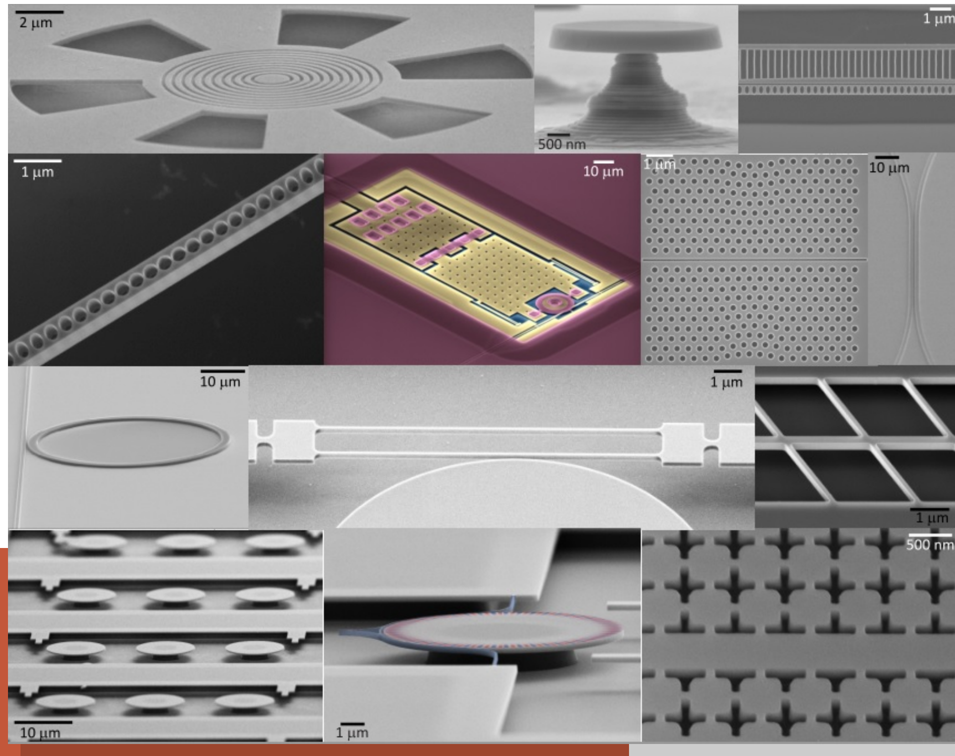
Nanolithography Toolbox

Version 2016.10.01

Email: Nanolithography.Toolbox@nist.gov

CNST
Center for Nanoscale Science & Technology

NIST
National Institute of Standards and Technology



Images from various CNST projects.

Chapter Contents

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Email: Nanolithography.Toolbox@nist.gov

1.1 Overview

Platform independent CNST Nanolithography toolbox for scripted layout generation and complex processing was designed to address aggressively scaled nanoscale device architectures. Within the layout design phase, imprecise representation of curved objects [1–37] at nanoscale dimensions results in increased line-edge roughness. Scattering events from the consequent asperities along device peripheries leads to enhanced dissipative effects. To circumvent these dilemmas, along with standard commercial layout tools, we have developed a custom CAD scripting software package for directly streaming complex shapes to GDSII.

At CNST, we have strong research efforts in nanoscale optics and photonics [38–69]. Consequently, we have developed a library of nanophotonics components (the CNST nanophotonics library contains microrings, S-bends based on Bezier curves, photonic crystals, variety of tapers, grating couplers [70–75] and other complex structures) with precise control of vertex location in the GDSII file. Accurate shape representation is of particular importance to high-resolution lithography, for example, using the either of the two NanoFab 100keV tools with sub-nm grid snapping capability. The flexible scripting interface enables significant user customization to lay out structures outside of the standard available designs. Furthermore, the toolbox is platform independent and will run on any operating system (Linux, Windows and MacOS X) with Java standard edition (SE) 8. In addition to standard Java libraries, the toolbox utilizes the freely available JGDS library for encoding shapes to GDS objects [76].

The CNST nanolithography toolbox also contains primitives (ellipses, torus, rectangles, etc), pillar-hole arrays (rectangular, hexagonal), a variety of spirals, fractals, gratings, verniers, arbitrary function generator (shapes defined by a mathematical function), label makers, text to GDS, postScript to GDS, zone plates, grayscale objects [77–82], images to GDS, polar arrays (also, hexagonal and rectangular), and many more customized shapes. Additionally, we include a MEMS library of elements containing variety of actuators, flexures, clamped beams, and interacting array structures[83–103]. The package also contains CNST-developed reticle generators for various steppers (barcode, label, reticle marks), a CNST ebeam lithography write time estimator, and a ebeam lithography job and schedule file generator with a graphical display of pattern placement (Figure 1.1).

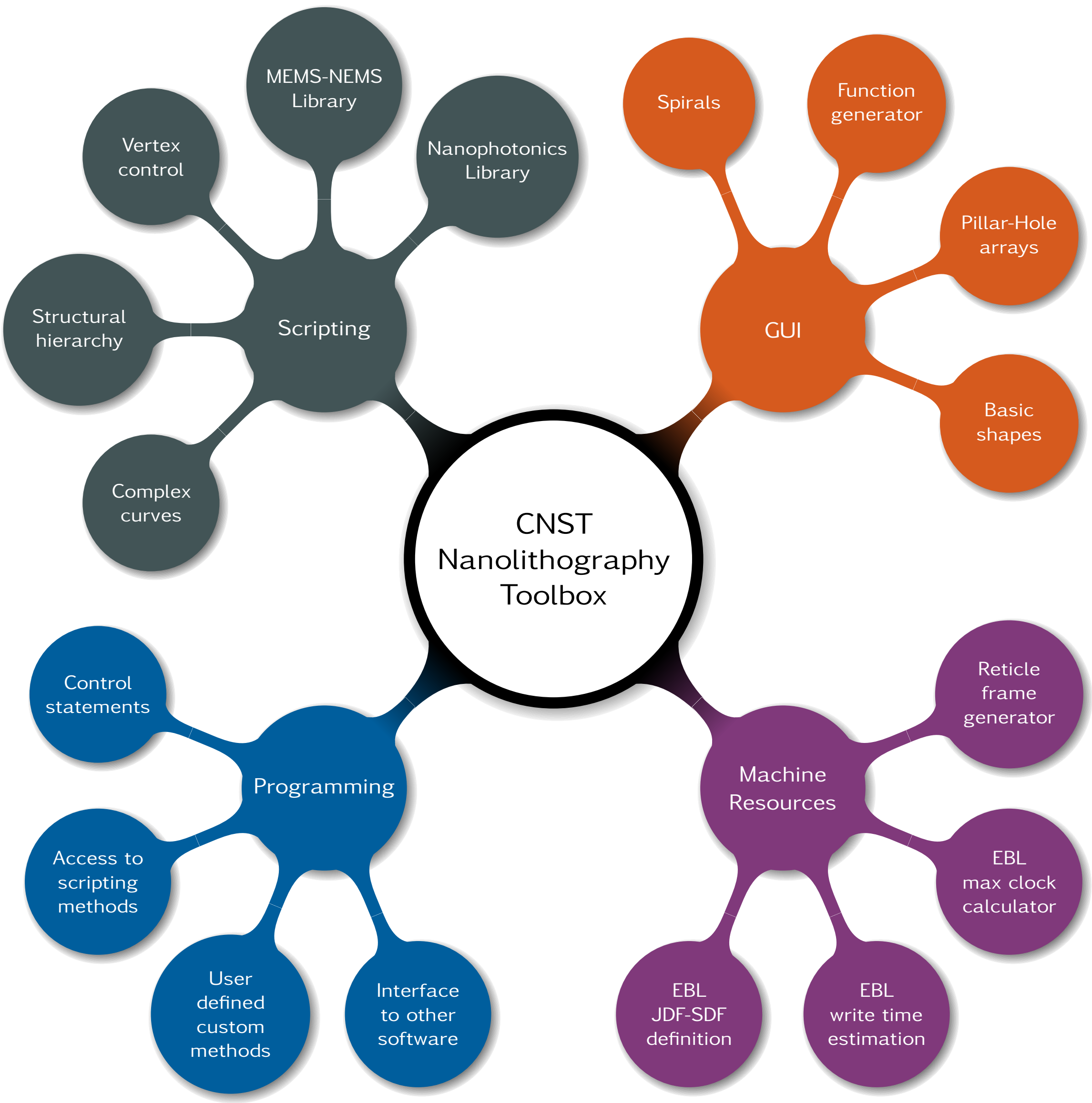


Figure 1.1: *CNST Nanolithography Toolbox chart illustrating a myriad of available complex shapes, objects and functions.*

1.1.1 Terms Of Use

1.1.2 Disclaimer

This manual identifies certain commercial equipment, instruments, and materials to specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the equipment, instruments, and materials identified are necessarily the best available for the purpose.

1.1.3 Acknowledgements

If you developed layouts using the CNST nanolithography toolbox, please acknowledge its use by including the following reference:
The Nanolithography Toolbox, K. C. Balram, D. A. Westly, M. Davanco, K. Grutter, Q. Li, T. Michels, C. H. Ray, L. Yu, R. Kasica, C. B. Wallin, I. Gilbert, B. A. Bryce, G. Simelgor, J. Topolancik, N. Lobontiu , Y. Liu, P. Neuzil, V. Svatos, K. A. Dill, N. A. Bertrand, M. Metzler, G. Lopez, D. A. Czaplewski, L. Ocola, K. Srinivasan, S. Stavis, V. Aksyuk, J. A. Liddle, S. Krylov and B. R. Ilic, J. Res. Natl. Inst. Stand. **121**, pp. 464-475 (2016). http://dx.doi.org/10.6028/jres.121.024

1.1.4 Development Team

Many researchers at NIST, CNST and external collaborators have made substantial contributions to the nanolithography toolbox. The development team most notably consists of Krishna C. Balram (University of Maryland), Daron A. Westly, Marcelo Davanco, Karen Grutter, Qing Li (University of Maryland), Thomas Michels, Christopher H. Ray, Liya Yu, Richard Kasica, Christopher B. Wallin (University of Maryland), Ian Gilbert (University of Maryland), Brian A. Bryce (Harvey Mudd College), Gregory Simelgor (Edico Genome), Juraj Topolancik (Roche Sequencing Solutions), Nicolae Lobontiu (University of Alaska), Yuxiang Liu (Worcester Polytechnic Institute), Pavel Neuzil (Brno University of Technology, KIST-Europe), Vojta Svatos (Brno University of Technology),Kristen A. Dill, Neal A. Bertrand, Meredith Metzler (University of Pennsylvania), Gerald Lopez (University of Pennsylvania), David A. Czaplewski (Argonne National Laboratory), Leonidas Ocola (Argonne National Laboratory), Kartik Srinivasan, Samuel Stavis, Vladimir Aksyuk, J. Alexander Liddle, Slava Krylov (Tel-Aviv University) and B. Robert Ilic.

1.1.5 Future Developments

The CNST nanolithography toolbox is broad in scope and continuously growing within the CNST community. The toolbox is distributed with the hope that it will be useful, but without any warranty, without even an implied warranty for any particular purpose. All efforts have been made to ensure that the CNST nanolithography toolbox is supported on Linux, Windows and MacOS X. Please direct comments, suggestions, encountered bugs to Nanolithography.Toolbox@nist.gov. The software will evolve over time, implementing features as the CNST identifies and prioritizes new applications.

1.1.6 Java 8 Requirements

The graphical user interface (GUI) was constructed using JavaFX components. The code employs a variety of elements contained in latest java standard edition (SE) 8, hence earlier versions will not work correctly. To determine the SE version, at the (windows command or linux/mac terminal) prompt type:

java –version

At the terminal prompt the following would appear:

java version "1.8.0_40"
Java(TM) SE Runtime Environment (build 1.8.0_40-b26)
Java HotSpot(TM) 64-Bit Server VM (build 25.40-b25, mixed mode)

1.8.X_XX indicates Java version 8 is available. To run the CNST NanoLithography Toolbox, either double click on the **CNSTnanoToolboxVXXXX.jar** file (X's represent version numbers) or run from a command prompt in a following manner:

java –jar CNSTnanoToolboxVXXXX.jar

Upon execution of the java code, the CNST Nanolithography Toolbox will appear in a similar fashion as seen in figure 1.2. The menu appearance may vary slightly depending on the operating system the interface is running under. Figure 1.2 shows the toolbox as it appears under 64-bit Windows 7.

1.1.7 Distribution Package

The package contains the following files and directories:

CNSTnanoToolboxVXXXX.jar	The CNST Nanolithography Toolbox executable Java JAR file. X's represent version numbers.
CNSTdefaultValues.xml	Default parameter values for the CNST ebeam tool module, load and save file directories.
Examples	Directory containing syntax coloring XML language definition file, numerous scripting, GUI module and programming examples.

1.1.8 Modes of Operation

1.1.8.1 CNST Scripting

The most powerful feature of the CNST nanolithography toolbox is scripting. Virtually any shape can be constructed using the CNST Scripting features. The scripting feature is listed as the first option within the resource menu. The scripting module reads in an ASCII file with a **.cnst** extension and converts

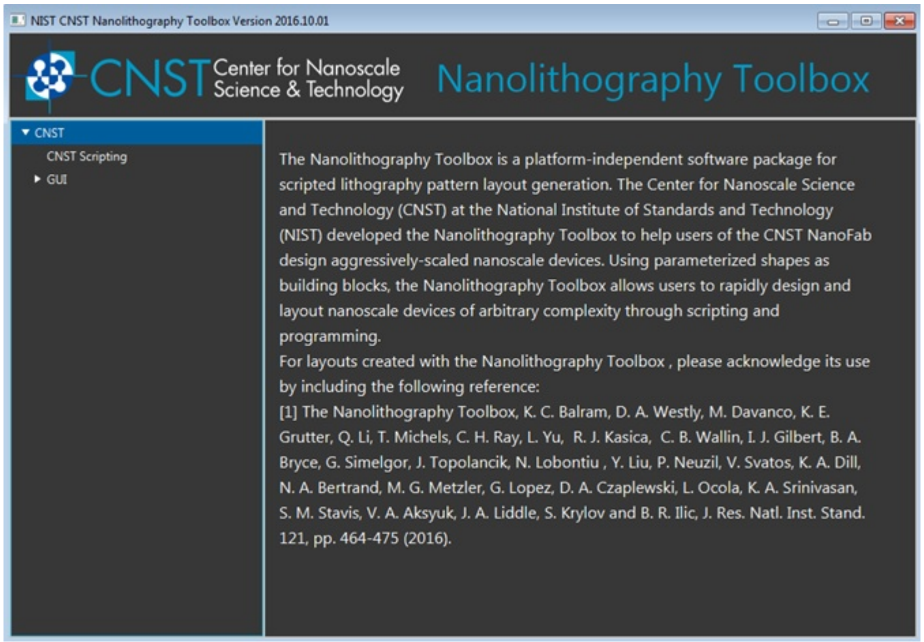


Figure 1.2: *CNST nanolithography toolbox graphical user interface running under Windows 7. Various features are displayed within the left panel in a collapsible tree menu. Highlighting a node of a particular branch will display feature content in the main panel display.*

complex objects directly to GDS. We also provide an extensive library of objects including numerous nanophotonic elements. During the pattern design phase, space is broken up into grid points between which the CNST scripting objects are rendered. Figure 1.3 shows various points connecting a variety of generated nanophotonic elements (exponential taper, photonic crystal waveguide, y-splitters, waveguides, s-bends and rings). Syntax coloring for **.cnst** files is available using NotePad++. This feature improves readability-structure and errors become visually distinct.

CNST scripting offers a myriad of options that are either not found or extremely difficult to implement within standard CAD packages that produce GDS files. The full command reference for CNST scripting is included in section 1.1.8.2. Figure 1.4 illustrates a variety of generated GDS shapes. CNST scripting is either carried out from the GUI or from the terminal command prompt (see section 2.1). Additionally, running batch execution of many **.cnst** files is described in section 2.1.5.

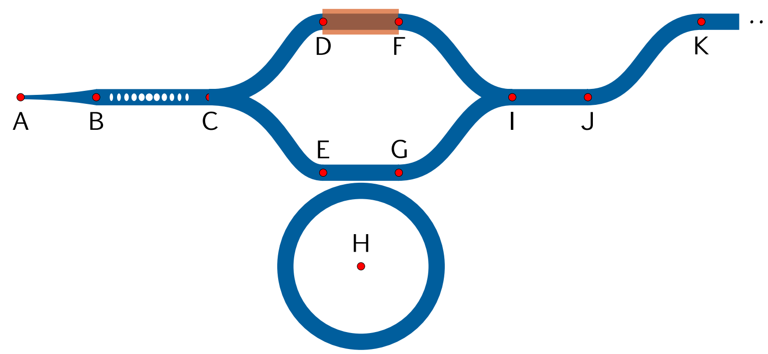


Figure 1.3: *Pattern layout design schematic highlighting various available nanophotonic elements.*

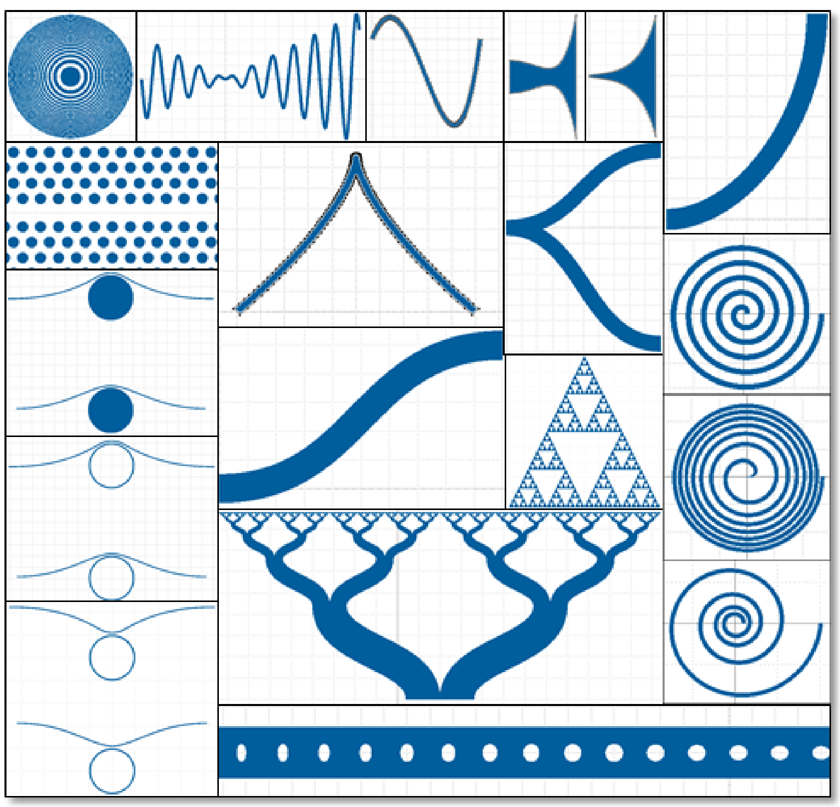


Figure 1.4: *CNST Scripting example illustrating a variety of available shapes streamed directly to GDSII.*

1.1.8.2 Graphical User Interface

The main window of the graphical used interface is divided into three parts. The top title panel has the CNST logo and is static. The left panel contains a collapsible tree with options representing available toolbox features. The large right panel is the dynamic canvas displaying selected module options.

Double clicking on a module feature or single clicking on the triangle directly to the left that node expands the menu options. Consequently, all module elements within that branch node are displayed. For instance, the **Basic Shapes** branch has several objects including polygon-based pillar-hole arrays, arrays of tori, grating couplers, spirals and gratings. Highlighting any of the accessible feature nodes will display available options of the specified module. In case pillar-hole arrays, user defined parameters within a text field such as GDS file name, number of sides (shape vertices), GDS layer, rotation, radius, object array options (position, number of elements and pitch) along with buttons to generate a GDS file with the specified options, an about button, and an Exit button. Figure 1.5 shows a highlighted *Pillar-Hole (Square/Hex) Array* branch node within the left panel. The main panel shows various available module parameters within the toolbox GUI.

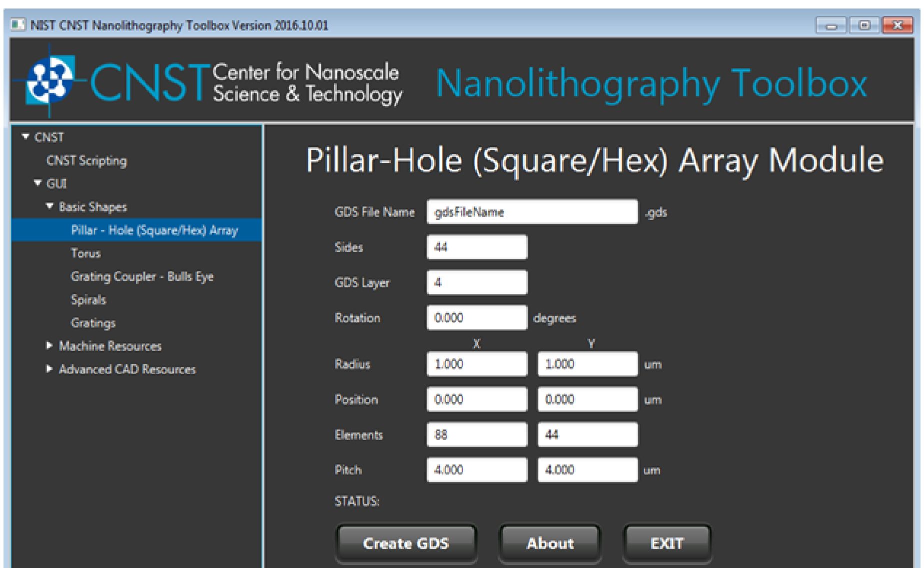


Figure 1.5: *Pillar-hole array module example showing various available options within the main panel of the toolbox GUI.*

Email: Nanolithography.Toolbox@nist.gov

2.1 Setup, Execution and Examples

Scripting execution takes place either from the graphical user interface or the terminal command prompt.

2.1.1 Quick Start Setup

1. Change the <OpenDirectory> and <SaveToDirectory> parameters in the `CNSTdefaultValues.xml` setup file (see section 2.1.2).

2. Setup syntax coloring within NotePad++ (see section 2.1.8).

3. Create script files with extension **.cnst**. See scripting examples in section 2.1.9.6 and constructors in this chapter.

4. Run scripts either within the graphical user interface (section 2.1.3) or via command prompt (section 2.1.4).

2.1.2 Setup - CNSTdefaultValues.xml open and save directories

The CNST NanoLithography ToolBox requires that the `CNSTdefaultValues.xml` setup file resides in the same directory as the Java executable `.jar` file.

The first step in running and executing scripts requires the modification of the open and save directory variables within the `CNSTdefaultValues.xml` file. The toolbox will not function on some operating systems if these values are not properly changed.

Open the `CNSTdefaultValues.xml` file within a text editor and change the <OpenDirectory> and <SaveToDirectory> parameters to a directory where `.cnst` script and GDS files are respectively read and saved. Figures 2.6 and 2.6 illustrate modifications for Windows and Mac/Unix/Linux platforms.

```
<OpenDirectory>C:\Users\user\CNSTnanoToolBox\loadFiles\</OpenDirectory>
<SaveToDirectory>C:\Users\user\CNSTnanoToolBox\saveFiles\</SaveToDirectory>
```

(a)

```
<OpenDirectory>/Users/user/CNSTnanoToolBox/loadFiles/</OpenDirectory>
<SaveToDirectory>/Users/user/CNSTnanoToolBox/saveFiles/</SaveToDirectory>
```

(b)

Figure 2.6: *Modification to open and save directory variables within the `CNSTdefaultValues.xml` setup file for (a) Windows and (b) Mac/Unix/Linux platforms.*

2.1.3 Graphical User Interface Execution

Start the graphical user interface by either double clicking on the executable `jar` file or at the prompt type:

java –jar CNSTnanoToolboxVXXXX.jar

When the interface appears, in the left panel click `CNST Scripting` (step 1) and then click the `Load Script` button (step 2). Within the file manager locate the `.cnst` script file (step 3), click `Open` (step 4) and the full path of the script file will appear in the `Script File:` label. Type in the desired GDS file name and click the `Create GDS` button. Under the `STATUS:` label, the full path of the saved GDS file will appear.

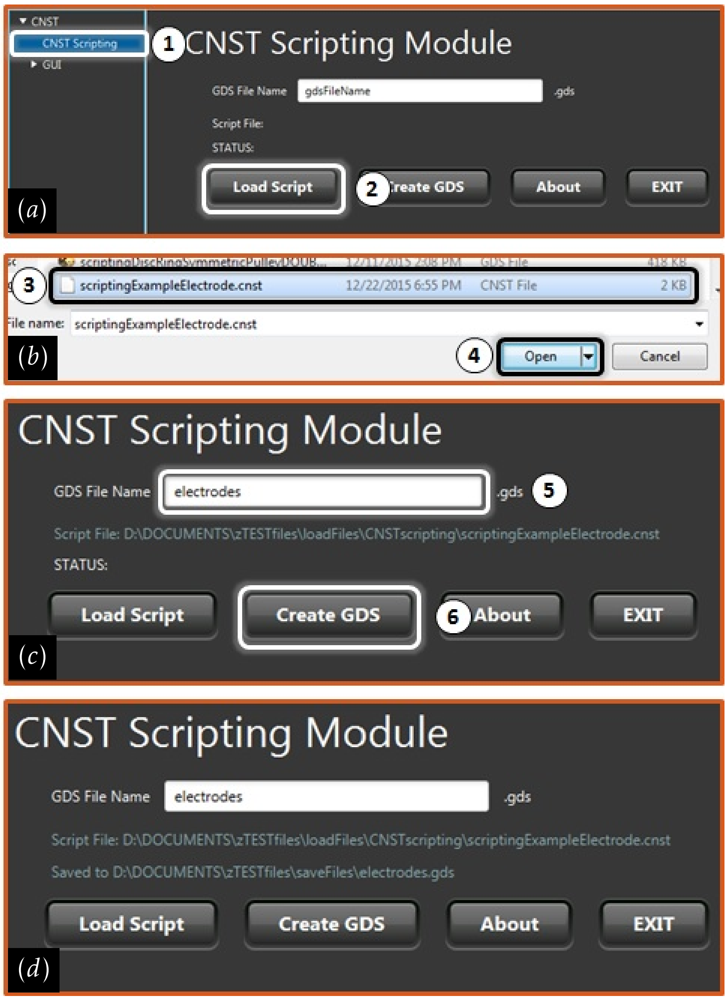


Figure 2.7: *GDS generation using the graphical scripting interface.*

2.1.4 Running CNST Scripts From a Terminal Command Prompt

At the terminal command prompt, the command below allows script execution without the graphical user interface. Additionally, using the **getfonts** option allows the extraction of all available system font names to be stored into atime/date stamped ASCII file.

java –jar CNSTnanoToolboxVXXXX.jar **[option]**

[option]

cnstscripting inputFileName.cnst outputFileName.gds

Process a CNST scripting file **inputFileName.cnst** and cast the resulting structures into an **outputFileName.gds** file.

getfonts

Obtain system fonts and store them into a time/date stamped file. Useful for correctly spelling font names within various available text constructors.

2.1.5 Running Multiple CNST Scripts - Batch File Mode

Batch mode execution of many CNST script files is performed from a terminal command prompt. In Windows, to open the command prompt, click `Start` then type `cmd` within the 'search programs and files'. Within the Linux and Mac environments open a terminal command prompt. First create a text file where each line entry has the format defined within the previous section (2.1.4). In Windows, name the file with an extension BAT, i.e. `CNSTbatchFile.BAT`. For instance, the text file would have the following entries:

```
java –jar CNSTnanoToolboxVXXXX.jar cnstscripting scriptFile01.cnst output01.gds
java –jar CNSTnanoToolboxVXXXX.jar cnstscripting scriptFile02.cnst output02.gds
                              ⋮
java –jar CNSTnanoToolboxVXXXX.jar cnstscripting scriptFileN.cnst outputN.gds
```

To execute the ASCII batch file, at the windows DOS prompt type the file name:

```
C:\Users\robilic\CNSTscripting>CNSTbatchFile.BAT
```

In Linux or Mac type dot then backslash followed by the filename:

```
robilic\CNSTscripting $>.\CNSTbatchFile.BAT
```

2.1.6 Running CNST Scripts Within Matlab

Matlab allows for execution of system commands and return outputs. Figure 2.1.6 shows how matlab generates a matlabScript.cnst file. Subsequently, using a system command, matlab runs `java` to create a GDS file. This was accomplished by using commands described in section 2.1.4. Lastly, another system command executes kLayout, an open source layout viewer and editor, in order to display the output GDS file. The generated file has two GDS structures. The first has a single ellipse, and the second has 100 ellipses, each cast into a different GDS layer, along a diagonal. The latter was generated using the `for` loop control statement.

The return status shows the command prompt output during code execution. In this case, the directory where the output GDS resides (see save directory information in section 2.1.2).

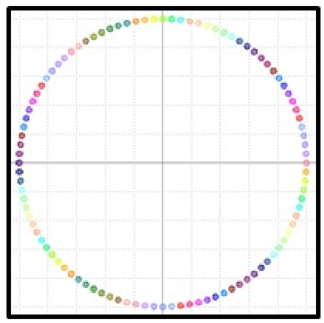
```
fileID = fopen('matlabScript.cnst','w');
fprintf(fileID,'0.001 gdsReso\n');
fprintf(fileID,'0.001 shapeReso\n\n');
fprintf(fileID,'# Creating a simple ellipse with Matlab\n');
fprintf(fileID,'<matlabEllipse struct>\n');
fprintf(fileID,'11 layer\n');
fprintf(fileID,'0 0 2 4 44 0 ellipse\n\n');
% array of 100 ellipses along a diagonal with different GDS layers
fprintf(fileID,'# Creating array of 100 ellipses along the diagonal\n');
fprintf(fileID,'<matlabEllipseArray struct>\n');
for i=1:100
    fprintf(fileID,'%s%s\n', int2str(i),' layer');
    fprintf(fileID,'%s%s%s%s\n', int2str(i), ' ', int2str(i),'  0.4 4 44 0 ellipse');
end
fclose(fileID);

% run the java code from matlab
[status,cmdout] = dos('java -jar CNSTnanoToolbox.jar cnstscripting matlabScript.cnst↙
matlabGDSoutput.gds');
status, cmdout

% open GDS with klayout - use quotes around directory names with spaces
[status,cmdout] = dos('"C:\Program Files\KLayout (64bit)\klayout" D:↙
\DOCUMENTS\zTESTfiles\saveFiles\matlabGDSoutput.gds');
status, cmdout
```

Figure 2.8: *GDS generation and viewing using a Matlab script.*

Example matlab files are located in `\EXAMPLES\CNSTscripting\Matlab`.

2.1.7 Python Script Generation

Python programming can be used to create complex CNST scripting files. Programming in general allows for variable initialization, loops, Booleans, branching, control statements, conditionals and other methods to be used when algorithmically constructing script files. The program shown in figure 2.9creates a `pythonScript.cnst` script file that contains two GDS structures, one with a single ellipse, and another with an array of circles along a circular path in another GDS structure. The latter is accomplished within a for loop repetition statement. Subsequently the nanolithography toolbox is used to create an output GDS file seen as an inset in figure 2.9. Example python files are located in `\EXAMPLES\CNSTscripting\Python`.



```
# -*- coding: utf-8 -*-
"""
Created on Wed Jan 20 21:21:47 2016

@author: rob
"""

import math

f = open('pythonScript.cnst', 'w')
f.write(str('0.001 gdsReso\n'))
f.write(str('0.001 shapeReso\n\n'))

f.write(str('# Creating a simple ellipse with Python'))

f.write(str('<pythonEllipse struct>\n'))
f.write(str('11 layer\n'))
f.write(str('0 0 2 4 44 0 ellipse\n\n'))

f.write(str('# 100 circles along a circular path\n'))
f.write(str('<pythonCirclesAlongPath struct>\n'))

radius = 10
num = 100
increment = 2*math.pi/num
for x in xrange(num):
    f.write(str('%d layer\n' %(x+1)))
    xCoord = radius * math.cos(x*increment)
    yCoord = radius * math.sin(x*increment)
    f.write(str('%.4f %.4f 0.2 0.2 44 0 ellipse\n'%(xCoord,yCoord)))
f.close
```

Figure 2.9: *Python programming example used to generate an array of 100 circles, each within a distint GDS layer, along a circular path. Inset shows the rendered GDS output of circles along a circular path.*

2.1.8 NotePad++ Syntax Coloring

The package provides a language definition XML file for Notepad++. The constructor keywords listed within the XML file could be used to create a language definition file for any text editor. Syntax coloring within NotePad++ is accomplished by reading in the provided **CNSTscripting.xml** language definition file. Subsequently, all files with extension **.cnst** will have proper syntax coloring (Figure 2.10). This is useful when visualizing and debugging scripts. The following is a procedure for NotePad++ syntax coloring:

1. Language -> Define your language.... -> click Import....

2. choose \EXAMPLES\CNSTscripting\NotePad++XML\CNSTscripting.xml language definition file and click open

3. close NotePad++ and reopen a file with extension .cnst

4. Some versions may require users to repeat this procedure

```
<postScript1 struct>
1 layer
40.801 202.615 m 62.605 218.252 82.602 238.932 98.328 262.112 c 109.402
 278.424 120.648 299.865 126.66 316.112 c 131.602 329.459 132.156 329.065
 119.484 321.201 c 88.063 301.713 81.117 296.862 71.086 287.424 c 57.43
274.576 48.113 259.424 41.59 239.428 c 37.141 225.803 31.551 197.69 33.297
 197.725 c 33.684 197.733 37.059 199.932 40.801 202.615 c h

<postScript2 struct>
2 layer
300.0 600.0 moveto
300.0 655.2284749830793 277.61423749153965 700.0 250.0 700.0 curveto
222.38576250846035 700.0 200.0 655.2284749830793 200.0 600.0 curveto
200.0 544.7715250169207 222.38576250846035 500.0 250.0 500.0 curveto
277.61423749153965 500.0 300.0 544.7715250169207 300.0 600.0 curveto
closepath

<verniersTest struct>
# Verniers between Layer 1 and Layer 4
<0 0 1 4 0.01 11 Lyr1 Layer4 10 1 50 4 verniers>

# constructing polar array
<polarArrayV1rotated  struct>
<myPattern  340.0 220.0 30.0 100.0 250.0 50.0 1R arrayPolar>
```

Figure 2.10: *Notepad++ screenshot illustrating syntax coloring of* ***.cnst*** *script files defined by the* ***CNSTscripting.xml*** *language definition file.*

2.1.9 Scripting Examples

2.1.9.1 Basic Scripting Example

Figure 2.11 shows a simple script that creates two structures, one with a rectangle and the other with two ellipses. The procedure for creating script files is the following:

1. gdsReso defines the output rendering resolution (in μm) of the GDS file. This parameter is included at the top of each file.

2. shapeReso defines the rendering resolution (in μm) of vectorized shapes. This parameter can be placed anywhere in the file and can be changed for each vectorized shape.

3. Create structures.

4. Initialize layers and dataTypes, then place objects into structures. The following subsections introduce a variety of constructors for creating complex shapes.

```
0.001 gdsReso
0.001 shapeReso

# create a GDS structure/cell to store shapes
<simpleRectangles struct>

# set GDS layer
4 layer

# create a rectangle
-5 20 0 28 0 rectangle


# create another structure
<circlesAndEllipses struct>

# create an ellipse
0 0 40 100 88 22.0 ellipse

# create ellipse in GDS layer 40 with a datatype 44
40 layer
44 dataType
100 80 40 40 44 0 ellipse
```

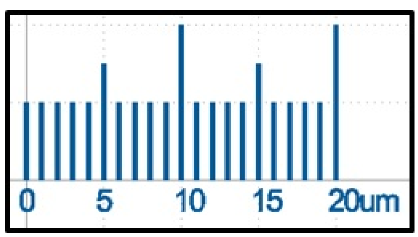
Figure 2.11: *Basic scripting example (scriptingExampleBasicScriptingExample.cnst).*

2.1.9.2 Scripting Example - Labeled Calibration Ruler

The example script creates a labeled calibration ruler. Tick marks are 250 nm wide and 5μm long. Markers labeled 5 and 10 markers are 7.5μm and 10μm long. This type structure is useful for calibrating (optical and electron) microscopes.

```
0.001 gdsReso
0.001 shapeReso
4 layer
# Example - Labelled Calibration Ruler

#### tick marks 5um long and 250nm wide
<tickMark struct>
-0.125 0 0.125 5 0 rectangle
#### tick mark extension 2.5um long and 250nm wide
<tickMarkExtension struct>
-0.125 0 0.125 2.5 0 rectangle

<calibrationRuler struct>
# 20um long
<tickMark 0 0 21 1 1 0 1 arrayRect>
# add tick mark extensions every 5um
<tickMarkExtension 5 5 4 1 5 0 1 arrayRect>
# add tick mark extensions every 10um
<tickMarkExtension 10 7.5 2 1 10 0 1 arrayRect>

# tick mark label (TAB delimited)
{0	5	10	15	20um	1	5	Arial	2	-0.5	-2	0	0	5	1	rowCol	labelMaker}
```

(*a*)



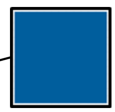
(*b*)

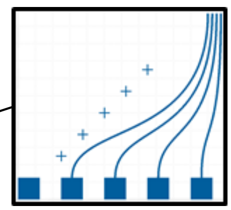
Figure 2.12: *Labeled calibration ruler example. (a) Example script (`scriptingExampleLabeledCalibrationRuler.cnst`) illustrates the construction of (b) a labeled calibration ruler.*

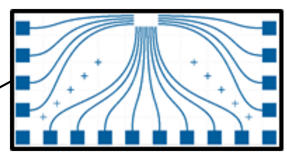
2.1.9.3 Labeled Electrodes

The script initiates with a 250μm bond pad. The structure is then instantiated into a 5×1 rectangular array, Bezier curves and alignment crosses are then added. This structure (`electrodeSegment`) is then instantiated to construct the `electrodeHalf`, which is then used to form the `electrodes` structure. Bond pad labels are then added and `electrodes` structure is instantiated into `top` using the instanceSym constructor, ensuring symmetric extents around the origin.

```
0.001 gdsReso
0.01 shapeReso

# 250um bondpad
<bondPad250um struct>
0 0 250 250 0 rectangle

# 1/8 electrode
<electrodeSegment struct>
<bondPad250um 0 0 5 1 500 1 1 arrayRect>
<625 250 625 900 2200 625 2200 2150 20 0 bezierCurve>
<1125 250 1125 900 2250 625 2250 2150 20 0 bezierCurve>
<1625 250 1625 900 2300 625 2300 2150 20 0 bezierCurve>
<2125 250 2125 900 2350 625 2350 2150 20 0 bezierCurve>
# JEOL alignment crosses
500 500 10  60 0 cross
750 750 10  60 0 cross
1000 1000 10    60 0 cross
1250 1250 10    60 0 cross
1500 1500 10    60 0 cross

#1/2 electrode
<electrodeHalf struct>
<electrodeSegment 0 0 N 1 0 instance>
<electrodeSegment 4750 0 Y 1 0 instance>
<electrodeSegment 0 0 Y 1 -90 instance>
<electrodeSegment 4750 0 N 1 90 instance>

# electrode set
<electrodes struct>
<electrodeHalf 0 0 N 1 0 instance>
<electrodeHalf 0 4750 X 1 0 instance>
# electrode labels top and bottom - Letters
{0  8   Serif   100 410 75   0    0    500 0    autoOutLett labelMaker}
{0  8   Serif   100 410 4575    0    0    500 0    autoOutLett labelMaker}
# electrode labels left and right - Numbers
{8  0   Serif   100 0    0    100 4275    0    500 autoOutLett labelMaker}
{8  0   Serif   100 0    0    4600    4275    0    500 autoOutLett labelMaker}

# top cell centered electrode cell using instanceSym
<top struct>
<electrodes 0 0 0 0 4750 4750 N 1 0 instanceSym>
```







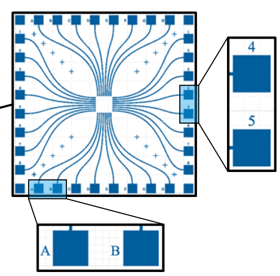


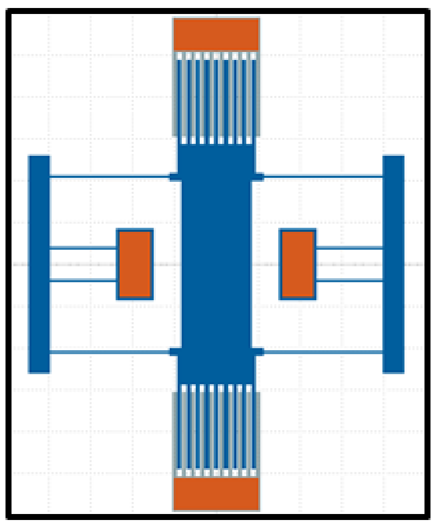
Figure 2.13: *Scripting example (`scriptingExampleElectrode.cnst`) illustrates the construction of electrodes with labels and 5 levels of alignment crosses.*

2.1.9.4 MEMS Comb Drive Flexures

The example script below first creates a microelectromechanical systems (MEMS) flexure with two anchored pads using the flexure2E constructor. Subsequently, two linear comb drive structures are connected to the flexure element.

```
0.001 gdsReso
0.001 shapeReso
4 layer

# Example - MEMS Flexure With Comb Drive Elements

<memsExample struct>
# Flexure
0 0 8.2 0.2 0.88 0.22 2.44 20 8 1.44 2.42 3.4 0.2 8.44 4.4 0.4 7 0 flexure2E
# Top Comb
-5.15 29.48 0.4 3.4 10.1 9.1 10 1.1 4.1 31 0.2 7 0 combDriveV1
# Bottom Comb
5.15 -29.48 0.4 3.4 10.1 9.1 10 1.1 4.1 31 0.2 7 180 combDriveV1
```

(a)



(b)

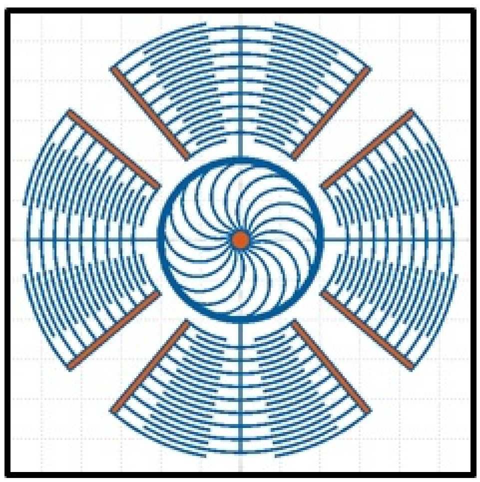
Figure 2.14: *MEMS linear comb drive actuating flexure example. (a) Example script (`scriptingExampleMEMSv1.cnst`) illustrates the construction of (b) comb drive elements connected to a movable flexure.*

2.1.9.5 MEMS Radial Comb Drive Circular Hub

The example script below first creates four radial comb structures connected to a circular hub.

```
0.001 gdsReso
0.001 shapeReso
4 layer

# Example - MEMS Flexure With Comb Drive Elements

<circularSpringExample struct>
# circular spring
0 0 1 4 3.4 40 128 18 0.2 7 0 circularSpring
# radial combs
10 0 4 40 1 30 1.1 2.2 10 32 40 20 1 7 0 combRadialV2
0 10 4 40 1 30 1.1 2.2 10 32 40 20 1 7 90 combRadialV2
-10 0 4 40 1 30 1.1 2.2 10 32 40 20 1 7 180 combRadialV2
0 -10 4 40 1 30 1.1 2.2 10 32 40 20 1 7 270 combRadialV2
```

(*a*)



(*b*)

Figure 2.15: *MEMS radial comb drive actuator example. (a) Example script (`scriptingExampleMEMSv2.cnst`) used to create (b) four radial comb drive elements connected to a circular hub.*

2.1.9.6 Scripting Example Files Description

CNST scripting offers a variety of constructor objects that allow for any conceivable shape to be rendered into a GDS output. This chapter includes a number of CNST scripting examples designed to elaborate on the functionality of these objects. Overall, the example collection covers each CNST scripting constructor. To improve the readability of the script, we included brief constructor documentation comments in each of the presented examples. The example scripts (`.cnst` files) and the corresponding GDS output files are contained in a folder `\loadFiles\CNSTscripting`. The folder also contains an Excel spreadsheet `CNSTscripting.xlsx` with data used in several presented examples. A brief description of each example script file is given below.

`scriptingAlignmentFeatures.cnst` contains examples of variety of multi-level preconfigured and custom user defined alignment mark strategies, verniers, and arrows. Details of these features are described in section 2.8.

`scriptingArraysAndInstancing.cnst` creates a structure with the name `myPattern` constructed from various primitive elements, including text and spiral objects. The structure is then instantiated at a 10X reduced magnification. Furthermore, the structure is arranged into rectangular, polar and hexagonal arrays.

`scriptingBasicShapes.cnst` is a simple script demonstrating the use of primitive shapes. First, we introduce line comments. Then, resolution features of the GDS rendered output and vectorized shapes is explained. Next, we present constructors for creating GDS structures (cells) and layers. Directly following, ellipses, vectorized ellipses, tori (arcs), rectangles, rounded rectangles, polygons, star shapes, and crosses are constructed within initialized GDS structures and layers.

`scriptingBezierCurve.cnst` illustrates the use of the Bezier curve constructor.

`scriptingBooleansGenAreasBiasTransformations.cnst` is an example demonstrating extraction of layer shapes from a GDS structure and casting the resulting shapes into a generalized area object. Using these objects boolean operations, general area copies, shape biasing and affine transformation of the areas is demonstrated.

`scriptingCNSTasmlContactLabelBarcodeGenerator.cnst` demonstrates the use of various constructors used to generate contact lithography (label and logo) and CNST ASML PAS5500 i-line stepper reticles (reticle marks, label, barcode and logo).

`scriptingCircleTorusWave.cnst` example demonstrates circular (section 2.3.3) and torus (section 2.3.16) structures with sinusoidally varying boundaries.

scriptingCustomTaper.cnst example employs data from the CNSTscripting.xlsx file (CustomTaper sheet) to create a taper defined by the (x, y) point pairs. Data was simply copied and pasted into the cnst script file, then terminated by T_x T_y $\theta_{(T_x,T_y)}$ **customTaper**.

scriptingDiscRingPulleysBezier.cnst(Bezier - angle defined coupling), scriptingDiscRingPulleysBezierLC.cnst (Bezier - coupling length defined) and scriptingDiscRingPulleysArc.cnst (Arcs - both angle and coupling length defined) show various examples of the disc pulley system described in sections 2.9.9.2 to 2.9.9.16.

scriptingDiscRingSymmetricPulleyDOUBLE1.cnst, scriptingDiscRingSymmetricPulleyDOUBLE2.cnst ,scriptingDiscRingSymmetricPulleyDOUBLE3.cnst and scriptingDiscRingSymmetricPulleyDOUBLE4.cnst show various examples of the ring-disc systems with two coupling regions described in sections 2.9.9.2 to 2.9.9.16.

scriptingExampleBasicScriptingExample.cnst is an example of a basic script shown in section 2.1.9.1.

scriptingExampleElectrode.cnst is an example script of labeled electrodes with alignment crosses as shown in section 2.1.9.3.

scriptingExampleLabeledCalibrationRuler.cnst example script creates the labeled calibration ruler in section 2.1.9.2.

scriptingExampleMEMSv1.cnst script creates a MEMS flexure with two linear comb drive elements. Details of this scripts are included in section 2.1.9.4.

scriptingExampleMEMSv2.cnst script creates four MEMS radial comb drives connected to a circular hub as described in section 2.1.9.5.

scriptingFractals.cnst shows the use of various fractal constructors defined in section 2.7.3.

scriptingFunctionPlot.cnst shows several functional plotting examples using constructors defined in section 2.7.4.

scriptingGratingsAndGratingCoupler.cnst is an example using constructors from sections 2.9.7.1 and 2.9.7.3.

scriptingGrayscale.cnst is an example using a variety of grayscale constructors from section 2.7.5.

scriptingInstanceExamples.cnst are a collection of examples using the **instance** constructor section 2.4.4.

scriptingLabelMaker.cnst was used to create the GDS rendered output in Figure 2.45.

scriptingLabelOutline.cnst illustrates the use of constructors from section 2.6.4. Here, text outlines are used to generate chip labels.

`scriptingLogos.cnst` example shows the use of the three logo constructors from section 2.6.6.

`scriptingMeanderChannels.cnst` illustrates various meandering channels with end reservoirs using constructors from section 2.7.8.

`scriptingMEMSactuators.cnst` shows various examples of MEMS actuators as described in section 2.10.1.

`scriptingMEMSarraysFLAT.cnst` and `scriptingMEMSarraysHIERARCHY.cnst` shows interacting MEMS arrays as described in section 2.10.7.

`scriptingMEMScantilevers.cnst` shows various examples of cantilevers of varying length extending from a base as described in section 2.10.5.

`scriptingMEMSdoublyClampedBeams.cnst` shows various examples of doubly clamped beams of varying length extending from a base as described in section 2.10.6.

`scriptingMEMSflexures.cnst` shows various MEMS accelerometer type anchored flexures with a proof mass as described in section 2.10.4.

`scriptingMEMSstressStrainMeasurementStructures.cnst` shows various MEMS stress-strain measurement devices including Guckel Rings (see section 2.10.8).

`scriptingMISCobjects.cnst` shows a variety of miscellaneous objects (interdigitated electrodes) found in section 2.7.

`scriptingMultiFile1.cnst`, `scriptingMultiFile2.cnst`, `scriptingMultiFile4.cnst` and `scriptingMultiFile8.cnst` are files used to generate `scriptingMultiFile.gds`. This is an example that calls multiple script files to generate a GDS output as seen in section 2.2.8.

`scriptingPhotonicCrystalsHexArrays.cnst` example demonstrates the use of photonic crystals defined in section 2.9.8.

`scriptingPhotonicsCoupledWaveguideDiscTip.cnst` example demonstrates the use of various coupled architectures of waveguides, discs and tips, as defined in section 2.9.15.

`scriptingPhotonicsCouplersBendsMisc.cnst` example demonstrates the use of various waveguides, slot waveguides and couplers defined in sections 2.9.1.1 to 2.9.3.15.

`scriptingPhotonicsGratingCouplersWithWaveguides.cnst` example highlights grating couplers with integrated waveguides as defined in section 2.9.7.4.

`scriptingPillarHoleHexagonalSquareArrays.cnst` example demonstrates the use of pillar-hole hexagonal and square arrays defined in section 2.4.6.

`scriptingPoints2Instance.cnst` is a script demonstrating structure instantiation at user defined (x, y) point pairs. In this case a structure `test` is created and instantiated along a spiral path. Coordinates for the path were calculated using Excel and presented in the supplementary `CNSTscripting.xlsx` file (SpiralArray sheet).

`scriptingPoints2Instance.cnst` script renders two user defined shapes. Both shapes are defined within the supplementary `CNSTscripting.xlsx` file (CustomTaper and Gaussian sheets).

`scriptingPolyPath.cnst` script creates two distinct paths along user defined (x, y) point pairs. Here, the two paths are defined within the supplementary `CNSTscripting.xlsx` file (CustomTaper and Gaussian sheets).

`scriptingPostScript.cnst` demonstrates postScript file conversion to a GDS rendered shape. Postscript statements were extracted from the supplementary file `scriptingPostScript.eps` using Figure 2.47 guidelines.

`scriptingRaceTrack.cnst` was used to create the GDS rendered output in Figure 2.131.

`scriptingSpiralDelayLines.cnst` describes the usage of spiral delay line constructors (section 2.9.5). The example illustrates the S_T (number of skipped turns) parameter from the **spiralDelayLineArchV2** constructor. In the example, S_T varies from 0 to 8 while all other parameters remain constant.

`scriptingSpiralDelayLinesInverse.cnst` similar to the previous example, except the spirals form a slot waveguide of width W defined by the exposure sleeve W_e. Example describes the inverse spiral delay line constructors (Archimedes and Fermat as defined in section 2.9.6) and illustrates the S_T (number of skipped turns) parameter from the **spiralDelayLineArchV2Inv** constructor. In the example, S_T varies from 0 to 4 while all other parameters remain constant.

`scriptingSpirals.cnst` demonstrates production of Archimedes, Fermat and Logarithmic spirals as defined in section 2.7.14.

`scriptingText.cnst` demonstrates the use of **textgds** constructor for creating text objects within GDS files.

`scriptingTextOutline.cnst` example shows the use of the **textOutline** constructor. As shown in figure 2.44, the rendered fonts are defined by a shape outline of a user-specified width (**fontOutline**). This feature is useful when labeling devices defined by write-time-limited, electron beam lithography systems.

`scriptingVerniers.cnst` illustrates the use of verniers between two lithographic levels.

`scriptingWaveGuidePhCs.cnst` example demonstrates the use of various photonic-crystal based waveguides defined in sections 2.9.10 to 2.9.14.

2.2 Interface Functions

2.2.1 Comments

Line comments begins with #. Comments begin with a new line. Comments cannot be appended within or at the end of a scripting command line.

2.2.2 Creating Structures (Cells)

The method creates a GDS structure (cell). Subsequent elements will be placed into the defined cell. If the cell already exists, then elements will be added to the existing structure. Structure names may be up to 32 characters long. Allowed structure character names are $A-Z$, $a-z$, $0-9$, underscore (_), question mark (?) and dollar sign ($).

$<structureName$ **struct>**

2.2.3 Layer

The method defines a GDS layer for subsequent shapes. Allowed GDS layer numbers range from $0-255$. Any value outside this range will automatically be set to GDS layer 0.

$layerNumber$ **layer**

2.2.4 Data Type

The method defines a GDS data-type for each layer. Allowed GDS data-type numbers range from $0-255$. Any value outside this range will automatically be set to GDS data-type 0.

$dataTypeNumber$ **dataType**

2.2.5 GDS Rendering Resolution

The method sets the snapping grid of the final GDS output. Default global value is 0.001μm. Parameter $gdsResolution$ is specified in units of micrometers.

$gdsResolution$ **gdsReso**

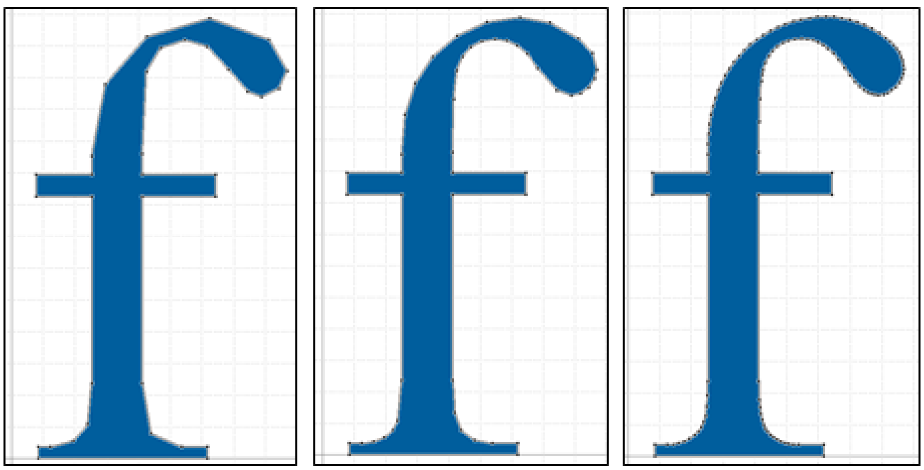
0.001 **gdsReso** defines a 0.001μm rendering resolution.

2.2.6 Shape Resolution

The method sets the rendering resolution resolution for subsequent shapes (primarily vector defined shapes, S-Bends, Y-Bends, postscript file conversions, Text elements, etc). Default global value is 0.001μm. This value could be changed for each shape, providing flexibility on the number of points used to define a particular GDS shape. Parameter $shapeResolution$ is specified in units of micrometers.

$shapeResolution$ **shapeReso**

0.001 **shapeReso** defines a 0.001μm rendering resolution.



(a) (b) (c)

Figure 2.16: *shapeReso example illustrating rendering a text object at (a) $1\mu m$ (b) $0.1\mu m$ and (c) $0.01\mu m$.*

2.2.7 Font Outline Width

The method sets the font outline width (in micrometers). This is used for outline text and label objects (see sections 2.44 and 2.6.4). Default global value is 0.1μm. This value could be changed for each outlined object

$fontOutlineWidth$ **fontOutline**

0.400 **fontOutline** defines a 0.400μm font outline width.

2.2.8 Calls To Multiple CNST Script Files

The **fileName** constructor allows script files to call other CNST script files. The called script contents (from file `cnstScriptFileName`) will be executed until the end of file is reached, then the execution process jumps back to the original script and continues to process shapes. Overall, this method allows users to break up the process flow over many script files.

<cnstScriptFileName **fileName>**

Script files residing in folders within the root directory can be called in the following manner:

Windows:

<dirName\cnstScriptFileName **fileName>**

Mac/Unix/Linux:

<dirName/cnstScriptFileName **fileName>**

NOTE: Directories and file names can not contain white characters such as spaces or tabs. This method assumes that `cnstScriptFileName` has the extension `.cnst`, i.e. `cnstScriptFileName.cnst`, hence `.cnst` must be omitted in the file label `cnstScriptFileName`. The root directory is defined by the <OpenDirectory> field within the `CNSTdefaultValues.xml` setup file. Also, backslash (Windows) and forward slash (MacOSX, Linux) characters are omitted prior to the first directory statement (`dirName`).

2.2.9 Log File Time Date Stamp

At the end of each GDS export a log file, containing a variety of information, including error messages, is created. The log filename assumes the name of the CNST script, with `.log` extension. During subsequent executions of a distinct script file, the log file will be overwritten. The constructor **logFileTimeDate** creates log files with filenames containing additional time and date information, hence each script execution will create a new log file.

2.3 Shapes

2.3.1 Circles and Ellipses

2.3.1.1 Primitive Ellipse

Elliptical shape is centered at (x, y), defined by two radii (r_x and r_y), the number of sides (N_{sides}) and rotated about the center at an angle $\theta_{(x,y)}$ expressed in degrees. In this scenario, the shape defining vertices are evenly distributed at angular increments of $2\pi/N_{sides}$.

x y r_x r_y N_{sides} $\theta_{(x,y)}$ **ellipse**

2.3.1.2 Vectorized Ellipse

Elliptical shape is constructed from Bezier curves, centered at (x, y), defined by two radii (r_x and r_y), and rotated about the center at an angle $\theta_{(x,y)}$ expressed in degrees. Rendering resolution of the vectorized shape (number of shape vertices) is controlled using the **shapeReso** parameter (see section 2.2.6). Unlike the primitive ellipse example where shape vertices are evenly distributed, since the vectorized form is constructed using Bezier curves, vertices are not regularly spaced. More vertices are allocated to regions of higher curvature.

x y r_x r_y $\theta_{(x,y)}$ **ellipseVector**

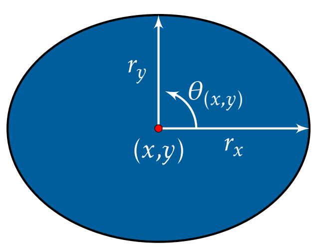


Figure 2.17: *ellipse* and *ellipseVector* constructor parameters.

2.3.2 Circle through three points

The resulting shape is defined by the the three points and the number of sides (N_{sides}).

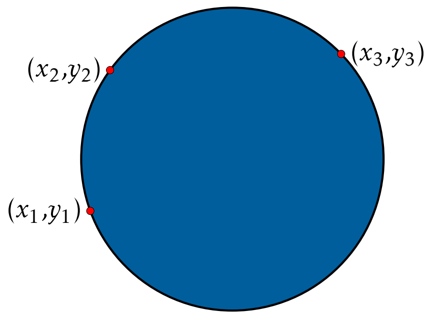


Figure 2.18: *circlethree parameters.*

x_1 y_1 x_2 y_2 x_3 y_3 N_{sides} **circlethree**

2.3.3 Circle With a Wave Boundary

Circular structure of radius r with a sinusoidal boundary centered at (x, y). A represents the sine wave amplitude, n is an integer number of oscillations along the boundary extending from 0 to 2π, N_s is the number of sides used to construct the boundary, and $\theta_{(x,y)}$ is the rotation about the center point.

$x \quad y \quad r \quad n \quad A \quad N_s \quad \theta_{(x,y)}$ **circleWave**

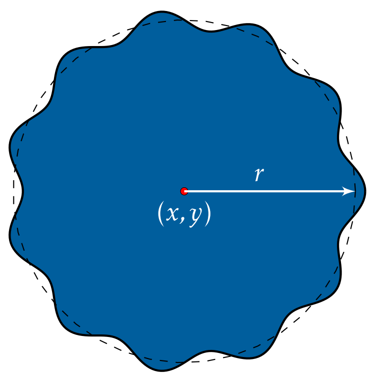


Figure 2.19: *Circle with a sinusoidal boundary variation.*

2.3.4 Cross

Cross is defined by the center (x, y), width (W), length (L) and rotation about the center at an angle $\theta_{(x,y)}$ expressed in degrees.

x y W L $\theta_{(x,y)}$ **cross**

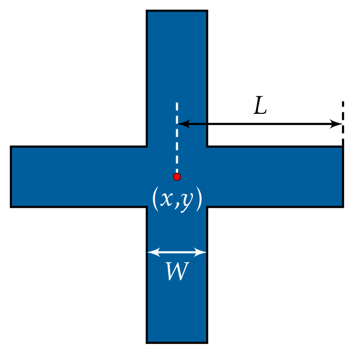


Figure 2.20: ***cross*** *constructor parameters.*

2.3.5 L-Shape

L-shape is defined by the center (x, y), widths (W_1 and W_2), lengths (L_1 and L_2) and rotation about the center at an angle $\theta_{(x,y)}$ expressed in degrees.

x y W_1 L_1 W_2 L_2 $\theta_{(x,y)}$ **Lshape**

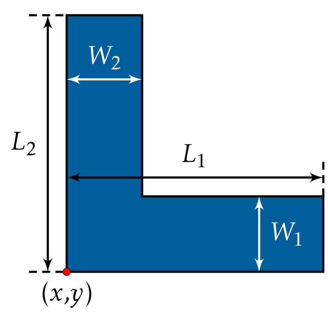


Figure 2.21: ***Lshape*** *constructor parameters.*

2.3.6 Pie Shaped Arc

Arc shape is centered at (x, y), defined by an two radii (r_x and r_y), sweep angles, the number of sides (N_{sides}) and rotated about the center point by $\theta_{(x,y)}$. Sweep angles, start and end angles (θ_s and θ_e), and $\theta_{(x,y)}$ are expressed in degrees.

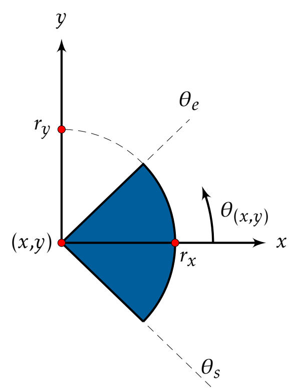


Figure 2.22: *arc constructor used to create user defined pie-shaped arc sections.*

x y r_x r_y θ_s θ_e N_{sides} $\theta_{(x,y)}$ **arc**

2.3.7 Pie Shaped Arc - Vector

The vectorized pie shaped arc is constructed using Bezier curves. Rendering resolution of the defined shape is controlled using the **shapeReso** parameter defined in section 2.2.6.

x y r_x r_y θ_s θ_e $\theta_{(x,y)}$ **arcVector**

Figure 2.23: *Illustration shows an arc section at one end of a waveguide. Rounding waveguide corners alleviates stress crowding at sharp corners. This is particularly useful when patterning thick stressed layers (resist, thin films, etc).*

2.3.8 Polygon

Polygon is defined by the center (x,y), outer radius (r), number of sides (N_{sides}), and rotation about the center at an angle $\theta_{(x,y)}$ expressed in degrees. A shape is characterized by an arbitrary number of vertices to form a closed figure.

$x \quad y \quad r \quad N_{sides} \quad \theta_{(x,y)}$ **polygon**

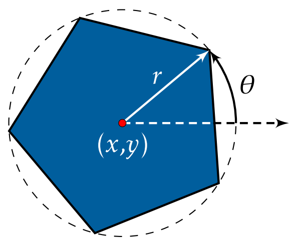


Figure 2.24: ***polygon*** *constructor parameters.*

2.3.9 Rectangle

The shape consists of four 90° corners. Three constructors are used to define the rectangular object.

x_{LL}	y_{LL}	x_{UR}	y_{UR}	$\theta_{(x_{LL},y_{LL})}$	rectangle
x_{LL}	y_{LL}	L	H	$\theta_{(x_{LL},y_{LL})}$	rectangleLH
x_C	y_C	L	H	$\theta_{(x_C,y_C)}$	rectangleC

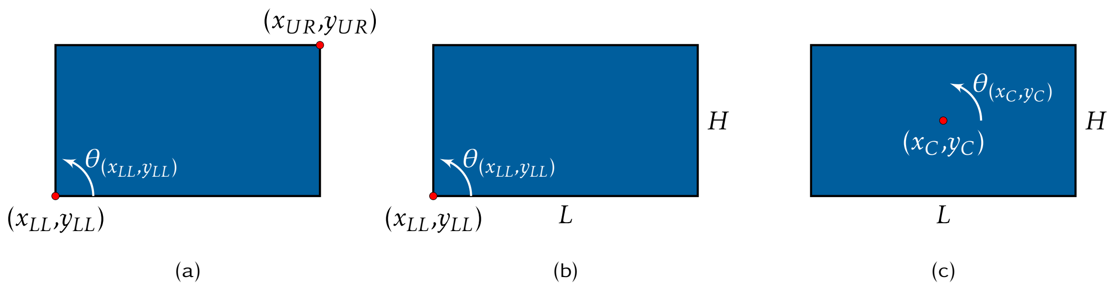


Figure 2.25: *Three rectangle constructors. (a)* ***rectangle****, (b)* ***rectangleLH****, and (c)* ***rectangleC***

2.3.10 Rounded Rectangle

Rounded rectangle constructor **roundrect** is defined using the lower left corner (x_{LL}, y_{LL}), length (L) and height values (H). The curved sections of the rounded rectangle are defined by the two radii (r_x and r_y) and are rendered using the specified **shapeReso** resolution parameter (see section 2.2.6). Rotation of the rounded rectangle is about the lower left corner (x_{LL}, y_{LL}). Rounded rectangles defined using **roundrectC** are of length L, height H and are centered at (x_C, y_C).

x_{LL}	y_{LL}	L	H	r_x	r_y	$\theta_{(x_{LL},y_{LL})}$	**roundrect**
x_C	y_C	L	H	r_x	r_y	$\theta_{(x_C,y_C)}$	**roundrectC**

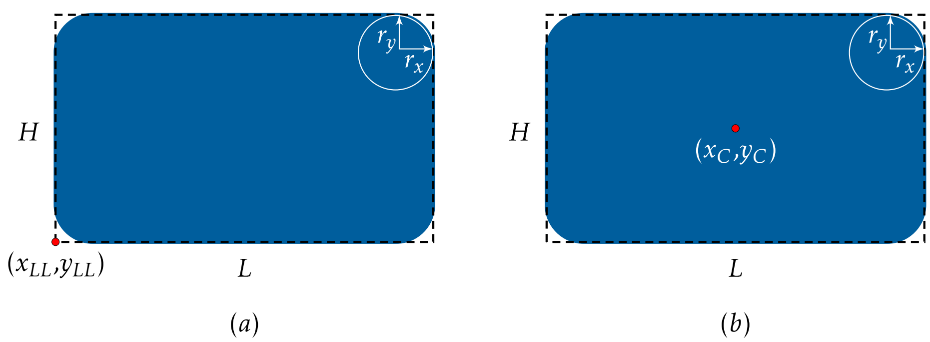


Figure 2.26: *Rounded rectangle constructors defined by (a) lower left corner (**roundrect**) and (b) center coordinates (**roundrectC**).*

2.3.11 Rectangular SU-Shape

The below constructor creates a rectangular S- and U-shape objects. Positive and negative values of the three lengths (L_i) allow for a variety of S- and U-shapes. These structures are useful for routing metal runners to bond pads.

$$x \quad y \quad L_1 \quad L_2 \quad L_3 \quad W \quad \theta_{(x,y)} \quad \textbf{rectSUshape}$$

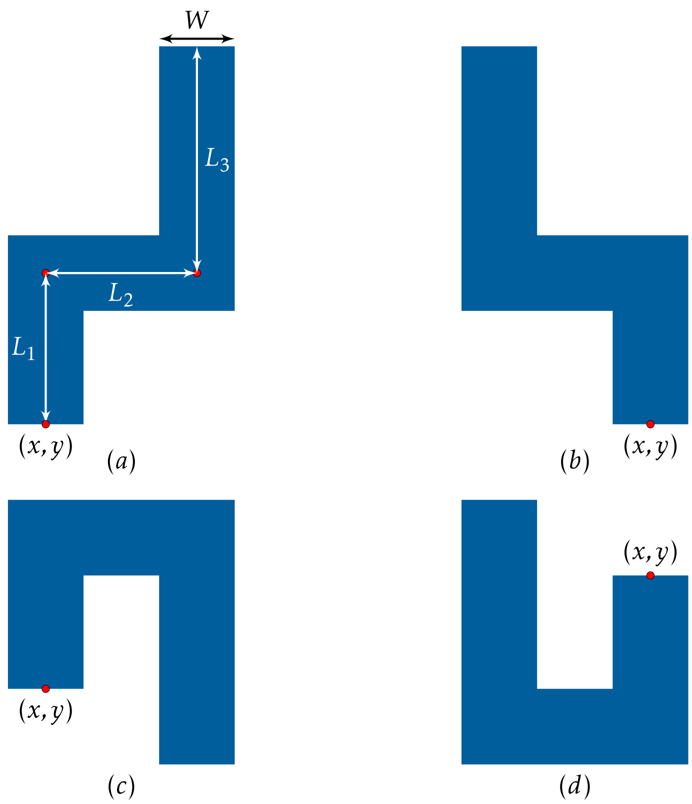


Figure 2.27: *Rectangular SU-shapes constructed using various length values. (a) all lengths L_i are positive,(b) L_1, L_3 positive, L_2 negative, (c) L_1, L_2 positive, L_3 negative and (d) L_1, L_2 negative, L_3 positive values.*

2.3.12 Rectangle With a Linear Taper

Below constructor creates a parametrized rectangle of width w_1 and length L_1 connected to a taper. Tapered region varies linearly over the taper length L_2 from a the rectangle width w_1 to the end taper width w_2.

$x \quad y \quad w_1 \quad L_1 \quad w_2 \quad L_2 \quad \theta_{(x,y)}$ **rectTaper**

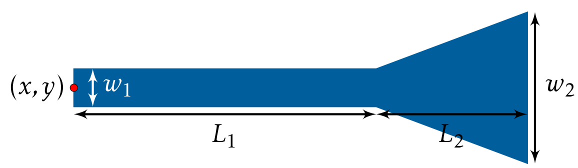


Figure 2.28: *Rectangle with a taper at one end.*

2.3.13 Star

Star is defined by the center (x, y), the two radii (r_i and r_o), number of points (N_{points}), and rotation about the center at an angle $\theta_{(x,y)}$ expressed in degrees.

$x \quad y \quad r_i \quad r_o \quad N_{points} \quad \theta_{(x,y)}$ **star**

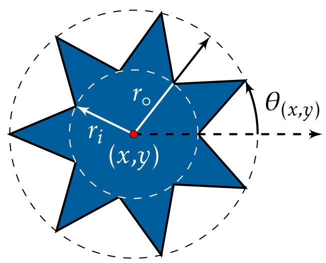


Figure 2.29: *star constructor parameters.*

2.3.14 Torus - Arc

A shape defined by **torus** is centered at (x, y), defined by an inner and outer radii (r_i and r_o), sweep angle, and the number of sides (N_{sides}). Sweep angles, start and end angles (θ_s and θ_e) are expressed in degrees. The **torusW** constructor creates a similar shape defined by the midpoint radius r and width w.

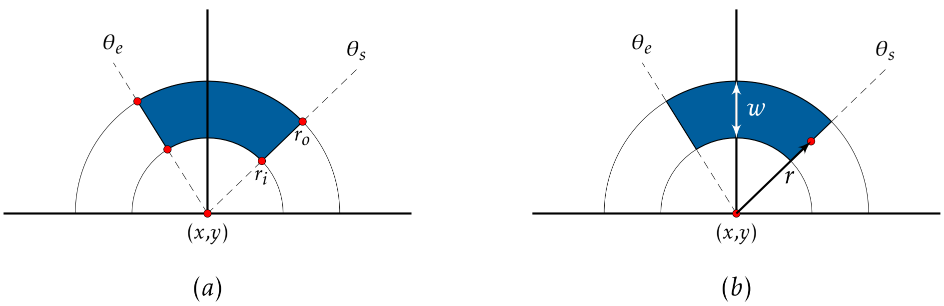


Figure 2.30: *Example of arc sections defined by (a)* ***torus*** *and (b)* ***torusW*** *constructors.*

$x \quad y \quad r_i \quad r_o \quad \theta_s \quad \theta_e \quad N_{sides}$ **torus**

$x \quad y \quad r \quad w \quad \theta_s \quad \theta_e \quad N_{sides}$ **torusW**

2.3.15 Torus - Vector

The vectorized torus is centered at (x, y) and defined by an inner and outer radii (r_i and r_o). The shape is constructed by subtracting two vectorized circles (vectorized ellipses with $r_x = r_y$, see section 2.3.1.2). Rendering resolution of the defined shape is controlled using the **shapeReso** parameter defined in section 2.2.6.

$x \quad y \quad r_i \quad r_o$ **torusVector**

2.3.16 Torus With a Wave boundary

Torus structure with a sinusoidal boundary of inner and outer radii r_i and $r_\circ$. The structure is centered at (x,y) with inner and outer sinusoidal boundaries in phase or $\frac{\pi}{2}$ out of phase. A represents the sine wave amplitude, n the number of oscillations along the inner and outer boundaries extending from 0 to 2π, N_s is the number of sides used to construct each boundary, and $\theta_{(x,y)}$ is the rotation about the center point.

$x \quad y \quad r_i \quad r_\circ \quad n \quad A \quad N_s \quad \theta_{(x,y)}$ **torusWaveIn**

$x \quad y \quad r_i \quad r_\circ \quad n \quad A \quad N_s \quad \theta_{(x,y)}$ **torusWaveOut**

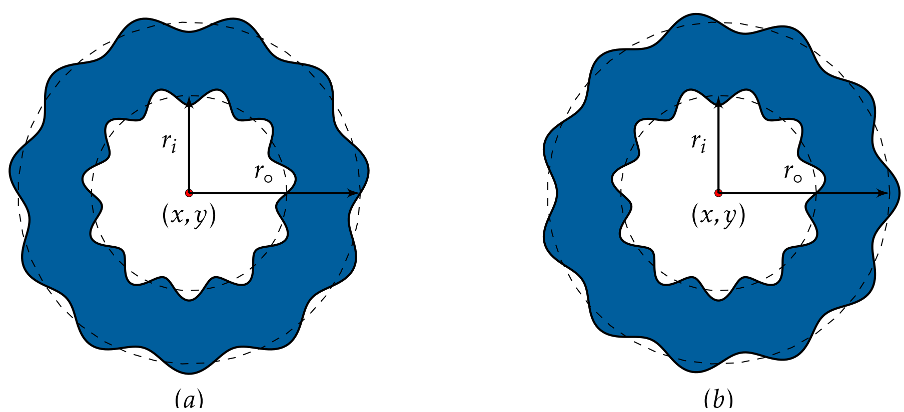
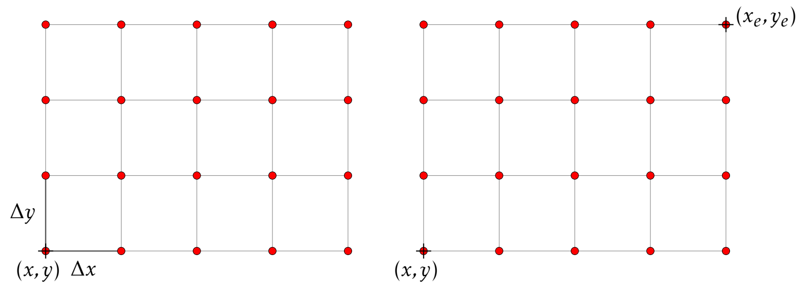


Figure 2.31: *Torus wave with inner and outer radii (a) in phase (**torusWaveIn**) and (b) $\frac{\pi}{2}$ out of phase (**torusWaveOut**).*

2.4 Arrays and Instances

2.4.1 Rectangular Arrays

The method instantiates and arrays a GDS structure on a periodic rectangular grid. 2 constructors are available. Both define the starting point of the array (x, y) along with the number of columns ($N_{columns}$) and rows (N_{rows}). First (denoted as the **1** parameter prior **arrayRect** constructor) has a defined pitch of Δx and Δy in the x and y directions respectively. The second (denoted as the **2** parameter prior **arrayRect** constructor) is characterized by the number of elements distributed evenly between the start (x, y) and end (x_e, y_e) points of the array.



(a) (b)

Figure 2.32: *Two versions of the rectangular array constructor* ***arrayRect*** *(a)* ***1*** *(b)* ***2****.*

<$structureToBeArrayed$ x y $N_{columns}$ N_{rows} Δx Δy **1** **arrayRect**>

<$structureToBeArrayed$ x y $N_{columns}$ N_{rows} x_e y_e **2** **arrayRect**>

2.4.2 Hexagonal Arrays

This method arrays GDS structures on a periodic hexagonal grid. The resulting arrayed structure consists of two rectangular arrays. Hexagonal arrays are characterized by the starting coordinate (x, y), number of columns and rows ($N_{columns}$ and N_{rows}) are specified, with previously defined structure instantiated on a hexagonal grid with spacing defined by Δs.

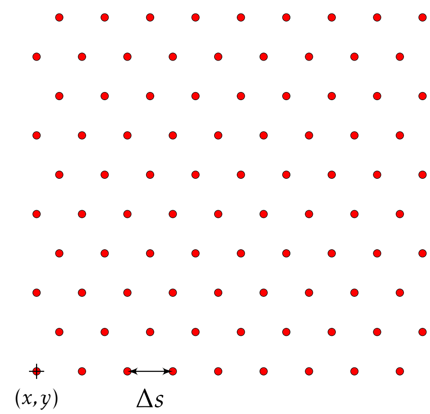


Figure 2.33: *arrayHex constructor used to create hexagonal arrays.*

<$structureToBeArrayed \quad x \quad y \quad N_{columns} \quad N_{rows} \quad \Delta s$ **arrayHex**>

2.4.3 Polar Arrays

The array method instantiates GDS structures in polar coordinates. There are 2 main versions of the array polar constructor, each with two variants. Versions 1 and 1R: Start (θ_s) and end angles (θ_e), along with start (r_s) and end (r_e) radii, are specified, with a previously defined structure instantiated at angular and radial increments defined respectively by $\Delta\theta$ and Δr. In figure 2.34a, GDS structure named $structureToBeArrayed$ is instantiated starting angularly at $\theta_s = 60$ to $\theta_e = 120$, in angular increments of 30 degrees, and radially starting at $r = 2.0\mu$m to $r = 4.0\mu$m with radial increments of 1.0μm. Version 1R rotates each instance to point towards $r = 0$.

Versions 2 and 2R: Start (θ_s) and end angles (θ_e), along with start (r_s) and end (r_e) radii, are specified, number of instances between the defined regions is defined by $\theta_\#$ and $r_\#$ in the angular and radial directions respectively. Region of space defined by the start and end parameters is uniformly subdivided. In figure 2.34b, structure $structureToBeArrayed$ is instantiated $\theta_\# = 5$ times starting angularly at $\theta_s = 60$ to $\theta_e = 120$, and radially $r_\# = 5$ times starting at $r = 2.0\mu$m to $r = 4.0\mu$m. Version 2R rotates each instance to point towards $r = 0$.

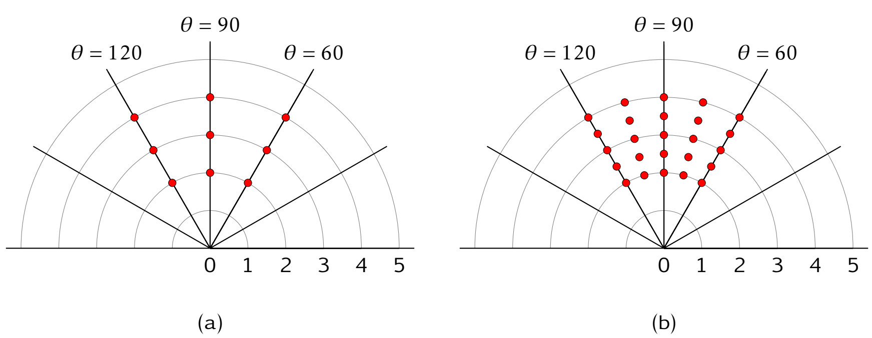


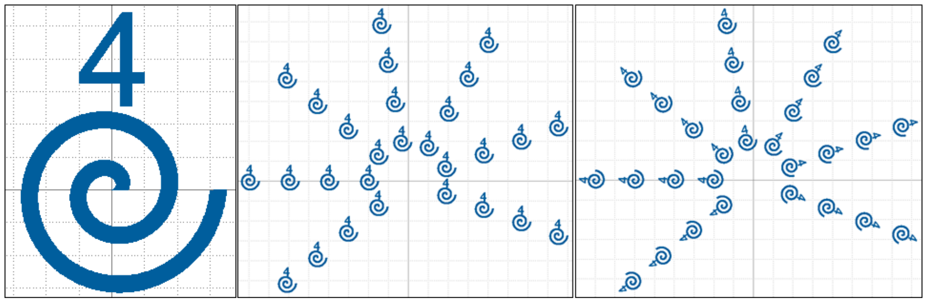
Figure 2.34: *Four versions of the polar array constructor* **arrayPolar***. (a)* ***1*** *and* ***1R****, (b)* ***2*** *and* ***2R****.*

<$structureToBeArrayed$ θ_s θ_e $\Delta\theta$ r_s r_e Δr 1 arrayPolar>

<$structureToBeArrayed$ θ_s θ_e $\Delta\theta$ r_s r_e Δr 1R arrayPolar>

<$structureToBeArrayed$ θ_s θ_e $\theta_\#$ r_s r_e $r_\#$ 2 arrayPolar>

<$structureToBeArrayed$ θ_s θ_e $\theta_\#$ r_s r_e $r_\#$ 2R arrayPolar>



(a) (b) (c)

Figure 2.35: *Polar Array example. (a) cell containing two objects, versions (b) 1 and (c) 1R of the* **arrayPolar** *constructor.*

2.4.4 Instancing GDS Structures

The method intantiates GDS structures at a point (x, y) within other structures. The resulting instances are characterized by mirror, scaling and rotation parameters. Mirroring parameter MIR assumes values of X and Y for symmetric reflections around respective axes. Any other MIR values represent unmirrored structures (i.e. using a single character other than X and Y, i.e. N). Magnification (MAG) and rotation (θ) are double values.

<structureToBeInstanced x y MIR MAG θ **instance**>

Below constructor first symmetrically centers the structure around the origin by employing user-defined pattern boundary parameters then transforms the instantiated structure. The bounding box is defined by the lower left (x_{LL}, y_{LL}) and upper right (x_{UR}, y_{UR}) coordinates of the structural boundary. This method could be useful when instantiating various structures for a multi-image stepper reticle design. Transformation parameters, translation (x, y), mirroring (MIR), magnification (MAG) and rotation (θ) are defined in an identical manner as for the **instance** constructor.

<structureToBeInstanced x y x_{LL} y_{LL} x_{UR} y_{UR} MIR MAG θ **instanceSym**>

2.4.5 Points To Instance

This method instantiates GDS structures along a list of user defined points. This methodology is accomplished within the following two step process: first, by defining the instanced structure in double brackets, then instantiating the structure at the specified coordinates, terminated by the constructor **points2instance**.

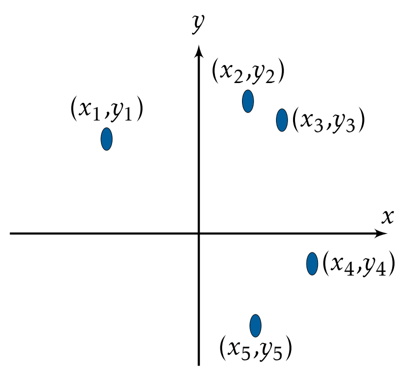


Figure 2.36: *points2instance constructor used to instantiate structures (cells) at user defined (x_i, y_i) positions.*

≪structureToBeInstanced≫

x_1 y_1 x_2 y_2 $\cdots$ x_n y_n **points2instance**

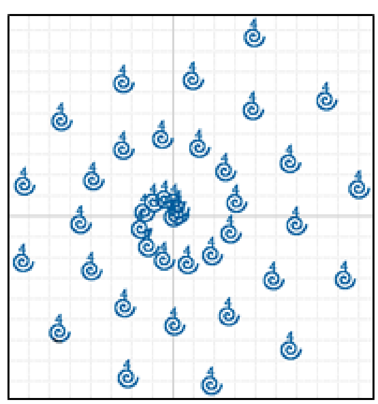


Figure 2.37: *Points to instance example. Structure instanced along a path defined by a set of (x, y) coordinate pairs.*

2.4.6 Pillar-Hole Hexagonal and Square Arrays

This method constructs hexagonal and square lattice $(N_x \times N_y)$ arrays of periodic structures. Number of vertex points (N_{sides}) defines the polygon, i.e. $N_{sides} = 8$ defines an octogon. Vertices of the vectorized shapes are defined by the **shapeReso** parameter. Vectorized array constructors are defined by the suffix **V**. Narrow elliptical shapes are best defined in vectorized forms. In this case, the curved section comprises a dense distribution of vertices. Each rendered shape has a rotational degree of freedom controlled by the θ parameter. Array positions are defined either by the center of the lower-left shape or by the array centroid (defined by the constructor suffix **C**).

Hexagonal and square pillar-hole arrays:

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad N_{sides} \quad p_x \quad p_y \quad N_x \quad N_y \quad \theta$ sqrPillar>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad N_{sides} \quad p_x \quad N_x \quad N_y \quad \theta$ hexPillar>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad N_{sides} \quad p_x \quad p_y \quad N_x \quad N_y \quad \theta$ sqrHole>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad N_{sides} \quad p_x \quad N_x \quad N_y \quad \theta$ hexHole>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad N_{sides} \quad p_x \quad p_y \quad N_x \quad N_y \quad \theta$ sqrPillarC>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad N_{sides} \quad p_x \quad N_x \quad N_y \quad \theta$ hexPillarC>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad N_{sides} \quad p_x \quad p_y \quad N_x \quad N_y \quad \theta$ sqrHoleC>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad N_{sides} \quad p_x \quad N_x \quad N_y \quad \theta$ hexHoleC>

Vectorized hexagonal and square pillar-hole arrays:

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad p_x \quad p_y \quad N_x \quad N_y \quad \theta$ sqrPillarV>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad p_x \quad N_x \quad N_y \quad \theta$ hexPillarV>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad p_x \quad p_y \quad N_x \quad N_y \quad \theta$ sqrHoleV>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad p_x \quad N_x \quad N_y \quad \theta$ hexHoleV>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad p_x \quad p_y \quad N_x \quad N_y \quad \theta$ sqrPillarVC>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad p_x \quad N_x \quad N_y \quad \theta$ hexPillarVC>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad p_x \quad p_y \quad N_x \quad N_y \quad \theta$ sqrHoleVC>

<$uniqueStructName \quad x \quad y \quad r_x \quad r_y \quad p_x \quad N_x \quad N_y \quad \theta$ hexHoleVC>

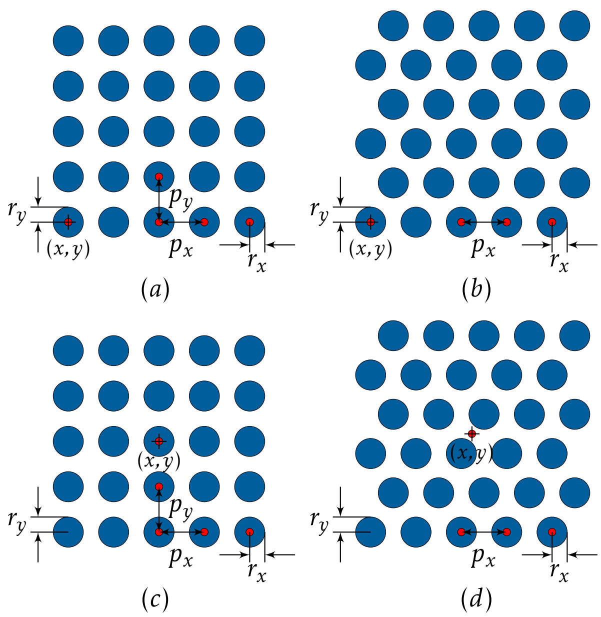


Figure 2.38: *Square and hexagonal arrays of holes defined by the lower-left corner* ((a) *and* (b)) *and by the centroid* ((c) *and* (d)).

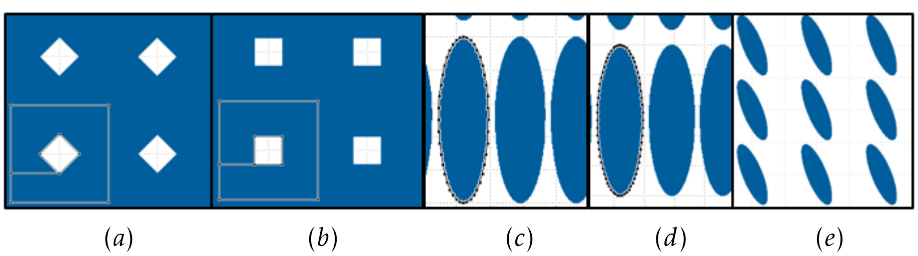


Figure 2.39: *Various pillar-hole examples. (a)* $N_{sides} = 4$*, (b)* $N_{sides} = 4$ *and* $\theta = 45$ *degrees, (c) ellipses with* N_{sides} *defined, (d) vectorized ellipses with denser number of vertices at curved sections where* ***shapeReso*** *defines the rendered resolution, (e) ellipse array with* $\theta = 22$ *degrees.*

2.5 General Area Operations

2.5.1 Boolean Operations

Constructive area geometry allows for the creation of complex shapes by means of Boolean operators between generalized areas. The processing strategy is to create objects within a variety of GDS structures. A collection of objects residing in a particular GDS Layer (`extractedGDSLayer`) are then extracted from an existing structure. Using the **genArea** constructor, the objects are then stored into a generalized area defined by a distinct string (`genAreaName`). This operation is repeated until two or more distinct generalized areas are created. Boolean operation between two generalized areas is then carried out in order to create desired compound geometries. The results of the Boolean operation are cast into a user defined GDS layer within an initialized GDS structure. Figure 2.40 illustrates the AND, OR, SUBTRACT and XOR operations between two general areas (A and B). Additionally, as shown in the following section (2.5.2)affine transformation could be implemented with **genArea** objects.

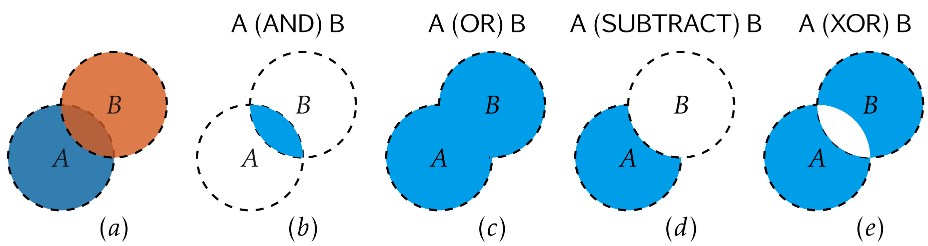


Figure 2.40: *Boolean operations between two generalized area objects. (a) two general area objects A and B, (b) A (AND) B, (c) A (OR) B, (d) A (SUBTRACT) B, (e) A (XOR) B.*

The following constructor extracts shapes residing in a GDS layer, from an existing GDS structure, and then stores the contents into a general area object. `genAreaName` is a string constructed form a continuous set of characters **without** spaces or tabs.

<genAreaName structName extractedGDSLayer **genArea**>

Boolean operations between two general area objects:

<genAreaName1 genAreaName2 resultGDSLayer **OPERATION**>

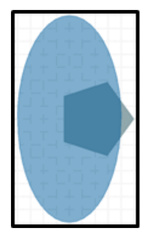
OPERATION constructor takes on the following values: AND, OR, SUBTRACT and XOR. Results from the operations are stored into a currently initialized GDS structure.

IMPORTANT NOTES: 1) `genAreaName` string identifier can not contain spaces or tabs. **2)** When extracting large instantiated GDS arrays, the **genArea** constructor flattens the data (i.e. the GDS structure hierarchy is not preserved). Similar to Boolean operations, the procedure is computationally intensive when large instantiated arrays are used. Consequently, these operations could take a considerable amount of time. For large periodic arrays, built using the **instance** constructor, the above process is considerably faster when operations are performed on a smaller instantiated GDS structure. This process circumvents a host of dillemas and preserves the hierarchy of the arrayed GDS structure. **3)** Processing large, clear-field arrayed patterns could lead, under certain operations, to shapes with a large number of vertices. Some commercial packages have an upper vertex limit per GDS shape.

Boolean SUBTRACT example:

```
0.001 gdsReso
0.001 shapeReso

<devices struct>
# create an ellipse in layer 11
11 layer
0 0 2 4 44 0 ellipse
# create a pentagon in layer 7
7 layer
1 0 1.5 1.5 5 0 ellipse

# extract shapes in layer 11 and store into variable genArea1
<genArea1 devices 11 genArea>

# extract shapes in layer 7 and store into variable genArea2
<genArea2 devices 7 genArea>

# create struct to store results
# genArea1 SUBTRACT genArea2 cast to GDS layer 44
<resultsSUBTRACT struct>
<genArea1 genArea2 44 subtract>
```

(*a*)



(*b*)

(*c*)

Figure 2.41: *Boolean SUBTRACT operation between an ellipse and a pentagon. (a) CNST script, (b) ellipse and a pentagon GDS shapes, (c) resulting GDS shape following a Boolean subtraction between an ellipse and a pentagon.*

2.5.2 General Area Copies, Shape Bias and Affine Transformations

This module copies general areas into a currently initialized GDS structure. The general areas are extracted using the genArea constructor. The objects then undergo affine transformations (translation, mirroring, scaling, rotation and shape bias). Resulting areas are then cast into a GDS layer and copied into a currently initialized GDS structure. The utility of this option is manifested in myriad forms, especially when casting multiple stepper images onto a single reticle from a multi-layer GDS structure design. Also, unlike instantiation, where layer properties are inherited from the parent structure, this module allows for users to define GDS layer numbers for each general area copy.

Variable `genAreaName` defines the areas extracted via genArea, x and y are translation directions in micrometers, MIRROR parameter is used to horizontally (around y-axis) or vertically (around x-axis) flip (mirror) the areas, MAG defines the pattern scaling, pattern rotation is defined by θ, and `resultGDSLayer` defines the GDS layer of the resulting general area shapes. MIRROR parameter assumes values of X and Y for symmetric reflections around respective axes. Any other MIRROR values represent unmirrored structures (i.e. using a single character other than X and Y, i.e. N). MAG is a positive double value indicating area magnification. MAG $= 1$ omits area scaling. Rotation defined by the parameter θ is expressed in degrees

BIAS parameter defines the amount of shape perimeter expansion (positive bias) or contraction (negative bias) in micrometers (see Figure 2.42).

The module supplies the following two constructors:
genAreaCopy - translates objects relative to the structural coordinates of the general area objects.
genAreaCopyC - first centers the object around the origin, then performs affine transformations, i.e. translation is with respect to to $(0, 0)$.

<genAreaName x y MIRROR MAG θ BIAS resultGDSLayer **genAreaCopy**>

<genAreaName x y MIRROR MAG θ BIAS resultGDSLayer **genAreaCopyC**>

These constructors copy a defined general area (flattened area) into an initialized GDS structure. Unlike `struct` instantiation, the process of copying areas does not retain hierarchy. Consequently the process results in larger files (see Important Notes comment in previous section 2.5.1).

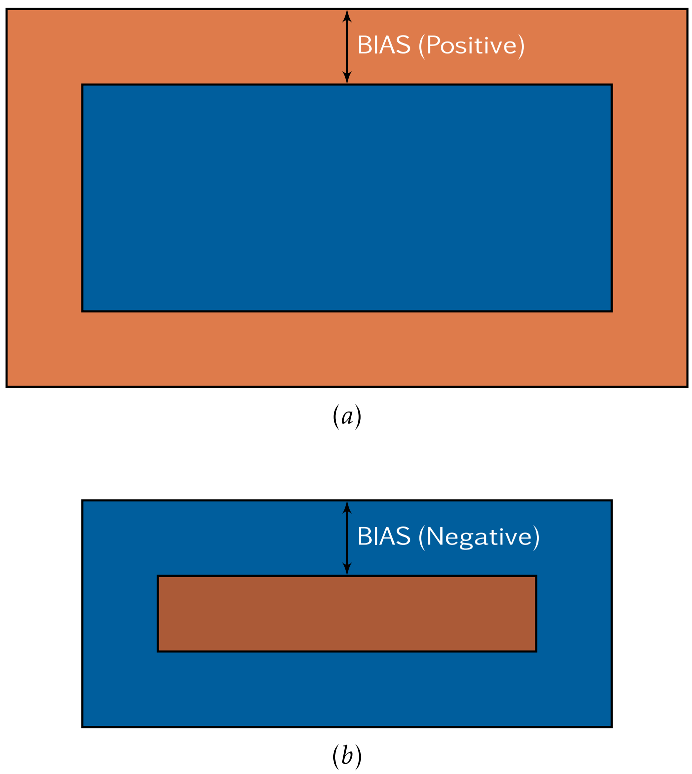


Figure 2.42: *Shape biasing (a) expanding and (b) contracting an area using a positive and negative bias.*

2.6 Text Labels, PostScript and Logos

2.6.1 Text

Text shape is characterized by a string of characters using vector based system fonts. Text shapes are directly placed within the active GDS structure. There are two constructors for text shapes, where placement is either at the lower left corner (**textgds**) or at center (**textgdsC**) of the text string. Interface function parameter $shapeReso$ defines the rendering resolution of the text. Parameter $someText$ represents all printable characters. If the *fontName* does not exist, "Serif" will be used and a comment will be placed within the error log file. If "Serif" does not exist, then first encountered font within the system font list will be used. (x, y) values are in micrometers. Font size is specified by conventional fontmetrics definitions, measured from the descender to the ascender line in micrometers.

<{{$someText$}} {{*fontName*}} *fontSize* x y **textgds**>

<{{$someText$}} {{*fontName*}} *fontSize* x y **textgdsC**>

Figure 2.43: *GDS rendered* ***textgds*** *example.*

The following are scripts used to generate the text in Figure 2.43:

<{{$SomeText!@\#\$$}} {{$Algerian$}} 20 0 0 **textgds**>

<{{$4!AaBbCc$}} {{$Serif$}} 20 0 0 **textgds**>

<{{$4!AaBbCc$}} {{$Arial$}} 20 0 0 **textgds**>

2.6.2 Text Outline

Text outline shapes are useful when lithographic write times (e.g. electron beam lithography) are of consideration. In a similar manner to **Text** shape in the previous section, the outline shape is characterized a string of text, font name and size, width of the outline and position (x, y). There are two constructors for text shapes, where placement is either at the lower left corner (**textOutline**) or at center (**textOutlineC**) of the text string. Interface function parameter $shapeReso$ defines the rendering resolution of the text. If the *fontName* does not exist, "Serif" will be used and a comment will be placed within the error log file. If "Serif" does not exist, then first encountered font within the system font list will be used. (x, y) values are in micrometers. Font size is specified by conventional fontmetrics definitions, measured from the descender to the ascender line in micrometers. Outline width is specified using the **fontOutline** parameter (see section 2.2.7).

<{{$someText$}} {{*fontName*}} *fontSize* x y **textOutline**>

<{{$someText$}} {{*fontName*}} *fontSize* x y **textOutlineC**>

Figure 2.44: *Text Outline GDS example.*

IMPORTANT NOTE: Within this object, errors dealing with exceeding maximum number of GDS vertices could be encountered. To circumvent this dilemma, when using larger letters, increase the $shapeReso$ parameter.

2.6.3 Label Maker

Label maker has 6 available constructors. 4 constructors automatically generate labels based on the number of rows and columns. Chip labels are either numbers (**autoOuter** and **autoRowColumn**)or a combination of numbers and letters (**autoOuterLetters** and **autoRowColumnLetters**). 2 remaining constructors generate custom, user-defined, labels (**outer** and **rowColumn**). Each constructor pair has an **outer** and **row-column** option. Label placement for the **outer** option is along the top and left side of the chip array. Top side placement starts at (x, y) and the left hand side placement initiates at (x_r, y_r). Label placement for the **row-column** option initiates with the top-left label at a position (x, y). In both cases number of rows (N_{row}) and columns (N_{col}), font name (*fontName*), font size (*fontSize* in μm), and the pitch along the two directions (Δ_x and Δ_y) are specified. Similarly, custom labels are defined by an additional set of label parameters ($L_1, L_2 \ldots L_n$). In all cases, if the font name is not contained within the system font list, label maker will default to a Serif font.

4 auto labels:

{N_{row} N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y **autoOut** **labelMaker**}

{N_{row} N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y **autoRowCol** **labelMaker**}

{N_{row} N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y **autoOutLett** **labelMaker**}

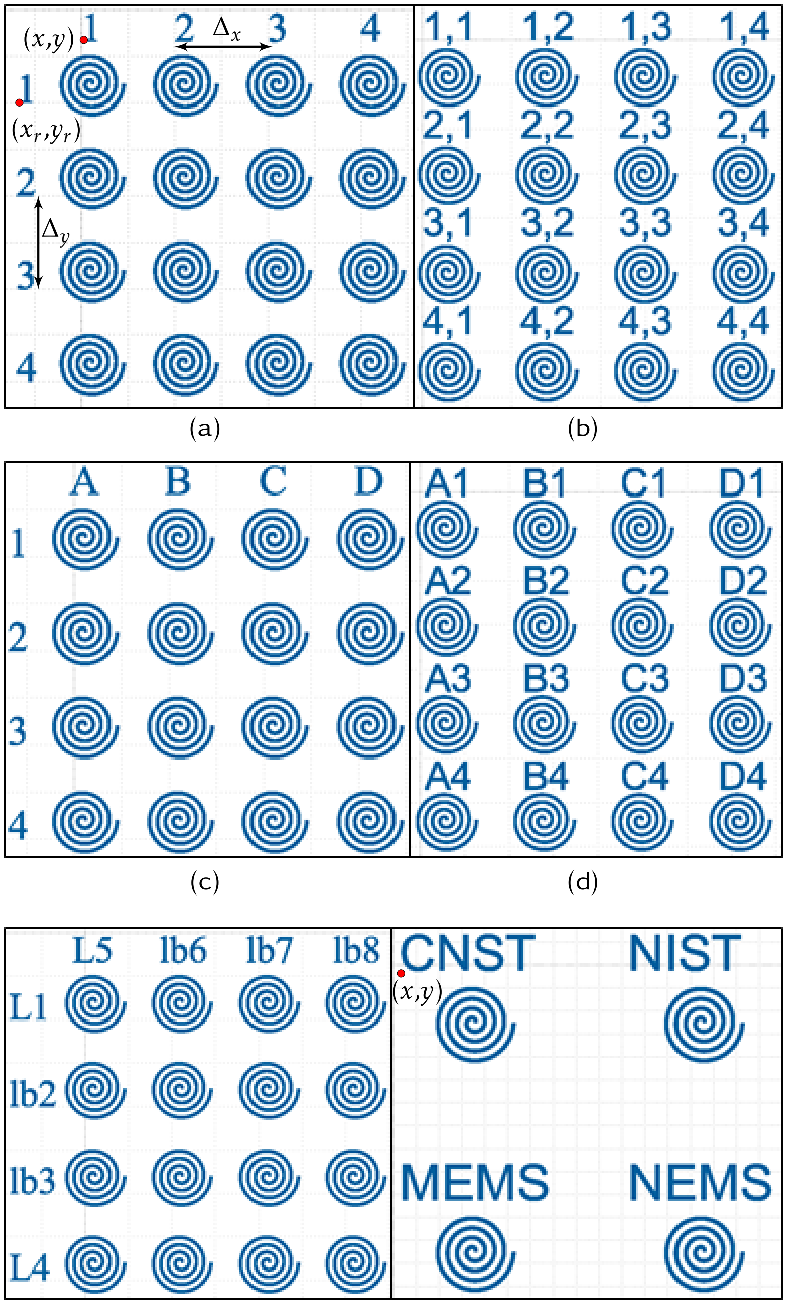
{N_{row} N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y **autoRowColLett** **labelMaker**}

2 custom labels where parameters are **TAB SEPARATED**:

{L_1 $L_2 \ldots$ L_n N_{row} N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y **out** **labelMaker**}

{L_1 $L_2 \ldots$ L_n N_{row} N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y **rowCol** **labelMaker**}

IMPORTANT NOTES: 1) Labels $L_1 \ldots L_n$ are constructed from any printable ASCII character, including the space character. Therefore, space separation between constructor parameters is **NOT** allowed. All specified parameters within above constructors must be **TAB** separated. **2)** Carriage returns cannot be used within the script line constructor.



(a) (b) (c) (d) (e) (f)

Figure 2.45: *Label Maker Constructor Examples: (a) **autoOut**, (b) **autoRowCol**, (c) **autoOutLett**, (d) **autoRowColLett**, (e) **out**, and (f) **rowCol**.*

2.6.4 Label Maker - Outline Text

This method is identical to the previously defined label maker section (2.6.3) with the exception that rendered shapes are outlined text objects. Outline width is specified using the fontOutline parameter (see section 2.2.7).

4 auto labels:

$\{N_{row}$ N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y autoOut labelOutline$\}$

$\{N_{row}$ N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y autoRowCol labelOutline$\}$

$\{N_{row}$ N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y autoOutLett labelOutline$\}$

$\{N_{row}$ N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y autoRowColLett labelOutline$\}$

2 custom labels where parameters are TAB SEPARATED:

$\{L_1$ $L_2 \ldots$ L_n N_{row} N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y out labelOutline$\}$

$\{L_1$ $L_2 \ldots$ L_n N_{row} N_{col} *fontName* *fontSize* x y x_r y_r Δ_x Δ_y rowCol labelOutline$\}$

IMPORTANT NOTES: 1) Labels $L_1 \ldots L_n$ are constructed from any printable ASCII character, including the space character. Therefore, space separation between constructor parameters is **NOT** allowed. All specified parameters within above constructors must be **TAB** separated. **2)** Carriage returns cannot be used within the script line constructor. **3)** Within this object, errors dealing with exceeding maximum number of GDS vertices could be encountered. To circumvent this dilemma, when using larger letters, increase the $shapeReso$ parameter.

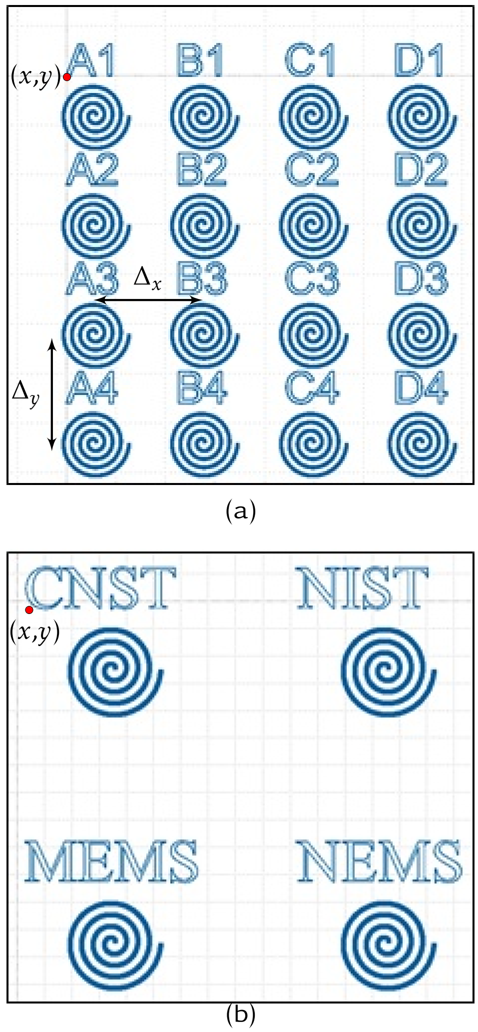


Figure 2.46: *Label Maker Outlined Text Constructor Examples: (a)* ***autoRowColLett*** *and (b)* ***rowCol****.*

2.6.5 PostScript to GDS

2.6.5.1 PostScript Pixel Value

PostScript shapes are defined by double values in conjunction with constructors (moveTo (m), lineTo (l), curveTo (c), etc). The pixel value defines scaling of these doubles. Default global value is 1.000. This implies that the postscript coordinate values are unscaled and in units of micrometers. Parameter $pixelScaling$ represents the scaling of the postscript coordinate values. For instance,

10.000 psPixelValue

scales each postscript value by 10 times. Alternatively,

0.100 psPixelValue

reduces the postscript image by 10. Once the value is set, subsequent postscript shapes are rendered to this value. This value could be changed for each postscript shape.

$pixelScaling$ psPixelValue

2.6.5.2 PostScript Fracturing

The following parameter defines the number of fractured postscript shapes. Default global value is 1, implying that the shape is unfractured. The psFracElements parameter allows direct control of number of vertices per GDS shape. This is important since aggressively scaled, large, continuous postscript shapes could exceed the maximum number of vertices per GDS shape.

20 psFracElements

implies that the overall postscript shape area will be subdivided into 20 segments along the y-direction. This value could be changed for each postscript shape.

$numberOfFracturedElements$ psFracElements

2.6.5.3 Defining Postscript Shapes

Bitmap images could be vectorized using either Illustrator, Inkscape (open source package) or some other package capable of exporting EPS files. Figure 2.47 illustrates the relevant portion of the EPS file. This information is copied and pasted within the CNST script file.

PostScript Example - PSshapeRaven.eps

```
%%EndProlog
%%Page: 1 1
%%BeginPageSetup
%%PageBoundingBox: 0 -1 151 87
%%EndPageSetup
q 0 -1 151 88 rectclip q
0 86.913 151 -87 re W n
0 g
143.895 0.167 m 142.457 0.456 140.961 0.925 140.039 1.378 c
138.094 2.331 135.961 3.824 134.777 5.058 c 134.176 5.687 134.035
5.913 134.035 6.249 c 134.035 6.593 134.09 6.675 134.363 6.738 c
135.105 6.913 136.297 6.339 137.813 5.074 c 138.77 4.277 139.641
3.843 140.852 3.562 c 142.531 3.175
                              ⋮
4.046 142.695 3.468 142.695 3.335 c 142.695 3.066 142.234 2.917
141.691 3.015 c 139.914 3.327 138.77 3.808 137.688 4.706 c 135.844
6.23 134.422 6.87 134.422 6.179 c 134.426 5.476 138.051 2.675
140.336 1.617 c 142.469 0.624 146.109 0.07 147.922 0.46 c h
f
Q Q
showpage
%%Trailer
```

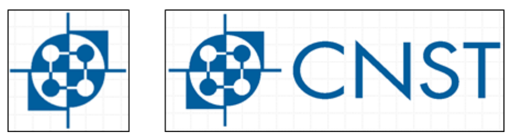
Figure 2.47: *PostScript scriptingPostScript.eps example. The arrow denotes the relevant text to be copied and pasted into the CNST script file.*

Figure 2.48: *GDS shape of the rendered postscript shape.*

2.6.6 CNST and NIST logos

Three constructors are available for placement of CNST and NIST logos. Individual (cnstEmblem, cnstLogo, nistLogo) or combined (nistCnstLogo) are placed at coordinates that define the centroid of the GDS logo shape. Since logos are cast using postscript values, the shapeReso parameter defines the rendering resolution of the logo shapes. Scaling of the resulting logo is set using the *scale* parameter.

x	y	$scale$	cnstEmblem
x	y	$scale$	cnstLogo
x	y	$scale$	nistLogo
x	y	$scale$	nistCnstLogo



(a) (b)

Figure 2.49: *CNST logos created using the (a)* ***cnstLogoEmblem*** *and (b)* ***cnstLogo*** *constructors.*

Figure 2.50: *NIST logo created using the* ***nistLogo*** *constructor.*

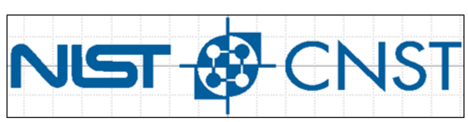


Figure 2.51: *Combined NIST and CNST logos created using the* ***nistCnstLogo*** *constructor.*

2.7 Objects

2.7.1 Arc (Torus-Circle) bounded square-hex arrays

The following constructors create a square or hexagonal array of dots inside of an arc boundary defined by an inner and outer radii (r_i and r_o), start and end angles (θ_s and θ_e) and the number of vertices (N). For a torus defined by r_i and r_o, $\theta_s = 0$ and $\theta_e = 360$. A circular boundary is represented by a radius r_o with $r_i = 0$, $\theta_s = 0$ and $\theta_e = 360$. The circular dots of radius r_s are either defined by a number of vertices n_s (**arcSquareFill** and **arcHexFill**) or by the **shapeReso** parameter for vectorized shapes (**arcSquareFillV** and **arcHexFillV**). Parameter $\theta_{(x,y)}$ defines the shape rotation about the arc origin (x, y).

$<uniqueStructName \quad x \quad y \quad r_i \quad r_o \quad \theta_s \quad \theta_e \quad N \quad \theta_{(x,y)} \quad r_s \quad n_s \quad \Delta x$ **arcSquareFill>**

$<uniqueStructName \quad x \quad y \quad r_i \quad r_o \quad \theta_s \quad \theta_e \quad N \quad \theta_{(x,y)} \quad r_s \quad \Delta x$ **arcSquareFillV>**

$<uniqueStructName \quad x \quad y \quad r_i \quad r_o \quad \theta_s \quad \theta_e \quad N \quad \theta_{(x,y)} \quad r_s \quad n_s \quad \Delta x$ **arcHexFill>**

$<uniqueStructName \quad x \quad y \quad r_i \quad r_o \quad \theta_s \quad \theta_e \quad N \quad \theta_{(x,y)} \quad r_s \quad \Delta x$ **arcHexFillV>**

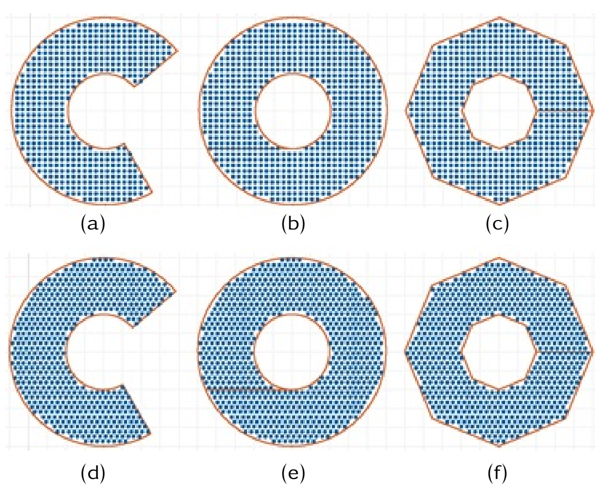


Figure 2.52: *Square array inside (a) an arc, (b) circular and (c) hexagonal ($N = 8$) boundary. Hexagonal array of dots inside (d) an arc, (e) circular and (f) hexagonal ($N = 8$) boundary.*

2.7.2 Bezier Curve

The toolbox employs Bezier curves to represent complex curved objects. The shapes are rendered to a resolution defined by the shapeReso parameter. In general, Bezier curve is a parametrized curve used as a path in computer vector graphics. Concatenation of multiple Bezier paths can be used to model smooth curves of arbitrary complexity. A Bezier curve is mathematically expressed as

$$B(t) = \sum_{k=0}^{n} {}^{n}C_k (1-t)^{n-1} t^k P_k \tag{2.1}$$

where n is the polynomial degree, k is the index, t is a variable ranging $0 \leq t \leq 1$, and ${}^{n}C_k$ is the binomial coefficient given by

$${}^{n}C_k = \binom{n}{k} = \frac{n!}{k!(n-k)!} \tag{2.2}$$

The nanolithography toolbox employs cubic Bezier curves for creating complex curved shapes. With with $n = 3$ equation 2.1 becomes

$$B(t) = (1-t)^3 P_0 + 3(1-t)^2 t P_1 + 3(1-t) t^2 P_2 + t^3 P_3 \tag{2.3}$$

where the corresponding start and end points are P_0 and P_3, with respective control points P_1 and P_2. Equation 2.3 for the two coordinates is written as

$$B(t)_x = (1-t)^3 P_{0x} + 3(1-t)^2 t P_{1x} + 3(1-t) t^2 P_{2x} + t^3 P_{3x} \tag{2.4}$$

$$B(t)_y = (1-t)^3 P_{0y} + 3(1-t)^2 t P_{1y} + 3(1-t) t^2 P_{2y} + t^3 P_{3y} \tag{2.5}$$

Figure 2.53 shows rendered curves at varying resolution. Rendered curves exhibit an increased vertex density at higher curvatures automatically. The points are uniformly spaced in t, but become closer together in (x, y) space as curvature increases.

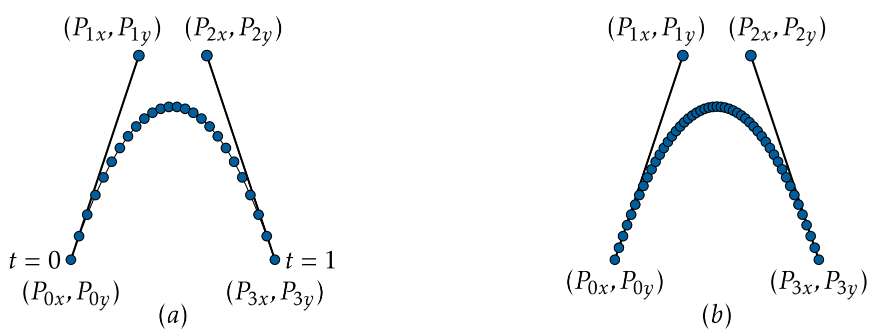


Figure 2.53: *Cubic Bezier curves rendered at a (a) lower and (b) higher resolution. Dots represent rendered curve vertices.*

Bezier Curve is defined using a start (x_1, y_1) and end (x_2, y_2) points, two control points (cx_1, cy_1) and (cx_2, cy_2), curve width (W) and $\theta_{(x_1,y_1)}$ rotation about (x_1, y_1). **shapeReso** parameter defines the rendering resolution of the Bezier curve.

<x_1 y_1 cx_1 cy_1 cx_2 cy_2 x_2 y_2 W $\theta_{(x_1,y_1)}$ **bezierCurve**>

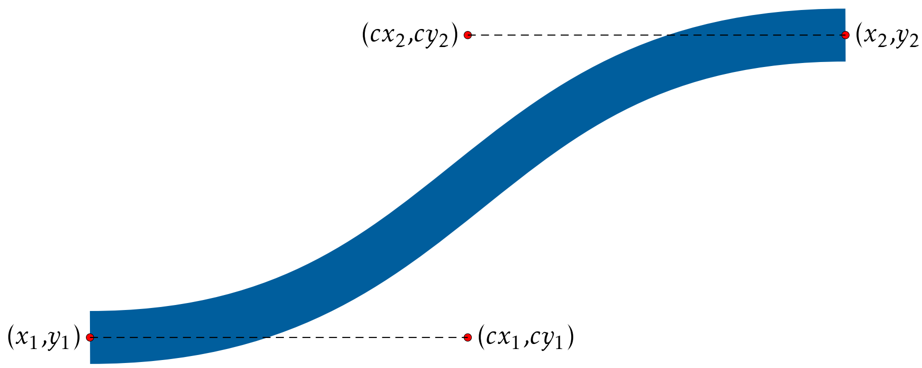


Figure 2.54: *Bezier Curve example showing the start and end points along with the corresponding control points.*

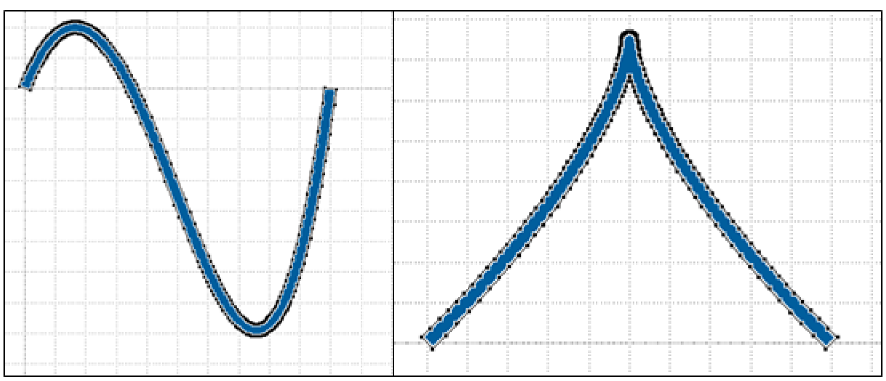


Figure 2.55: *Two example GDS shapes of the **bezierCurve** constructor. Highlighted periphery shows curved sections with densely packed vertices.*

$<x_1 \quad y_1 \quad cx_1 \quad cy_1 \quad cx_2 \quad cy_2 \quad x_2 \quad y_2 \quad W_e \quad W_s \quad \theta_{(x_1,y_1)}$ **bezierCurveInv**>

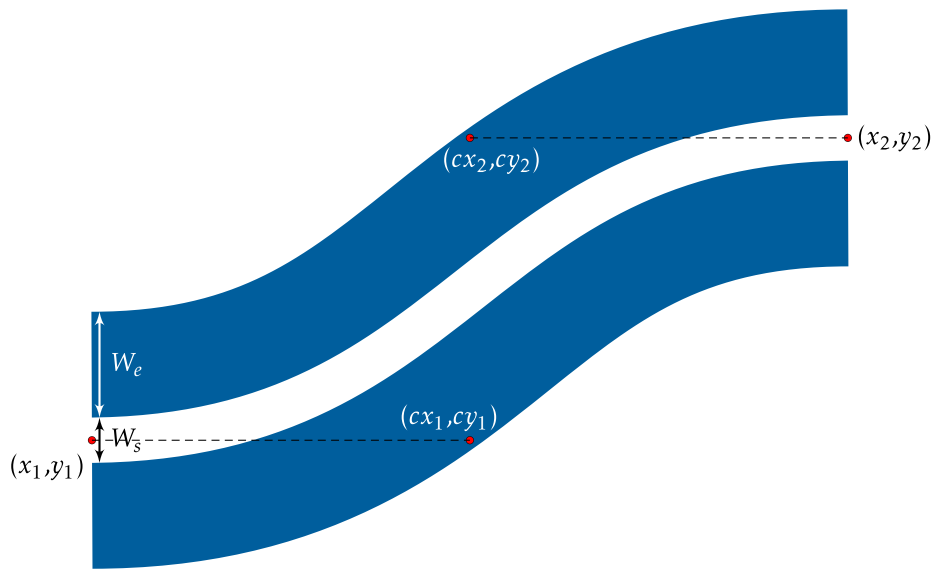


Figure 2.56: *Schematic illustration showing various parameters from the **bezierCurveInv** constructor.*

<x_1 y_1 cx_1 cy_1 cx_2 cy_2 x_2 y_2 W_e W_s g $\theta_{(x_1,y_1)}$ **bezierCurveInvSlot**>

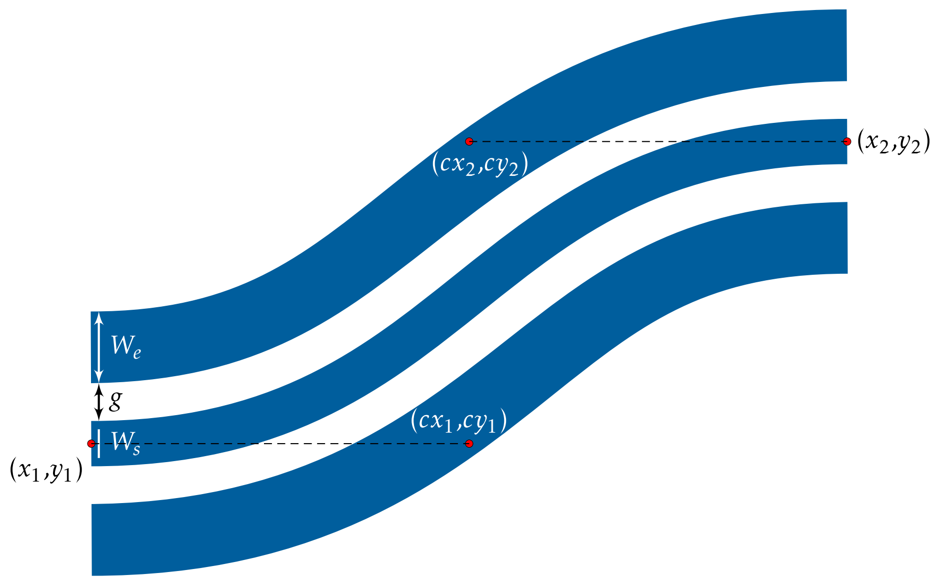


Figure 2.57: *Schematic illustration of the **bezierCurveInvSlot** constructor.*

2.7.3 Fractals

Several constructor methods are available for creating self-similar structures, including Sierpinski triangle and carpet, Vicsek saltire and cross, curved trees and various other tree-like structures. The last GDS structure iteration constructed by the recursive fractal generator is instantiated at (x, y). Iteration numbers are postfix appended to the $shortStructName$ parameter.

<$shortStructName$ x y $iterations$ $Length$ sierpinskiTriangle>

<$shortStructName$ x y $iterations$ $Length$ sierpinskiCarpet>

<$shortStructName$ x y $iterations$ $Length$ vicsekSaltire>

<$shortStructName$ x y $iterations$ $Length$ vicsekCross>

<$shortStructName$ x y $iterations$ $Length$ $Width$ curvedTree>

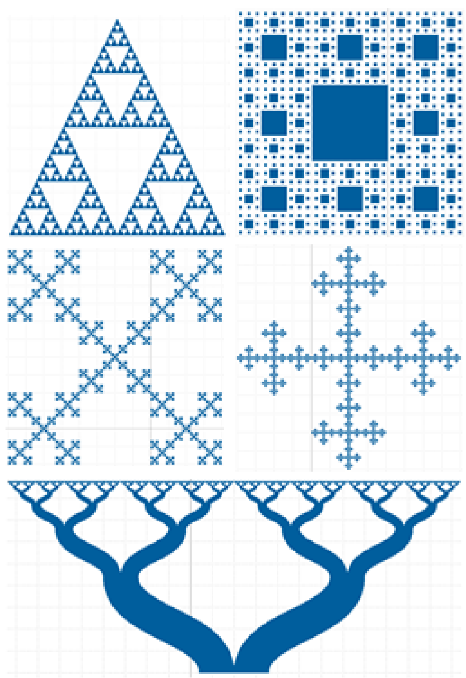


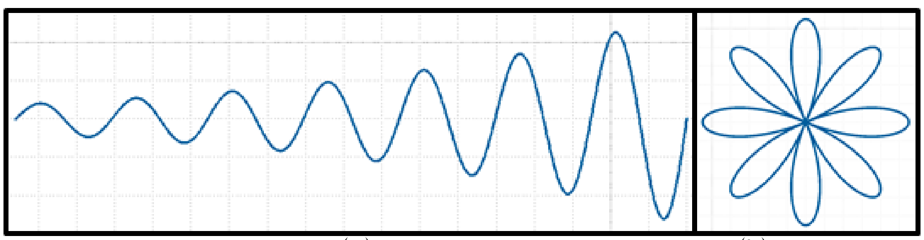
Figure 2.58: *Generated GDS fractal examples shapes.*

2.7.4 Function Plot

Functional plot method allows functional representation in (x, y) and (r, θ) coordinate systems. Generated curves are defined by a function, translation (x, y), lower (x_L and θ_L) and upper limits (x_U and θ_U), number of segments (N), width (W), cap and join parameters. Cap is represented by the following integer values $BUTT = 0$, $ROUND = 1$, or $SQUARE = 2$. Join is represented by the following integer values $MITER = 0$, $ROUND = 1$, $BEVEL = 2$. In order to avoid exceeding GDS shape point limits, each function is fractured horizontally and vertically about the centroid.

$<\{\{y(x)\}\} \quad x \quad y \quad x_L \quad x_U \quad N \quad W \quad CAP \quad JOIN \quad \theta_{(x,y)}$ functionXY>

$<\{\{r(t)\}\} \quad x \quad y \quad \theta_L \quad \theta_U \quad N \quad W \quad CAP \quad JOIN \quad \theta_{(x,y)}$ functionRT>



(a) (b)

Figure 2.59: *Function plots (a) $y(x)$ and (b) $r(\theta)$.*

Functional plots in figures 2.59(a) and 2.59b are respectively rotated by $180°$ and $22.5°$ about $(10, -10)$. Both curves were constructed using $N = 1000$, a width of 0.22μm, $CAP = ROUND$ and $JOIN = MITER$. Functional representation for the two curves is correspondingly given by

$$y(x) = 14 \sin\left(\frac{x}{2}\right) e^{-\frac{x}{44}} \tag{2.6}$$

$$r(\theta) = 11 \sin(4\theta) \tag{2.7}$$

The following scripts (see example file `scriptingFunctionPlot.cnst`) to generate functional plots in Figure 2.59:

$<\{\{14 * Math.sin(x/2) * Math.exp(-x/44)\}\} \quad 10 \quad -10 \quad 0 \quad 88 \quad 1000 \quad 0.22 \quad 1 \quad 0 \quad 180$ functionXY>

$<\{\{11 * Math.sin(4 * t)\}\} \quad 10 \quad -10 \quad 0 \quad 6.28 \quad 1000 \quad 0.22 \quad 1 \quad 0 \quad 22.5$ functionRT>

As seen above, in polar coordinates (r, θ), θ parameter is represented as a variable t. Mathematical functions are represented in terms of the Java

Math class methods. For instance $sin(x)$ is represented as $Math.sin(x)$. Several methods from the Java Math class are shown below. The entire Java Math class method summary documentation, including argument limits, is available online.

Math.sin(x)	$\sin(x)$	Math.sinh(x)	$\sinh(x)$
Math.cos(x)	$\cos(x)$	Math.cosh(x)	$\cosh(x)$
Math.tan(x)	$\tan(x)$	Math.tanh(x)	$\tanh(x)$
Math.exp(x)	e^x	Math.expm(x)	$e^x - 1$
Math.log(x)	$\ln(x)$	Math.log10(x)	$log_{10}(x)$
Math.sqrt(x)	$\sqrt{x}$	Math.pow(x,n)	x^n
Math.PI	π	Math.random()	random number in $[0,1)$

2.7.5 Grayscale

2.7.5.1 Polygons

This section offers a variety of means for constructing grayscale objects from segmented polygons. GDS layers are assigned to each of the sections with layer numbers ranging from $n-1$ (outer) to 0 (inner). Figures 2.60a, b and c show evenly distributed grayscale structure are centered at (x, y), with n number of segmentations, the outermost dimensions defined by d_x, d_y, r_x and r_y, and $\theta_{(x,y)}$ rotation about the origin. Rectangular structures (figure 2.60a) are equivalent to 45 degree rotated n-gon structures where the number of sides $N_s = 4$ (figure 2.60c).

$x \quad y \quad d_x \quad d_y \quad n \qquad \theta_{(x,y)}$ **grayER**

$x \quad y \quad r_x \quad r_y \quad n \quad N_s \quad \theta_{(x,y)}$ **grayENgon**

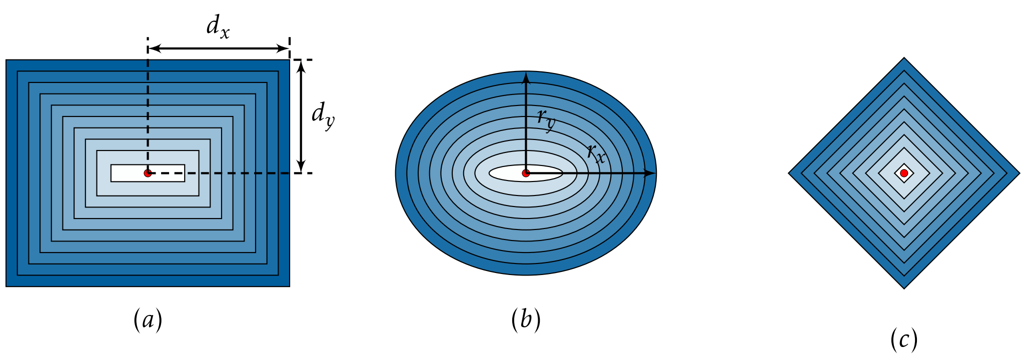


Figure 2.60: *Evenly distributed grayscale segments for (a) rectangles and n-gons with (b) large number of vertices (N_s) and (c) $N_s = 4$, $r_x = r_y$.*

User defined grayscale segments are shown in figures 2.61a, b and c. The respective constructors are defined by (d_{xi}, d_{yi}) (or (r_{x_i}, r_{y_i})) coordinate pairs. The outer most segment is defined by (d_{x_1}, d_{y_1}) (or (r_{x_1}, r_{y_1})). The constructors further assume that $d_{x_1} > d_{x_2} > d_{x_3} \cdots > d_{x_n}$ and $d_{y_1} > d_{y_2} > d_{y_3} \cdots > d_{y_n}$. Similarly, for n-gon segments $r_{x_1} > r_{x_2} > r_{x_3} \cdots > r_{x_n}$ and $r_{y_1} > r_{y_2} > r_{y_3} \cdots > r_{y_n}$.

$x \quad y \quad d_{x_1} \quad d_{y_1} \quad d_{x_2} \quad d_{y_2} \quad \cdots \quad d_{x_n} \quad d_{y_n} \qquad \theta_{(x,y)}$ **grayUDR**

$x \quad y \quad r_{x_1} \quad r_{y_1} \quad r_{x_2} \quad r_{y_2} \quad \cdots \quad r_{x_n} \quad r_{y_n} \quad N_s \quad \theta_{(x,y)}$ **grayUDNgon**

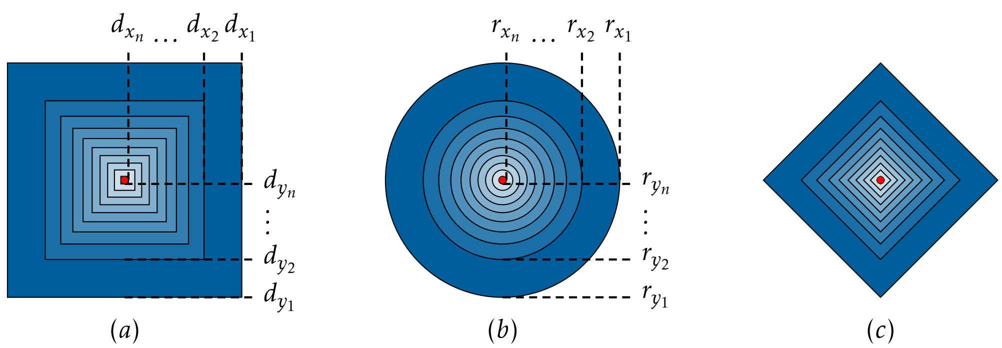


Figure 2.61: *User defined distribution of grayscale segments for (a) rectangles and n-gons with (b) large number of vertices* (N_s) *and (c)* $N_s = 4$, $r_{x_i} = r_{y_i}$.

2.7.5.2 Ramp

grayERamp constructor allows ramping with either UP = 1, where the d_x is subdivided into n segments with GDS layer numbers range from 0 to $n - 1$. Alternatively, with UP = 0, the GDS layer numbers range from $n-1$ to 0. **grayERamp2** constructor forms a double ramp (up then down) with evenly divided segments where GDS layers range from

$$L = \begin{cases} L_{\frac{n}{2}} \ldots L_0 \ldots L_{\frac{n}{2}-1} & n \text{ is even} \\ L_{\frac{n-1}{2}} \ldots L_0 \ldots L_{\frac{n-1}{2}} & n \text{ is odd} \end{cases} \tag{2.8}$$

$x \quad y \quad d_x \quad d_y \quad n \quad$ UP $\quad \theta_{(x,y)}$ **grayERamp**

$x \quad y \quad d_x \quad d_y \quad n \quad \theta_{(x,y)}$ **grayERamp2**

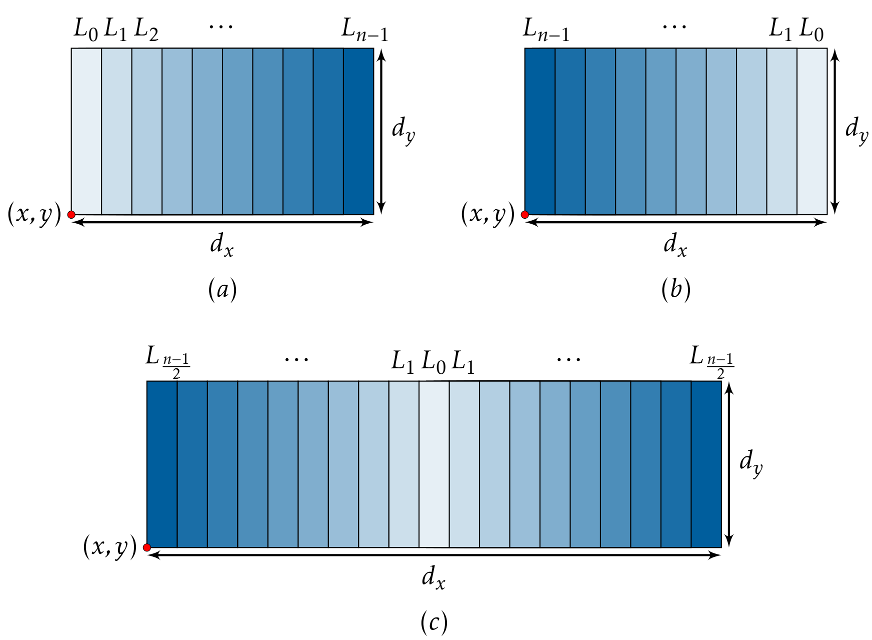


Figure 2.62: *Evenly distributed grayscale ramp segments using **grayERamp** with UP values of (a) 1 and (b) 0. (c) Grayscale ramp up/down segments using the **grayERamp2** constructor.*

Similarly, user defined ramp segments are defined using the below constructors. Number of constructed shapes is equal to $n-1$, where n is the number of defined segment positions. Grayscale segments undergo a translation by (x_t, y_t) and rotation $\theta_{(x_t,y_t)}$. Constructors assume $x_1 < x_2 < x_3 \cdots < d_{x_n}$, $n > 1$ with GDS layers for **grayUDRamp2** defined:

$$L = \begin{cases} L_{\frac{n}{2}-1} \ldots L_0 \ldots L_{\frac{n}{2}-1} & n \text{ is even} \\ L_{\frac{n-3}{2}} \ldots L_0 \ldots L_{\frac{n-1}{2}} & n \text{ is odd and } n > 3 \\ L_0, L_1 & n = 3 \\ L_0 & n = 2 \end{cases} \tag{2.9}$$

$x_t \quad y_t \quad x_1 \quad x_2 \quad \ldots \quad x_n \quad d_y$ UP $\theta_{(x_t,y_t)}$ **grayUDRamp**

$x_t \quad y_t \quad x_1 \quad x_2 \quad \ldots \quad x_n \quad d_y \quad \theta_{(x_t,y_t)}$ **grayUDRamp2**

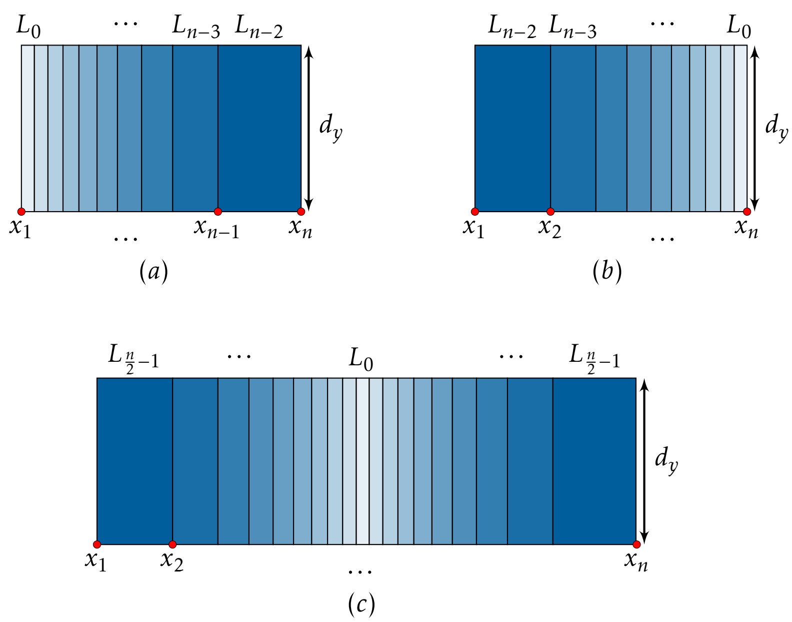


Figure 2.63: *User defined grayscale ramp segments using **grayURRamp** with UP values of (a) 1 and (b) 0. (c) Grayscale ramp up/down segments using the **grayURRamp2** constructor with an even number of points n.*

2.7.5.3 Spiral Staircase

The spiral structure is constructed using overlapping arc segments cast to different GDS layers (L_i). The resulting structure is defined by the center position (x, y), inner and outer radii (r_i and $r_\circ$), number of arc segments (n), number of sides of each segment (N_{sides}) and the rotation angle ($\theta_{(x,y)}$).

$x \quad y \quad r_i \quad r_\circ \quad n \quad N_{sides} \quad \theta_{(x,y)}$ **graySpiralStairOverlap**

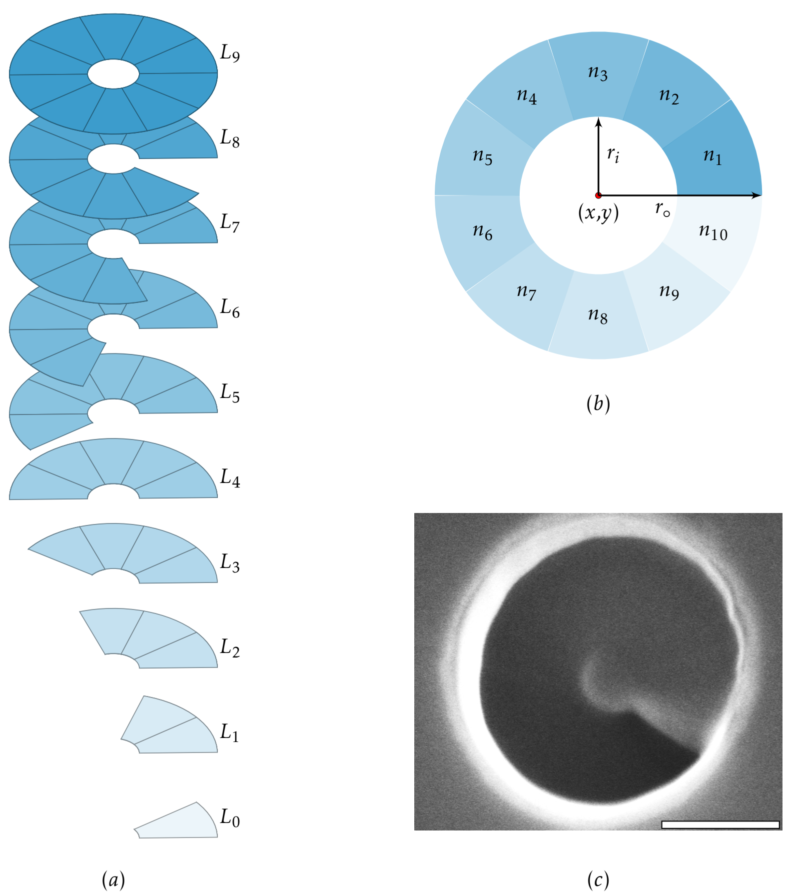
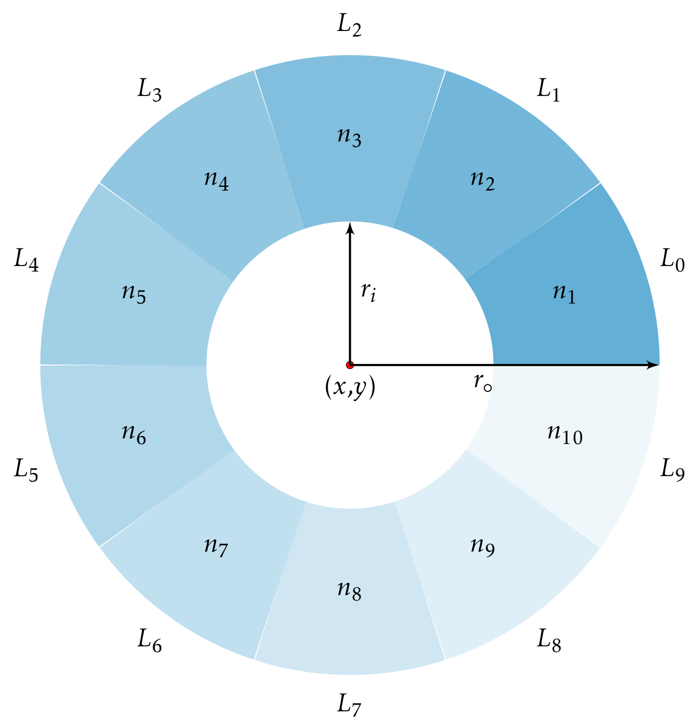


Figure 2.64: *Grayscale spiral staircase with overlapping segments. (a) 3D projection and (b) 2D illustration showing various constructor parameters. (c) Scanning electron micrograph of a focused ion beam fabricated structure. Scale bar corresponds to 200 nm. (Courtesy of L. Ocola [82])*

The following constructor creates a grayscale spiral staircase structure without overlapping arc segments.

$$x \quad y \quad r_i \quad r_\circ \quad n \quad N_{sides} \quad \theta_{(x,y)} \quad \textbf{graySpiralStair}$$

Here, each segment (n_i) is represented by a distinct GDS layer.



(b)

Figure 2.65: *Grayscale spiral staircase.*

2.7.6 Interdigitated Electrodes

$x \quad y \quad w_1 \quad w_2 \quad l_1 \quad l_2 \quad l_3 \quad N \quad p \quad b_H \quad b_W \quad \theta_{(x,y)}$ **intElec1**

$x \quad y \quad w_1 \quad w_2 \quad l_1 \quad l_2 \quad l_3 \quad N \quad p \quad b_H \quad b_W \quad \theta_{(x,y)}$ **intElec2**

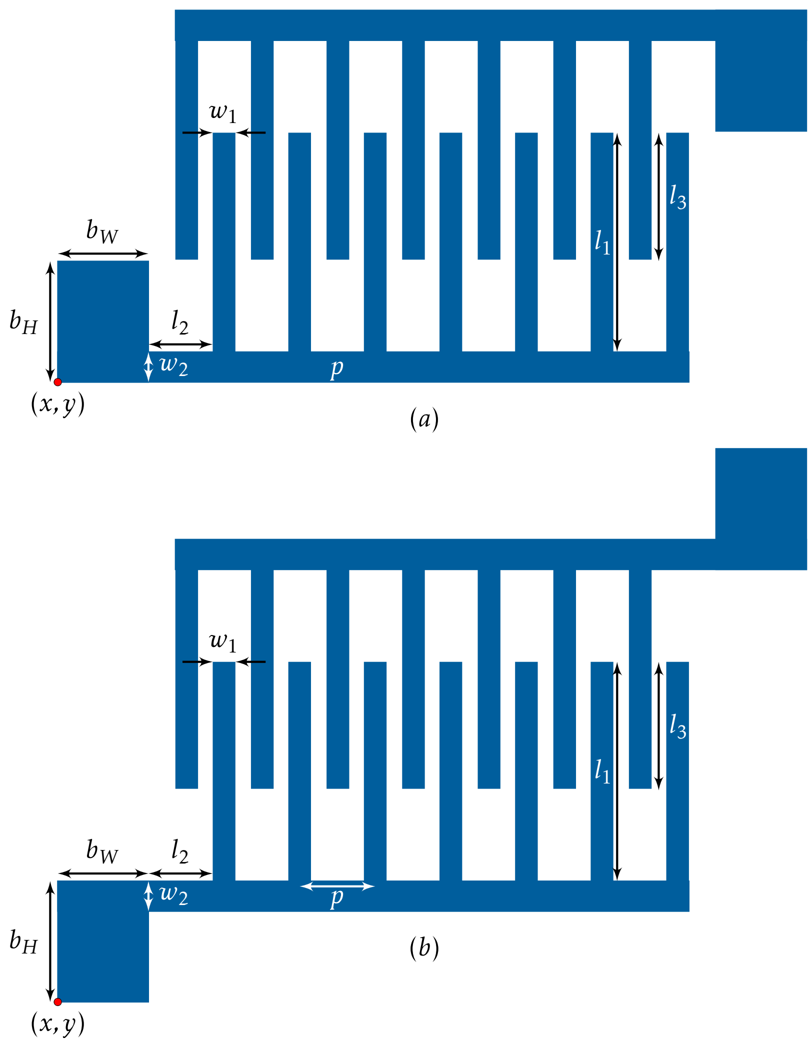


Figure 2.66: *Interdigitated electrodes (a)* ***intElec1*** *and (b)* ***intElec2****.*

$x \quad y \quad w_1 \quad w_2 \quad l_1 \quad l_2 \quad l_3 \quad N \quad p \quad b_H \quad b_W \quad \theta_{(x,y)}$ **intElec3**

$x \quad y \quad w_1 \quad w_2 \quad l_1 \quad l_2 \quad l_3 \quad N \quad p \quad b_H \quad b_W \quad \theta_{(x,y)}$ **intElec4**

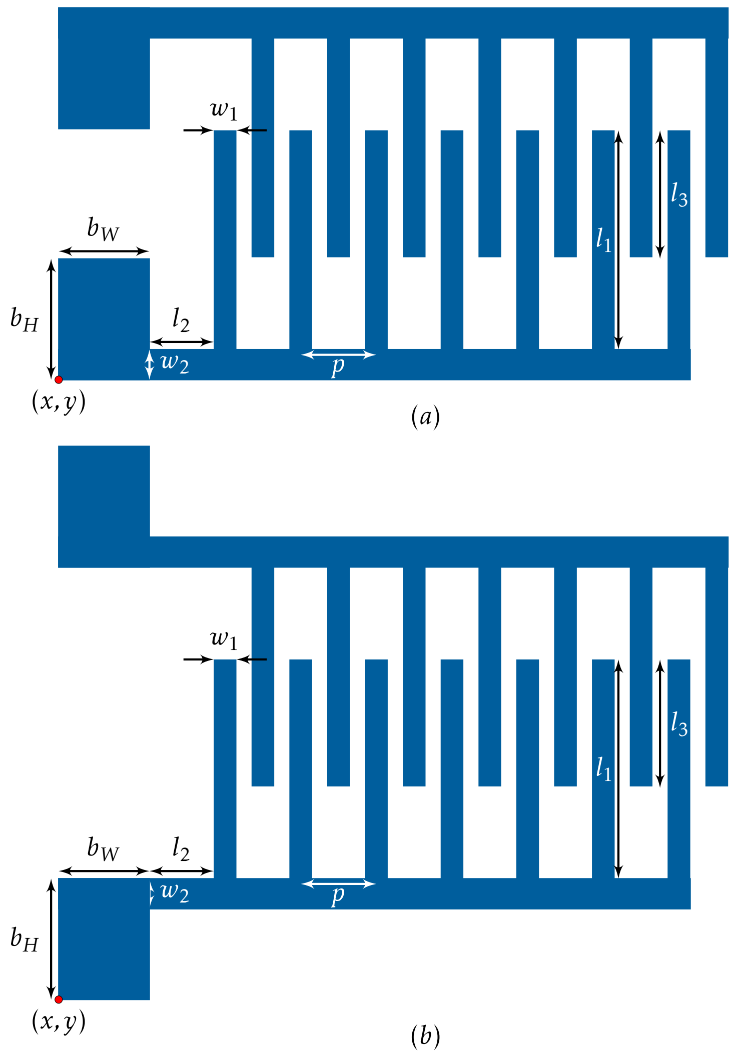


Figure 2.67: *Interdigitated electrodes (a) intElec3 and (b) intElec4.*

$x \quad y \quad w_1 \quad w_2 \quad l_1 \quad l_2 \quad l_3 \quad N \quad p \quad b_H \quad b_W \quad \theta_{(x,y)}$ **intElec5**

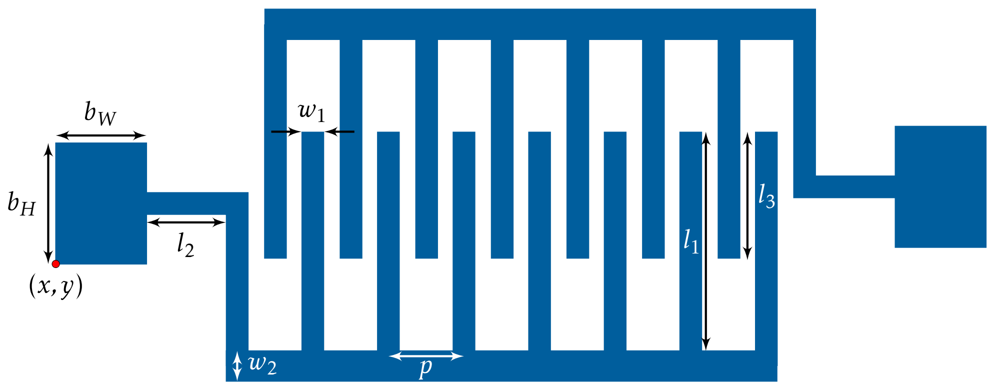


Figure 2.68: *Interdigitated electrodes* ***intElec5****.*

2.7.7 Junctions

2.7.7.1 T Junction

$x \;\; y \;\; w_1 \;\; w_2 \;\; L_1 \;\; L_2 \;\; r \;\; N_{sides} \;\; \theta_{(x,y)}$ **tJunction**

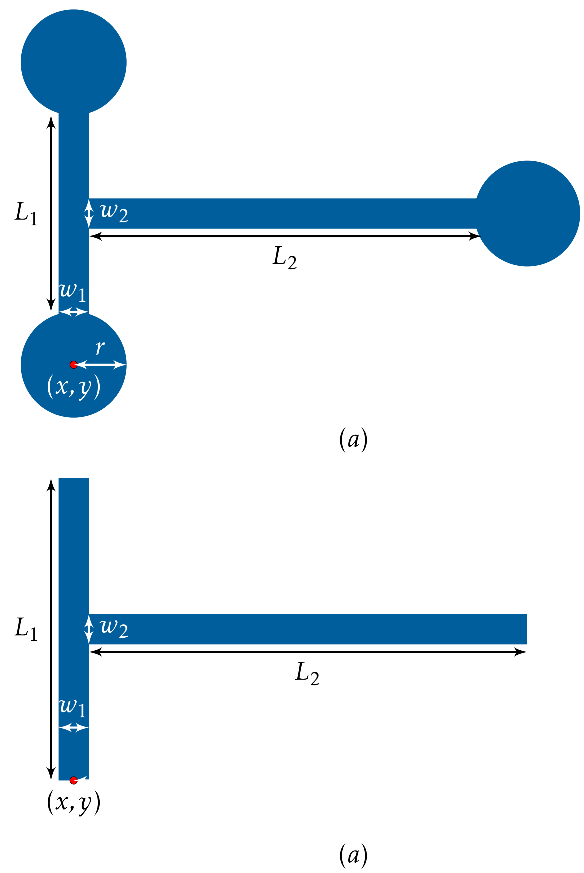


Figure 2.69: *T junction (a) with and (b) without ($r = 0$) circular ports.*

2.7.7.2 H Junction

$x \;\; y \;\; w_1 \;\; w_2 \;\; L_1 \;\; L_2 \;\; r \;\; N_{sides} \;\; \theta_{(x,y)}$ **hJunction**

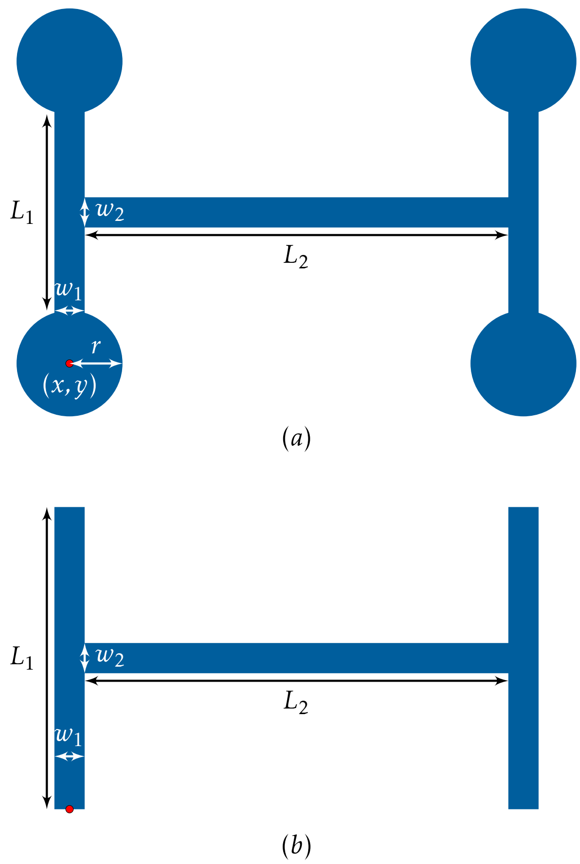


Figure 2.70: *H junction (a) with and (b) without ($r = 0$) circular ports.*

2.7.7.3 Arrow Junction

$x \;\; y \;\; w_1 \;\; w_2 \;\; L_1 \;\; L_2 \;\; r \;\; N_{sides} \;\; \theta \;\; \theta_{(x,y)}$ **arrowJunction**

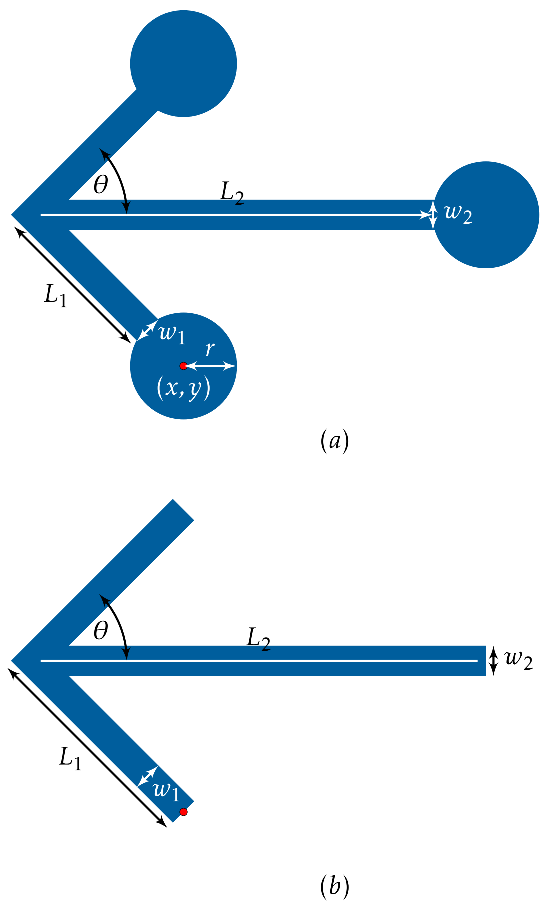


Figure 2.71: *Arrow junction (a) with and (b) without ($r = 0$) circular ports.*

2.7.8 Meander Channel

The method constructs a meandering channel with rectangular ports. These structures find potential use in fluidic and gas delivery system applications. Four available constructors represent various wavelike structures including sine, square, ramp and triangle. Rectangular ports, residing at each channel end, are defined by the length (L_1 and L_2) and height (H_1 and H_2) parameters. Connections to the reservoirs are made through segments a and b of width W. Wave structures initiate at $x = a$ and are of length b. Number of wave periods is defined by N. The sine wave structure is constructed from a number of segments defined by the parameter $N_{segments}$.

<x y L_1 H_1 L_2 H_2 W A N $N_{segments}$ a b c $\theta_{(x,y)}$ **meanderSin>**

<x y L_1 H_1 L_2 H_2 W A N a b c $\theta_{(x,y)}$ **meanderSqr>**

<x y L_1 H_1 L_2 H_2 W A N a b c $\theta_{(x,y)}$ **meanderRamp>**

<x y L_1 H_1 L_2 H_2 W A N a b c $\theta_{(x,y)}$ **meanderTri>**

Figure 2.72 illustrates the four meander channel configurations with respective parameters. As shown in Figurer̃efmeanderPortsExample, rectangular reservoirs at each channel end can be eliminated by setting respective length and height parameters equal to 0, i.e. $L_1 = H_1 = 0$ and/or $L_2 = H_2 = 0$.

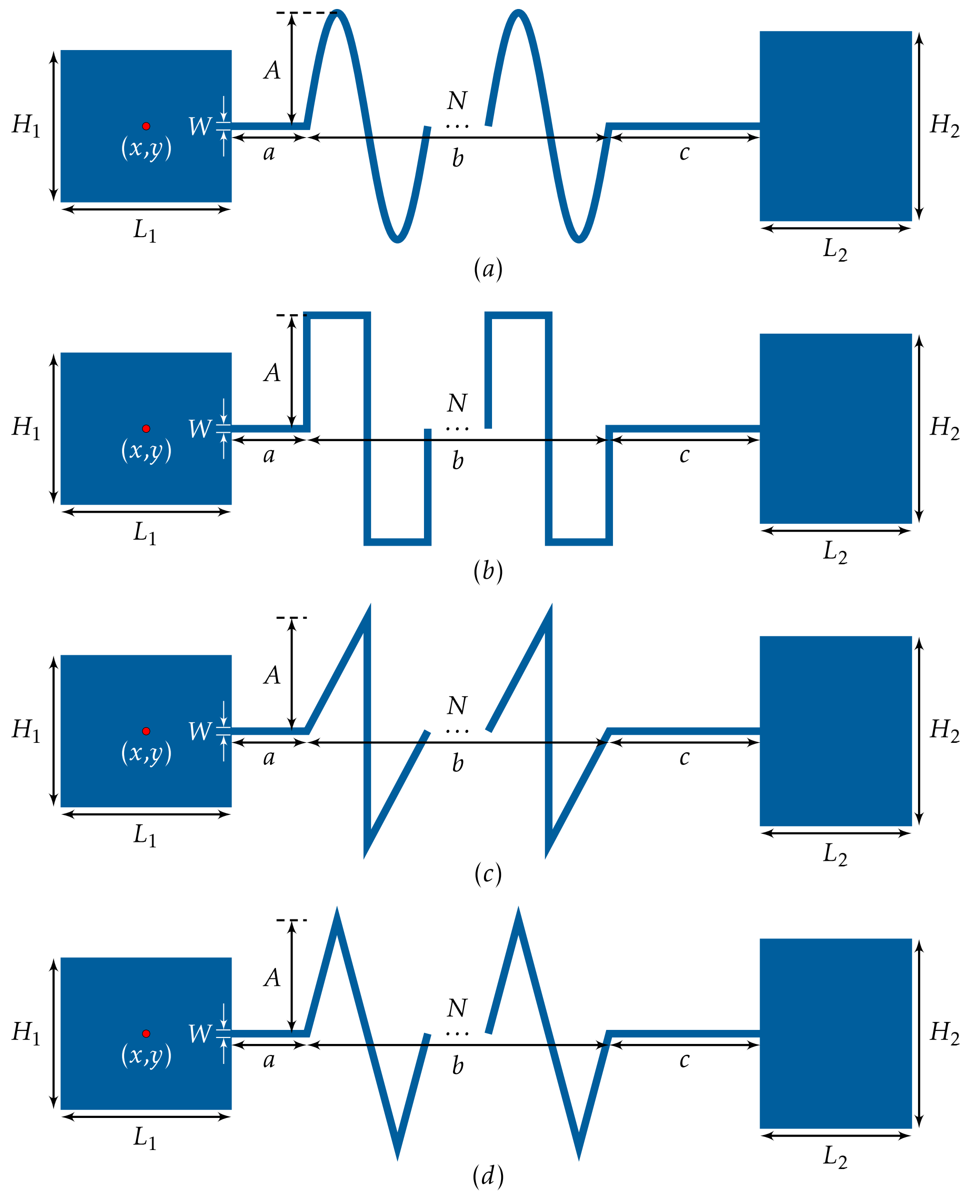


Figure 2.72: *Example shapes illustrating various parameters from the (a)* ***meanderSin****, (b)* ***meanderSqr****, (c)* ***meanderRamp*** *and (d)* ***meanderTri*** *constructors.*

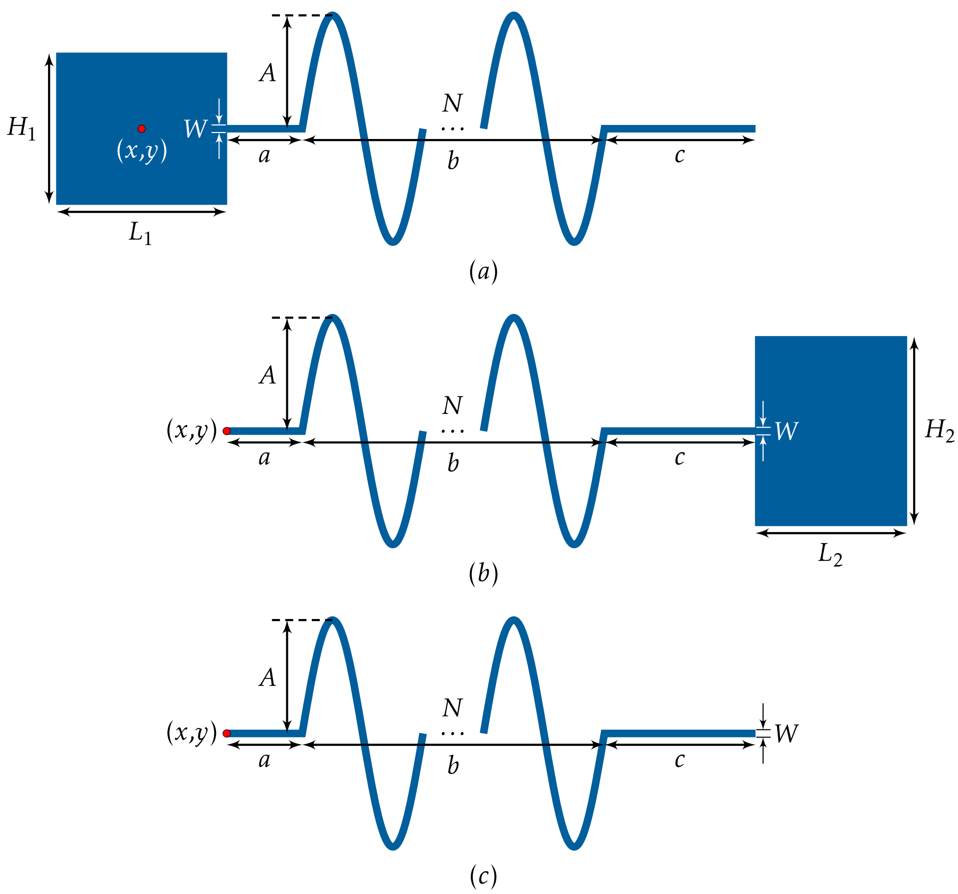


Figure 2.73: *Meander channel example illustrating various rectangular reservoir configurations. Structures without (a) right reservoir using $L_2 = H_2 = 0$, (b) left reservoir using $L_1 = H_1 = 0$ and (c) reservoirs using $L_1 = H_1 = L_2 = H_2 = 0$.*

2.7.9 Points To Shape

The method creates a polygon from user defined (x, y) point pairs. Last point (x_n, y_n) connects the first (x_1, y_1) to close the shape.

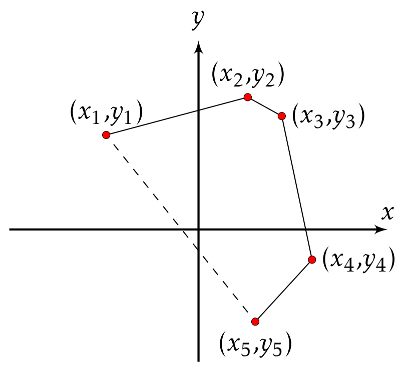


Figure 2.74: *Example of the **points2shape** constructor illustrating a closed shape constructed from points 5 points, $(x_1, y_1)\ldots(x_5, y_5)$.*

$x_1 \;\; y_1 \;\; x_2 \;\; y_2 \;\; \cdots \;\; x_n \;\; y_n$ **points2shape**

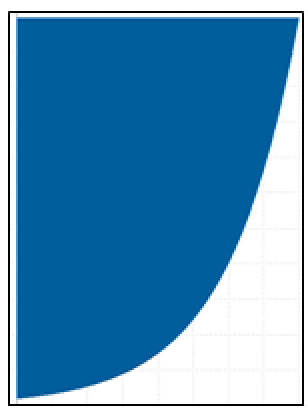


Figure 2.75: ***points2shape** example illustrating a GDS rendered polygon.*

2.7.10 Polygon Along a Path

The method creates a polygon of a specified width (W) along a path defined by (x, y) point pairs. Cap is represented by the following integer values $BUTT = 0$, $ROUND = 1$, or $SQUARE = 2$. Join is represented by the following integer values $MITER = 0$, $ROUND = 1$, $BEVEL = 2$.

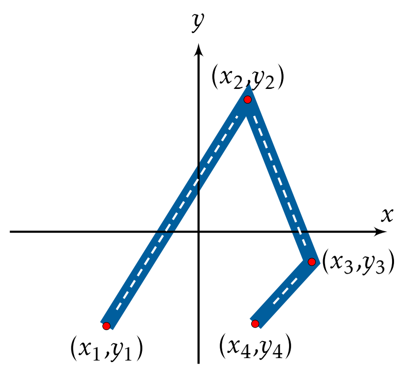


Figure 2.76: *Example of the* **polypath** *constructor illustrating a rendered shape constructed from points 5 points,* $(x_1, y_1)\ldots(x_5, y_5)$.

$x_1 \quad y_1 \quad x_2 \quad y_2 \quad \cdots \quad x_n \quad y_n \quad W \quad Cap \quad Join$ **polypath**

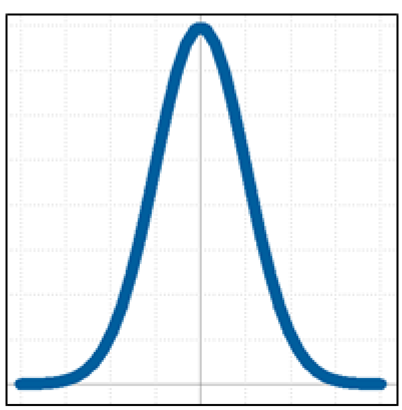


Figure 2.77: ***polypath*** *example illustrating a GDS polygon along a Gaussian path.*

2.7.11 Random Polygons

The below constructor creates randomly placed polygons into a user defined area. Single polygon of radius r with N_s sides is created and cast into a GDS struct with the name `uniqueStructName`. The N_e number of shapes are then instantiated into an area of width W and height H. Separation parameter S defines the minimum separation between the outer radial perimeter of the objects. If the randomly generated coordinate violates the minimum separation distance, the module will keep generating random coordinates until the maximum number of failures (defined by the parameter iteration parameters I) is reached. The lower left corner of the random array is positioned at (x, y).

Random rotation is enabled if R_R is set to 1, each shape will be randomly rotated within the current GDS structure. Any other numeric value or R_R will leave the shape element unchanged. Enabling the R_R option for for features with many sides is not particularly useful, however, with $S = 3$ and $R_R = 1$ produces randomly oriented triangles (see Figure 2.78).

<$uniqueStructName \quad x \quad y \quad W \quad H \quad r \quad N_s \quad S \quad N_e \quad I \quad R_R$ randomPolygons>

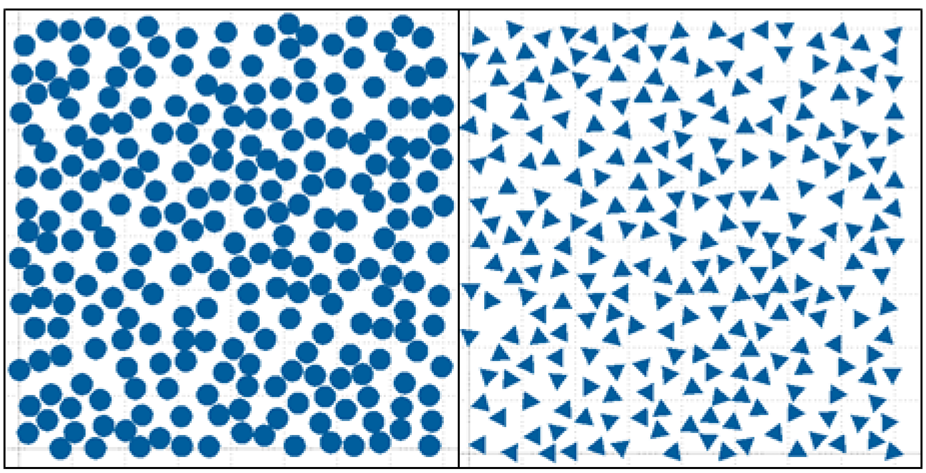


Figure 2.78: *View of a generated GDS file using the Random Polygons module. The area was $40\mu m \times 40\mu m$, number of elements and iterations were set to 400, with an element radius and separation of $1\mu m$ and $2\mu m$ respectively. Generated shapes had (a) 44 sides and (b) 3 sides with random rotation enabled.*

2.7.12 Random Ellipses and Vectorized Ellipses

Similar to the random polygon example, the following constructors create random ellipses (**randomEllipses**) and vectorized ellipses (**randomEllipsesV**). **shapeReso** defines the rendering resolution of **randomEllipsesV**.

<$uniqueStructName$ x y W H r_x r_y N_s S N_e I R_R **randomEllipses**>

<$uniqueStructName$ x y W H r_x r_y S N_e I R_R **randomEllipsesV**>

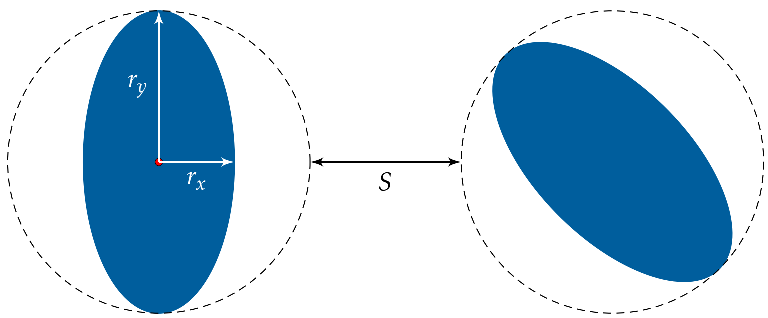


Figure 2.79: *Random ellipse example showing separation (S) between adjacent circular boundaries defined by the radius r_y.*

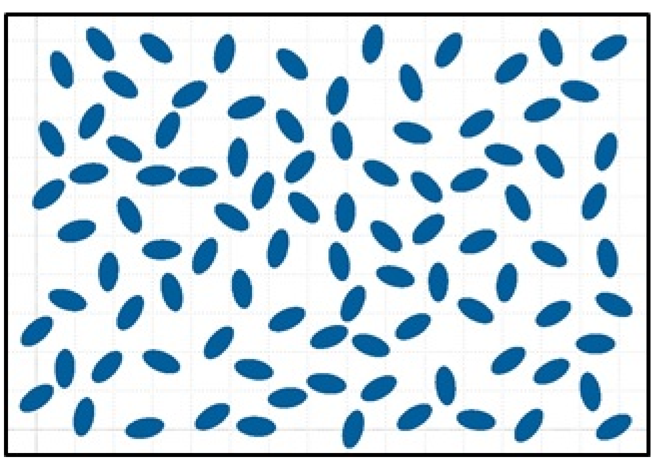


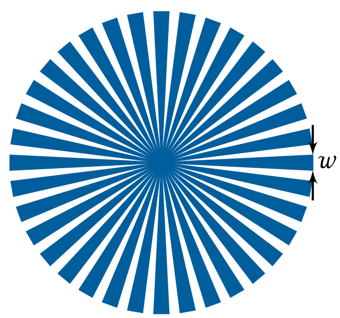
Figure 2.80: *GDS rendered random ellipses with random rotation enabled ($R_R = 1$).*

2.7.13 Resolution Test Pattern

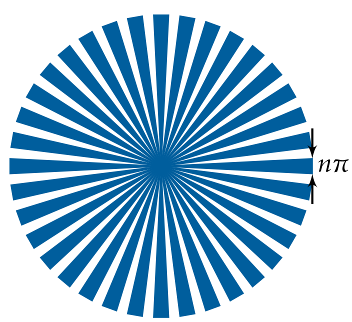
Radial pattern below is useful for characterizing the stigmation of a lithography tool. Using the resoPattern constructor, the structure is defined by the center origin (x, y), radius (r) and width (w). In this scenario, to ensure pattern symmetry, $360/w = i$, where $i = 2, 4, \ldots, n$ is an even positive integer. For even distribution of segments across the $2\pi r$ circumference, i can be any positive integer greater than zero. The second constructor (resoPatternPi) creates a similar figure where the end-segment is an integer of π width.

$x \;\; y \;\; r \;\; w \;\; \theta_{(x,y)}$ **resoPattern**

$x \;\; y \;\; r \;\; n \;\; \theta_{(x,y)}$ **resoPatternPi**



(a)



(b)

Figure 2.81: *Resolution patterns using (a) resoPattern and (b) resoPatternPi constructors.*

Resolution pattern formed using two rows of rectangles of width W, height H, pitch $2W$ and N elements in each row. A text label is placed directly above the array of lines indicating the value of W. The font resolution is defined using the global **shapeReso** parameter. The font height is equal to the value of H (text label in Figure 2.82 is not shown to scale).

$x \quad y \quad W \quad H \quad N \quad \theta_{(x,y)}$ **resoPatternRS**

The following constructor creates arrays of rectangular shaped resolution patterns using a start and end width values (W_s and W_e), with a δ incremental variation. The space between the arrays is defined by the parameter S in micrometer units.

$x \quad y \quad W_s \quad W_e \quad \delta \quad H \quad N \quad S \quad \theta_{(x,y)}$ **resoPatternRSA**

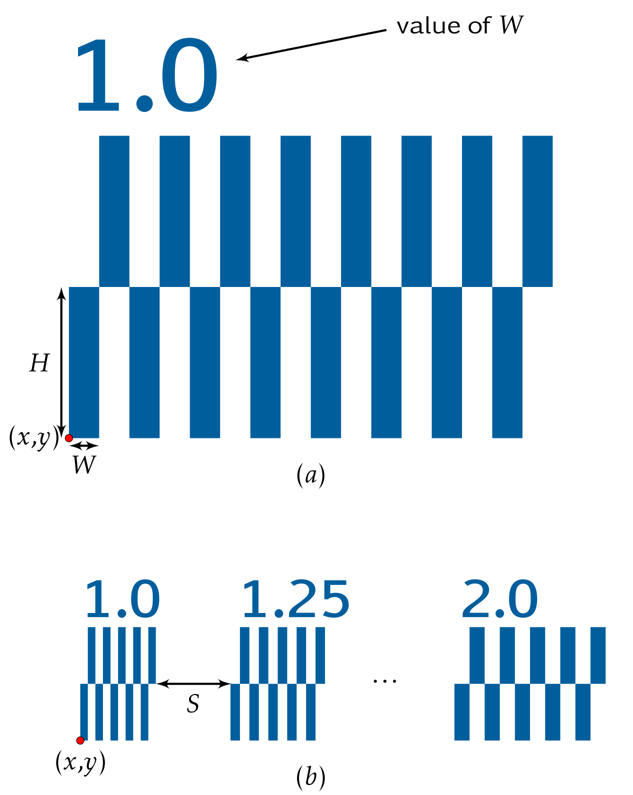


Figure 2.82: *Resolution pattern of rectangular lines using (a)* ***resoPatternRS*** *and (b)* ***resoPatternRSA*** *constructors.*

The following resolution patter is formed using L-shapes of width W, height H, pitch $2W$ and N number of shapes. The maximum number of generated shapes is defined when $W = H$. Text label definition is identical to one described for the **resoPatternRS** constructor (previous example).

$$x \quad y \quad W \quad H \quad N \quad \theta_{(x,y)} \quad \textbf{resoPatternLS}$$

An arrayed version of the above constructor is defined by a start and end width values (W_s and W_e), with a δ incremental variation. The space between the arrays is defined by the parameter S in micrometer units.

$$x \quad y \quad W_s \quad W_e \quad \delta \quad H \quad N \quad S \quad \theta_{(x,y)} \quad \textbf{resoPatternLSA}$$

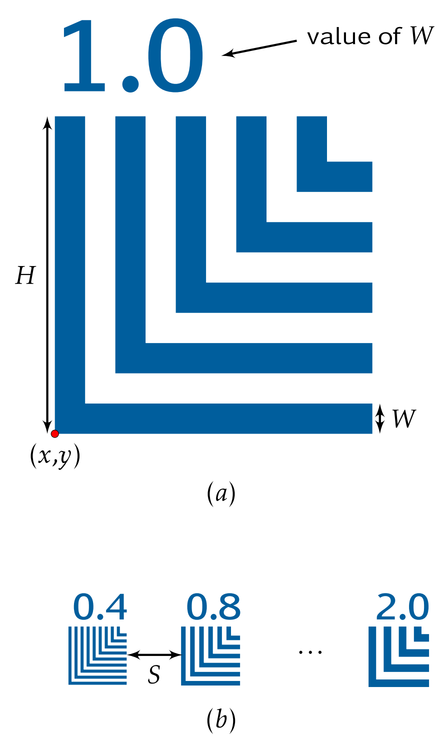


Figure 2.83: *Resolution pattern of rectangular lines using (a) **resoPatternLS** and (b) **resoPatternLSA** constructors.*

2.7.14 Spirals

Spiral objects are characterized by uniform, converging and diverging spacing between subsequent turns. Constant spacing represents an Archimedes spiral where $r = m\theta$, where $m = (separation + width)/(2\pi)$ (Figure 2.84a). *Separation* parameter defines the pitch between subsequent spiral turns. Fermats spiral, defined as $r = \sqrt{a^2\theta}$, is shown in Figure 2.84b. The logarithmic spiral, defined as $r = ae^{b\theta}$, is shown in Figure 2.84c. Center of each spiral is defined by the point (x, y).

x	y	$Width$	N_{turns}	$Separation$		$increment$	spiralArch
x	y	$Width$	N_{turns}	a		$increment$	spiralFermat
x	y	$Width$	N_{turns}	a	b	$increment$	spiralLog

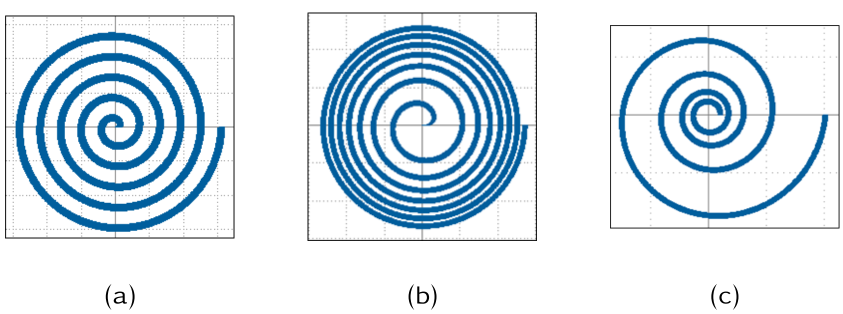


Figure 2.84: *GDS rendered spiral examples. (a) Archimedes (b) Fermat and (c) Logarithmic spiral.*

The following scripts were used to generate the spirals centered around the origin $(x = 0, y = 0)$ in Figure 2.84:

0	0	1.0	5	2.0		0.010	spiralArch
0	0	2.5	7	8		0.010	spiralFermat
0	0	4.4	4	8.0	0.1	0.010	spiralLog

2.7.15 Spiral - Rectangular

Below constructor creates a rectangular spiral of $N_t urns$, of width w, start length L_s and pitch p between turns.

$$x \quad y \quad w \quad L_s \quad p \quad N_{turns} \quad \theta_{(x,y)} \quad \textbf{spiralRect}$$

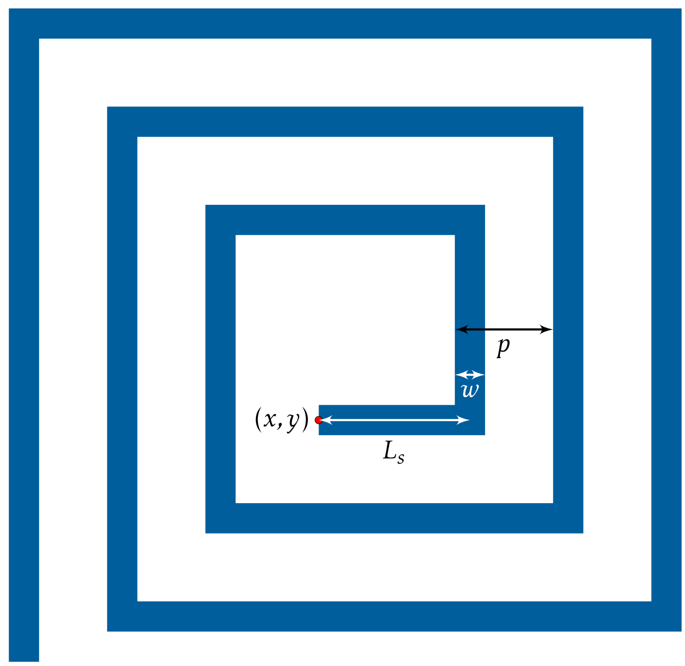


Figure 2.85: *Rectangular spiral.*

2.8 Alignment and Reticle Elements

2.8.1 Alignment Marks - Predefined

The following section includes a variety of predefined, multilevel alignment mark strategies for lithographic applications. Within these methods, alignment mark size and shape values are predefined. The central dark circular aperture within each of the structures defines the (x, y) position. The $\theta_{(x,y)}$ defines the rotation (in degrees) about (x, y).

The following are constructors for two- and three-level alignment marks shown in figures 2.86 and 2.87. L_a, L_b and L_c are integer values $(0-255)$ representing GDS layer numbers. Pattern extents for **alignFFFB1** and **alignFFFB2** alignment patterns in figure 2.86) range from $(-80\mu\text{m}, -80\mu\text{m})$ to $(80\mu\text{m}, 80\mu\text{m})$. For the three-level alignment mark system (**align3Level**), pattern extents range from $(-1000\mu\text{m}, -1000\mu\text{m})$ to $(1000\mu\text{m}, 1000\mu\text{m})$.

<x y L_a L_b $\theta_{(x,y)}$ **alignFFFB1**>

<x y L_a L_b $\theta_{(x,y)}$ **alignFFFB2**>

<x y L_a L_b L_c $\theta_{(x,y)}$ **align3Level**>

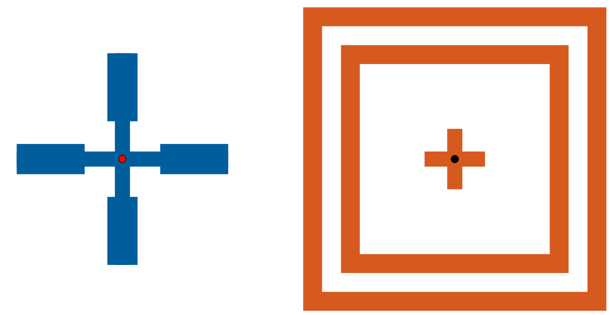
The following defines a constructor for a two level alignment system with verniers and options for tone reversal of layers within a specified region (figure 2.88). As defined above, L_a and L_b are integer values defining the two rendered GDS layer numbers. Parameter $vernReso$ defines the resolution between the two verniers in units of μm. Layers L_a and/or L_b are tone-reversed within an area defined by the inversion length (I_L) and width (I_W) if their respective boolean flags INV_a and INV_b are activated. The boolean inversion parameters are activated using any integer value other than 0. Pattern extents range from $(-900\mu\text{m}, -900\mu\text{m})$ to $(900\mu\text{m}, 900\mu\text{m})$.

<x y L_a L_b $vernReso$ INV_a INV_b I_L I_W $\theta_{(x,y)}$ **alignVern**>

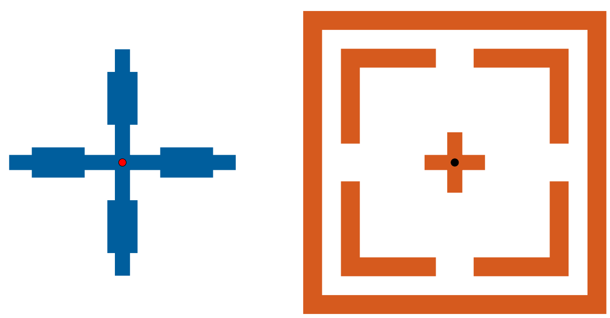
Two-level alignment strategies defined in figure 2.89 contains verniers and GDS layer number labels. As defined directly above, L_a and L_b are GDS layer numbers, and $vernReso$ parameter defines the resolution between the two verniers. **alignVernLb1** pattern extents in range from $(-1000\mu\text{m}, -1000\mu\text{m})$ to $(1000\mu\text{m}, 1000\mu\text{m})$, whereas **alignVernLb2** pattern extents in range from $(-230\mu\text{m}, -230\mu\text{m})$ to $(117\mu\text{m}, 155\mu\text{m})$.

<x y L_a L_b $vernReso$ $\theta_{(x,y)}$ **alignVernLb1**>

<x y L_a L_b $vernReso$ $\theta_{(x,y)}$ **alignVernLb2**>



(a)



(b)

Figure 2.86: *Two level lithography alignment mark strategies constructed using (a)* ***alignFFFB1*** *and (b)* ***alignFFFB2****. Two layers L_a, and L_b are shown separately as blue (left) and orange (right). These methods could be used for front-to-front or front-to-back alignment.*

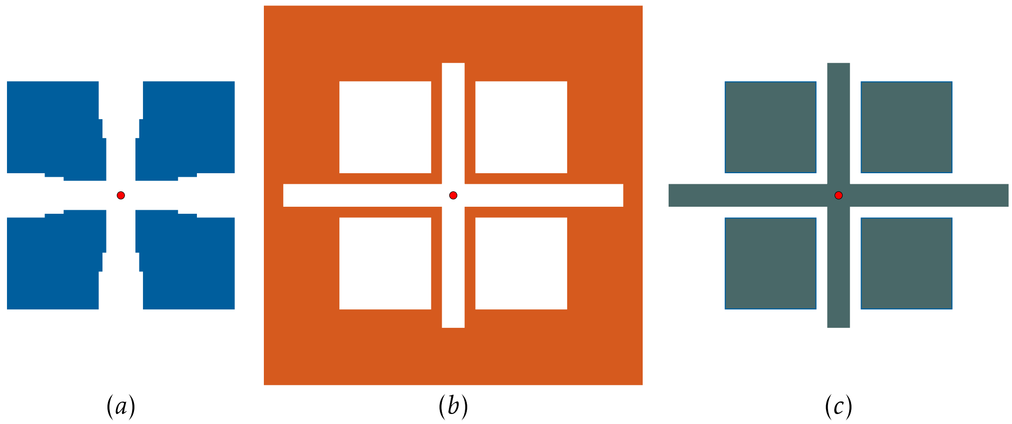


Figure 2.87: *Three-level, front-side, lithography alignment mark strategy constructed using* ***align3Level*** *with layers (a) L_a, (b) L_b and (c) L_c.*

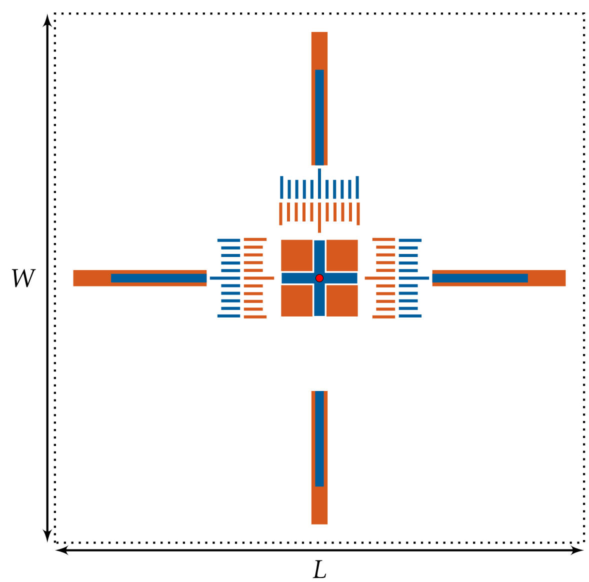
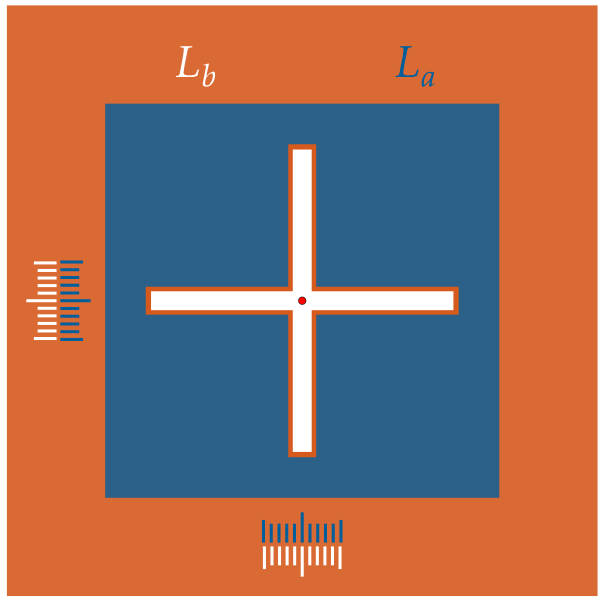
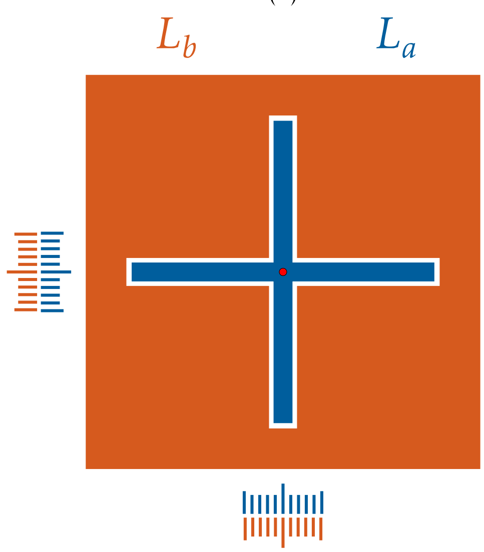


Figure 2.88: *Two-level alignment mark strategy with x and y verniers constructed using* ***alignVern****. Blue and orange layers are L_a and L_b respectively. Length (I_L) and width (I_W) parameters define the region extent used for tone reversal of the specified alignment layers. This method is suitable for conventional overlay lithography applications.*



(a)



(b)

Figure 2.89: *Two-level alignment mark strategies with x and y verniers, and layer labels constructed using (a)* ***alignVernLb1*** *and (b)* ***alignVernLb2****. Blue and orange layers are L_a and L_b respectively. These method is suitable for conventional overlay lithography applications.*

2.8.2 Alignment Marks - Custom

The following section includes 4 types of cross-based marks for multilevel lithographic alignment. Unlike section 2.8.1 with predefined marks, the following mark definitions are fully customizable by user defined parameters. Figure 2.90 shows a small circle at the center of each shape denoting the translation point (x, y). Each shape undergoes a rotation by $\theta_{(x,y)}$ about the center point (x, y). The dotted box of length I_L and width I_W denotes the boundary within which layer inversion takes place. Boolean tone reversal (inversion) is activated by the parameter INV. A value $INV = 0$ signifies that tone reversal within the specified boundary will not take place. Any other integer value for INV will invert the tone of the mark. Layers are set by the usual layer command (see section 2.2.4).

Figure 2.90a shows a simple cross defined by a width (W), a horizontal and vertical length segments (L_1 and L_2).

<$x \quad y \quad L_1 \quad W \quad L_2 \quad INV \quad I_L \quad I_W \quad \theta_{(x,y)}$ alignCustC1>

Figure 2.90b shows a cross of width (W), length (L), paddle length (P_L) and width (P_W).

<$x \quad y \quad L \quad W \quad P_L \quad P_W \quad INV \quad I_L \quad I_W \quad \theta_{(x,y)}$ alignCustC2>

Figure 2.90c shows a cross of width (W), length (L), paddle length (P_L) and width (P_W) offset by a length (L_X) from the edge.

<$x \quad y \quad L_1 \quad W \quad P_L \quad P_W \quad L_X \quad INV \quad I_L \quad I_W \quad \theta_{(x,y)}$ alignCustC3>

Figure 2.90d shows a cross defined by a width (W), a horizontal and vertical length segments (L_1 and L_2), and a rectangle of length (B_L) and width (B_W) at a distance (d) from the cross edge.

<$x \quad y \quad L_1 \quad W \quad L_2 \quad d \quad B_L \quad B_W \quad INV \quad I_L \quad I_W \quad \theta_{(x,y)}$ alignCustC4>

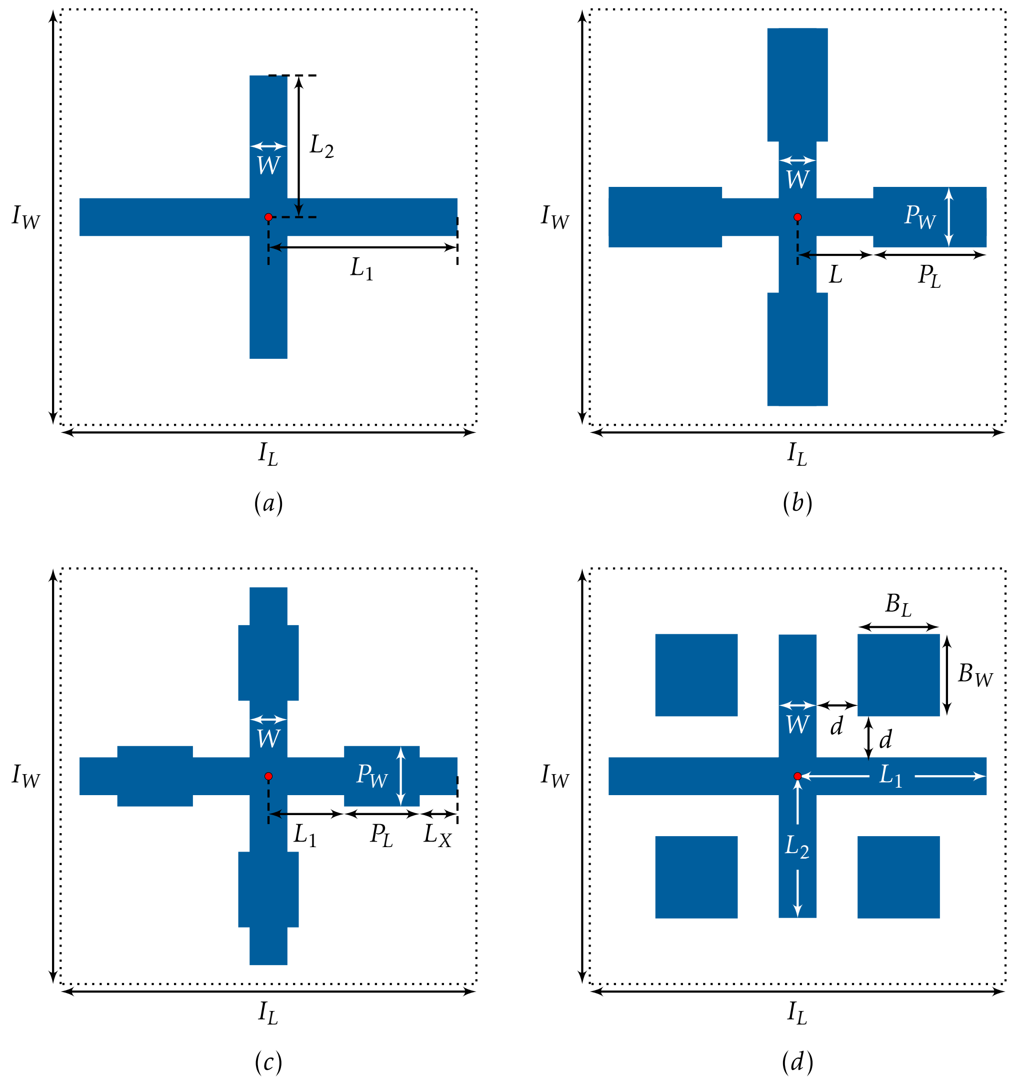


Figure 2.90: *Custom alignment crosses using (a)* ***alignCustC1****, (b)* ***alignCustC2****, (c)* ***alignCustC3****, (d)* ***alignCustC4*** *constructors.*

2.8.3 Reticle Barcode and Label Frames

The following methods create reticle marks, barcodes and labels for the CNST ASMLPAS5500 i-line stepper and reticle labels for contact lithography tools (5 inch and 7 inch). Contact reticle frames contain a label (up to 22 characters) along with a NIST and CNST logos. In all cases MIRROR is parameter that defines if the final structure will be mirrored. Any integer other than 0 will mirror the resulting reticle frame.

CNST ASML PAS5500 stepper frame with reticle marks, barcode, label and logo:

<{{labelText}} {{barCode}} MIRROR **cnstASML**>

Contact Frames:

<{{labelText}} MIRROR **cnstContact5**>

<{{labelText}} MIRROR **cnstContact7**>

Figure 2.91: *CNST ASML PAS5500 reticle frame with MIRROR=* 0.

2.8.4 Vernier

Figure 2.92 shows a vernier structure with a central element of length (L), width (W), and pitch (p). Dotted rectangle of length (I_L) and width (I_W) represent a boundary within which layer tone reversal takes place. With inversion parameters set to 0, i.e. $I_a = 0$ and/or $I_b = 0$, boolean inversion of layers L_a and/or L_b will **not** take place. Any other integer value will invert the pattern within the bounding box. Parameter $vernReso$ defines the resolution of the verniers.

<x y L_a L_b L W p $vernReso$ s I_a I_b I_L I_W $\theta_{(x,y)}$ **alignCustVern**>

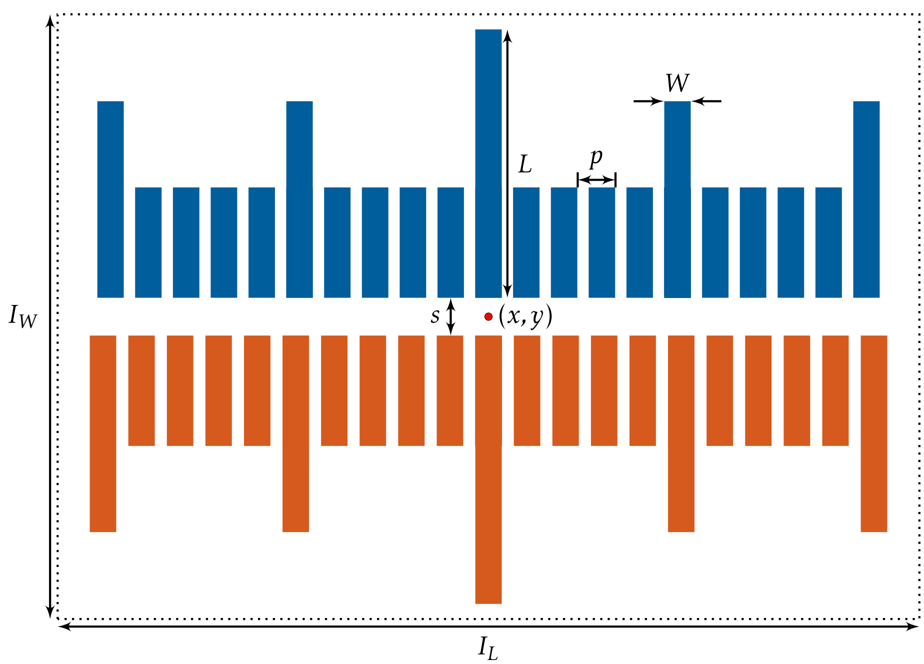


Figure 2.92: *Verniers between layers L_a (blue) and L_b (orange) created using the **alignCustVern** constructor.*

2.8.5 Vernier With Labels

The method constructs verniers between two lithographic levels. Text resolution is set by shapeReso. Text font used is Serif. The verniers are centered at position (x, y). Vernier resolution is in micrometers. The two layer parameters, $LyrA$ and $LyrB$ are GDS layer numbers (integers from 0 to 255), Parameter N_{ticks} represents the total number of vernier bars. Text labels are defined by the $fontSize$ and string parameters $LblA$ and $LblB$. These strings cannot have white characters (spaces/tabs) and are generally short layer descriptions. The width, length and pitch parameters define the vernier bars.

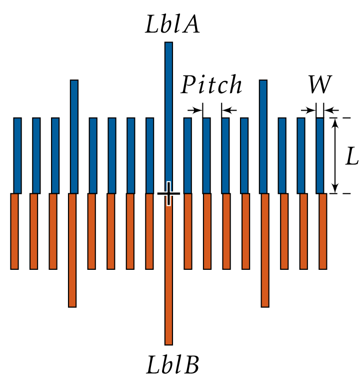


Figure 2.93: *Example of the* ***veniers*** *constructor illustrating parameters between two layers.*

<$x\ \ y\ \ LyrA\ \ LyrB\ \ vernierReso\ \ N_{ticks}\ \ LblA\ \ LblB\ \ fontSize\ \ W\ \ L\ \ Pitch$ verniers>

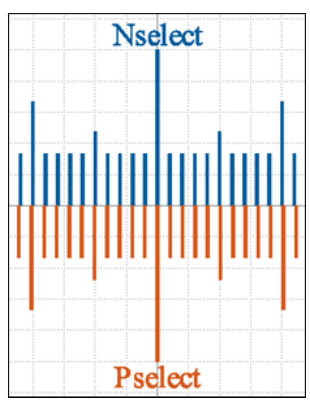


Figure 2.94: *GDS rendered output of the* ***verniers*** *example between two lithographic levels.*

2.8.6 Arrows

This method constructs arrow structures that are useful in a variety of lithographic applications including labeling features and as an aid in finding features of interest, for instance, arrows pointing towards alignment marks or small, isolated devices. Each constructor is defined by parameters in the below table. An isolated arrow head is used to construct the **arrow** element. Constructor **arrowArray** defines a linear array of N **arrow** features.

<x	y	W_a	L_a	W			$\theta_{(x,y)}$	arrowHead>
<x	y	W_a	L_a	W	L		$\theta_{(x,y)}$	arrow>
<x	y	W_a	L_a	W	L	N	$\theta_{(x,y)}$	arrowArray>

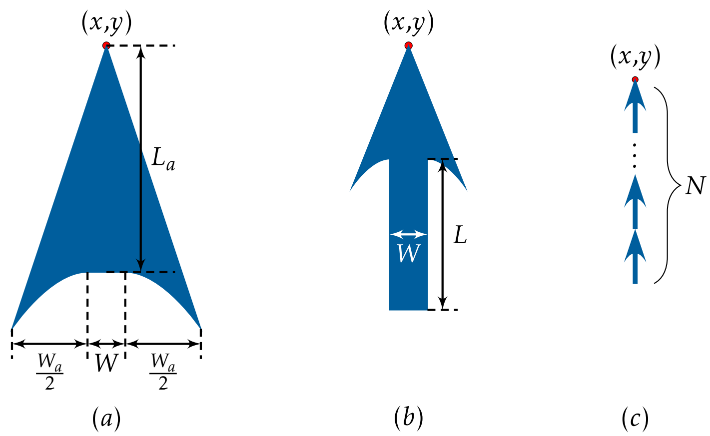


Figure 2.95: *Example shapes illustrating various parameters from the (a) **arrowHead**, (b) **arrow** and (c) **arrowArray** constructors.*

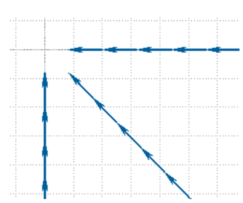


Figure 2.96: *Rendered GDS file example with **arrowArray** structures.*

2.9 CNST Nanophotonics Library

This section contains a variety of shapes commonly encountered nanophotonic applications. Many of these shapes (tapers, S-bends, Y-bends, etc) could be used for micro- and nano-fluidics, MEMS/NEMS and other fields of applied sciences. Each element has several constructor definitions, allowing the user to create structures using either positive or negative tone resists. Additionally, constructors allow for addition of endcaps at the structural termination points. This in turn alleviates stresses at sharp field crowding corners, thereby preventing undesired formation of stress cracks. Figure 2.97 shows an example of 600 nm patterned ZEP layer on top of 700 nm stoichiometric silicon nitride deposited using low pressure chemical vapor deposition. In this case, cracks initiated at the sharp edges within the nitride layer during the reactive ion etch step (figure 2.97a, b). The dilemma was circumvented by corner rounding (figure 2.97c, d).

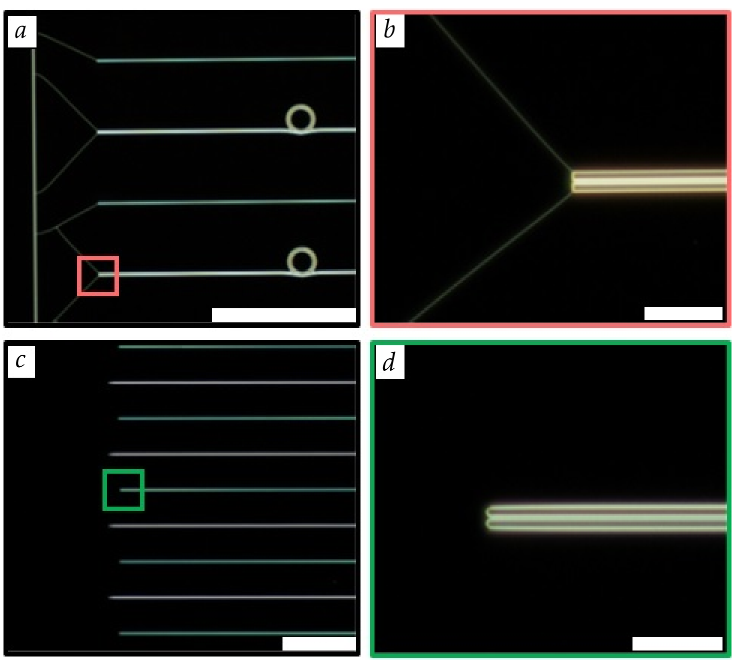


Figure 2.97: *Silicon nitride waveguides with square ((a) and (b)) and rounded corners ((c) and (d)). Waveguides with square corners show cracks initiating at the waveguide edges. Waveguides with rounded corners alleviate stresses at sharp corners, thereby preventing cracks formation. Scale bar in (a) and (c) represents $250\mu m$ and in (b) and (d) represents $20\mu m$.*

2.9.1 Waveguides

2.9.1.1 Waveguide

This method is useful when creating waveguides with a negative tone resist. Rectangular shape characterized by start point (x_1, y_1), end point (x_2, y_2), width (W) and rotation about point (x_1, y_1). The waveguide is defined in the horizontal direction, condition i.e. $x_1 = x_2$ must be satisfied. For vertical waveguides, choose $\theta_{(x_1,y_1)} = 90$. Waveguide endcaps are defined by parameters EC_{left} and EC_{right}. Endcap values of 0 and 1 correspond to slot waveguides without and with endcaps.

<x_1 y_1 x_2 y_2 W $\theta_{(x_1,y_1)}$ EC_{left} EC_{right} **waveguide**>

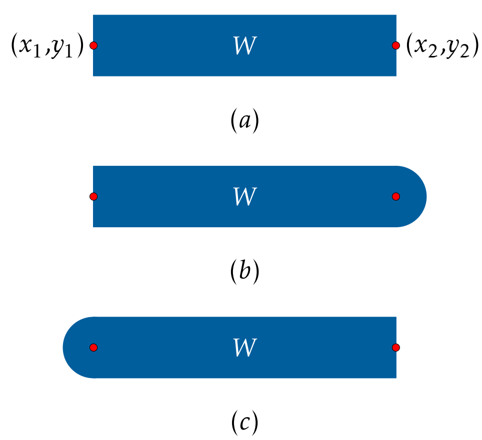


Figure 2.98: *Waveguide example using the* **waveguide** *constructor. The method is beneficial when creating waveguides from a negative tone resist. Waveguides examples (a) without endcaps ($E_{left} = E_{right} = 0$), (b) with left end cap ($E_{left} = 1, E_{right} = 0$), (c) with right endcap ($E_{left} = 0, E_{right} = 1$).*

2.9.1.2 Waveguide Slot

This method is useful when creating slot waveguides with a negative tone resist. Positive-tone resist exposure creates a waveguide of width W_{slot}. The shape characterized by start point (x_1, y_1), end point (x_2, y_2), waveguide width (W), slot width (W_{slot}) and rotation about point (x_1, y_1). The waveguide is defined in the horizontal direction, condition i.e. $x_1 = x_2$ must be satisfied. For vertical waveguides, choose $\theta_{(x_1,y_1)} = 90$. Waveguide endcaps are defined by parameters EC_{left} and EC_{right}. Endcap values of 0 and 1 correspond to slot waveguides without and with endcaps.

<x_1 y_1 x_2 y_2 W W_{slot} $\theta_{(x_1,y_1)}$ EC_{left} EC_{right} **waveguideSlot**>

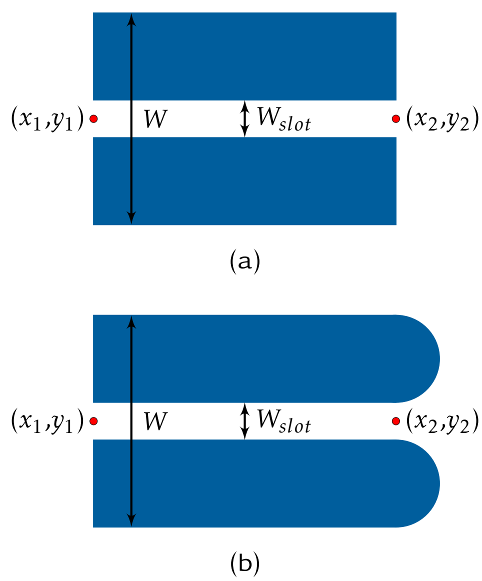
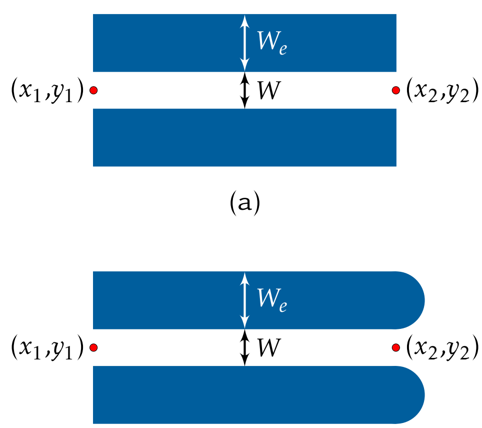


Figure 2.99: *Slot waveguide example using the* **waveguideSlot** *constructor. The method is beneficial when creating waveguides from a negative tone resist. Positive-tone resist exposure creates a waveguide of width W_{slot}. Slot waveguide examples (a) without endcaps ($E_{left} = E_{right} = 0$), (b) with right end cap ($E_{left} = 0, E_{right} = 1$).*

2.9.1.3 Waveguide Inverse

This method is useful when creating waveguides with a positive tone resist. The shape characterized by start point (x_1, y_1), end point (x_2, y_2), waveguide width (W), exposed sleeve width (W_e) and rotation about point (x_1, y_1). The waveguide is defined in the horizontal direction, condition i.e. $y_1 = y_2$ must be satisfied. For vertical waveguides, choose $\theta_{(x_1,y_1)} = 90$. Waveguide endcaps are defined by parameters EC_{left} and EC_{right}. Endcap values of 0 and 1 correspond to slot waveguides without and with endcaps.

<x_1 y_1 x_2 y_2 W W_e $\theta_{(x_1,y_1)}$ EC_{left} EC_{right} **waveguideInv>**



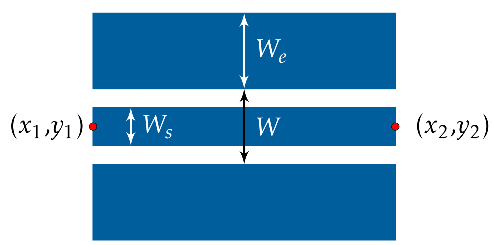
(b)

Figure 2.100: *Waveguide example using the* **waveguideInv** *constructor. The method is beneficial when creating waveguides from a positive tone resist. Inverse waveguide examples (a) without endcaps ($E_{left} = E_{right} = 0$), (b) with right end cap ($E_{left} = 0, E_{right} = 1$).*

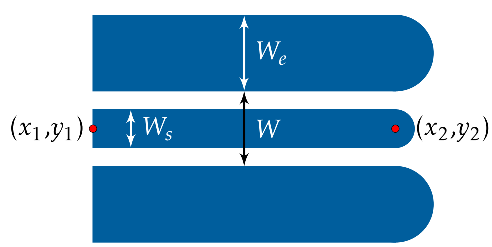
2.9.1.4 Waveguide Inverse Slot

This method is useful when creating slot waveguides with a positive tone resist. The shape characterized by start point (x_1, y_1), end point (x_2, y_2), waveguide width (W), slot width (W_s), exposed sleeve width (W_e) and rotation about point (x_1, y_1). The waveguide is defined either in the horizontal or vertical direction, condition i.e. $x_1 = x_2$ must be satisfied.

<x_1 y_1 x_2 y_2 W W_s W_e $\theta_{(x_1,y_1)}$ EC_{left} EC_{right} **waveguideInvSlot**>



(a)



(b)

Figure 2.101: *Inverse slot waveguide example using the* **waveguideInvSlot** *constructor. The method is beneficial when creating waveguides from a positive tone resist. Inverse slot waveguide examples (a) without endcaps ($E_{left} = E_{right} = 0$), (b) with right end cap ($E_{left} = 0, E_{right} = 1$).*

2.9.1.5 Waveguide Expander

The waveguide expander is defined by width w, length L, length division ΔL, TE mode angle θ, beam waist w_0, wavelength λ, base height b_H and two dimensionless parameters a and b. Wavelength λ is represented in nanometers. All other parameters $(L, \Delta L, w, w_0, b_H)$are in micrometers. The variable gap is defined by

$$g(x) = \frac{1}{b} ln\left(\frac{2\lambda\pi^{1.5}}{aw} exp\left(\frac{\frac{-x^2}{w^2}}{1 - erf(\frac{x}{w})}\right)\right) \tag{2.10}$$

where

$$w = \frac{w_0}{\sin\theta} \tag{2.11}$$

<x y w L ΔL a b θ w_0 λ b_H $\theta_{(x,y)}$ **wgExpander**>

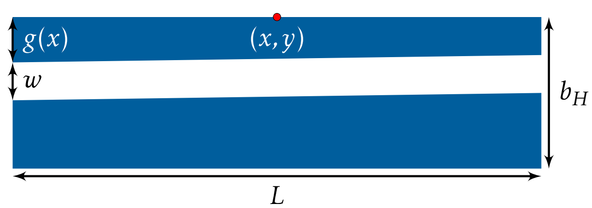


Figure 2.102: *Waveguide expander*

2.9.2 Tapers

2.9.2.1 Linear Taper

The linear waveguide taper method is beneficial with negative tone resists. Trapezoidal shape characterized by start point (x_1, y_1), end point (x_2, y_2), width at start (W_1) and end (W_2) points, and rotation about point (x_1, y_1). The linear taper shape is defined either in the horizontal or vertical direction, condition i.e. $x_1 = x_2$ or $y_1 = y_2$ must be satisfied.

<x_1 y_1 x_2 y_2 W_1 W_2 $\theta_{(x_1,y_1)}$ linearTaper>

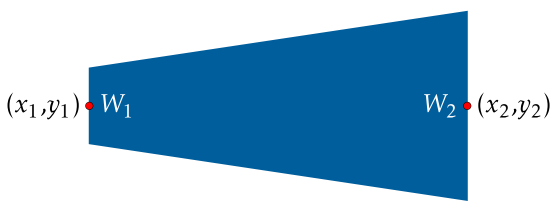


Figure 2.103: *Linear waveguide taper generated using the **linearTaper** constructor. Structure is useful with negative tone resists.*

2.9.2.2 Linear Taper Slot

The slot linear waveguide taper is beneficial with negative tone resists. With positive tone resists, this structure would result in a tapered waveguide structure. Trapezoidal shape characterized by start point (x_1, y_1), end point (x_2, y_2), width at start (W_1) and end (W_2) points, slot width at start (W_{s1}) and end (W_{s2}) points, and rotation about point (x_1, y_1). The linear taper shape is defined either in the horizontal or vertical direction, condition i.e. $x_1 = x_2$ or $y_1 = y_2$ must be satisfied.

<$x_1 \quad y_1 \quad x_2 \quad y_2 \quad W_1 \quad W_2 \quad W_{s1} \quad W_{s2} \quad \theta_{(x_1,y_1)}$ **linearTaperSlot**>

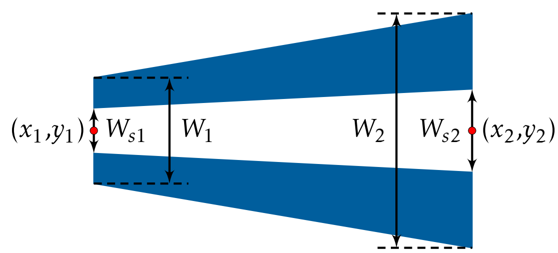


Figure 2.104: *Linear taper slot waveguide structure created using the **linearTaperSlot** constructor. Structure is useful with negative tone resists. Positive tone resists generate a tapered waveguide structure of start and end with of W_{s1} and W_{s3} respectively.*

2.9.2.3 Linear Taper Inverse Slot

The inverse slot linear waveguide taper is beneficial with negative tone resists. With positive tone resists, this structure would result in a tapered slot waveguide structure. Trapezoidal shape characterized by start point (x_1, y_1), end point (x_2, y_2), width at start (W_1) and end (W_2) points, slot width at start (W_{s1}) and end (W_{s2}) points, gap (g), and rotation about point (x_1, y_1). The linear taper shape is defined either in the horizontal or vertical direction, condition i.e. $x_1 = x_2$ or $y_1 = y_2$ must be satisfied.

<x_1 y_1 x_2 y_2 W_1 W_2 g W_{s1} W_{s2} $\theta_{(x_1,y_1)}$ **linearTaperInvSlot**>

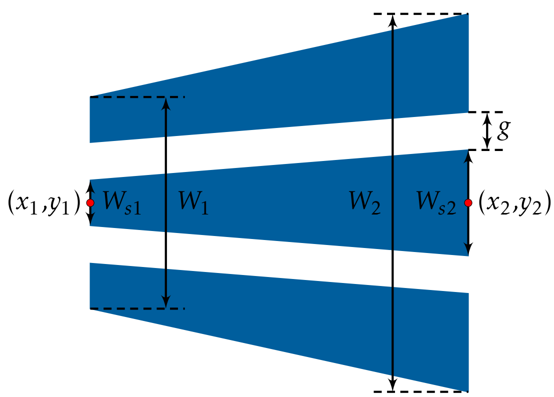


Figure 2.105: *Example of the* ***linearTaper*** *constructor.*

2.9.2.4 Exponential Taper

Tapered shape characterized by a width (W_1) at start point (x_1, y_1) exponentially increasing to (W_2) at a length L from (x_1, y_1), and rotation about point (x_1, y_1). The exponential curve is constructed from N segments.

<x_1 y_1 L W_1 W_2 N $\theta_{(x_1,y_1)}$ exponentialTaper>

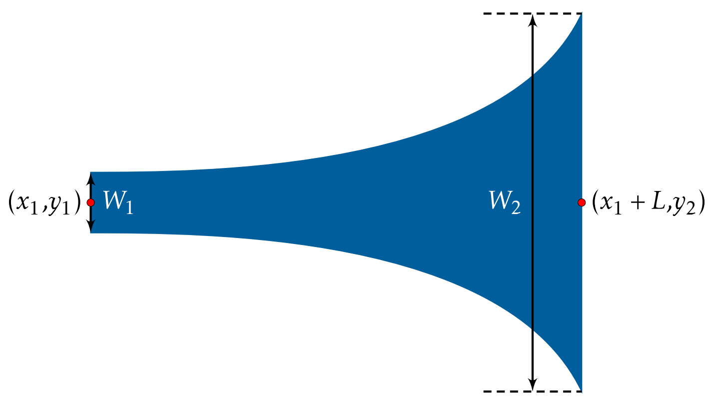


Figure 2.106: *Example of the exponentialTaper constructor.*

2.9.2.5 Exponential Taper Inverse

Tapered shape characterized by a width (W_1) at start point (x_1, y_1) exponentially increasing to (W_2) at a length L from (x_1, y_1), exposed sleeve width (W_e) and rotation about point (x_1, y_1). The exponential curve is constructed from N segments.

<x_1 y_1 L W_1 W_2 N W_e $\theta_{(x_1,y_1)}$ exponentialTaperInv>

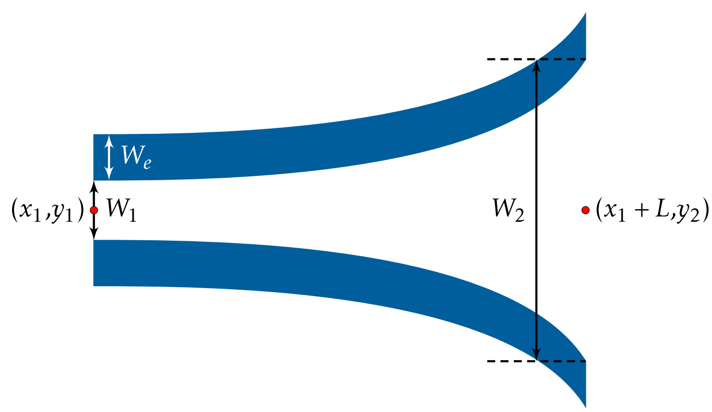


Figure 2.107: *Tapered exponential shape created using the* ***exponentialTaperInv*** *constructor.*

2.9.2.6 Exponential Taper Inverse Slot

Tapered shape characterized by a width (W_1) at start point (x_1, y_1) exponentially increasing to (W_2) at a length L from (x_1, y_1), start and end slot widths (W_{s1} and W_{s2}), exposed sleeve width (W_e) and rotation about point (x_1, y_1). The exponential curve is constructed from N segments.

<x_1 y_1 L W_1 W_2 N W_e W_{s1} W_{s2} $\theta_{(x_1,y_1)}$ exponentialTaperInvSlot>

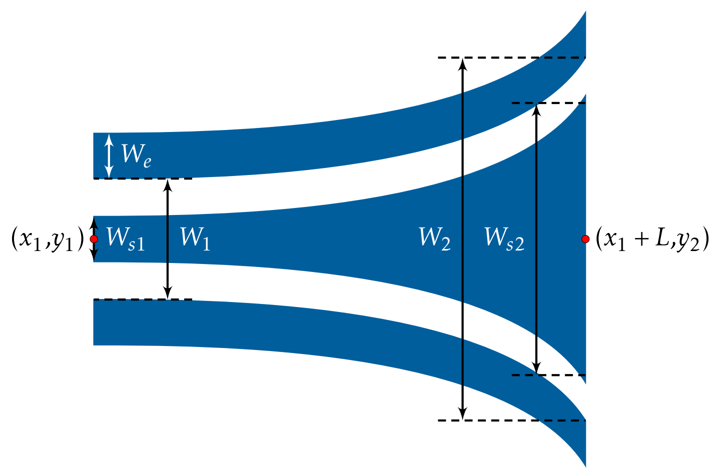


Figure 2.108: *Tapered exponential slot waveguide shape created using the* ***exponentialTaperInvSlot*** *constructor.*

2.9.2.7 Custom Taper

Custom tapered shape characterized by user-defined (x, y) coordinates. Points (x1, y1) to (xn, yn) are generated (top portion of the curve) and mirrored around y = 0, closing the tapered shape that's translated to (T_x, T_y) and rotated about the translation point $\theta_{(T_x,T_y)}$.

$x_1 \quad y_1 \quad x_2 \quad y_2 \quad \cdots \quad x_n \quad y_n \quad T_x \quad T_y \quad \theta_{(T_x,T_y)}$ **customTaper**

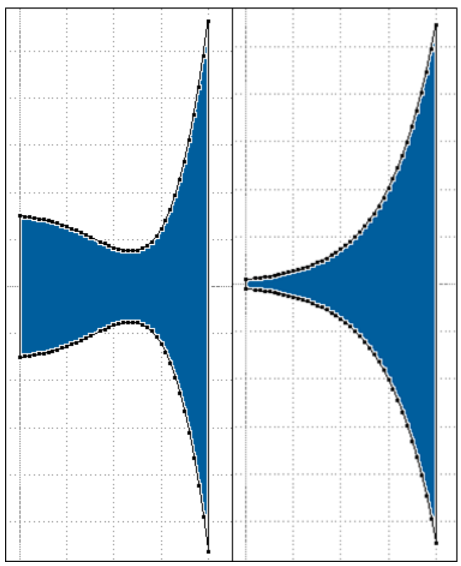


Figure 2.109: *Two example GDS shapes of the **customTaperExamples** constructor with highlighted user defined vertices.*

2.9.3 Couplers

2.9.3.1 Directional Couplers

<x y L_1 w_1 w_{e1} L_2 L_3 w_2 w_{e2} g r N_{sides} $\theta_{(x,y)}$ **directionalCoupler1**>

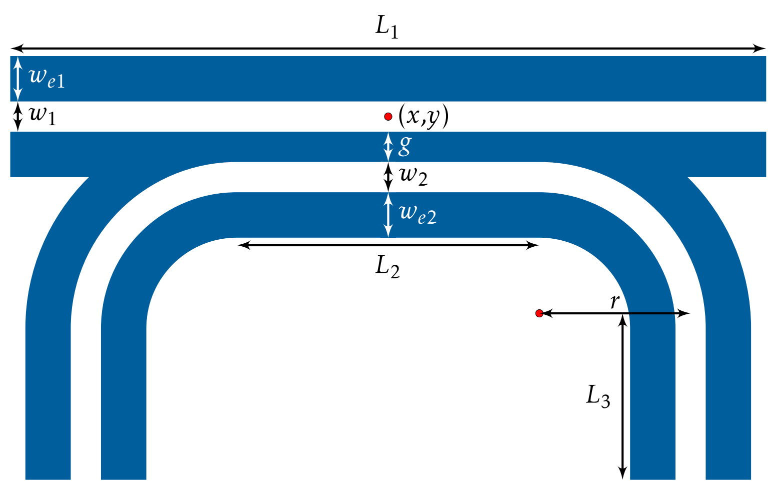


Figure 2.110: *Directional coupler example using the **directionalCoupler1** constructor.*

<x y L_1 w_1 w_{e1} L_2 L_3 w_2 w_{e2} g r N_{sides} $\theta_{(x,y)}$ **directionalCoupler2**>

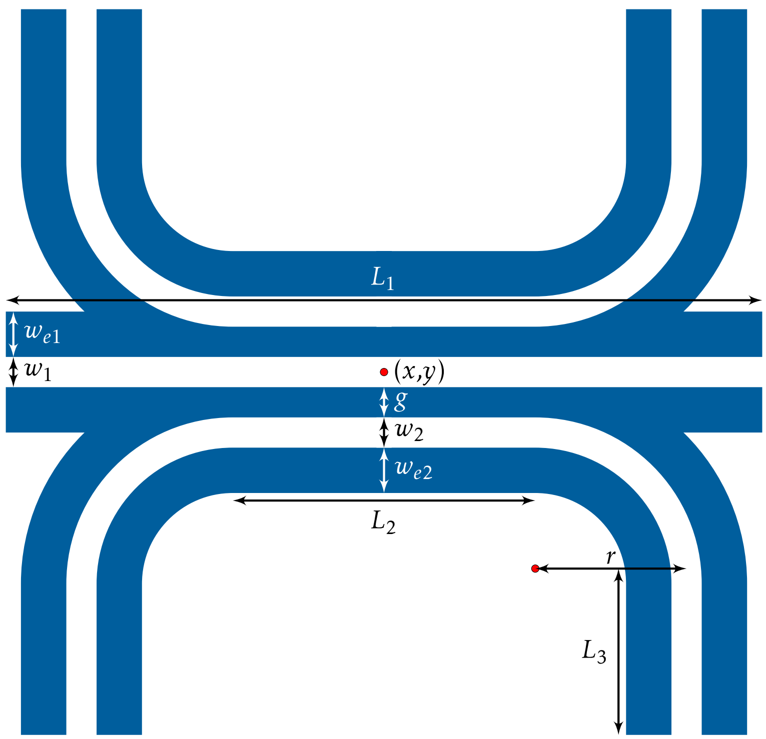


Figure 2.111: *Directional coupler example using the* ***directionalCoupler2*** *constructor.*

<x y w w_e g L_1 L_2 r N_{sides} $\theta_{(x,y)}$ directionalCoupler3>

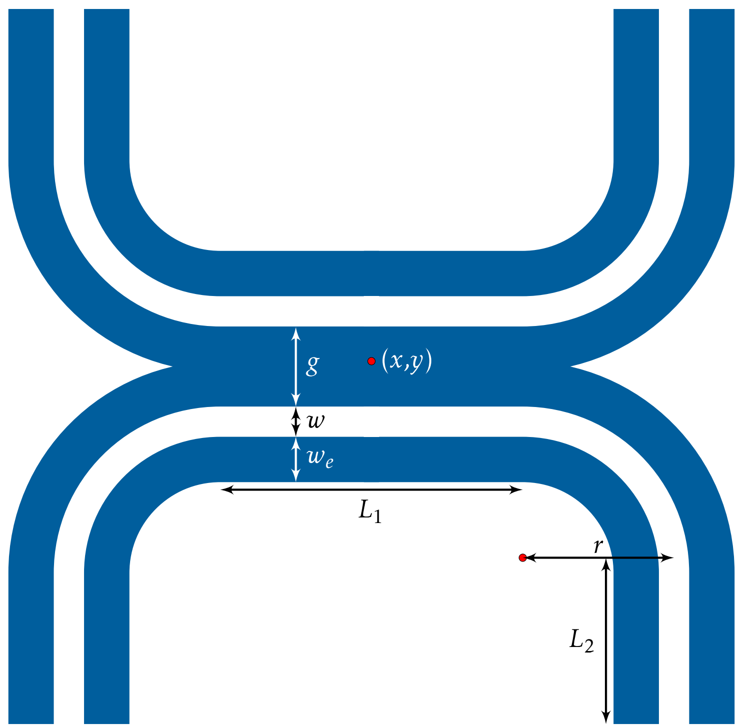


Figure 2.112: *Directional coupler example using the **directionalCoupler3** constructor.*

<x y w w_e g L_1 L_B H_B $\theta_{(x,y)}$ **directionalCoupler4**>

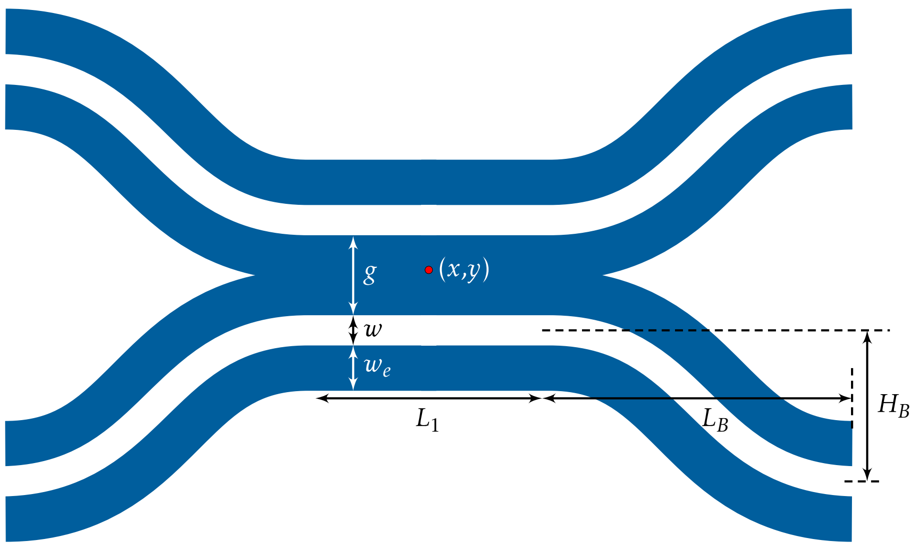


Figure 2.113: *Directional coupler example using the **directionalCoupler4** constructor.*

2.9.3.2 S-Bend Taper

S-Bend taper is characterized by the start coordinate (x, y), length (L), height (H), start (W_{start}) and end (W_{end}) waveguide widths, and rotation about point (x, y). **shapeReso** parameter defines the rendering resolution of the S-bend (Bezier based) curve.

<x y L H W_{start} W_{end} $\theta_{(x,y)}$ **sBendTaper**>

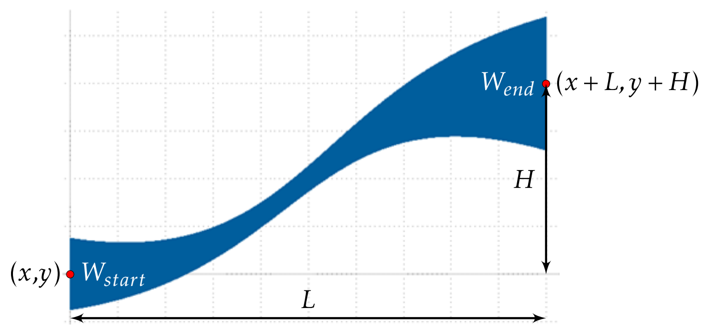


Figure 2.114: *An example GDS shape of the* ***sBendTaper*** *constructor.*

2.9.3.3 S-Bend Funnel

S-Bend funnel is characterized by the start coordinate (x, y), length (L), height (H), start (W) and rotation about point (x, y). **shapeReso** parameter defines the rendering resolution of the S-bend (Bezier based) curve.

<x y L H W $\theta_{(x,y)}$ **sBendFunnel**>

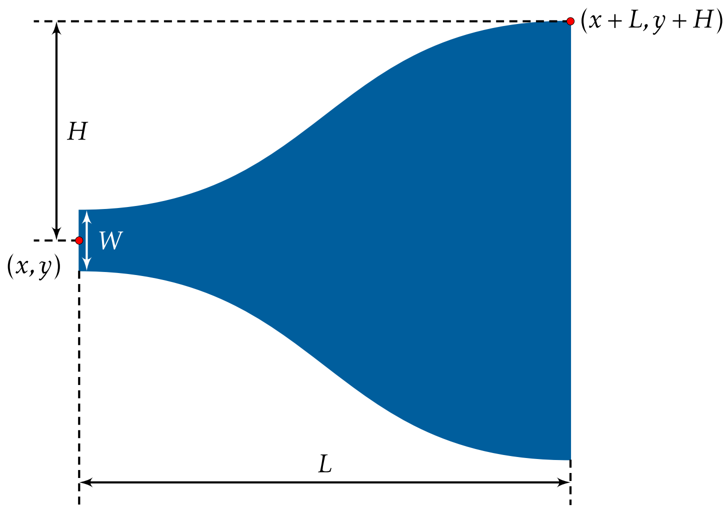


Figure 2.115: *Schematic illustration showing various parameters from the* ***sBendFunnel*** *constructor.*

2.9.3.4 S-Bend

S-Bends are Bezier curves characterized by two constructors. First consists of the start (x_1, y_1) and end (x_2, y_2) points. The second is characterized by the start point (x_1, y_1), length (L) and height (H) parameters. Both constructors are characterized by a waveguide width (W) and the rotation about the start point (x_1, y_1). shapeReso parameter defines the rendering resolution of the S-bend (Bezier based) curve. Both L and H parameters are defined by positive and negative double precision values relative to the start coordinate point (x_1, y_1). For instance, a negative value of H would place the end point at $y_1 - H$.

<x_1 y_1 x_2 y_2 W $\theta_{(x_1,y_1)}$ sBend>

<x_1 y_1 L H W $\theta_{(x_1,y_1)}$ sBendLH>

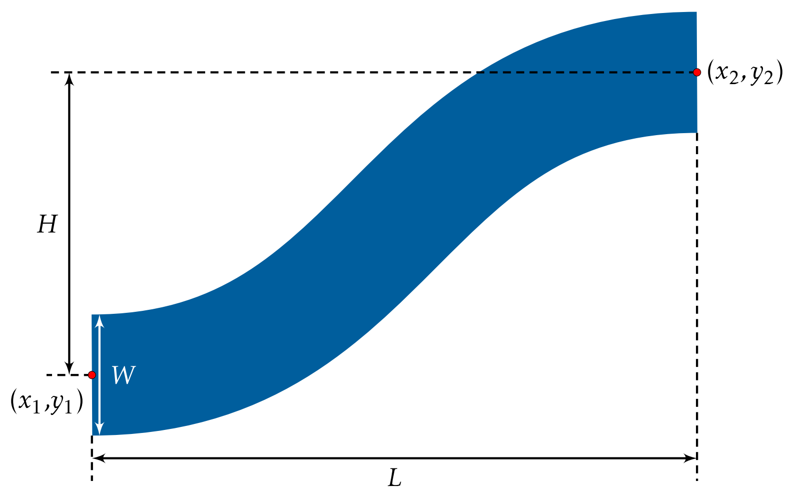


Figure 2.116: *An example S-Bend GDS shape illustrating various parameters from the two sBend constructors.*

2.9.3.5 S-Bend Inverse

Similar to S-Bends (section 2.9.3.4), **sBendInv** constructor is used to create s-bend waveguides using a positive tone resist. Alternatively, using a negative tone resist, a slot-waveguide of width $W + W_e$ and a slot of width W is constructed. The shape is characterized by the start point (x_1, y_1), length (L), height (H), waveguide width (W), exposure sleeve width (W_e) and the rotation about the start point (x_1, y_1). **shapeReso** parameter defines the rendering resolution of the S-bend (Bezier based) curve. Both L and H parameters are defined by positive and negative double precision values relative to the start coordinate point (x_1, y_1). For instance, a negative value of H would place the end point y value at $y_1 - H$.

<x_1 y_1 L H W W_e $\theta_{(x_1,y_1)}$ **sBendInv**>

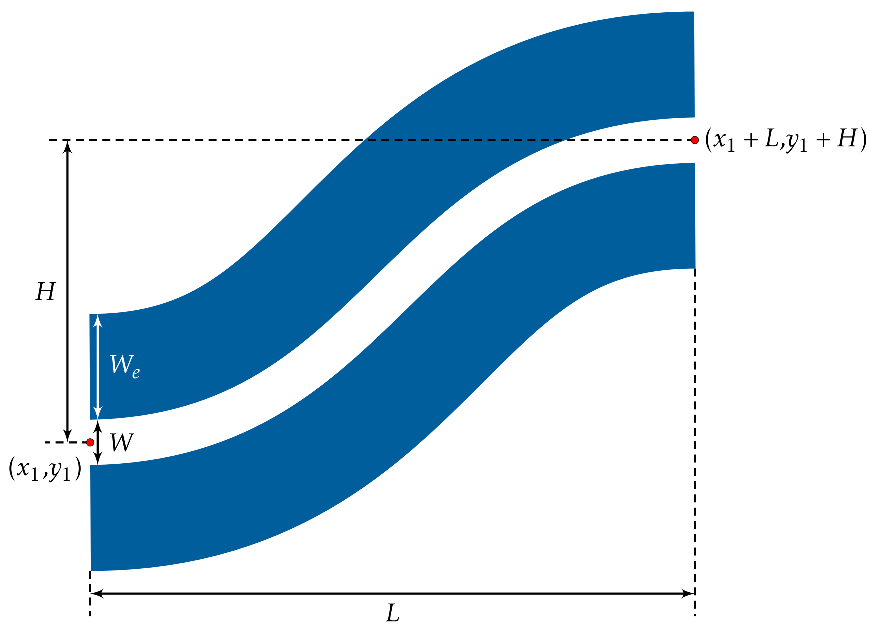


Figure 2.117: *Schematic illustration showing various parameters from the **sBendInv** constructor.*

2.9.3.6 S-Bend Inverse Slot

Similar to S-Bends (section 2.9.3.4), **sBendInvSlot** constructor is used to create s-bend slot waveguides using a positive tone resist. The shape is characterized by the start point (x_1, y_1), length (L), height (H), slot width (W_s), gap (g), exposure sleeve width (W_e) and the rotation about the start point (x_1, y_1) parameters. **shapeReso** parameter defines the rendering resolution of the S-bend (Bezier based) curve. Both L and H parameters are defined by positive and negative double precision values relative to the start coordinate point (x_1, y_1). For instance, a negative value of H would place the end point y value at $y_1 - H$.

<x_1 y_1 L H W_s g W_e $\theta_{(x_1,y_1)}$ **sBendInvSlot**>

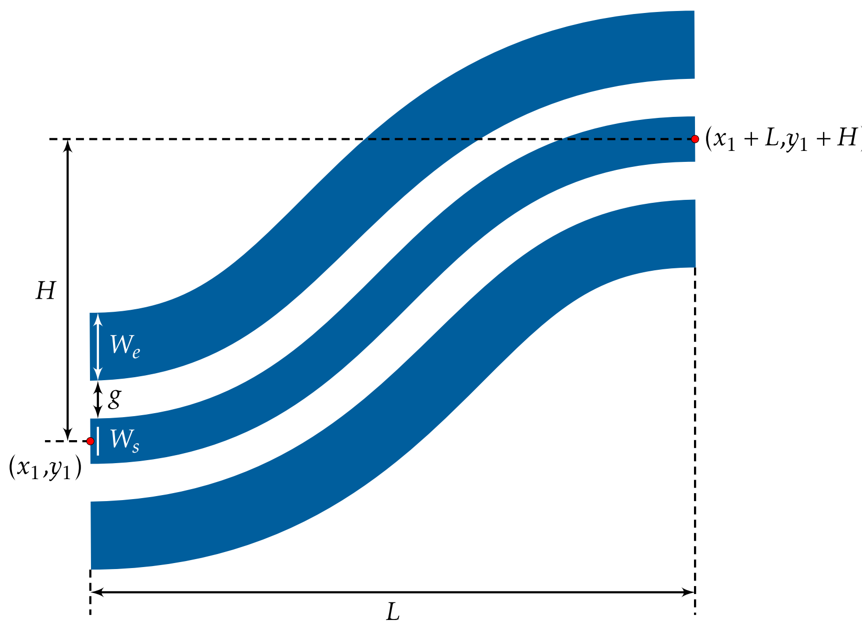


Figure 2.118: *Schematic illustration showing various parameters from the* ***sBendInvSlot*** *constructor.*

2.9.3.7 Y-Bend

Y-Bends are constructed by merging two S-Bend curves. Similarly to the S-Bend curve defined in the section 2.9.3.4, Y-Bends are characterized by two constructors. First consists of the start (x_1, y_1) and two end (x_2, y_2) points $((x_2, y_2)$ and $(x_3, y_3))$. The second is characterized by the start point (x_1, y_1), pair of length (L_2 and L_3) and pair of height (H_2 and H_3) parameters. Both constructors are characterized by a waveguide width (W) and the rotation about the start point (x_1, y_1). **shapeReso** parameter defines the rendering resolution of the Y-bend (Bezier based) curve. The length and height parameters are defined by positive and negative double precision values relative to the start coordinate point (x_1, y_1). For instance, a negative value of H_3 would place the end point y value at $y_1 - H_3$. Figure 2.119 shows a negative H_3 value.

<x_1 y_1 x_2 y_2 x_3 y_3 W $\theta_{(x_1,y_1)}$ **yBend>**

<x_1 y_1 L_2 H_2 L_3 H_3 W $\theta_{(x_1,y_1)}$ **yBendLH>**

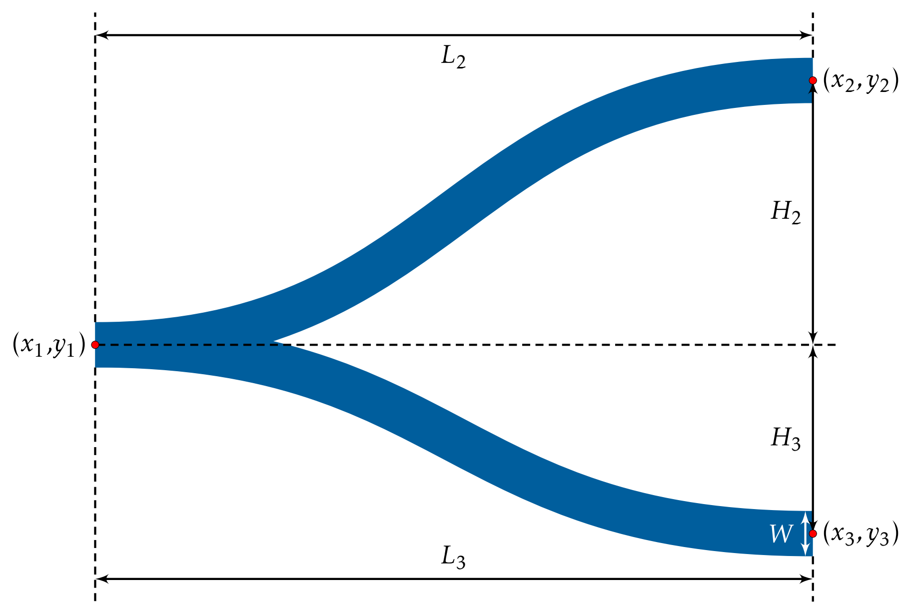


Figure 2.119: *An example Y-Bend GDS shape illustrating various parameters from the two yBend constructors.*

2.9.3.8 Y-Bend Inverse

Similar to Y-Bends (section 2.9.3.7), **yBendInv** constructor is used to create a y-bend waveguide bifurcation using a positive tone resist. Alternatively, using a negative tone resist, a slot-waveguide of width $W + W_e$ and a slot of width W is constructed. The shape characterized is characterized by the start coordinate point (x_1, y_1), a pair of lengths (L_2 and L_3), a pair of heights (H_2 and H_3), waveguide width (W), exposure sleeve (W_e) and the rotation about the start point (x_1, y_1) parameters. **shapeReso** parameter defines the rendering resolution of the Y-bend (Bezier based) curve. Both length and height parameters are defined by positive and negative double precision values relative to the start coordinate point (x_1, y_1). For instance, a negative value of H_3 would place the end point y value at $y_1 - H_3$, hence value of H_3 value in Figure 2.120 is negative .

<x_1 y_1 L_2 H_2 L_3 H_3 W W_e $\theta_{(x_1,y_1)}$ **yBendInv>**

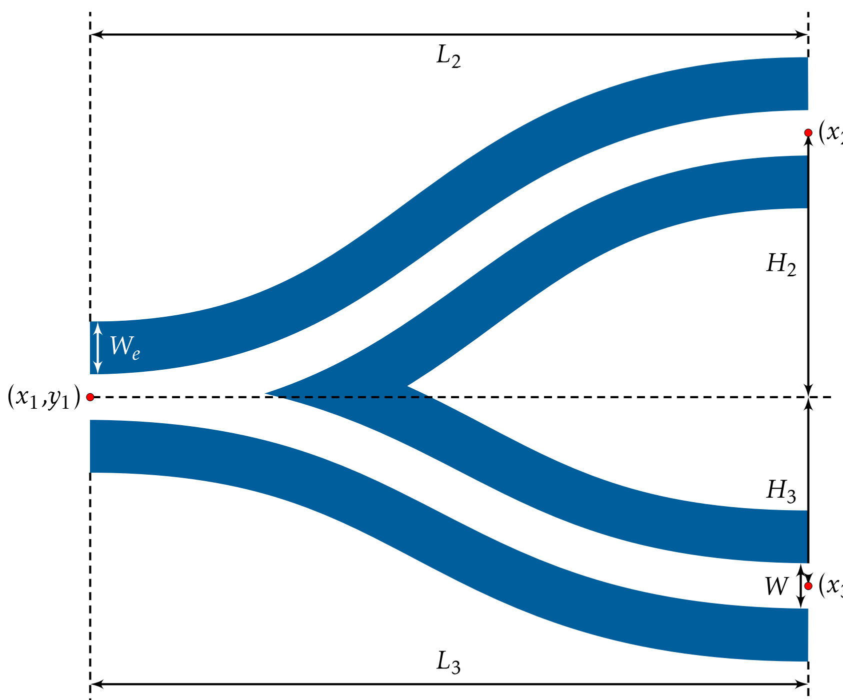


Figure 2.120: *Schematic illustration showing various parameters from the* ***yBendInv*** *constructor.*

2.9.3.9 Y-Bend Inverse Slot

Similar to Y-Bends (section 2.9.3.7), **yBendInv** constructor is used to create a y-bend slot waveguide bifurcation using a positive tone resist. The shape characterized is characterized by the start coordinate point (x_1, y_1), a pair of lengths (L_2 and L_3), a pair of heights (H_2 and H_3), slot width (W_s), gap (g), exposure sleeve width (W_e) and the rotation about the start point (x_1, y_1) parameters. **shapeReso** parameter defines the rendering resolution of the Y-bend (Bezier based) curve. Both length and height parameters are defined by positive and negative double precision values relative to the start coordinate point (x_1, y_1). For instance, a negative value of H_3 would place the end point y value at $y_1 - H_3$, hence value of H_3 value in Figure 2.121 is negative .

<x_1 y_1 L_2 H_2 L_3 H_3 W_s g W_e $\theta_{(x_1,y_1)}$ **yBendInvSlot>**

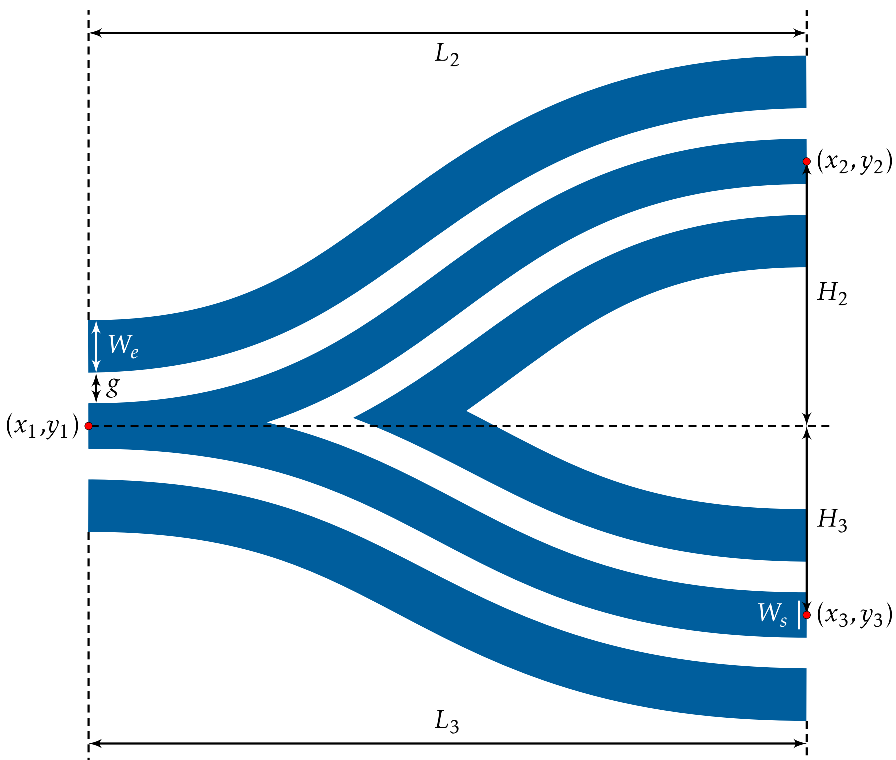


Figure 2.121: *Schematic illustration showing various parameters from the* ***yBendInvSlot*** *constructor.*

2.9.3.10 Y-Bend - 90 degree

<$x \quad y \quad r_1 \quad r_2 \quad w \quad N_{sides} \quad \theta_{(x,y)}$ **yBend90**>

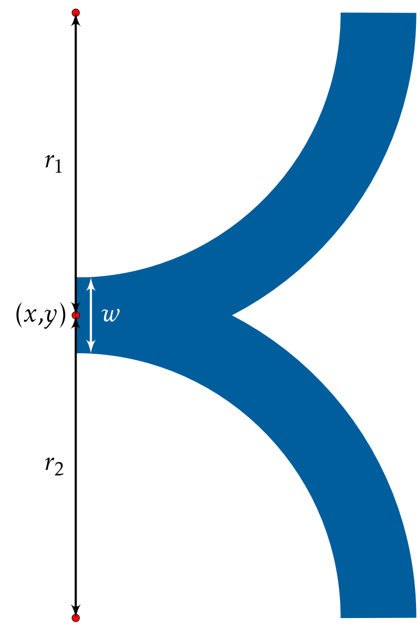


Figure 2.122: *An example of a 90 degree Y-Bend.*

2.9.3.11 Y-Bend Inverse - 90 degree

$<x \quad y \quad r_1 \quad r_2 \quad w \quad w_e \quad N_{sides} \quad \theta_{(x,y)}$ **yBendInv90>**

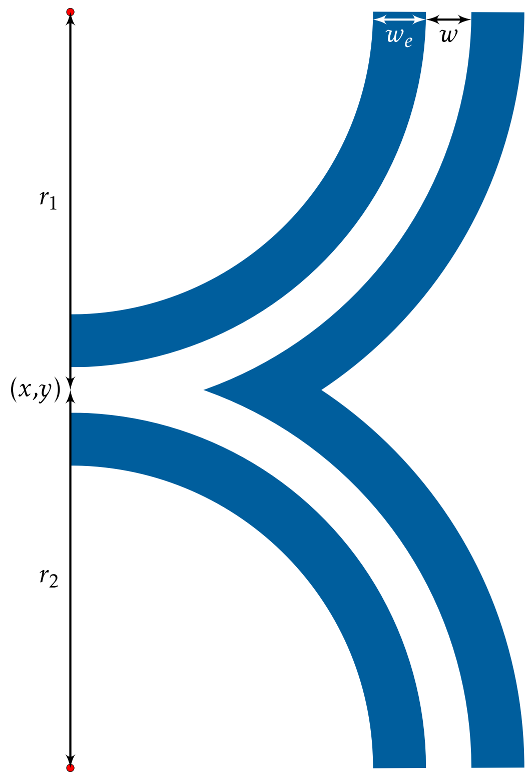


Figure 2.123: *An example of a 90 degree Y-Bend inverse shape.*

2.9.3.12 Y-Bend Inverse Slot - 90 degree

<x y r_1 r_2 w_s g w_e N_{sides} $\theta_{(x,y)}$ yBendInvSlot90>

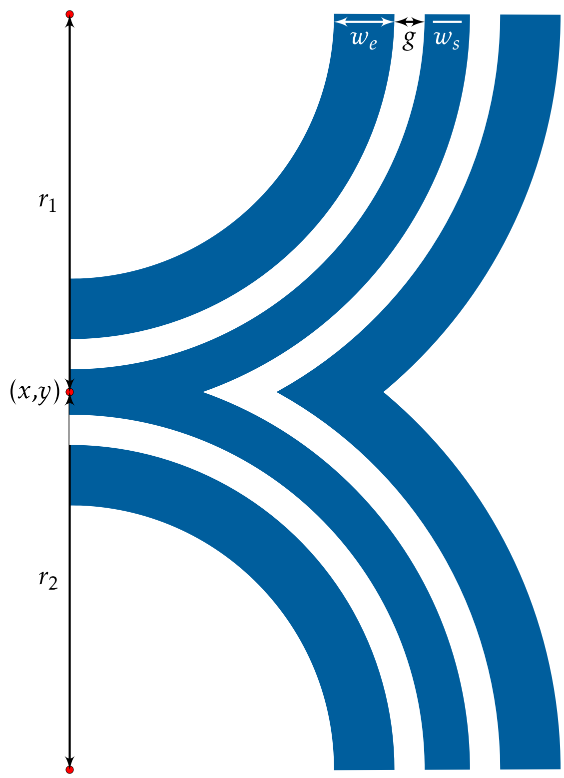


Figure 2.124: *An example of a 90 degree Y-Bend inverse slot shape.*

2.9.3.13 90 Degree Bend

90 Degree Bends are Bezier curves characterized by two constructors. First consists of the start (x_1, y_1) and end (x_2, y_2) points. The second is characterized by the start point (x_1, y_1), length (L) and height (H) parameters. Both constructors are characterized by a waveguide width (W) and the rotation about the start point (x_1, y_1). **shapeReso** parameter defines the rendering resolution of the 90 Degree Bend (Bezier-based) curve.

<x_1	y_1	x_2	y_2	W	$\theta_{(x_1,y_1)}$	**90degreeBend>**
<x_1	y_1	L	H	W	$\theta_{(x_1,y_1)}$	**90degreeBendLH>**

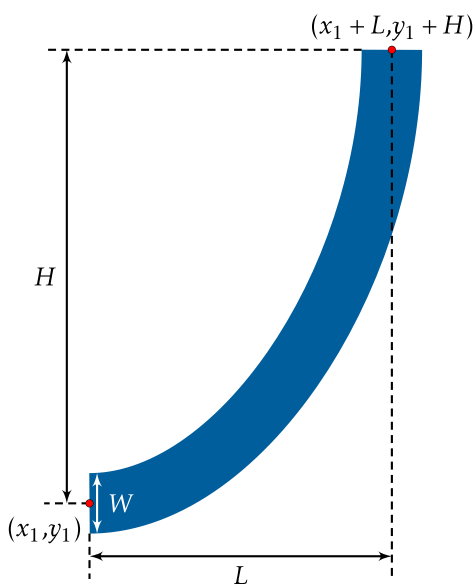


Figure 2.125: *An example 90 degree bend GDS shape illustrating various parameters from the two constructors.*

2.9.3.14 90 Degree Bend Inverse

Similar to 90 Degree Bends (section 2.9.3.13), **90degreeBendInv** constructor is used to create a 90 degree bend waveguide structure using a positive tone resist. Alternatively, using a negative tone resist, a slot-waveguide of width $W + W_e$ and a slot of width W is constructed. The shape is characterized by the start coordinate point (x_1, y_1), length (L), height (H), waveguide width (W), exposure sleeve (W_e) and the rotation about the start point (x_1, y_1) parameters. **shapeReso** parameter defines the rendering resolution of the 90 degree (Bezier based) curve. Both length and height parameters are defined by positive and negative double precision values relative to the start coordinate point (x_1, y_1). For instance, a negative value of H would place the end point y value at $y_1 - H$, hence value of H in Figure 2.126 is positive .

<x_1 y_1 L H W W_e $\theta_{(x_1,y_1)}$ **90degreeBendInv**>

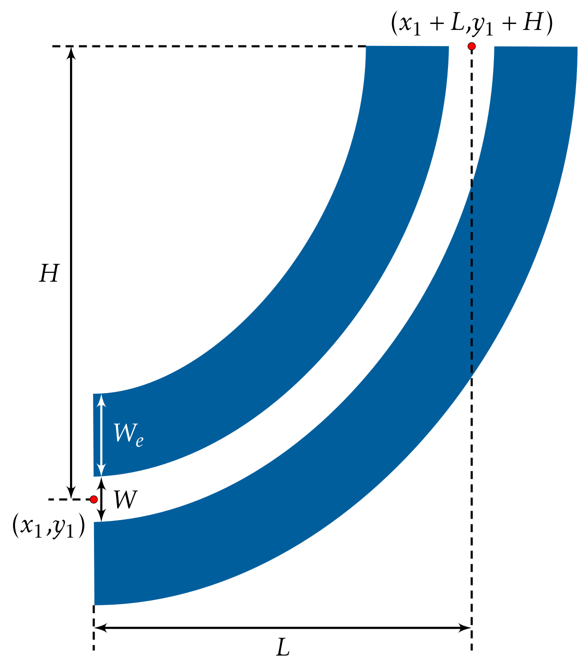


Figure 2.126: *Schematic illustration showing various parameters from the* ***90degreeBendInv*** *constructor.*

2.9.3.15 90 Degree Bend Inverse Slot

Similar to 90 Degree Bends (section 2.9.3.13), **90degreeBendInv** constructor is used to create a 90 degree bend slot waveguide structure using a positive tone resist. The shape characterized is characterized by the start coordinate point (x_1, y_1), length (L), height (H), slot width (W_s), gap (g), exposure sleeve width (W_e) and the rotation about the start point (x_1, y_1) parameters. **shapeReso** parameter defines the rendering resolution of the 90 degree (Bezier-based) curve. Both length and height parameters are defined by positive and negative double precision values relative to the start coordinate point (x_1, y_1). For instance, a negative value of H would place the end point y value at $y_1 - H$, hence value of H in Figure 2.127 is positive.

<x_1 y_1 L H W g W_e $\theta_{(x_1,y_1)}$ **90degreeBendInvSlot**>

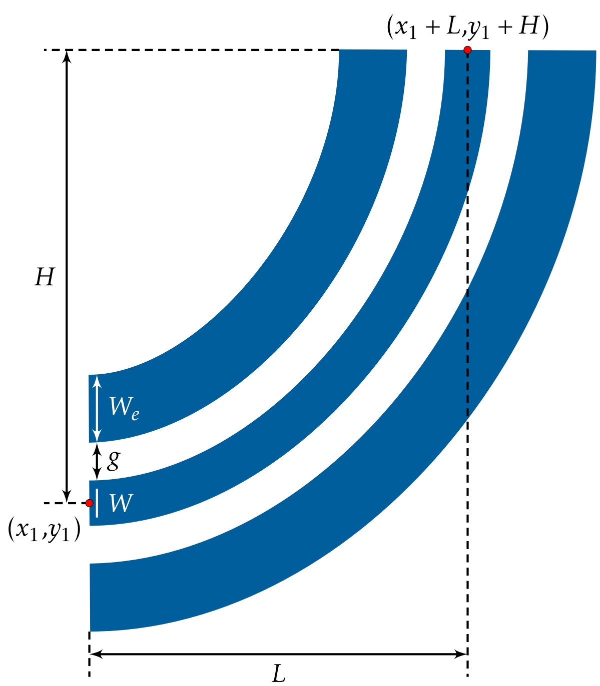


Figure 2.127: *Schematic illustration showing various parameters from the* ***90degreeBendInvSlot*** *constructor.*

2.9.3.16 180 Degree Bend

The 180 degree, u-shaped, bend is characterized by a lengths L_1 and L_2 with a coupled half torus of diameter D. The number of vertices constructing the torus is represented by the N parameter. D is measured from the midpoints of the two length segments.

<x y L_1 L_2 D W N $\theta_{(x,y)}$ 180degreeBend>

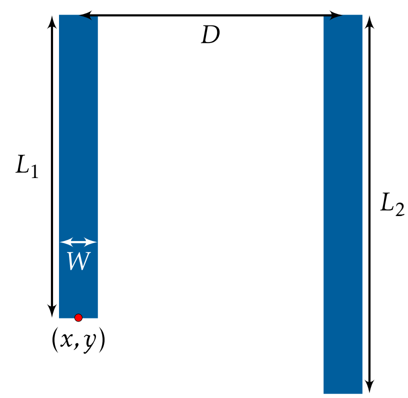


Figure 2.128: *180 degree bend example.*

2.9.3.17 180 Degree Bend Inverse

Similar to the 180 degree bend in the previous section (2.9.3.16), the inverse device has an additional exposure sleeve parameter W_e.

<x y L_1 L_2 D W W_e N $\theta_{(x,y)}$ **180degreeBendInv**>

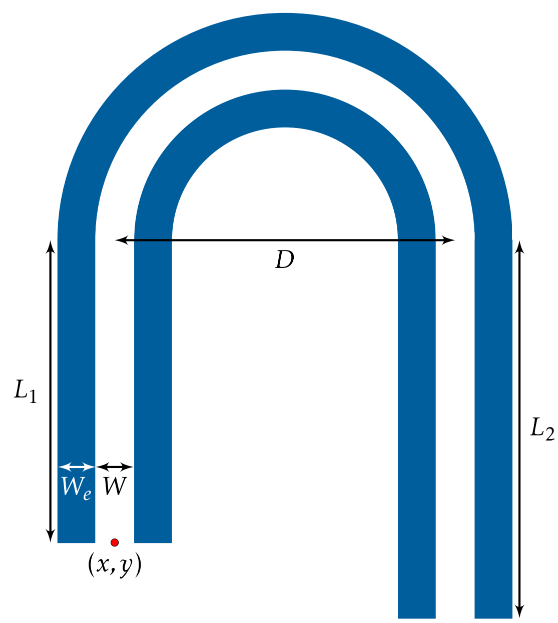


Figure 2.129: *180 degree bend inverse example.*

2.9.3.18 180 Degree Bend Inverse Slot

Similar to the 180 degree inverse bend in the previous section (2.9.3.17), the inverse slot device has an additional gap parameter g.

<x y L_1 L_2 D W g W_e N $\theta_{(x,y)}$ 180degreeBendInvSlot>

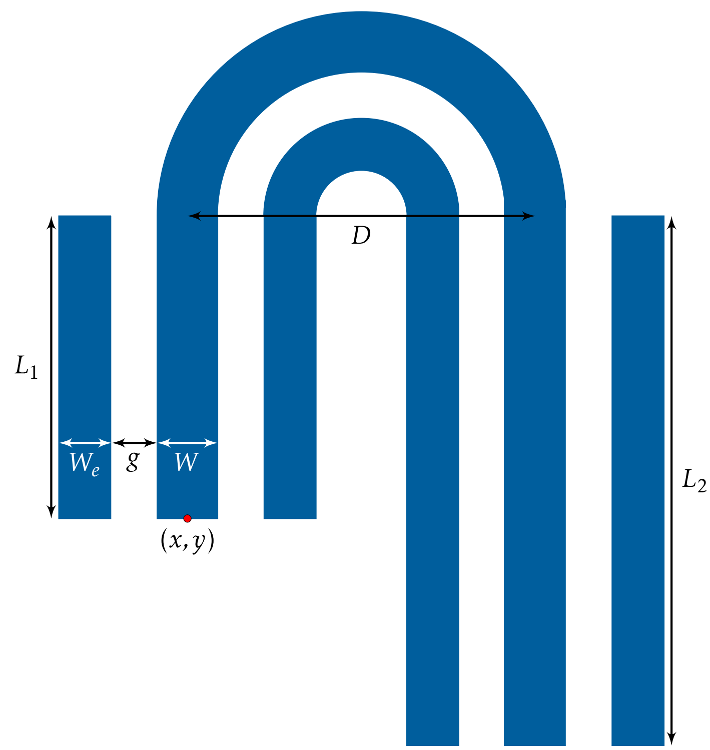


Figure 2.130: *180 degree bend inverse slot example.*

2.9.4 Racetrack

Racetrack object is characterized by the center coordinate (x, y), length of the straight section (L), track width (W), inner radius (r_{in}), rotation about the center point $(\theta_{(x,y)})$, and the number of segments creating each of the curved sections (N).

<x y L W r_{in} $\theta_{(x,y)}$ N **raceTrack**>

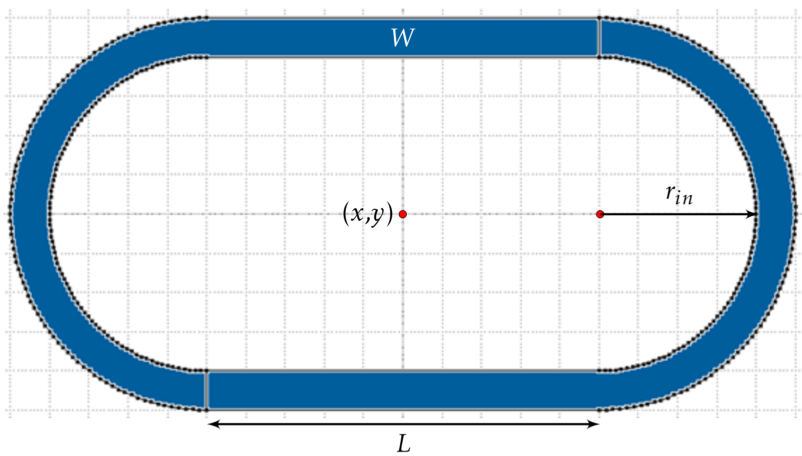


Figure 2.131: *An example GDS shape illustrating various parameters from the* **raceTrack** *constructors. Dots along the structural periphery represent the number of points (N) used to construct the curved racetrack sections.*

2.9.5 Spiral Delay Line

Interdigitated spiral delay line objects are characterized by either uniform (Archimedes) and converging (Fermat's) spacing between subsequent turns. Constant spacing Archimedes spiral delay line illustrated in Figure 2.9.5a is represented by

$$r(\theta) = \begin{cases} m\theta & (2.12) \\ -m\theta & (2.13) \end{cases}$$

where $m = (S+W)/(2\pi)$, and the separation parameter S defines the pitch between subsequent spiral turns. Spiral is further defined by Δ_R defining the resolution of the spiral, the length of the coupling waveguide (L), the rotation about center ($\theta_{(x,y)}$), and $EC = 1$ or 0 corresponding to the waveguide coupling segment without and with semi-circular endcaps. Fermat's spiral spiral delay line illustrated in Figure 2.9.5b is represented by

$$r(\theta) = \begin{cases} \sqrt{a^2\theta} & (2.14) \\ -\sqrt{a^2\theta} & (2.15) \end{cases}$$

$x \quad y \quad W \quad N_{turns} \quad S \quad \Delta_R \quad L \quad \theta_{(x,y)} \quad EC$ **spiralDelayLineArch**

$x \quad y \quad W \quad N_{turns} \quad a \quad \Delta_R \quad L \quad \theta_{(x,y)} \quad EC$ **spiralDelayLineFermat**

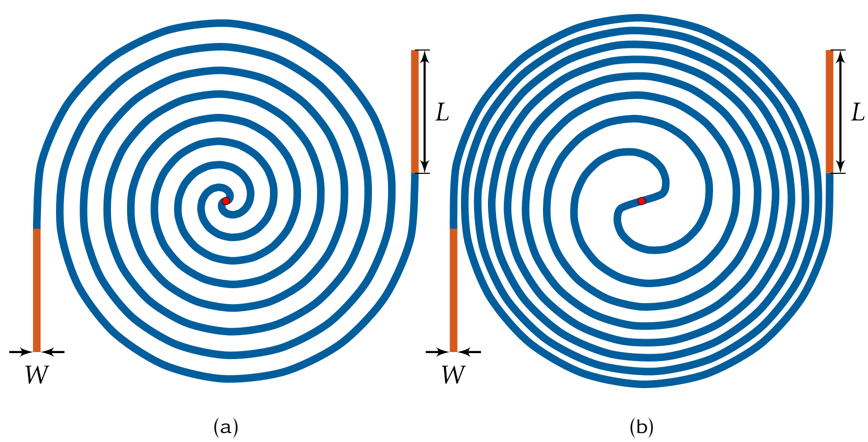


Figure 2.132: *Spiral delay lines for the (a) Archimedes spiral constructor **spiralDelayLineArch** and (b) Fermat spiral constructor **spiralDelayLineFermat**. Central dot represents the coordinate defined by (x, y).*

IMPORTANT NOTE: The above interdigitated spirals are created and fractured along the y–axis. On the one hand, this action eliminates any possibility of exceeding maximum number of allowed points per GDS shape. On the opposite end of the spectrum, this action is computation intensive, consuming large amounts of RAM and takes a considerable amount of time for spirals of many turns defined by a large collection points.

The following is an interdigitated Archimedes spiral delay line that alleviates some of the computational strains of the previous version. The delay line illustrated in Figure 2.133 is characterized by a center point (x, y), spiral width, the number of turns (N_{turns}), separation (S) between subsequent turns, points per turn (P_T), and the number of skipped turns before spiral rendering initiates (S_T). In this case, points per spiral turn are controlled, hence for spirals containing many turns, the resolution of the outermost ring will be coarser than the internal rings. This spiral is generated much faster than ones shown in Figure 2.132.

$x \quad y \quad W \quad N_{turns} \quad S \quad P_T \quad S_T \quad L \quad \theta_{(x,y)} \quad EC$ **spiralDelayLineArchV2**

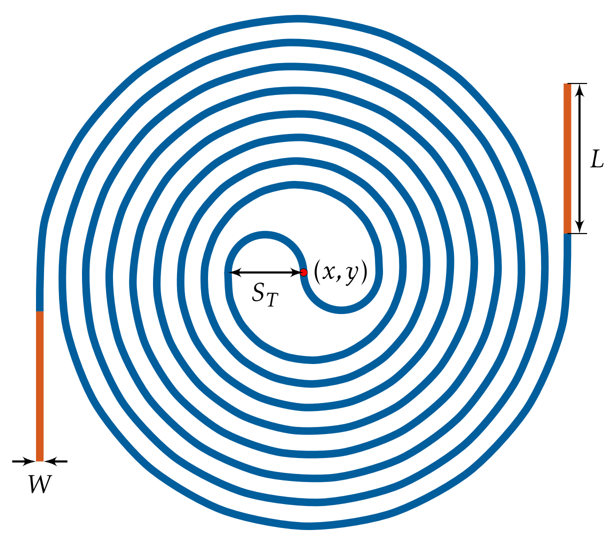


Figure 2.133: *Archimedes interdigitated spiral delay line constructed by* **spiralDelayLineArchV2** *constructor. Parameter S_T is an integer $(S_T \geq 0)$ defining the number of skipped turns before rendering of the spiral initiates.*

2.9.6 Inverse Spiral Delay Line

Inverse spiral delay line objects are characterized by either uniform (Archimedes) and converging (Fermat's) spacing between subsequent turns. Section 2.9.5 shows details for the construction of the two spirals. These spirals are defined by the center point (x, y), slot width W, exposure sleeve width W_e, number of turns (N_{turns}), separation (S) between turns, and the Δ_R value defining resolution rendering of the spiral.

$x \quad y \quad W \quad W_e \quad N_{turns} \quad S \quad \Delta_R \quad L \quad \theta_{(x,y)} \quad EC$ **spiralDelayLineArchInv**

$x \quad y \quad W \quad W_e \quad N_{turns} \quad a \quad \Delta_R \quad L \quad \theta_{(x,y)} \quad EC$ **spiralDelayLineFermatInv**

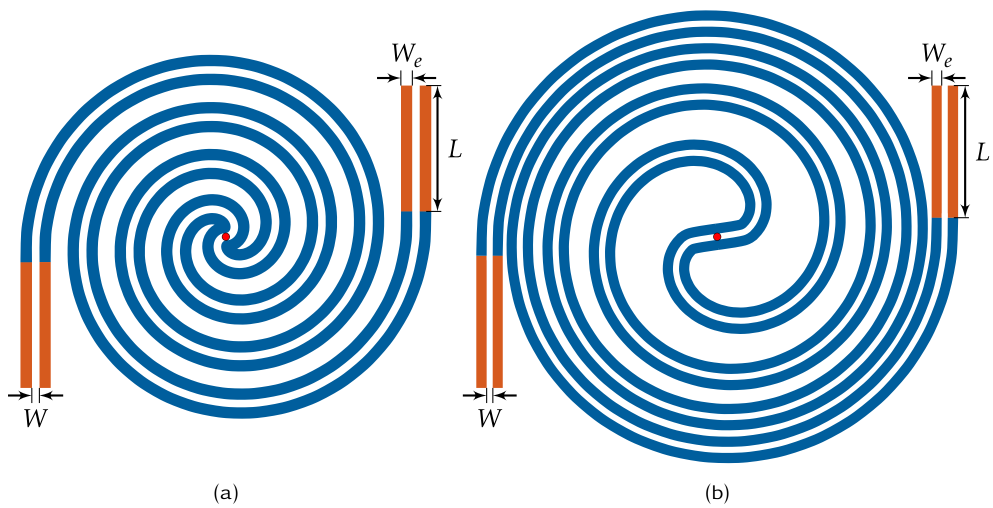


Figure 2.134: *Inverse spiral delay lines for the (a) Archimedes spiral constructor* ***spiralDelayLineArchInv*** *and (b) Fermat spiral constructor* ***spiralDelayLineFermatInv****. Central dot represents the coordinate defined by (x, y), W and W_e are the corresponding slot and exposure sleeve widths.*

The following is another version of the inverted Archimedes spiral delay line. The delay line illustrated in Figure 2.135 is characterized by a center point (x, y), spiral width, exposure sleeve width, the number of turns (N_{turns}), separation (S) between subsequent turns, points per turn (P_T), and the number of skipped turns before spiral rendering initiates (S_T). In this case, points per spiral turn are controlled, hence for spirals containing many turns, the resolution of the outermost ring will be coarser than the internal rings.

$x \quad y \quad W \quad W_e \quad N_{turns} \quad S \quad P_T \quad S_T \quad L \quad \theta_{(x,y)} \quad EC$ **spiralDelayLineArchV2Inv**

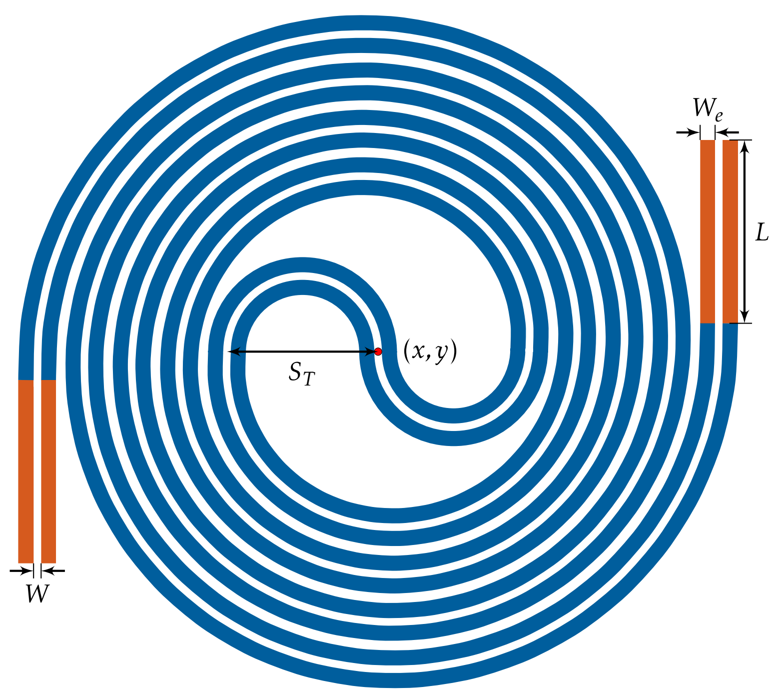


Figure 2.135: *Archimedes interdigitated spiral delay line constructed by **spiralDelayLineArchV2Inv** constructor. Parameter S_T is an integer $(S_T \geq 0)$ defining the number of skipped turns before rendering of the spiral initiates.*

IMPORTANT NOTE: The above interdigitated spirals (Figures 2.134- 2.135) are created and fractured along the y–axis. As mentioned in the previous section, fracturing eliminates any possibility of exceeding maximum number of allowed points per GDS shape. Unfortunately, the fracturing is computationally intensive, consuming large amounts of RAM for spirals of many turns defined by a large collection points.

2.9.7 Gratings

2.9.7.1 Grating

Grating structure is defined by the line width, length and pitch. A single line is cast into a GDS structure $singleRectangleStructName$ and arrayed (instantiated) at the specified pitch within the existing GDS structure. N_{lines} parameter represents the number of instantiated lines.

<$singleRectangleStructName$ x y W L $Pitch$ N_{lines} **grating**>

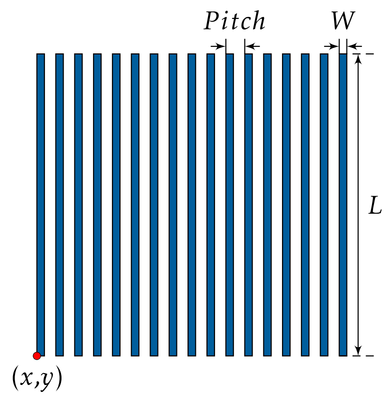


Figure 2.136: *Example of the* ***grating*** *constructor.*

2.9.7.2 Apodized Grating

The apodized grating structure is defined by the grating length (G_L), the increment (ΔG_L), grating line height (H), duty cycle cutoff (d_{CC}), and grating parameters p_i and d_i. The grating extends from ($-\frac{G_L}{2}$) to ($+\frac{G_L}{2}$) with the lower edge centered around (x, y).

<x y G_L ΔG_L H d_{CC} p_1 p_2 p_3 p_4 d_1 d_2 d_3 d_4 d_5 $\theta_{(x,y)}$ **apodizedGrating**>

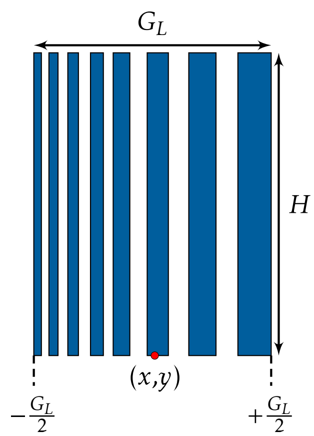


Figure 2.137: *Example of the apodizedGrating constructor.*

2.9.7.3 Grating Coupler

Structure characterized by a center (x, y), distance (r) from center to the mid-point of the first arc section, width (W) and pitch (p) of the arc section, start (θ_s) and end angles (θ_e), number of sides (N_{sides}) for each of the arc sections and number of elements $(N_{elements})$.

<x y r W p θ_s θ_e N_{sides} $N_{elements}$ gratingCoupler>

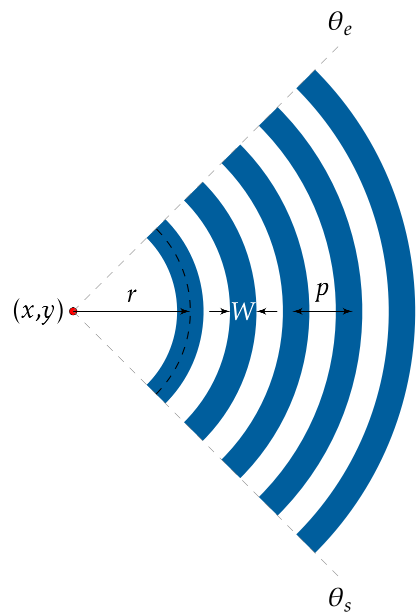


Figure 2.138: *Example illustrating various parameters of the **gratingCoupler** constructor.*

2.9.7.4 Grating Couplers With Waveguides

The following constructors generate grating couplers with integrated waveguides within the $x-y$ plane using

$$q\lambda_\circ = n_{eff}\sqrt{x^2+y^2} - xn_c\cos\theta_c \tag{2.16}$$

where the focal point is located at the origin (x,y) with x along the waveguide axis, q is an integer for each grating line, θ_c is the grating angle span, n_c and n_{eff} are the respective cladding and effective refractive index values, and $\lambda_\circ$ is the wavelength. The following are the constructors for the waveguide (GDS Layer L_{wg}) with an integrated grating coupler (GDS Layer L_g)

<$x\ \ y\ \ w\ \ L\ \ H\ \ s\ \ \lambda_\circ\ \ n_{eff}\ \ n_c\ \ \theta_c\ \ R\ \ g_p\ \ ratio\ \ N_g\ \ N_s\ \ L_{wg}\ \ L_g\ \ EC\ \ \theta_{(x,y)}$ **gratingCWGinv**>

<$x\ \ y\ \ w\ \ L\ \ H\ \ \lambda_\circ\ \ n_{eff}\ \ n_c\ \ \theta_c\ \ R\ \ g_p\ \ ratio\ \ N_g\ \ N_s\ \ L_{wg}\ \ L_g\ \ EC\ \ \theta_{(x,y)}$ **gratingCWG**>

As labeled in Figures 2.139 and 2.140, the structure is placed and rotated $(\theta_{(x,y)})$ relative to the origin (x,y). Waveguides are constructed using a bezier s-bend curve and defined by a width (w), length (L) and height (H). A negative value of H will extend the waveguide below the y-axis. Sleeve width for inverse waveguides (Figures 2.139a and 2.140a) is defined by s, R is the distance to the outermost grating, g_p is the grating pitch and the duty cycle is defined by the $ratio$ value. Consequently the grating line width is given by

$$g_w = g_p * ratio \tag{2.17}$$

N_g defines the number of generated grating lines with the maximum number grating lines within R given by

$$N_{max} = ceil\ \frac{n_{eff}R}{\lambda_\circ} \tag{2.18}$$

The outer and inner radius of each ring is defined by

$$r_{q(out)} = \frac{q\lambda_\circ}{n_{eff} - n_c\cos\alpha_i\cos\theta} \tag{2.19}$$

$$r_{q(in)} = r_{q(out)} - (g_p * ratio) = r_{q(out)} - g_w \tag{2.20}$$

where

$$\theta = \arccos\ n_{eff} - \frac{\lambda_\circ}{g_p} \tag{2.21}$$

and α_i is the angular range from $-\theta_x$ to θ_c. Parameter $(x,y,w,L,H,s,\lambda_\circ,R,g_p)$ dimensions are expressed in micrometers.

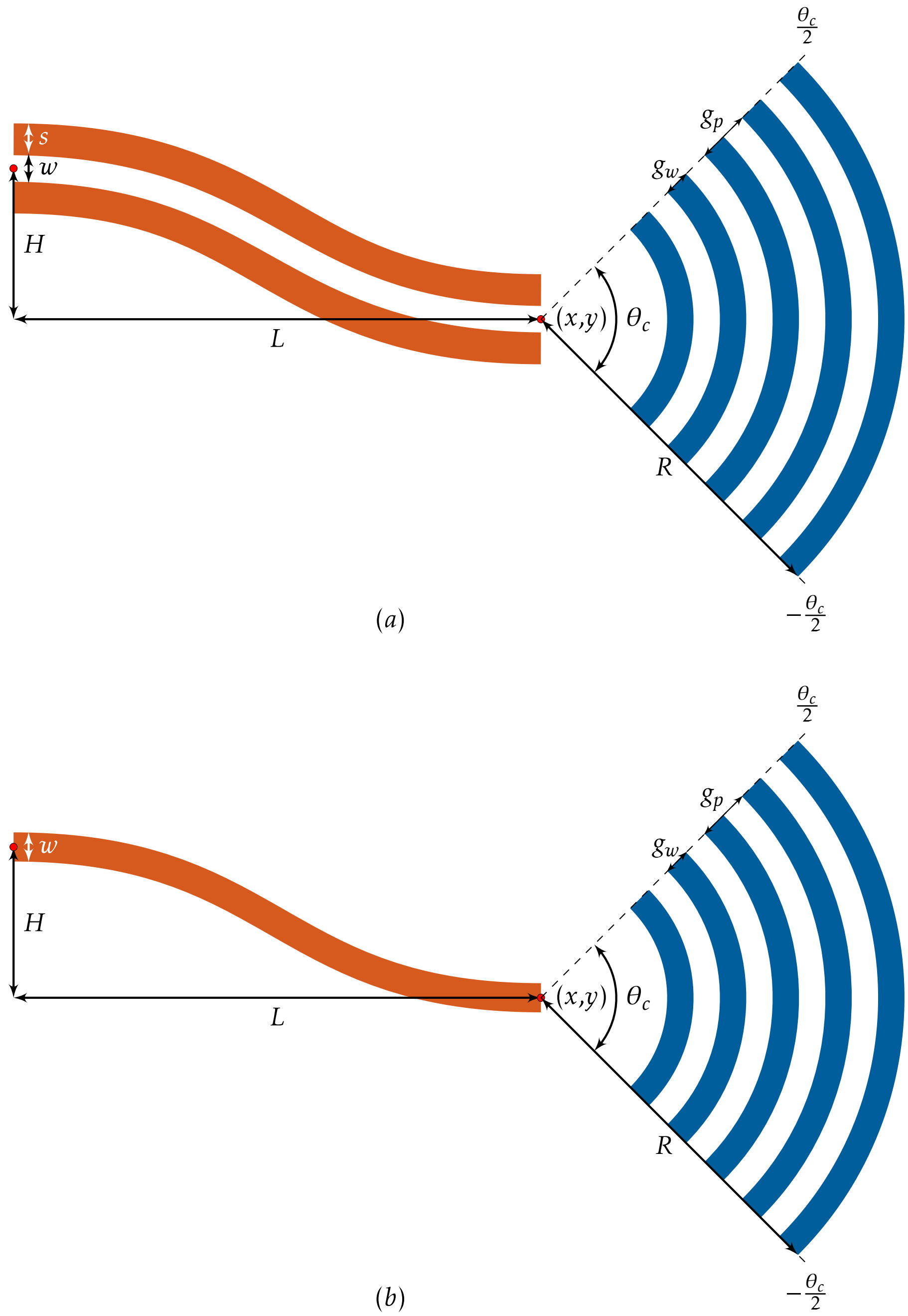


Figure 2.139: *Grating couplers (a) waveguide with sleeve and (b) waveguide with* $EC = 0$.

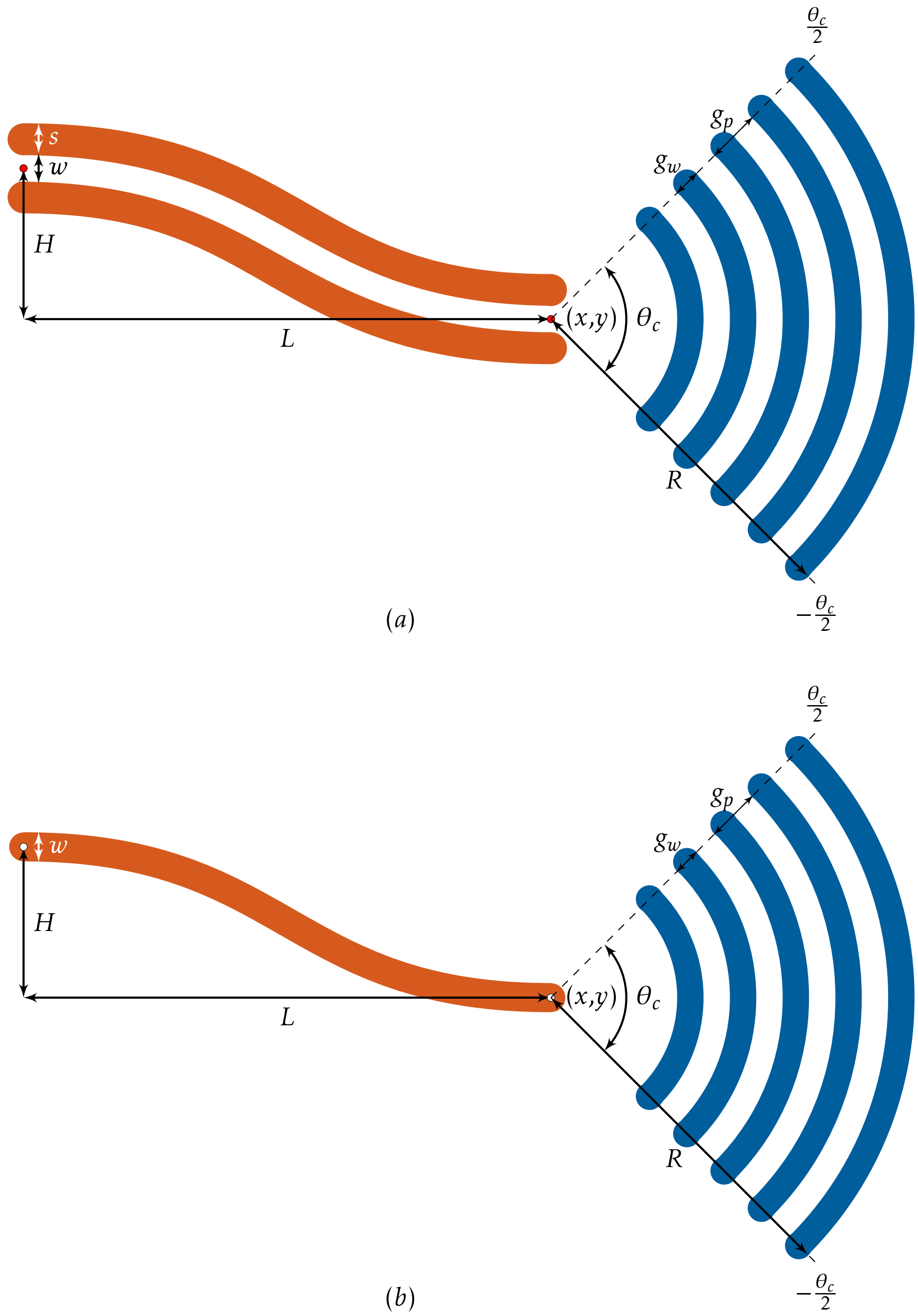


Figure 2.140: *Grating couplers with endcaps. (a) waveguide with sleeve and (b) waveguide with $EC = 1$.*

2.9.8 Photonic Crystals and Hexagonal Arrays

Photonic crystal and hexagonal array structures characterized by a center (x, y), circle radius (r), pitch (x_p), number of elements N_x and N_y in the corresponding x and y directions, and spacing (δ) between the two arrays. Parameter `uniqueStructName` represents the name for the structure (cell) for the circular element. The circular element is then arrayed to construct the photonic crystal structure.

Within constructors **phC** and **hex**, parameter N_{sides} defines the number of sides of the individual polygon/circular apertures. When using vectorized constructors (**phCV** and **hexV**), resulting structures are circles with number of sides determined by the shape rendering resolution parameter **shapeReso**.

<$uniqueStructName$ x y r x_p N_x N_y N_{sides} δ phC>

<$uniqueStructName$ x y r x_p N_x N_y δ phCV>

<$uniqueStructName$ x y r x_p N_x N_y N_{sides} hex>

<$uniqueStructName$ x y r x_p N_x N_y hexV>

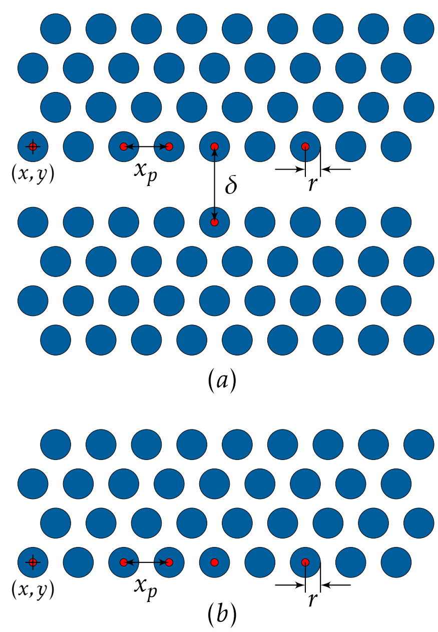


Figure 2.141: *(a) Photonic crystal and (b) hexagonal array examples illustrating various constructor parameters.*

2.9.9 Disc-Ring Architectures

2.9.9.1 Disc-Ring - Bezier Curves, Arcs and Endcaps

The following sections illustrate coupled waveguides to disc and ring structures. The coupling region is defined by an arc section that symmetrically interacts with the disc/ring structure. The waveguide region leading away from the coupling region is defined by either a Bezier or an arc segment.

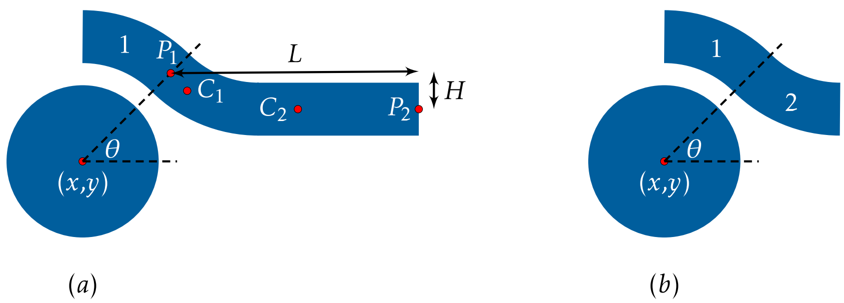


Figure 2.142: *Schematic illustration highlighting the waveguide coupling region constructed using (a) Bezier and (b) arc segments.*

Figure 2.142a illustration has coupling region (labeled as 1) defined by an arc. The continuing segment ending at a distance L is defined by a Bezier curve consisting of start and end points (P_1 and P_2) and their corresponding control points C_1 and C_2. Control points are defined as,

$$C_{1x} = P_{1x} + \frac{R}{4} * \cos(\phi) \tag{2.22a}$$

$$C_{1y} = P_{1x} - \frac{R}{4} * \sin(\phi) \tag{2.22b}$$

$$C_{2x} = P_{2x} - \frac{L}{2} \tag{2.22c}$$

$$C_{2y} = P_{2y} \tag{2.22d}$$

where $R = \sqrt{H^2 + L^2}$, and $\phi = 90 - \theta$.

Figure 2.142b shows a coupling region defined by two arc segments. For this segment, the straight waveguide portion of length L is omitted. In both cases, the drawn structures are mirrored around the y−axis.

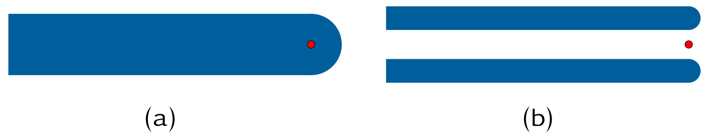


Figure 2.143: *Illustrations showing semicircular encaps on the right hand side of (a) a waveguide and (b) an inverse and inverse positive waveguide. Endcaps are included on both left and right sides of the waveguide when parameter* $EC = 1$*. The red circle denotes the end point of the waveguide structure. Semicircular endcap radius of the equals half of the waveguide width.*

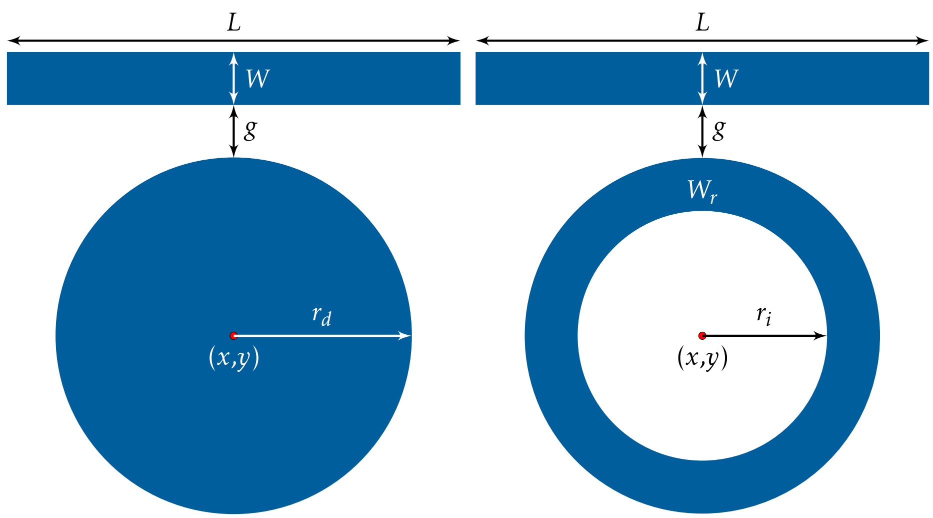
Figure 2.143 shows shows waveguide structures with semicircular endcaps. The structures are encountered in subsequent sections and are useful when stressed thin film underlayers are patterned using thick resists. The corner rounding at the waveguide termination end alleviates the stress field, thereby mitigating resist and thin film cracking during subsequent reactive ion etch processing steps.

2.9.9.2 Disc-Ring Infinite

Shapes characterized by a straight waveguide ($R_{wg} = \infty$) above a disc and ring objects. Both objects are described by the center coordinate (x, y), number of segments (N), gap between the object and shape (g), waveguide length (L) and width (W). Disc object is defined by a radius (r_d) and the ring is characterized by an inner radius r_i and ring width (W_r). Boolean parameter EC controls if semicircular endcaps are incorporated in the waveguide structure. EC is an integer value with zero representing false, hence waveguides without endcaps, i.e. $EC = 0$ and $EC = 1$ for waveguides without and with endcaps, respectively.

<x y r_d N g L W EC **discInfinite**>

<x y r_i W_r N g L W EC **ringInfinite**>



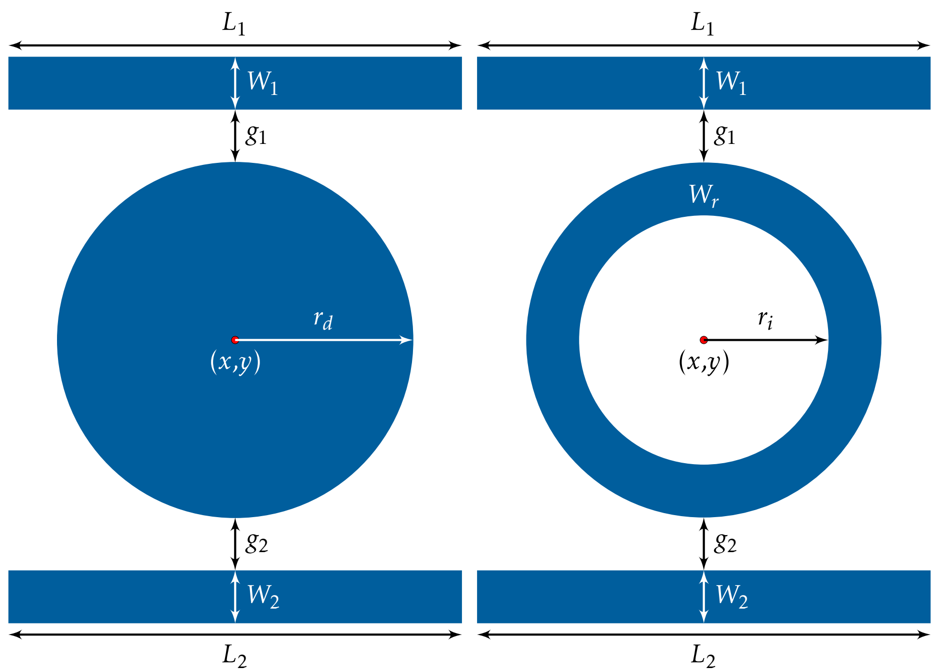
(a) (b)

Figure 2.144: *Examples illustrating various parameters of the (a)* **discInfinite** *and (b)* **ringInfinite** *constructors.*

Infinite disc and ring structures with an additional coupling waveguide.

<x y r_d N g_1 L_1 W_1 g_2 L_2 W_2 EC **discInfDS**>

<x y r_i W_r N g_1 L_1 W_1 g_2 L_2 W_2 EC **ringInfDS**>



(a) (b)

Figure 2.145: *Examples illustrating various parameters of the (a)* ***discInfDS*** *and (b)* ***ringInfDS*** *constructors.*

2.9.9.3 Disc-Ring Infinite Inverse

The structure is similar to the disc-ring waveguide infinite structure defined in the previous section 2.9.9.2. Here, a slot waveguide of width W is formed by exposing a surrounding rectangular region of width W_e. The overall shapes are characterized by a straight waveguide ($R_{wg} = \infty$) above a disc and ring objects. Both objects are described by the center coordinate (x, y), number of segments (N), gap between the object and shape (g), waveguide length (L), waveguide width (W) and exposure sleeve width (W_e). Disc object is defined by a radius (r_d) and the ring is characterized by an inner radius (r_i) and ring width (W_r). Boolean parameter EC controls if semicircular endcaps are incorporated in the waveguide structure ($EC = 0$ and $EC = 1$ for waveguides without and with endcaps, respectively).

<x	y	r_d		N	g	L	W	W_e	EC	discInfiniteInv>
<x	y	r_i	W_r	N	g	L	W	W_e	EC	ringInfiniteInv>

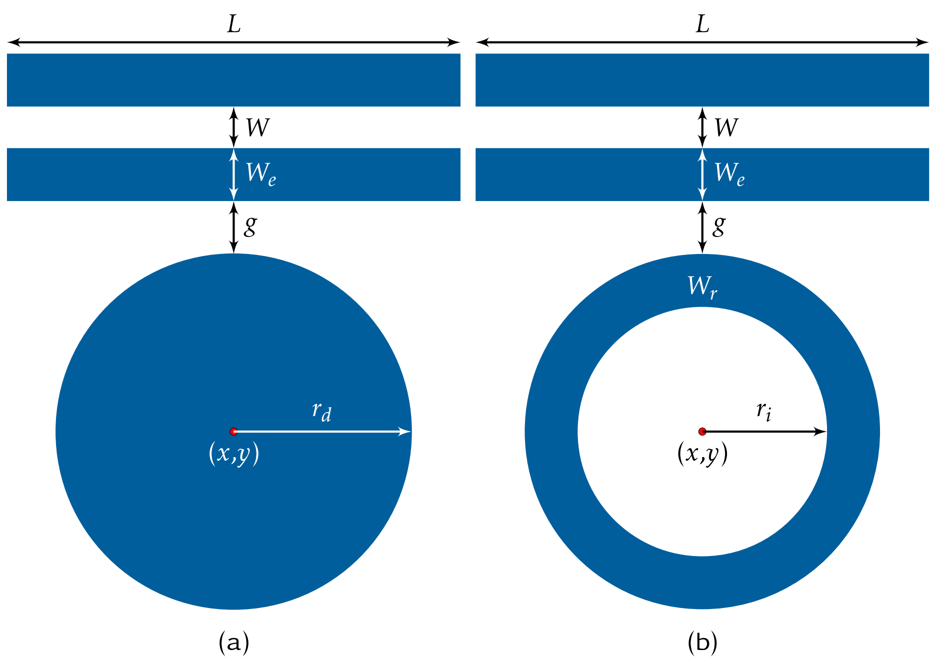


Figure 2.146: *Examples illustrating various parameters of the (a)* ***discInfiniteInv*** *and (b)* ***ringInfiniteInv*** *constructors.*

Infinite inverse disc and ring structures with an additional waveguide.

<x y r_d N g_1 L_1 W_1 W_{e1} g_2 L_2 W_2 W_{e2} EC **discInfInvDS**>

<x y r_i W_r N g_1 L_1 W_1 W_{e1} g_2 L_2 W_2 W_{e2} EC **ringInfInvDS**>

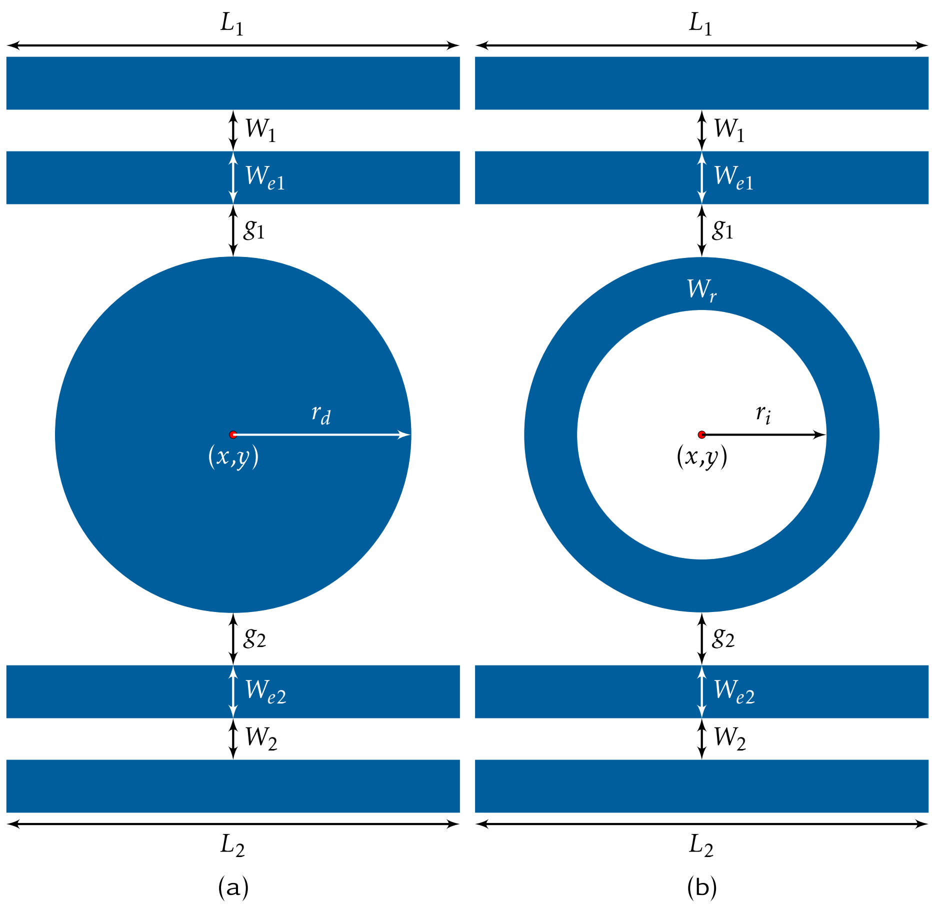


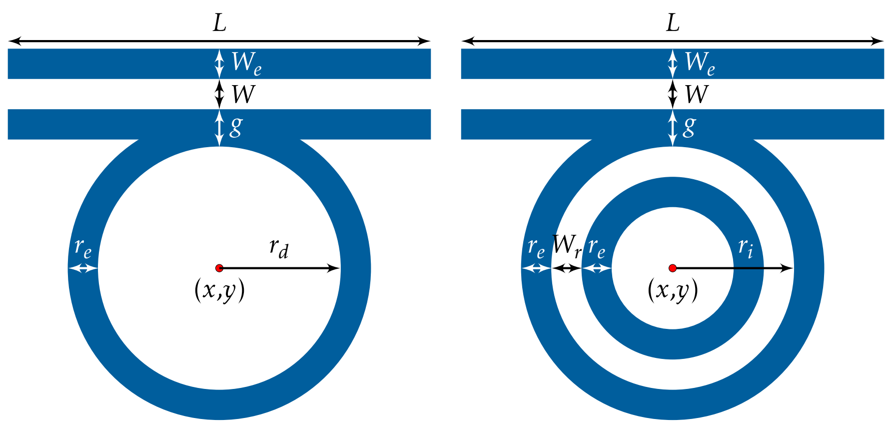
Figure 2.147: *Examples illustrating various parameters of the (a)* ***discInfInvDS*** *and (b)* ***ringInfInvDS*** *constructors.*

2.9.9.4 Disc-Ring Infinite Inverse Positive Tone

The structure is similar to the disc-ring waveguide structure defined in section 2.9.9.2. Here, a waveguide of width W and either a ring of width W_r or disc of radius $r_d - r_e$ are formed by positive tone resist exposure of the respective exposure sleeve regions W_e and r_e. The overall shapes are characterized by a straight waveguide ($R_{wg} = \infty$) above a disc and ring objects. Both objects are described by the center coordinate (x, y), number of segments (N), gap between the object and shape (g), waveguide length (L), waveguide width (W) and exposure sleeve width (W_e). Disc object is defined by a radius (r_d) and the ring is characterized by a radius (r_i) and ring width (W_r).

<x y r_d r_e N g L W W_e EC discInfiniteInvPos>

<x y r_i W_r r_e N g L W W_e EC ringInfiniteInvPos>



(a) (b)

Figure 2.148: *Examples illustrating various parameters of the (a) **discInfiniteInvPos** and (b) **ringInfiniteInvPos** constructors.*

Infinite inverse positive disc and ring structures with an additional coupling waveguide.

<x y r_d r_e N g_1 L_1 W_1 W_{e1} g_2 L_2 W_2 W_{e2} EC **discInfInvPosDS**>

<x y r_i W_r r_e N g_1 L_1 W_1 W_{e1} g_2 L_2 W_2 W_{e2} EC **ringInfInvPosDS**>

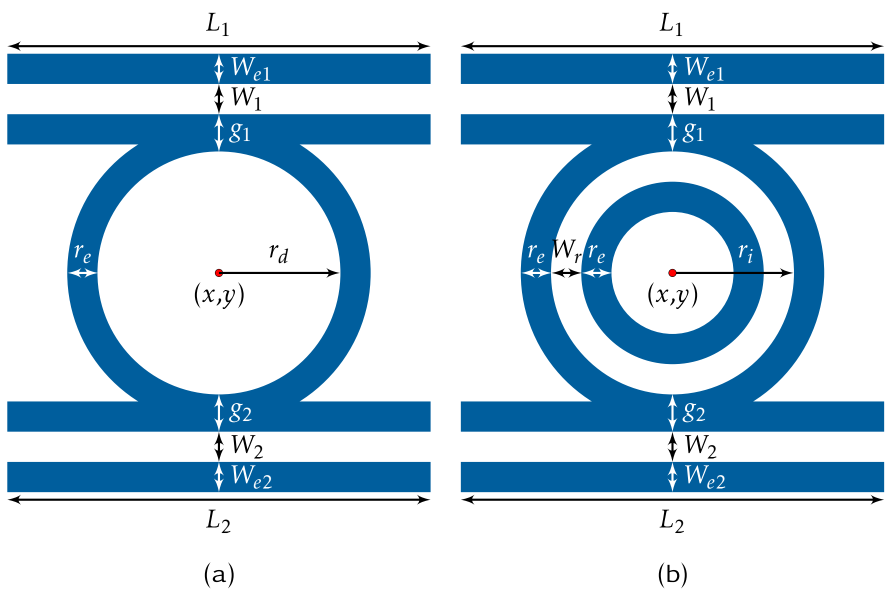


Figure 2.149: *Examples illustrating various parameters of the (a)* ***discInfInvPosDS*** *and (b)* ***ringInfInvPosDS*** *constructors.*

2.9.9.5 Disc-Ring Symmetric Bezier

Shapes characterized by a curved waveguide above a disc ($R_{waveGuide} = -R_{Disc}$) and ring ($R_{waveGuide} = -R_{Ring}$)objects. Both objects (disc/ring) are described by the center coordinate (x, y), number of segments (N), gap between the object and waveguide (g), waveguide opening angle (θ), number of sides (N_{wg}), width (W), length (L), height (H), disc radius, (r_d), ring radius (r_i) and width (W_r). $EC = 0$ and $EC = 1$ for waveguides without and with endcaps, respectively.

<x y r_d N g θ N_{wg} W L H EC **discSymmetric**>

<x y r_i W_r N g θ N_{wg} W L H EC **ringSymmetric**>

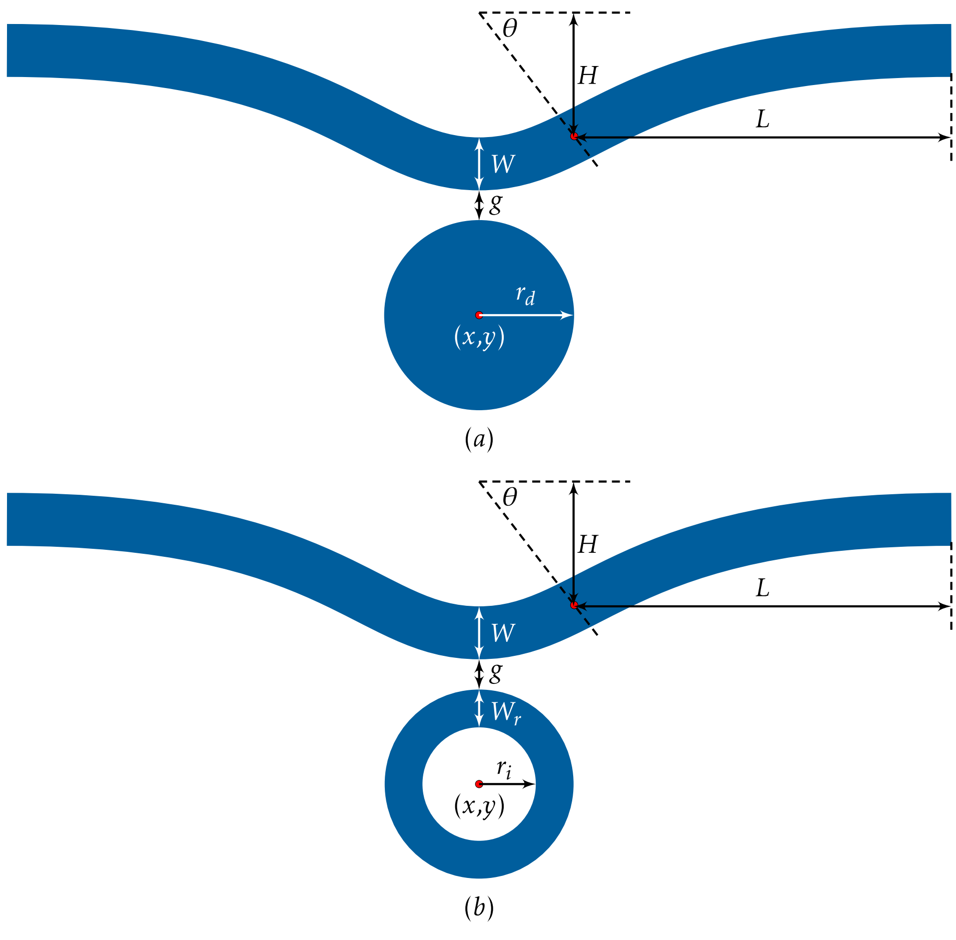


Figure 2.150: *Example shapes illustrating various parameters from the (a)* ***discSymmetric*** *and (b)* ***ringSymmetric*** *constructors.*

Disc symmetric structure with an additional coupling waveguide.

<x y r_d N g_1 θ N_{wg} W_1 L_1 H g_2 W_2 L_2 EC **discSymDS**>

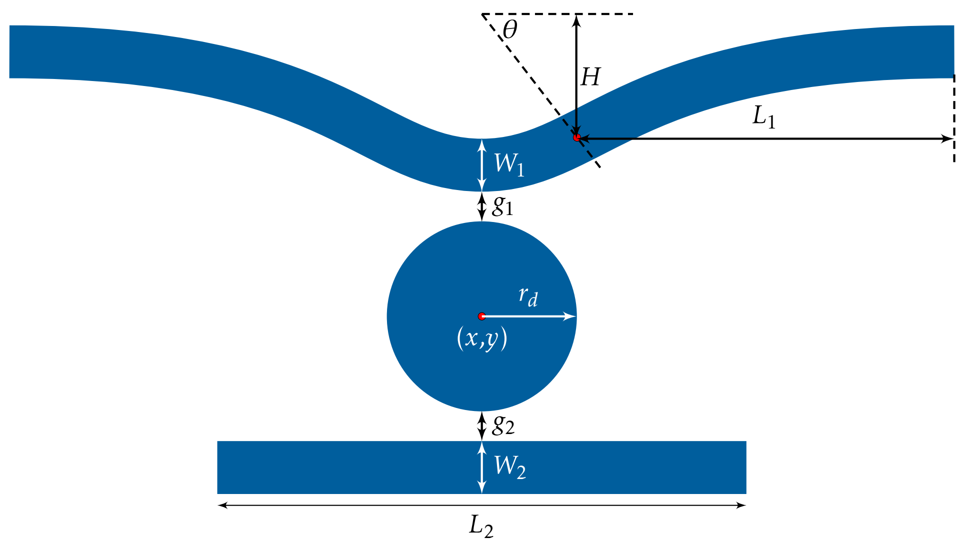


Figure 2.151: *Example shape illustrating various parameters from the **discSymDS** constructor.*

Disc symmetric structure with an additional coupling pulley.

<x y r_d N g_1 θ_1 N_{wg} W_1 L_1 H_1 g_2 θ_2 W_2 L_2 H_2 EC **discSymPul**>

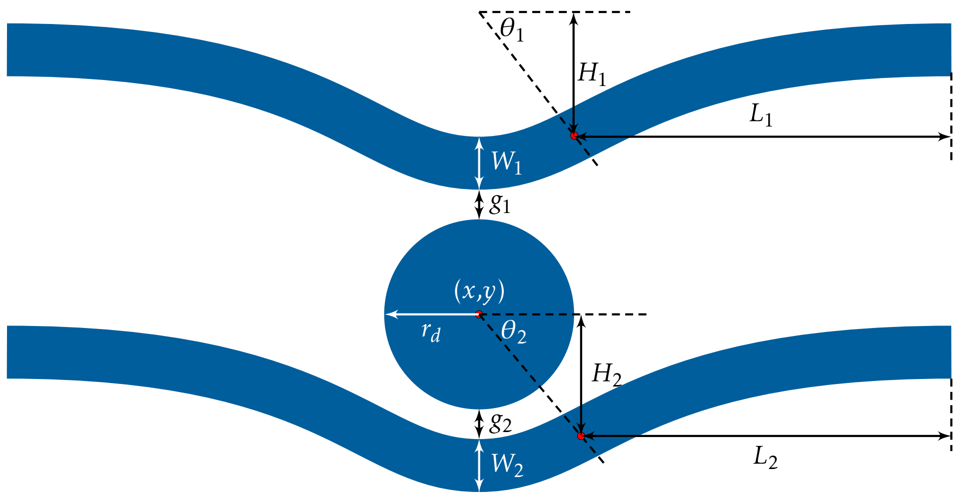


Figure 2.152: *Example shape illustrating various parameters from the* ***discSymPul*** *constructors.*

Ring symmetric structure with an additional coupling waveguide.

<x y r_i W_r N g_1 θ N_{wg} W_1 L_1 H g_2 W_2 L_2 EC **ringSymDS**>

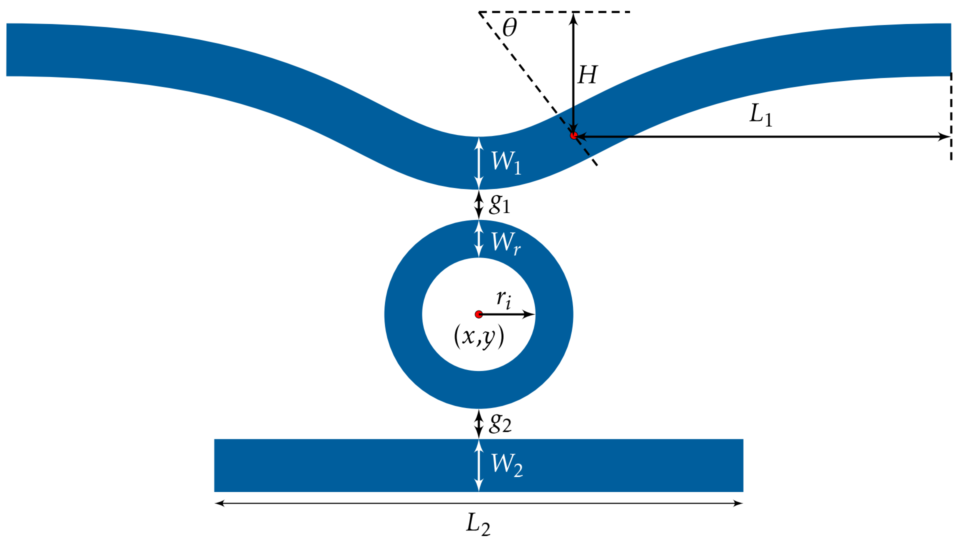


Figure 2.153: *Example shape illustrating various parameters from the* ***ringSymDS*** *constructor.*

Ring symmetric structure with an additional coupling pulley.

<x y r_i W_r N g_1 θ_1 N_{wg} W_1 L_1 H g_2 θ_2 W_2 L_2 H_2 EC **ringSymPul**>

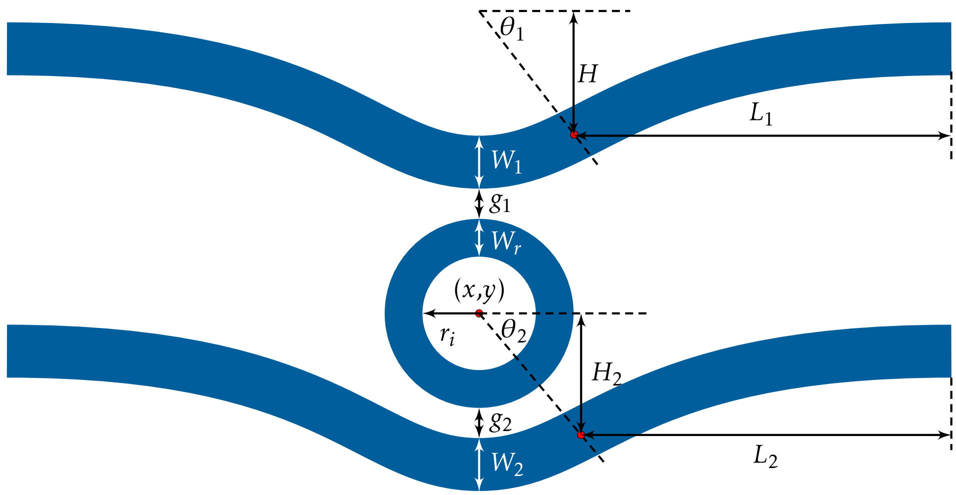


Figure 2.154: *Example shape illustrating various parameters from the* ***ringSymPul*** *constructor.*

The following disc-ring waveguide symmetric structures are defined by the coupling length parameter L_c.

<x y r_d N g L_c N_{wg} W L H EC **discSymmetricLC**>

<x y r_i W_r N g L_c N_{wg} W L H EC **ringSymmetricLC**>

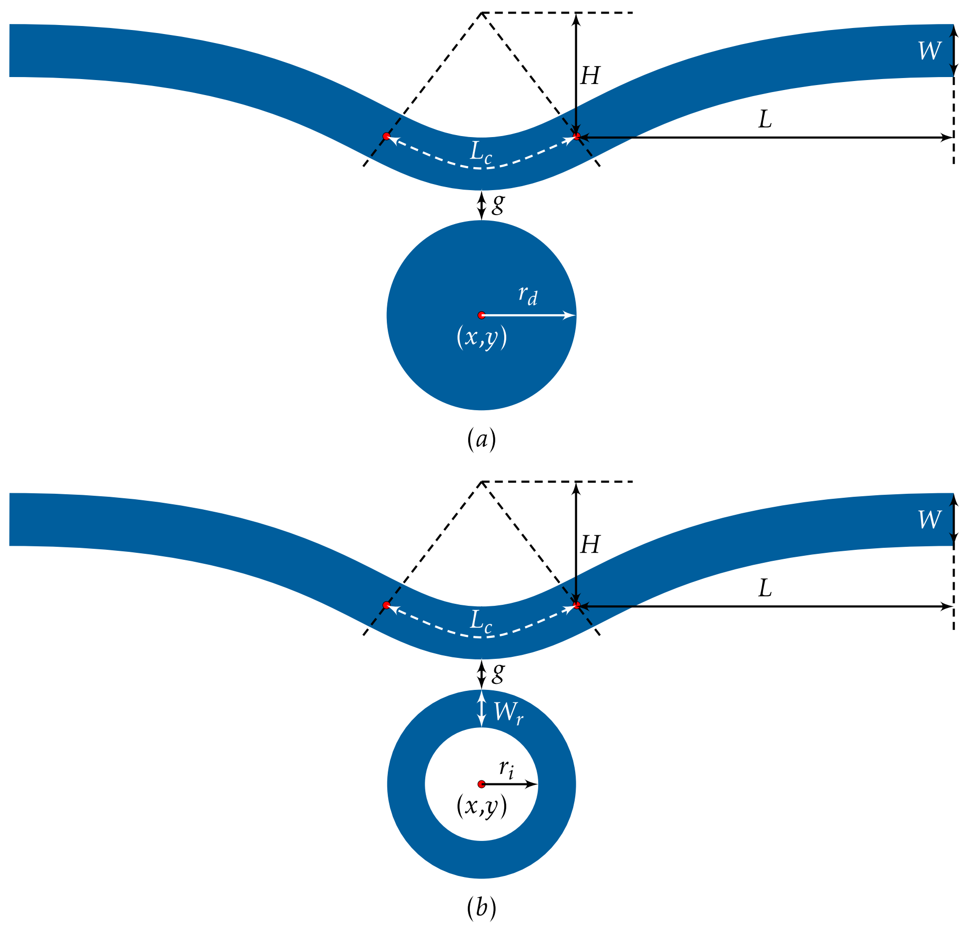


Figure 2.155: *Example shapes illustrating various parameters from the (a)* ***discSymmetricLC*** *and (b)* ***ringSymmetricLC*** *constructors.*

Disc symmetric structure with an additional coupling waveguide.

<x y r_d N g_1 L_c N_{wg} W_1 L_1 H g_2 W_2 L_2 EC **discSymLCDS**>

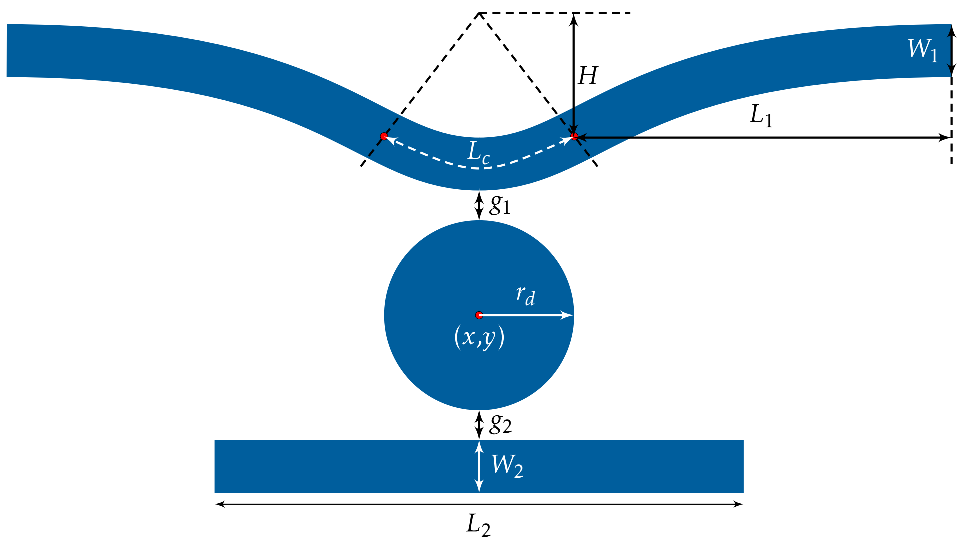


Figure 2.156: *Example shape illustrating various parameters from the* ***discSymLCDS*** *constructor.*

Disc symmetric structure with an additional coupling pulley.

<x y r_d N g_1 L_{c1} N_{wg} W_1 L_1 H_1 g_2 L_{c2} W_2 L_2 H_2 EC **discSymLCPul**>

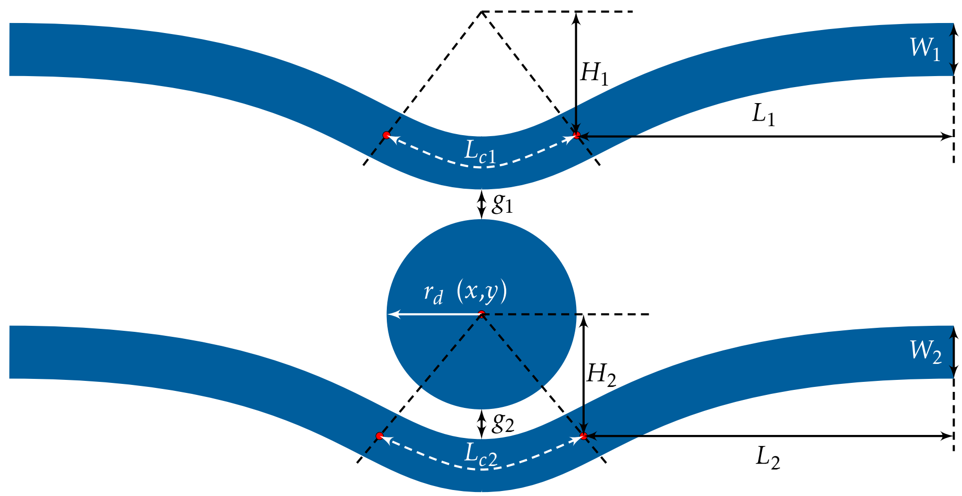


Figure 2.157: *Example shape illustrating various parameters from the* ***discSymLCPul*** *constructor.*

Ring symmetric structure with an additional coupling waveguide.

<x y r_i W_r N g_1 L_c N_{wg} W_1 L_1 H g_2 W_2 L_2 EC **ringSymLCDS**>

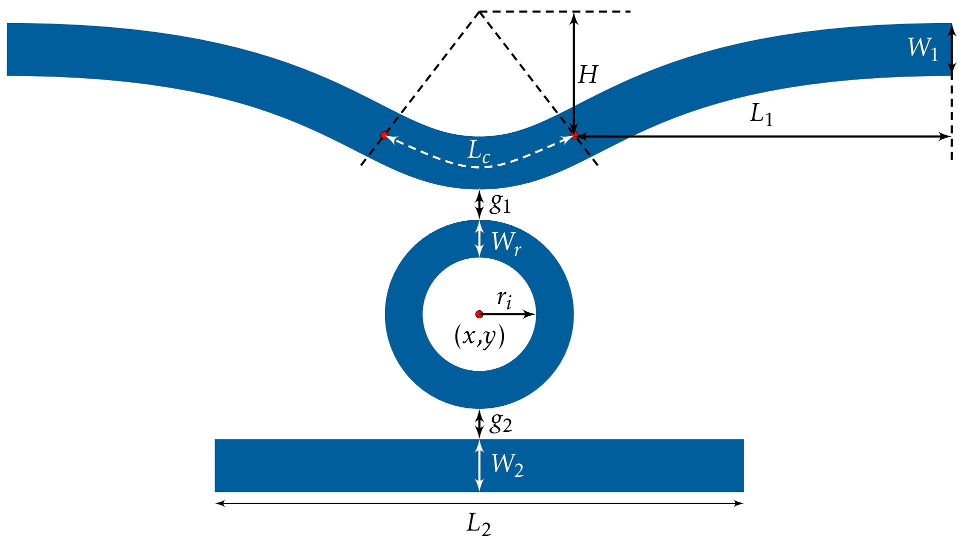


Figure 2.158: *Example shape illustrating various parameters from the* ***ringSymLCDS*** *constructor.*

Ring symmetric structure with an additional coupling pulley.

<x y r_i W_r N g_1 L_{c1} N_{wg} W_1 L_1 H_1 g_2 L_{c2} W_2 L_2 H_2 EC **ringSymLCPul**>

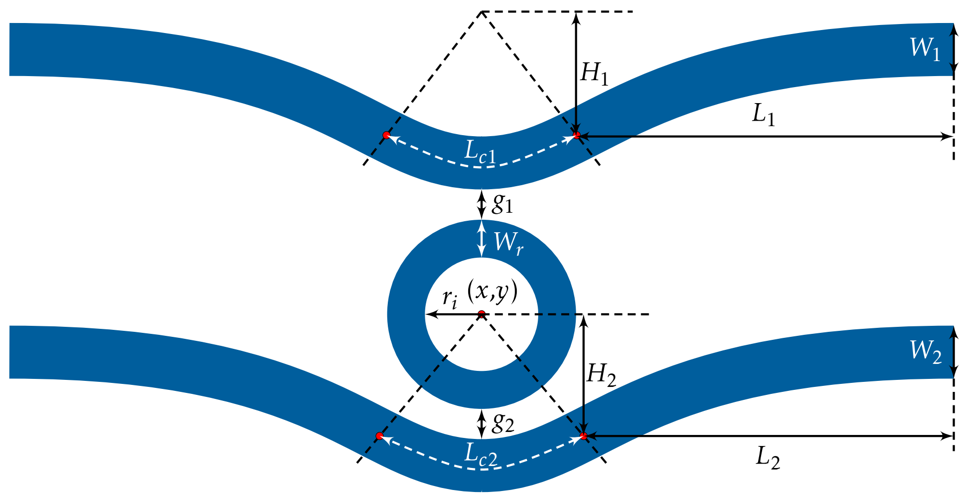


Figure 2.159: *Example shape illustrating various parameters from the* ***ringSymLCPul*** *constructor.*

2.9.9.6 Disc-Ring Symmetric Arc

Symmetric structures similar to ones described in section 2.9.9.5 with coupling regions constructed using arcs. Both objects (disc/ring) are described by the center coordinate (x, y), number of segments (N), gap between the object and waveguide (g), waveguide opening angle (θ), number of sides (N_{wg}), width (W), and length of the connecting straight waveguide section (L_S), disc radius, (r_d), ring radius (r_i) and width (W_r). $EC = 0$ and $EC = 1$ for waveguides without and with endcaps, respectively.

<x y r_d N g θ N_{wg} W L_S EC discSymmetricA>

<x y r_i W_r N g θ N_{wg} W L_S EC ringSymmetricA>

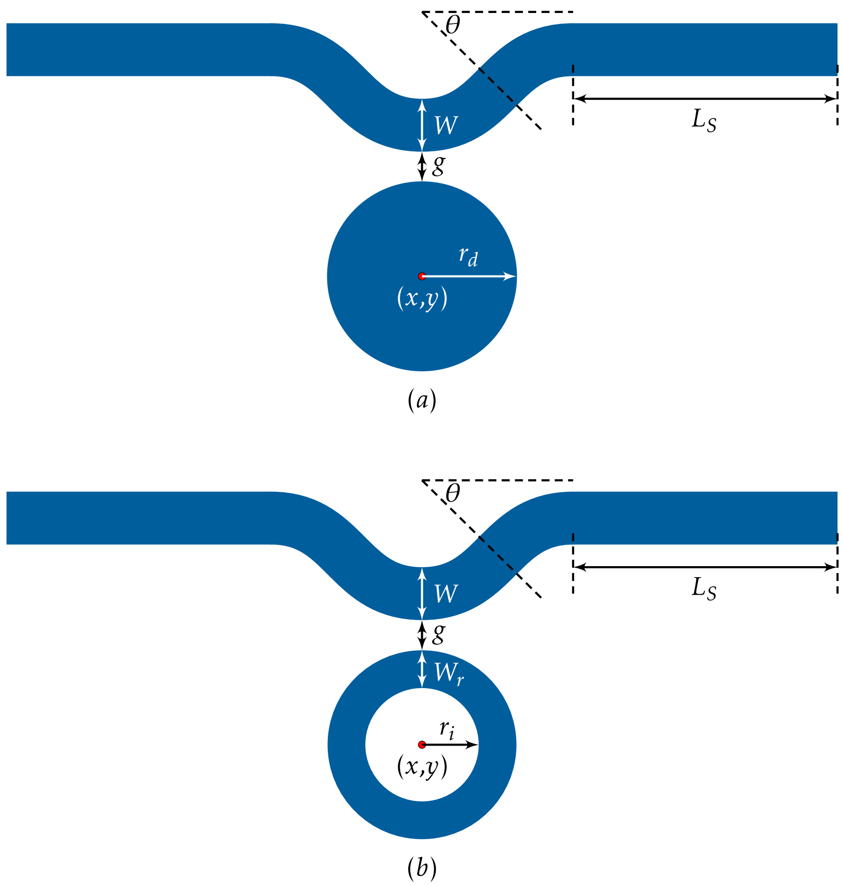


Figure 2.160: *Example shapes illustrating various parameters from the (a) **discSymmetricA** and (b) **ringSymmetricA** constructors.*

Disc symmetric arc structure with an additional coupling waveguide.

<x y r_d N g_1 θ N_{wg} W_1 L_S g_2 W_2 L_2 EC **discSymADS**>

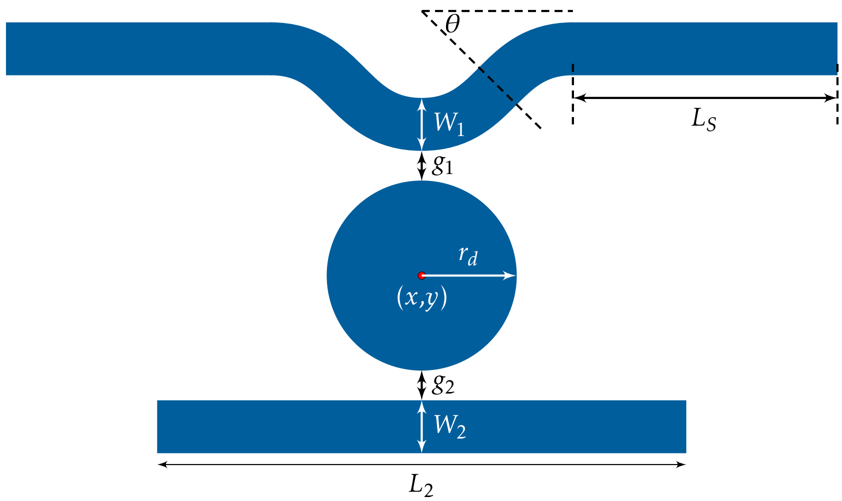


Figure 2.161: *Example shape illustrating various parameters from the **discSymADS** constructor.*

Disc symmetric arc structure with an additional coupling pulley.

<x y r_d N g_1 θ_1 N_{wg} W_1 L_{S1} g_2 θ_2 W_2 L_{S2} EC **discSymAPul**>

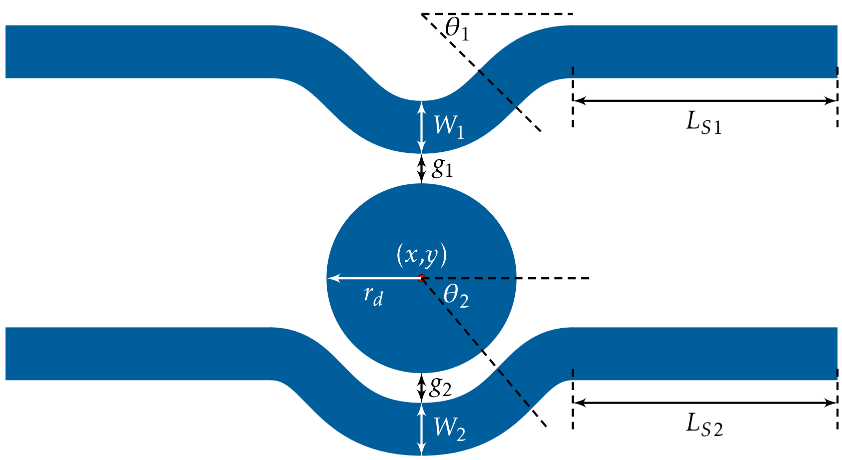


Figure 2.162: *Example shape illustrating various parameters from the* **discSymAPul** *constructor.*

Ring symmetric arc structure with an additional coupling waveguide.

<x y r_i W_r N g_1 θ N_{wg} W_1 L_S g_2 W_2 L_2 EC **ringSymADS**>

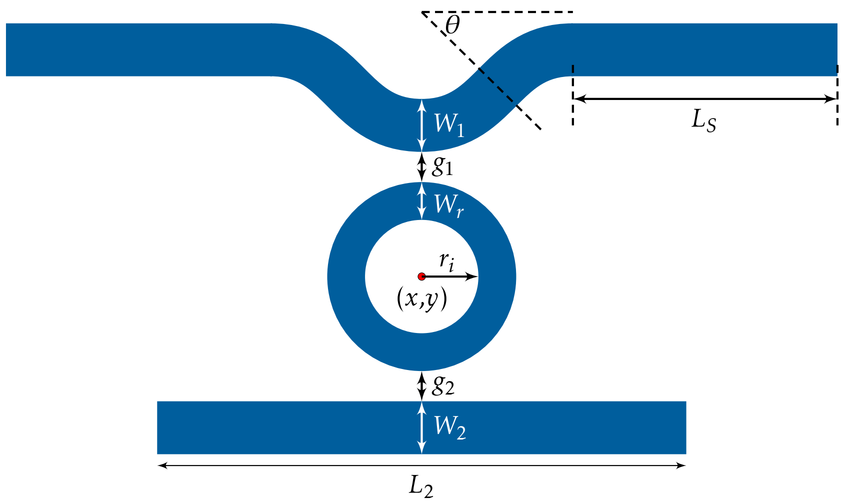


Figure 2.163: *Example shape illustrating various parameters from the* ***ringSymADS*** *constructor.*

Ring symmetric arc structure with an additional coupling pulley.

<x y r_i W_r N g θ_1 N_{wg} W L_S g_2 θ_2 W_2 L_{S2} EC **ringSymAPul**>

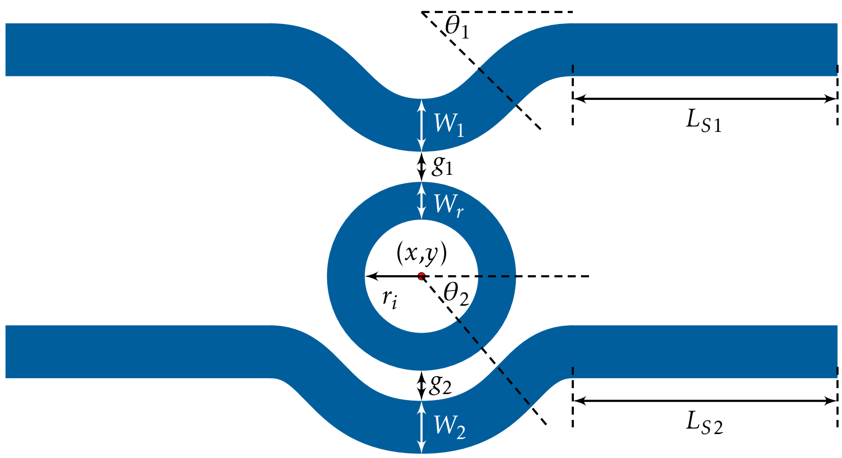


Figure 2.164: *Example shape illustrating various parameters from the* ***ringSymAPul*** *constructor.*

The following arc based, disc-ring waveguide symmetric structures are defined by the coupling length parameter L_c.

<x y r_d N g L_c N_{wg} W L_S EC discSymmetricLCA>

<x y r_i W_r N g L_c N_{wg} W L_S EC ringSymmetricLCA>

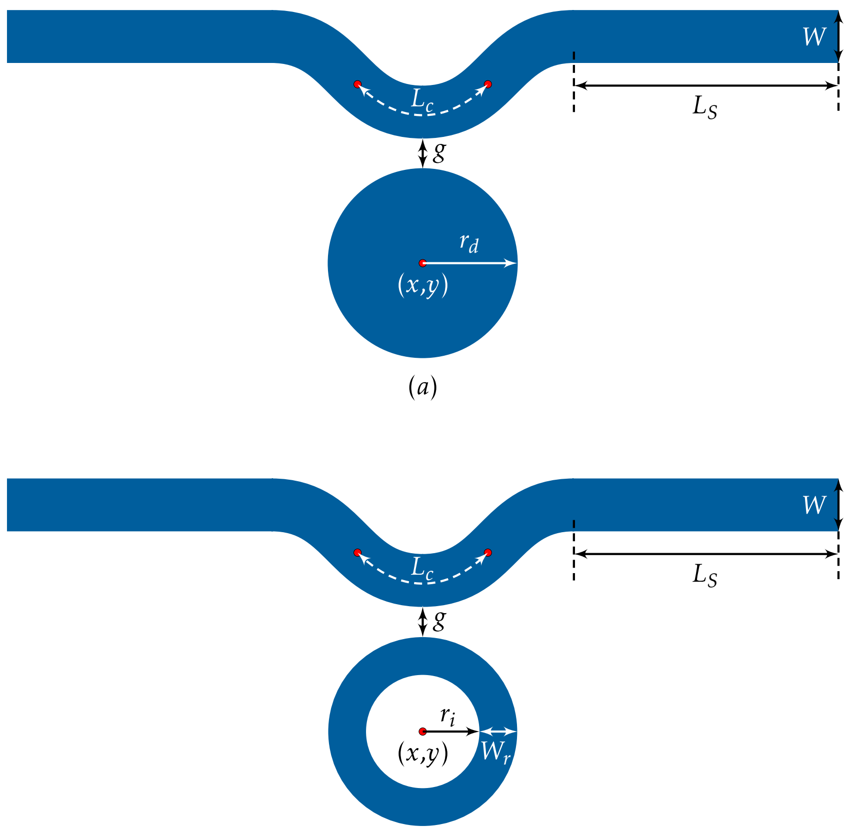


Figure 2.165: *Example shapes illustrating various parameters from the (a) discSymmetricLCA and (b) ringSymmetricLCA constructors.*

Disc symmetric arc structure with an additional coupling waveguide.

<x y r_d N g_1 L_c N_{wg} W_1 L_S g_2 W_2 L_2 EC **discSymLCADS**>

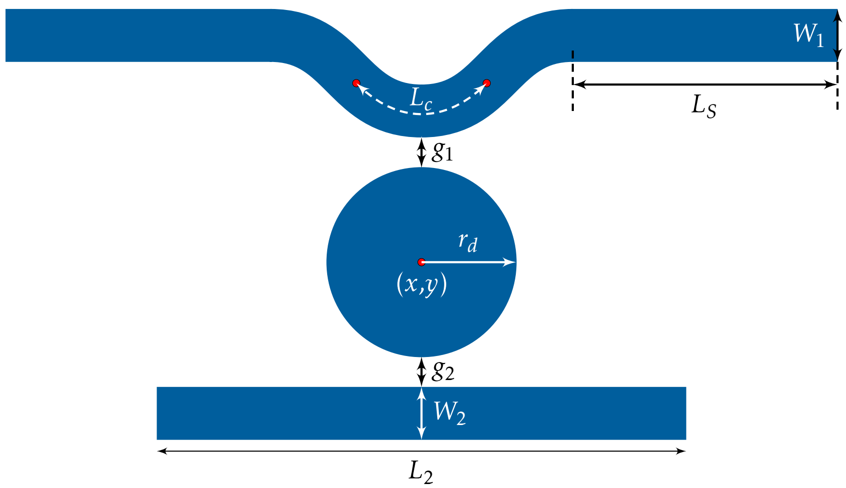


Figure 2.166: *Example shape illustrating various parameters from the (a) **discSymLCADS** constructor.*

Disc symmetric arc structure with an additional coupling pulley.

<x y r_d N g_1 L_{c1} N_{wg} W_1 L_{S1} g_2 L_{c2} W_2 L_{S2} EC **discSymLCAPul**>

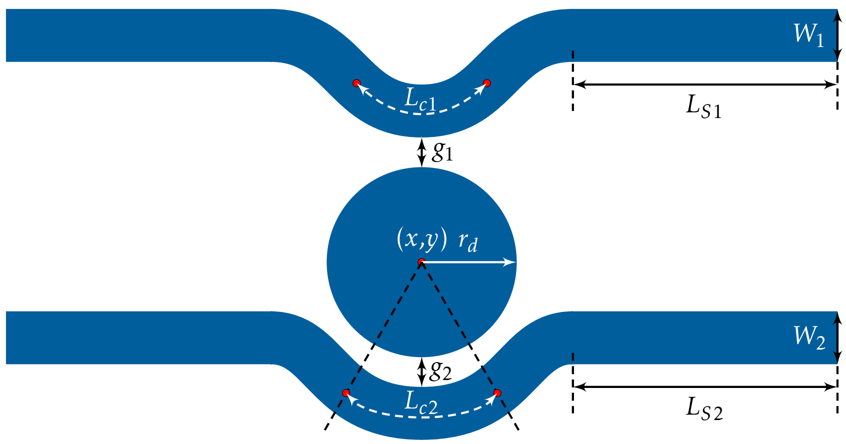


Figure 2.167: *Example shape illustrating various parameters from the (a)* ***discSymLCAPul*** *constructor.*

Ring symmetric arc structure with an additional coupling waveguide.

<x y r_i W_r N g_1 L_c N_{wg} W_1 L_S g_2 W_2 L_2 EC **ringSymLCADS**>

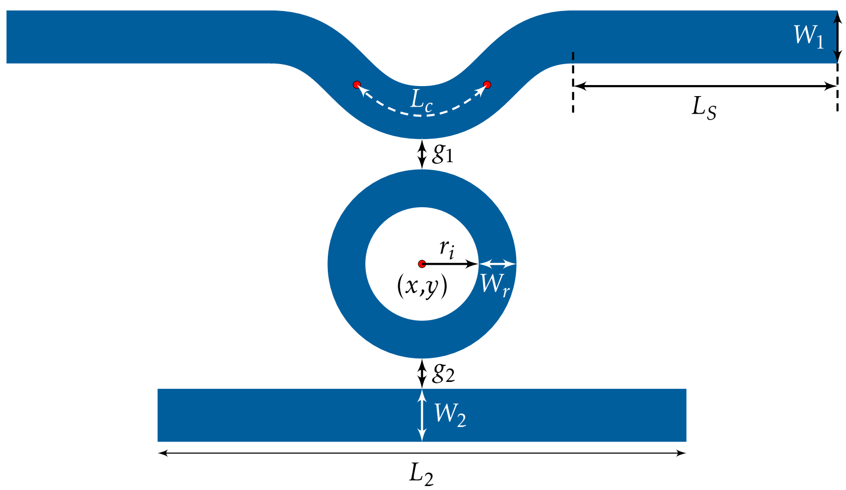


Figure 2.168: *Example shape illustrating various parameters from the* ***ringSymLCADS*** *constructor.*

Ring symmetric arc structure with an additional coupling pulley.

$<x\ y\ r_i\ W_r\ N\ g_1\ L_{c1}\ N_{wg}\ W_1\ L_{S1}\ g_2\ L_{c2}\ W_2\ L_{S2}\ EC$ **ringSymLCAPul>**

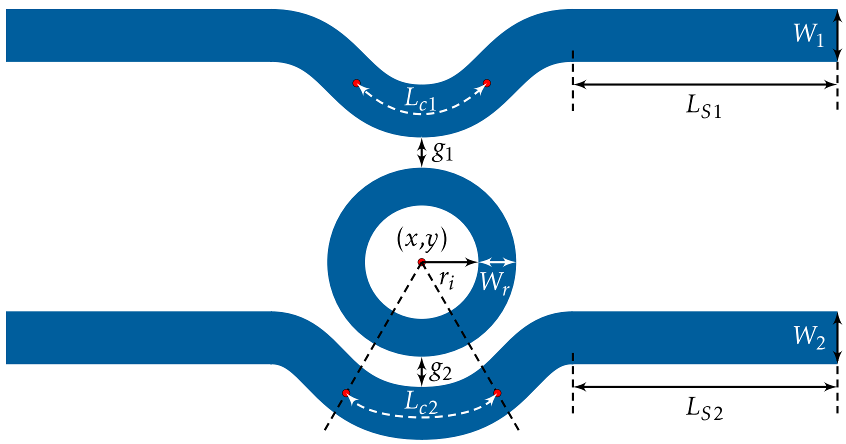


Figure 2.169: *Example shape illustrating various parameters from the* ***ringSymLCAPul*** *constructor.*

2.9.9.7 Disc-Ring Symmetric Inverse Bezier

The structure is similar to the disc-ring waveguide symmetric structure defined in the previous section (2.9.9.5). Here, a slot waveguide of width W is formed by exposing a surrounding rectangular region of width W_e. Using a negative tone resist, the resulting structure would produce a disc or ring shape at a distance g to a slotted waveguide.

<x y r_d N g θ N_{wg} W W_e L H EC **discSymmetricInv**>

<x y r_i W_r N g θ N_{wg} W W_e L H EC **ringSymmetricInv**>

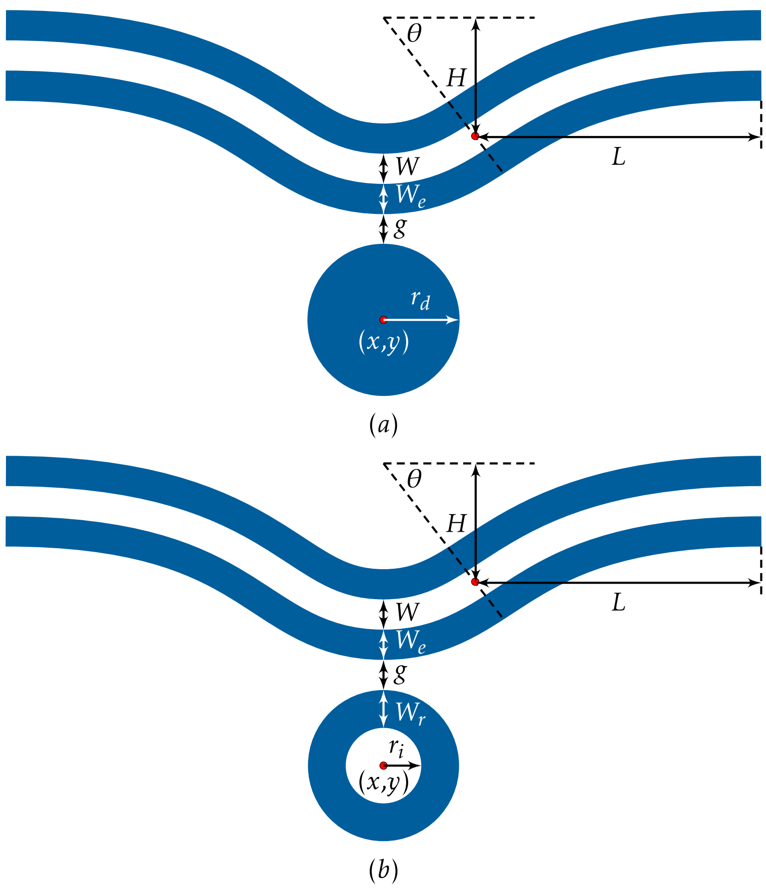


Figure 2.170: *Example shapes illustrating various parameters from the (a) **discSymmetricInv** and (b) **ringSymmetricInv** constructors.*

Disc symmetric inverse structure with an additional coupling waveguide.

<x y r_d N g_1 θ N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **discSymInvDS**>

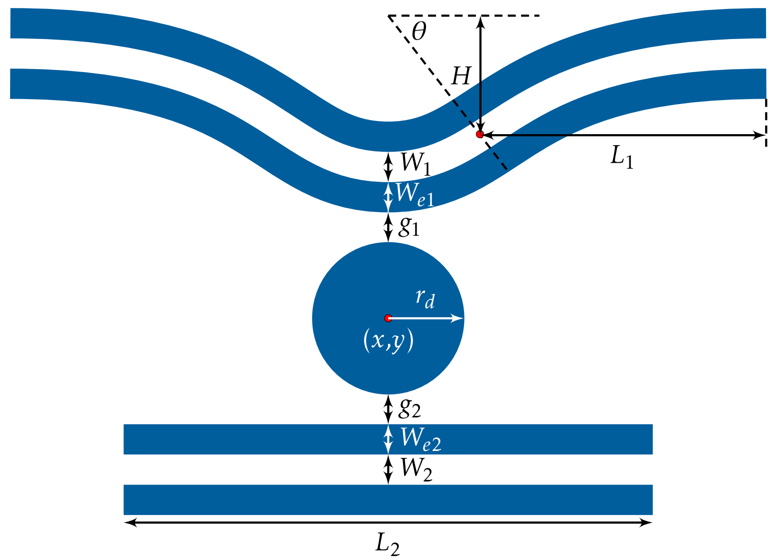


Figure 2.171: *Example shape illustrating various parameters from the (a)* ***discSymInvDS*** *constructor.*

Disc symmetric inverse structure with an additional coupling pulley.

<x y r_d N g_1 θ_1 N_{wg} W_1 W_{e1} L_1 H_1 g_2 θ_2 W_2 W_{e2} L_2 H_2 EC **discSymInvPul**>

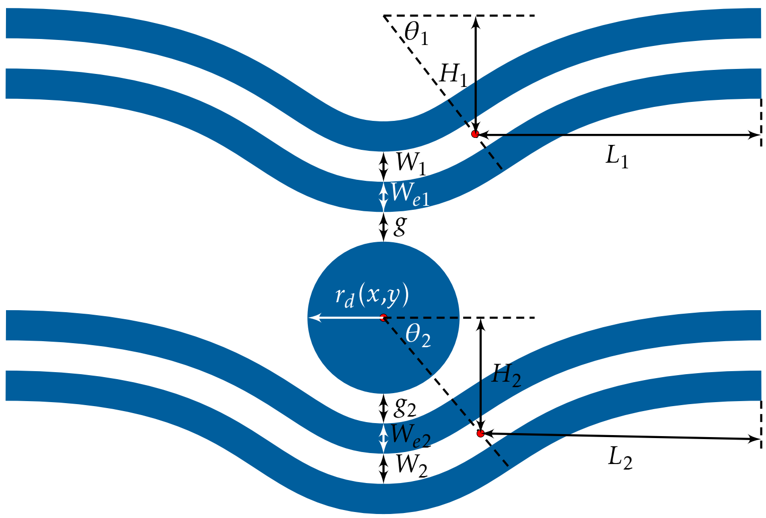


Figure 2.172: *Example shape illustrating various parameters from the (a)* ***discSymInvPul*** *constructor.*

Ring symmetric inverse structure with an additional coupling waveguide.

<$x\ y\ r_i\ W_r\ N\ g_1\ \theta\ N_{wg}\ W_1\ W_{e1}\ L_1\ H\ g_2\ W_2\ W_{e2}\ L_2\ EC$ **ringSymInvDS**>

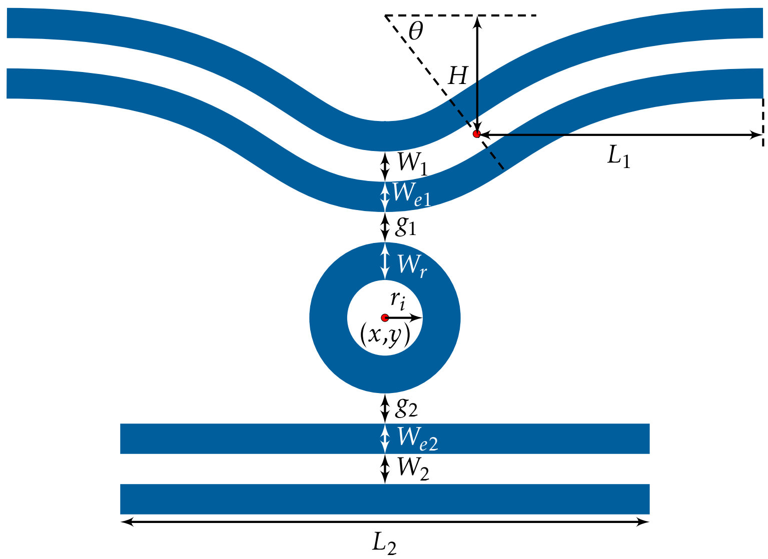


Figure 2.173: *Example shape illustrating various parameters from the* ***ringSymInvDS*** *constructor.*

Ring symmetric inverse structure with an additional coupling pulley.

<x y r_i W_r N g_1 θ_1 N_{wg} W_1 W_{e1} L_1 H_1 g_2 θ_2 W_2 W_{e2} L_2 H_2 EC **ringSymInvPul**>

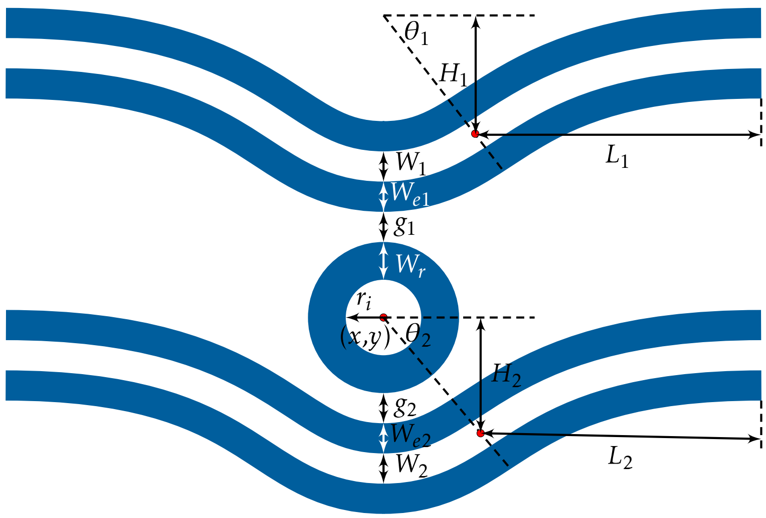


Figure 2.174: *Example shape illustrating various parameters from the* ***ringSymInvPul*** *constructor.*

The following disc-ring waveguide symmetric inverse structures are defined by the coupling length parameter L_c.

<x y r_d N g L_c N_{wg} W W_e L H EC **discSymmetricInvLC**>

<x y r_i W_r N g L_c N_{wg} W W_e L H EC **ringSymmetricInvLC**>

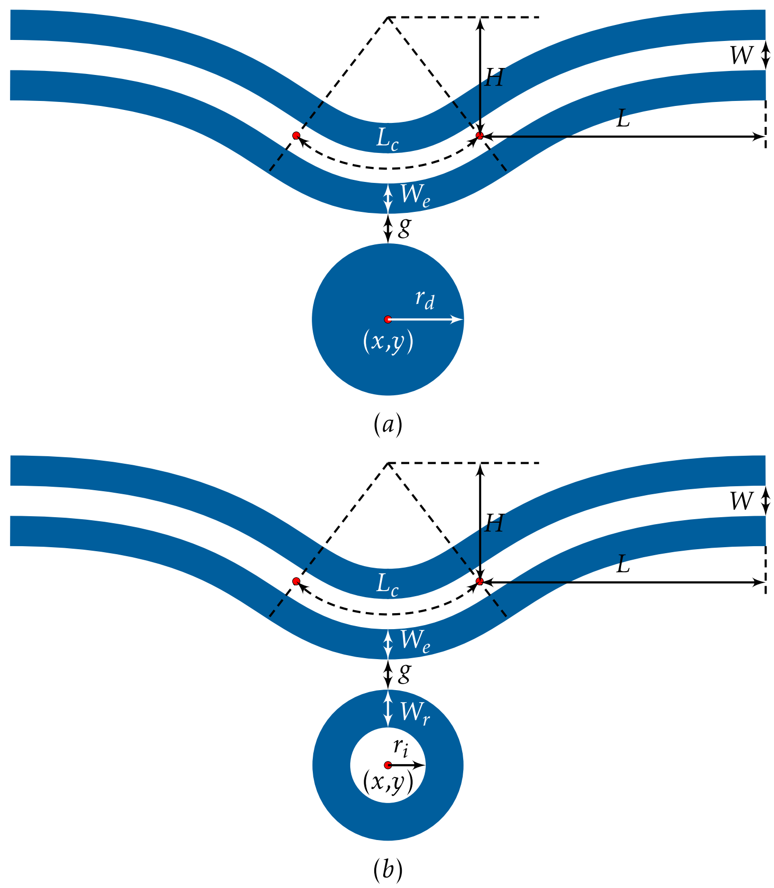


Figure 2.175: *Example shapes illustrating various parameters from the (a)* ***discSymmetricInvLC*** *and (b)* ***ringSymmetricInvLC*** *constructors.*

Disc symmetric inverse structure with an additional coupling waveguide.

<x y r_d N g_1 L_c N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **discSymInvLCDS**>

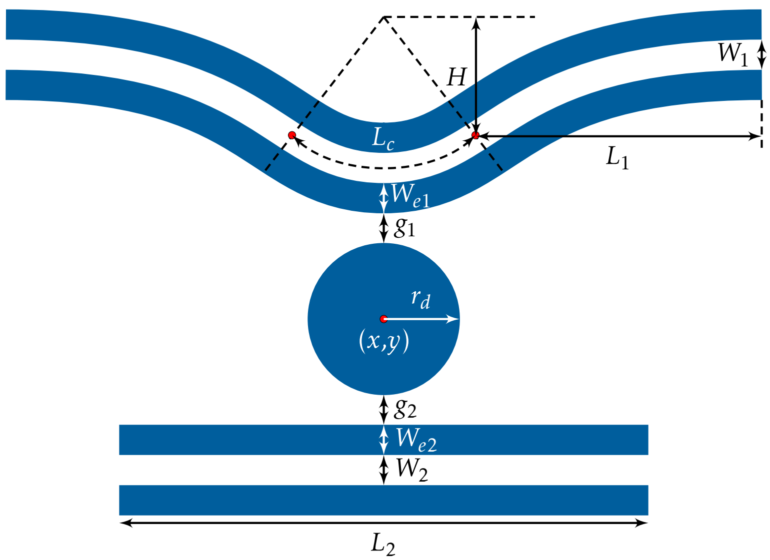


Figure 2.176: *Example shape illustrating various parameters from the (a)* ***discSymInvLCDS*** *constructor.*

Disc symmetric inverse structure with an additional coupling pulley.

<x y r_d N g_1 L_{c1} N_{wg} W_1 W_{e1} L_1 H_1 g_2 L_{c2} W_2 W_{e2} L_2 H_2 EC **discSymInvLCPul**>

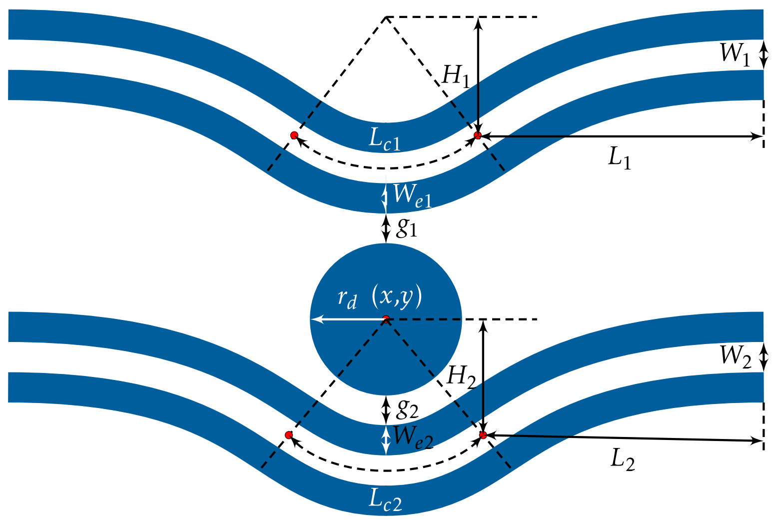


Figure 2.177: *Example shape illustrating various parameters from the (a)* ***discSymInvLCPul*** *constructor.*

Ring symmetric inverse structure with an additional coupling waveguide.

<x y r_i W_r N g_1 L_c N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **ringSymInvLCDS**>

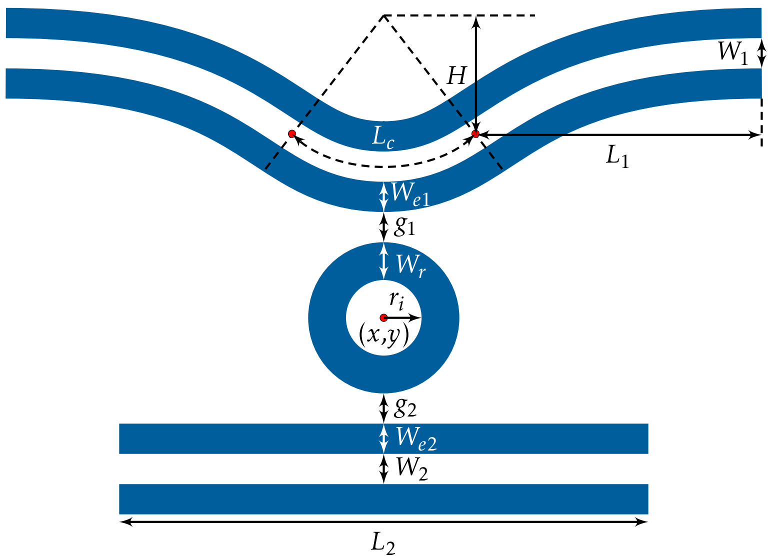


Figure 2.178: *Example shape illustrating various parameters from the* ***ringSymInvLCDS*** *constructor.*

Ring symmetric inverse structure with an additional coupling pulley.

<$x\ y\ r_i\ W_r\ N\ g_1\ L_{c1}\ N_{wg}\ W_1\ W_{e1}\ L_1\ H_1\ g_2\ L_{c2}\ W_2\ W_{e2}\ L_2\ H_2\ EC$ **ringSymInvLCPul**>

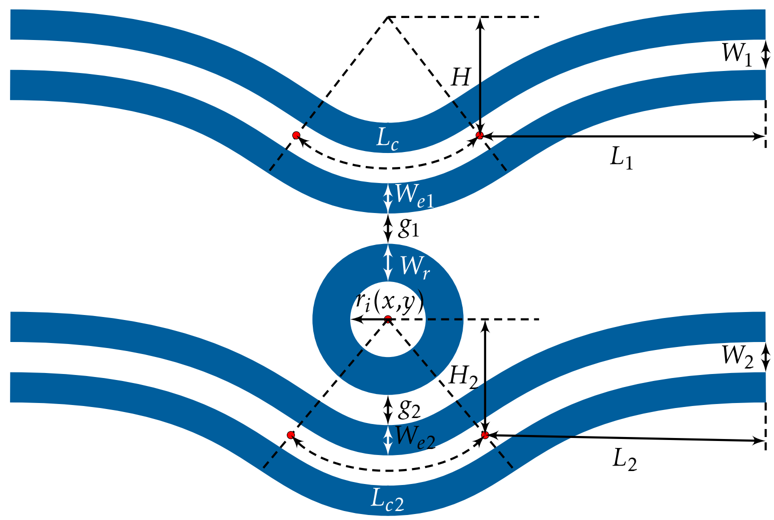


Figure 2.179: *Example shape illustrating various parameters from the* ***ringSymInvLCPul*** *constructor.*

2.9.9.8 Disc-Ring Symmetric Inverse Arc

Symmetric inverse structures constructed using arcs are similar to ones described in section 2.9.9.6. Here, a slot waveguide of width W is formed by exposing a surrounding rectangular region of width W_e. Using a negative tone resist, the resulting structure would produce a disc or ring shape at a distance g to a slotted waveguide.

<x y r_d N g θ N_{wg} W W_e L_S EC **discSymmetricInvA**>

<x y r_i W_r N g θ N_{wg} W W_e L_S EC **ringSymmetricInvA**>

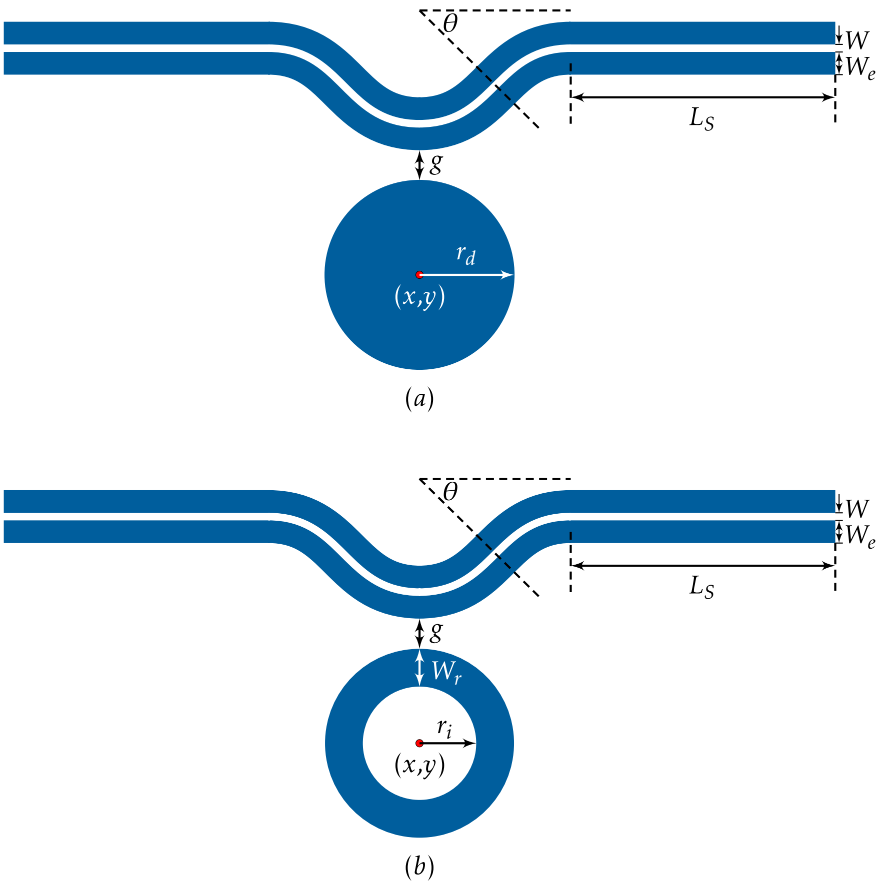


Figure 2.180: *Example shapes illustrating various parameters from the (a)* ***discSymmetricInvA*** *and (b)* ***ringSymmetricInvA*** *constructors.*

Disc symmetric inverse arc structure with an additional coupling waveguide.

<$x\ \ y\ \ r_d\ \ N\ \ g_1\ \ \theta\ \ N_{wg}\ \ W_1\ \ W_{e1}\ \ L_S\ \ g_2\ \ W_2\ \ W_{e2}\ \ L_2\ \ EC$ **discSymInvADS**>

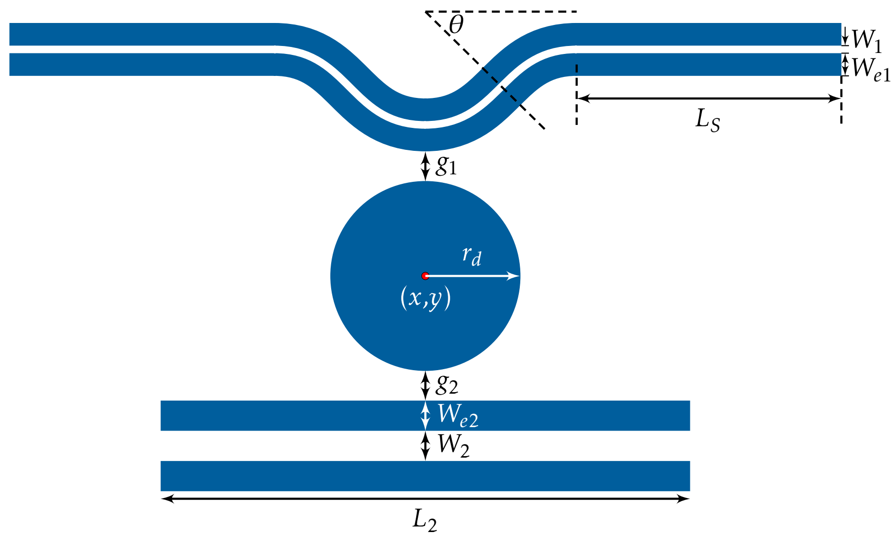


Figure 2.181: *Example shape illustrating various parameters from the* ***discSymInvADS*** *constructor.*

Disc symmetric inverse arc structure with an additional coupling pulley.

$<x\ y\ r_d\ N\ g_1\ \theta_1\ N_{wg}\ W_1\ W_{e1}\ L_{S1}\ g_2\ \theta_2\ W_2\ W_{e2}\ L_{S2}\ EC$ **discSymInvAPul**$>$

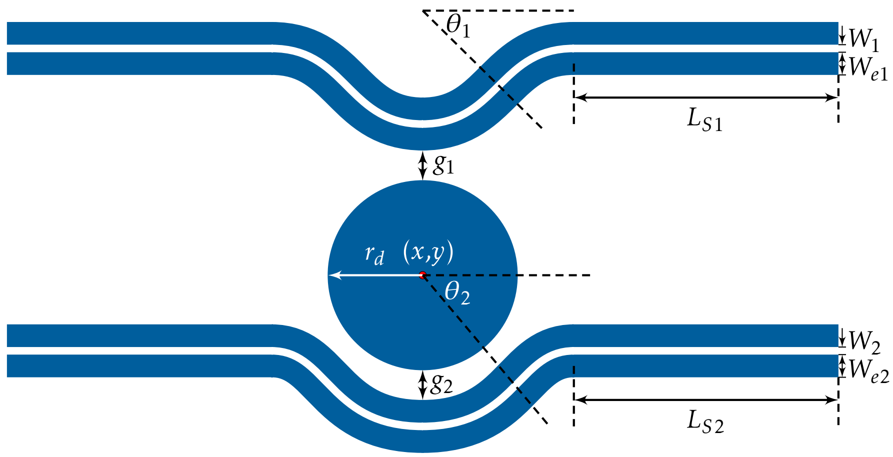


Figure 2.182: *Example shape illustrating various parameters from the* ***discSymInvAPul*** *constructor.*

Ring symmetric inverse arc structure with an additional coupling waveguide.

<x y r_i W_r N g_1 θ N_{wg} W_1 W_e L_S g_2 W_2 W_{e2} L_2 EC **ringSymInvADS**>

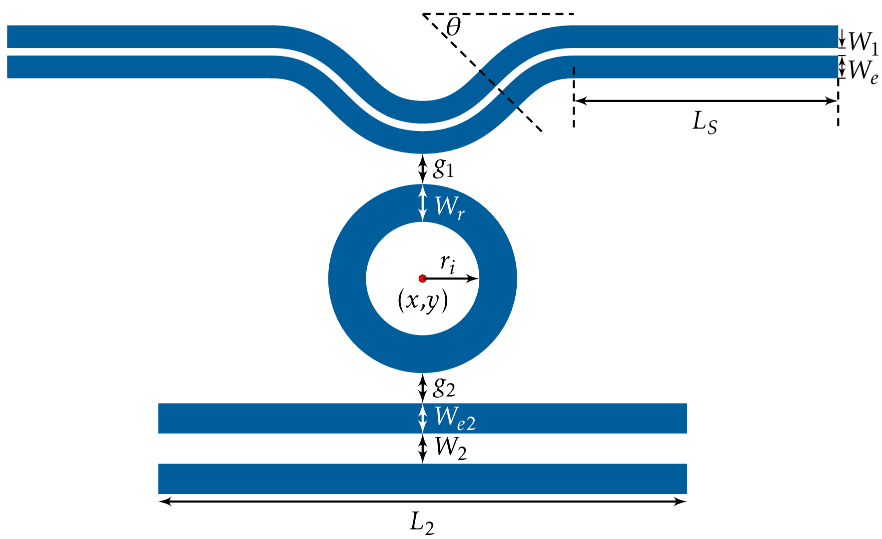


Figure 2.183: *Example shapes illustrating various parameters from the* ***ringSymInvADS*** *constructor.*

Ring symmetric inverse arc structure with an additional coupling pulley.

<x y r_i W_r N g_1 θ_1 N_{wg} W_1 W_{e1} L_{S1} g_2 θ_2 W_2 W_{e2} L_{S2} EC **ringSymInvAPul**>

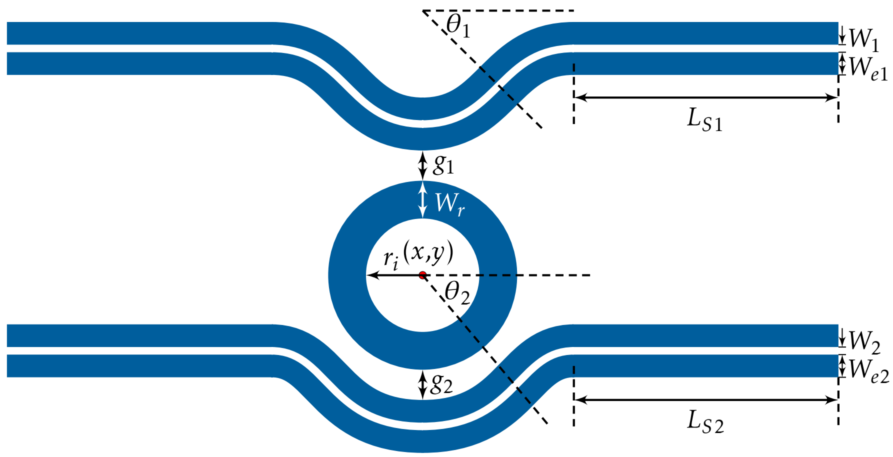


Figure 2.184: *Example shapes illustrating various parameters from the* ***ringSymInvAPul*** *constructor.*

The following arc based, disc-ring waveguide symmetric inverse structures are defined by the coupling length parameter L_c.

<x y r_d N g L_c N_{wg} W W_e L_S EC **discSymmetricInvLCA**>

<x y r_i W_r N g L_c N_{wg} W W_e L_S EC **ringSymmetricInvLCA**>

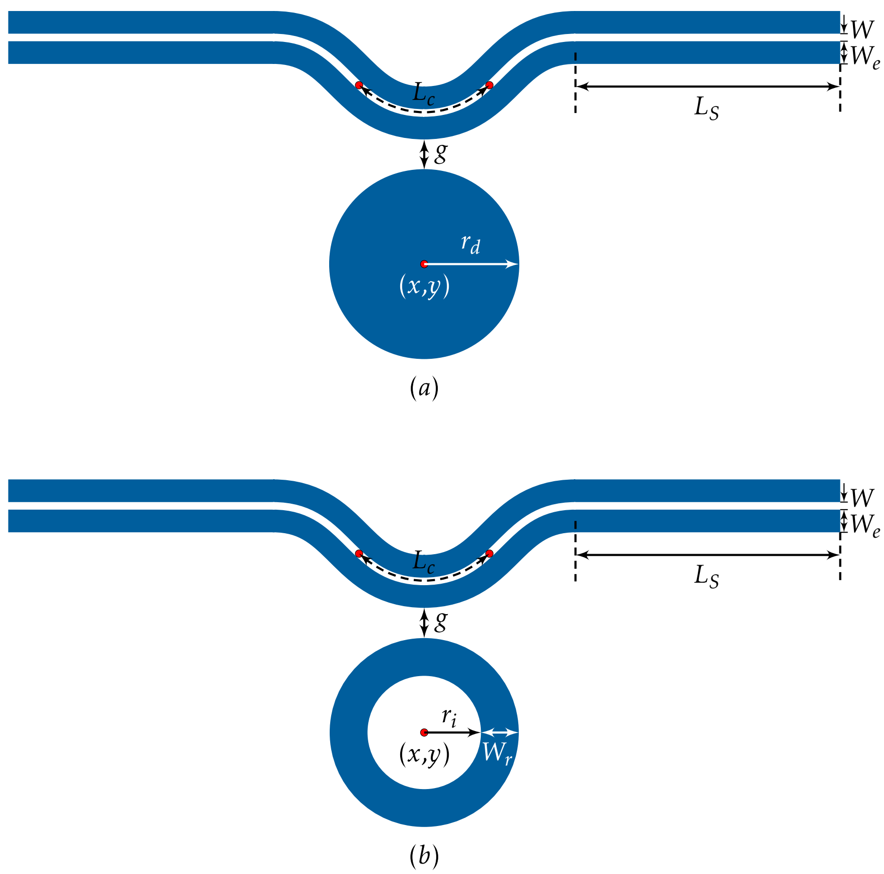


Figure 2.185: *Example shapes illustrating various parameters from the (a)* ***discSymmetricInvLCA*** *and (b)* ***ringSymmetricInvLCA*** *constructors.*

Disc symmetric inverse arc structure with an additional coupling waveguide.

<x y r_d N g_1 L_c N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **discSymInvLCADS**>

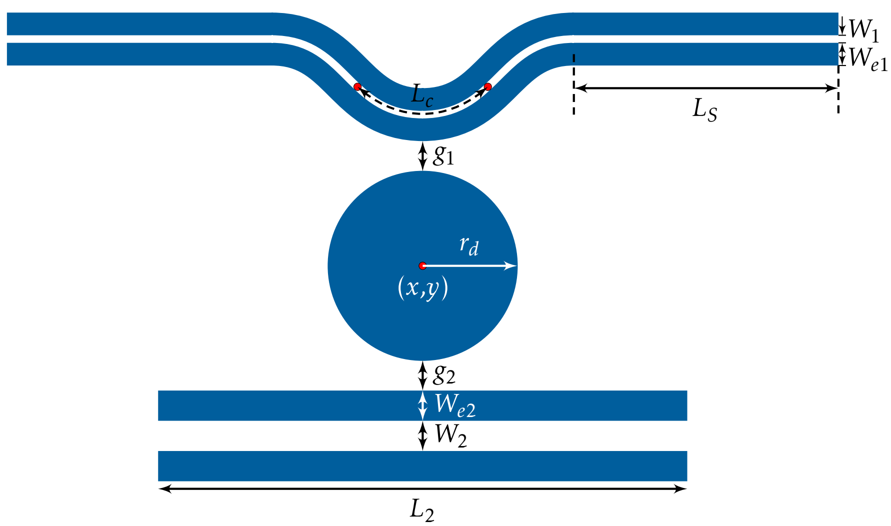


Figure 2.186: *Example shape illustrating various parameters from the **discSymInvLCADS** constructor.*

Disc symmetric inverse arc structure with an additional coupling pulley.

<x y r_d N g_1 L_c N_{wg} W_1 W_{e1} L_{S1} g_2 L_{c2} W_2 W_{e2} L_{S2} EC **discSymInvLCAPul**>

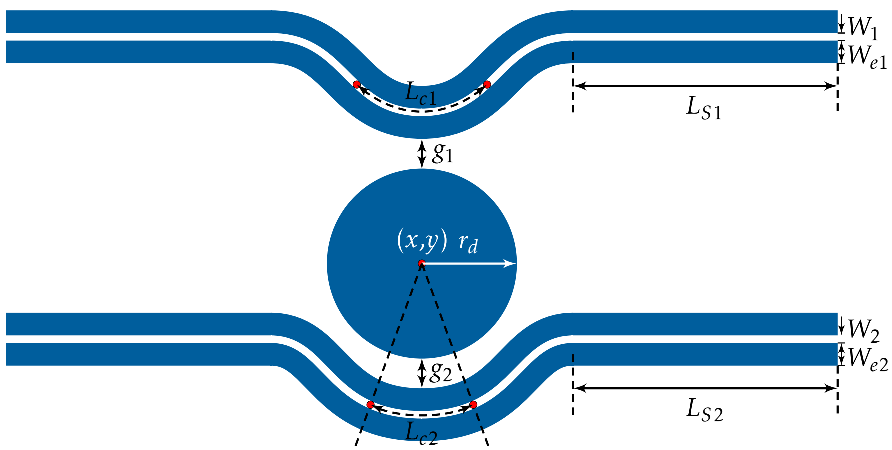


Figure 2.187: *Example shape illustrating various parameters from the* **discSymInvLCAPul** *constructor.*

Ring symmetric inverse arc structure with an additional coupling waveguide.

<x y r_i W_r N g_1 L_c N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **ringSymInvLCADS**>

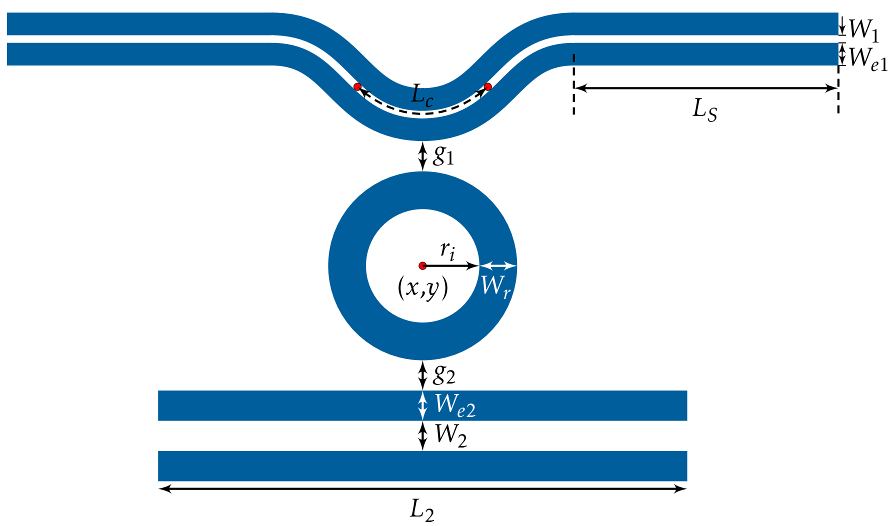


Figure 2.188: *Example shape illustrating various parameters from the* ***ringSymInvLCADS*** *constructor.*

Ring symmetric inverse arc structure with an additional coupling pulley.

<x y r_i W_r N g_1 L_{c1} N_{wg} W_1 W_{e1} L_{S1} g_2 L_{c2} W_2 W_{e2} L_{S2} EC **ringSymInvLCAPul**>

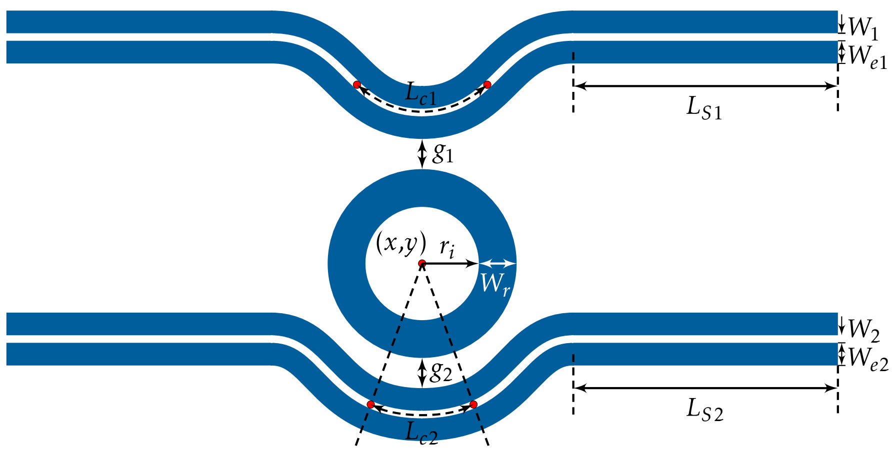


Figure 2.189: *Example shape illustrating various parameters from the* ***ringSymInvLCAPul*** *constructor.*

2.9.9.9 Disc-Ring Symmetric Inverse Positive Tone Bezier

The structure is similar to the disc-ring waveguide symmetric structure defined in section 2.9.9.5. Here, a slot waveguide is formed at a distance g away from a disc or a ring structure using a positive resist exposure of the exposure sleeve elements W_e and r_e.

<$x \quad y \quad r_d \qquad r_e \quad N \quad g \quad \theta \quad N_{wg} \quad W \quad W_e \quad L \quad H \quad EC$ **discSymmetricInvPos**>

<$x \quad y \quad r_i \quad W_r \quad r_e \quad N \quad g \quad \theta \quad N_{wg} \quad W \quad W_e \quad L \quad H \quad EC$ **ringSymmetricInvPos**>

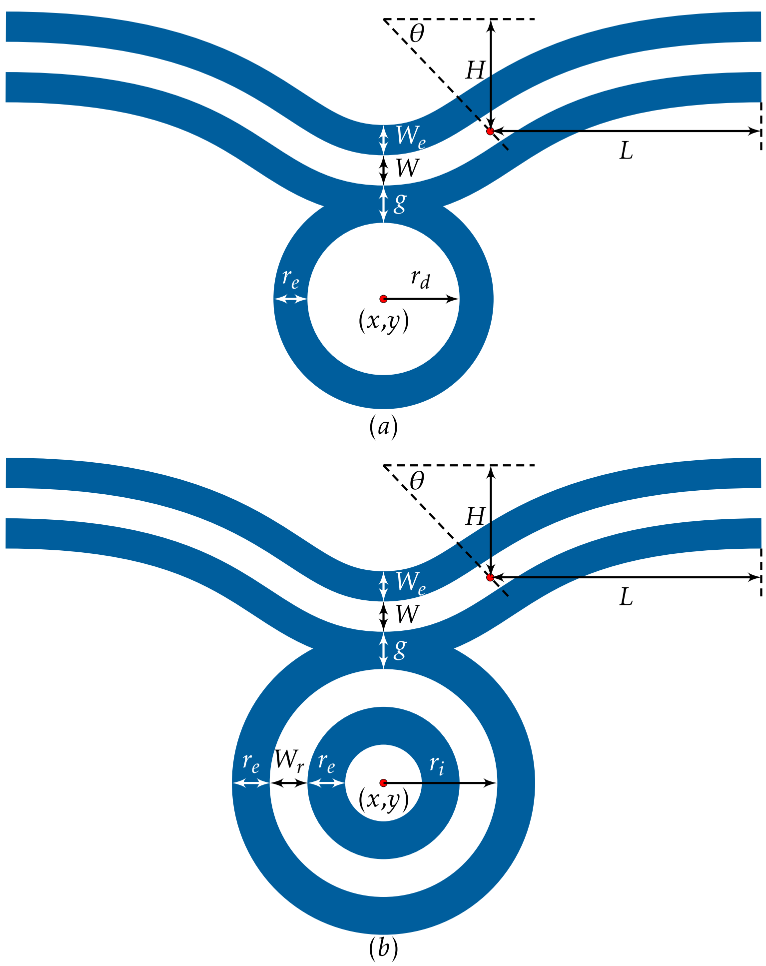


Figure 2.190: *Example shapes illustrating various parameters from the (a)* ***discSymmetricInvPos*** *and (b)* ***ringSymmetricInvPos*** *constructors.*

Disc symmetric inverse positive structure with an additional coupling waveguide.

<x y r_d r_e N g_1 θ N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **discSymInvPosDS**>

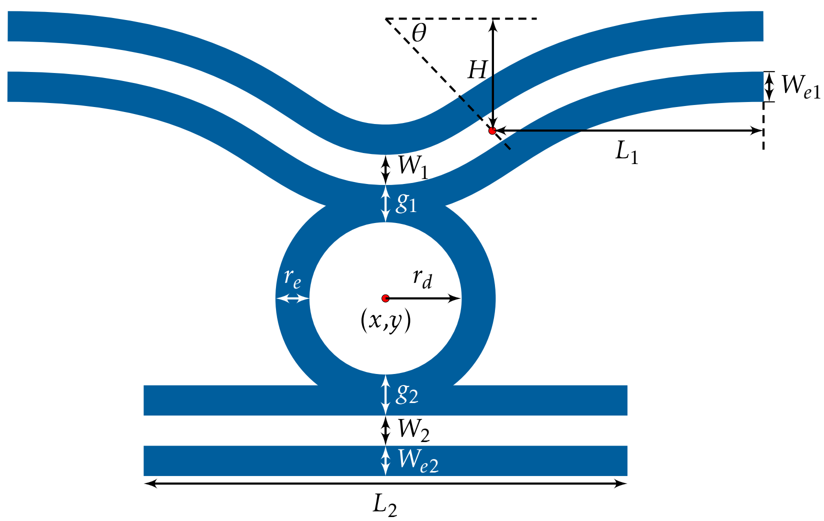


Figure 2.191: *Example shape illustrating various parameters from the* ***discSymInvPosDS*** *constructor.*

Disc symmetric inverse positive structure with an additional coupling pulley.

<x y r_d r_e N g_1 θ_1 N_{wg} W_1 W_{e1} L_1 H_1 g_2 θ_2 W_2 W_{e2} L_2 H_2 EC **discSymInvPosPul**>

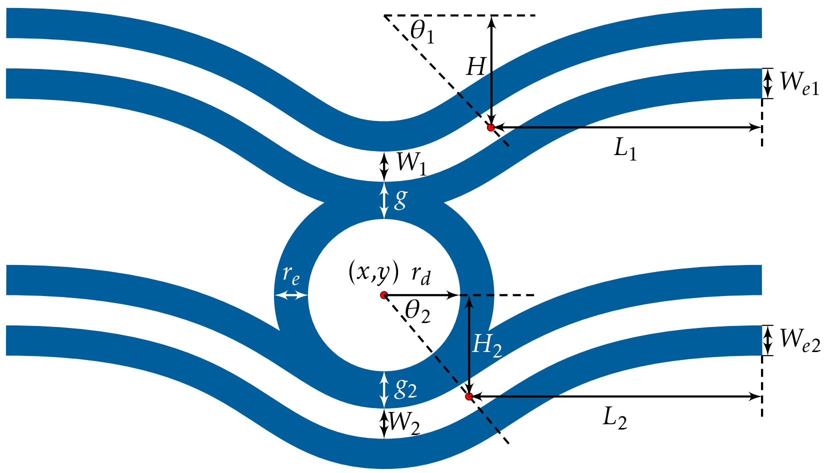


Figure 2.192: *Example shape illustrating various parameters from the* ***discSymInvPosPul*** *constructor.*

Ring symmetric inverse positive structure with an additional coupling waveguide.

<x y r_i W_r r_e N g_1 θ N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **ringSymInvPosDS**>

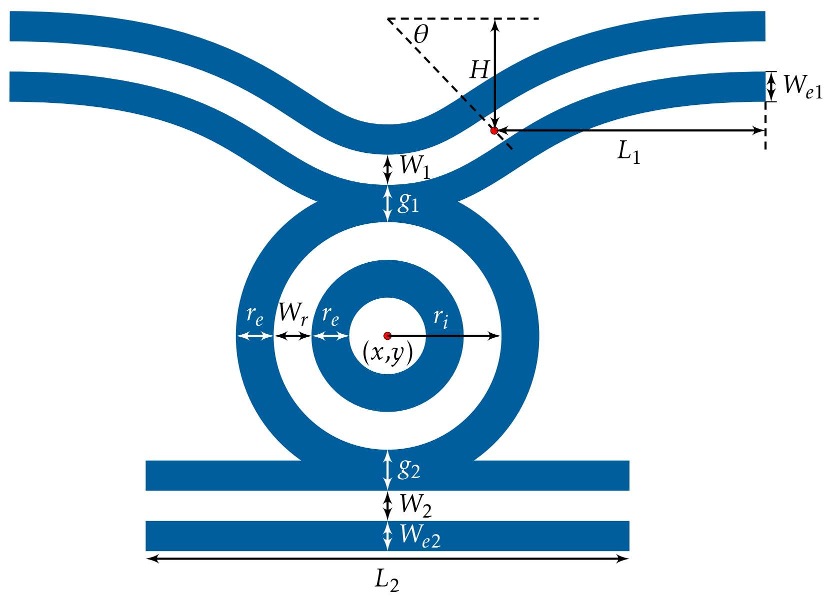


Figure 2.193: *Example shape illustrating various parameters from the* ***ringSymInvPosDS*** *constructor.*

Ring symmetric inverse positive structure with an additional coupling pulley.

<$x\ y\ r_i\ W_r\ r_e\ N\ g_1\ \theta_1\ N_{wg}\ W_1\ W_{e1}\ L_1\ H_1\ g_2\ \theta_2\ W_2\ W_{e2}\ L_2\ H_2\ EC$ ringSymInvPosPul>

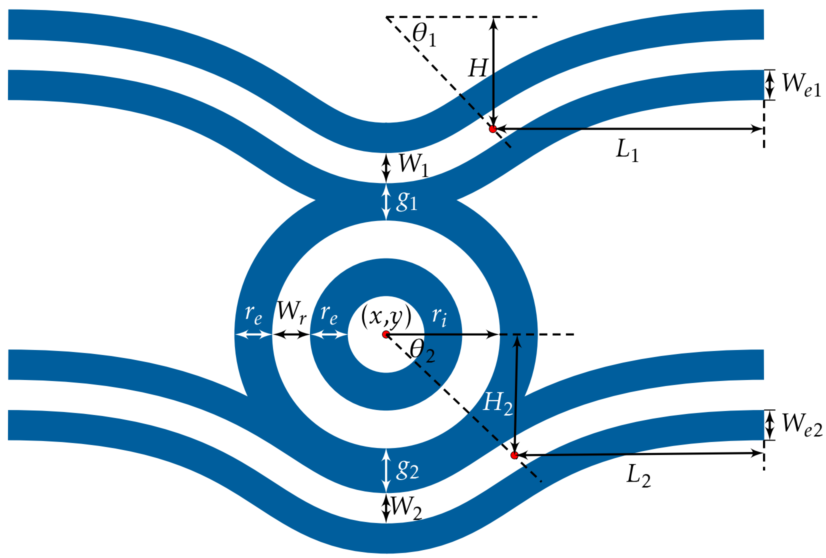


Figure 2.194: *Example shape illustrating various parameters from the* ***ringSymInvPosPul*** *constructor.*

The following disc-ring waveguide symmetric inverse positive tone structures are defined by the coupling length parameter L_c.

<$x\ \ y\ \ r_d\ \ \ \ \ \ \ \ r_e\ \ N\ \ g\ \ L_c\ \ N_{wg}\ \ W\ \ W_e\ \ L\ \ H\ \ EC$ **discSymmetricInvPosLC**>

<$x\ \ y\ \ r_i\ \ W_r\ \ r_e\ \ N\ \ g\ \ L_c\ \ N_{wg}\ \ W\ \ W_e\ \ L\ \ H\ \ EC$ **ringSymmetricInvPosLC**>

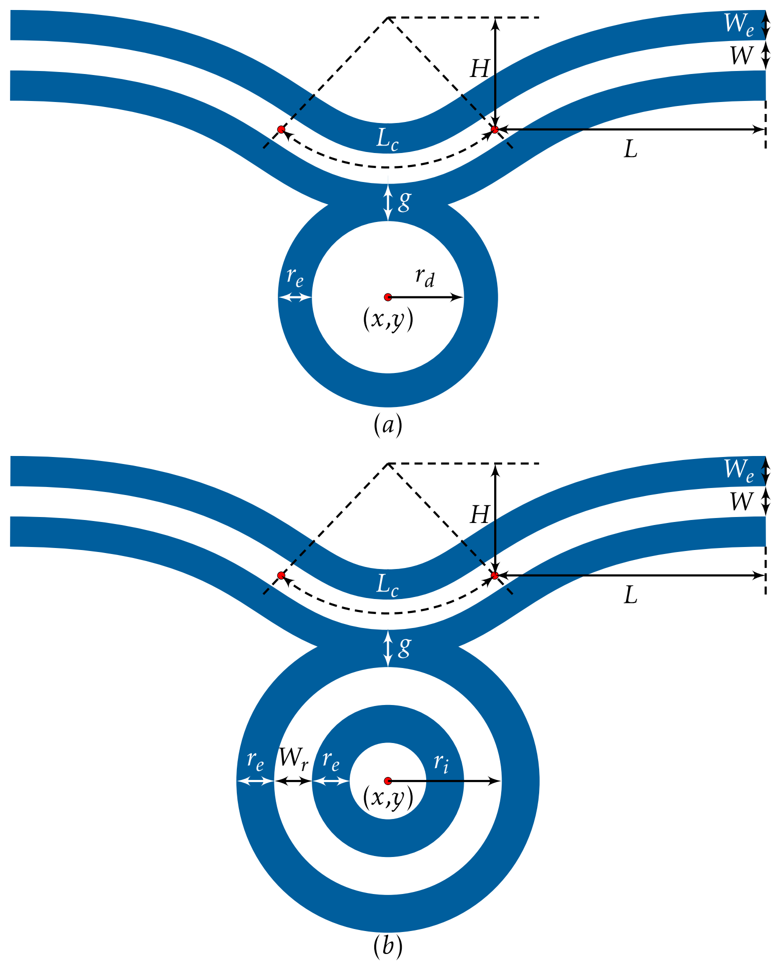


Figure 2.195: *Example shapes illustrating various parameters from the (a)* ***discSymmetricInvPosLC*** *and (b)* ***ringSymmetricInvPosLC*** *constructors.*

Disc symmetric inverse positive structure with an additional coupling waveguide.

<x y r_d r_e N g_1 L_c N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **discSymInvPosLCDS**>

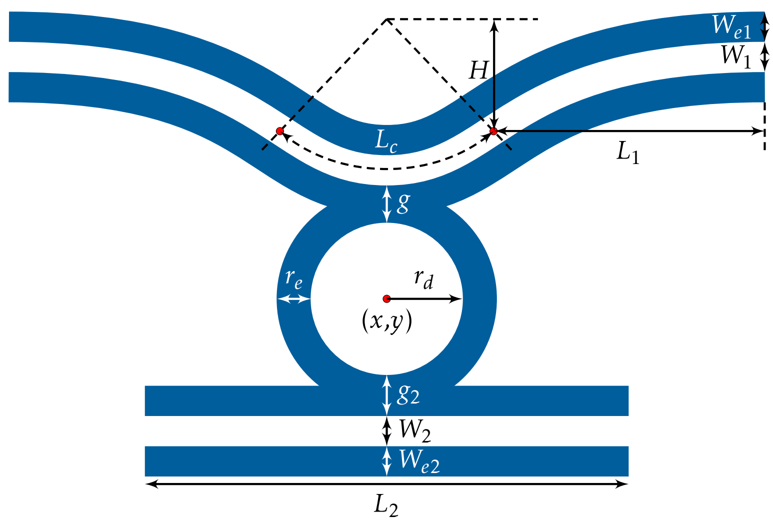


Figure 2.196: *Example shape illustrating various parameters from the* ***discSymInvPosLCDS*** *constructor.*

Disc symmetric inverse positive structure with an additional coupling pulley.

<x y r_d r_e N g_1 L_{c1} N_{wg} W_1 W_{e1} L_1 H_1 g_2 L_{c2} W_2 W_{e2} L_2 H_2 EC **discSymInvPosLCPul**>

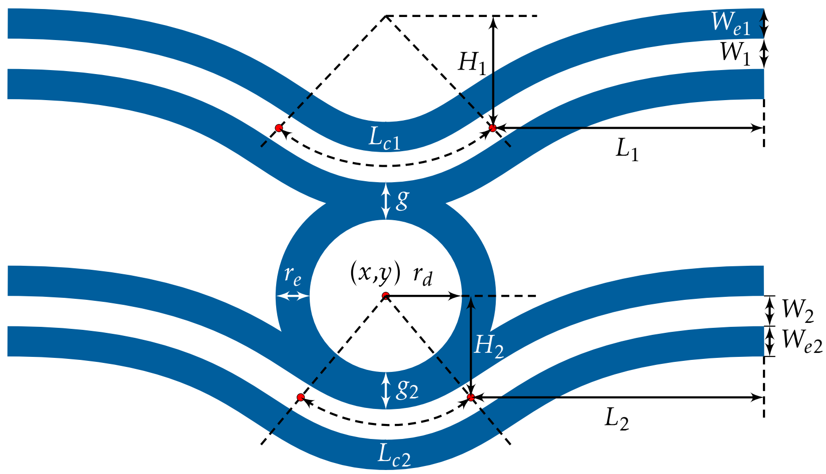


Figure 2.197: *Example shape illustrating various parameters from the **discSymInvPosLCPul** constructor.*

Ring symmetric inverse positive structure with an additional coupling waveguide.

<x y r_i W_r r_e N g_1 L_c N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **ringSymInvPosLCDS**>

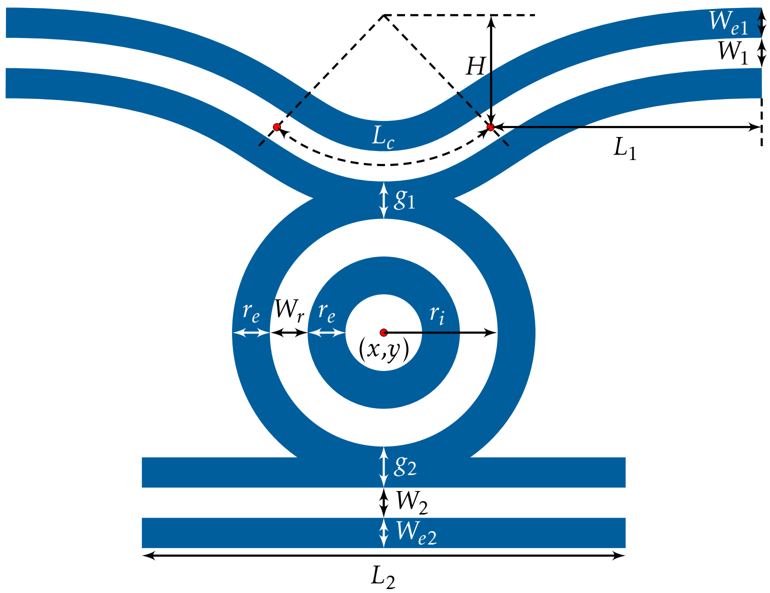


Figure 2.198: *Example shape illustrating various parameters from the* ***ringSymInvPosLCDS*** *constructor.*

Ring symmetric inverse positive structure with an additional coupling pulley.

<x y r_i W_r r_e N g_1 L_{c1} N_{wg} W_1 W_{e1} L_1 H_1 g_2 L_{c2} W_2 W_{e2} L_2 H_2 EC **ringSymInvPosLCPul**>

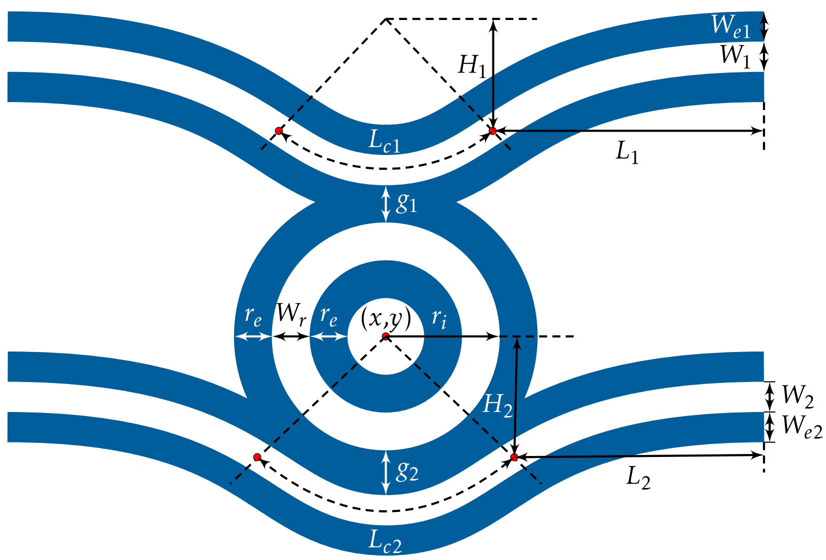


Figure 2.199: *Example shape illustrating various parameters from the* ***ringSymInvPosLCPul*** *constructor.*

2.9.9.10 Disc-Ring Symmetric Inverse Positive Tone Arc

Symmetric inverse positive tone structures constructed using arcs are similar to ones described in section 2.9.9.6. Here, a slot waveguide is formed at a distance g away from a disc or a ring structure using a positive resist exposure of the exposure sleeve elements W_e and r_e.

<x y r_d r_e N g θ N_{wg} W W_e L_S EC **discSymmetricInvPosA**>

<x y r_i W_r r_e N g θ N_{wg} W W_e L_S EC **ringSymmetricInvPosA**>

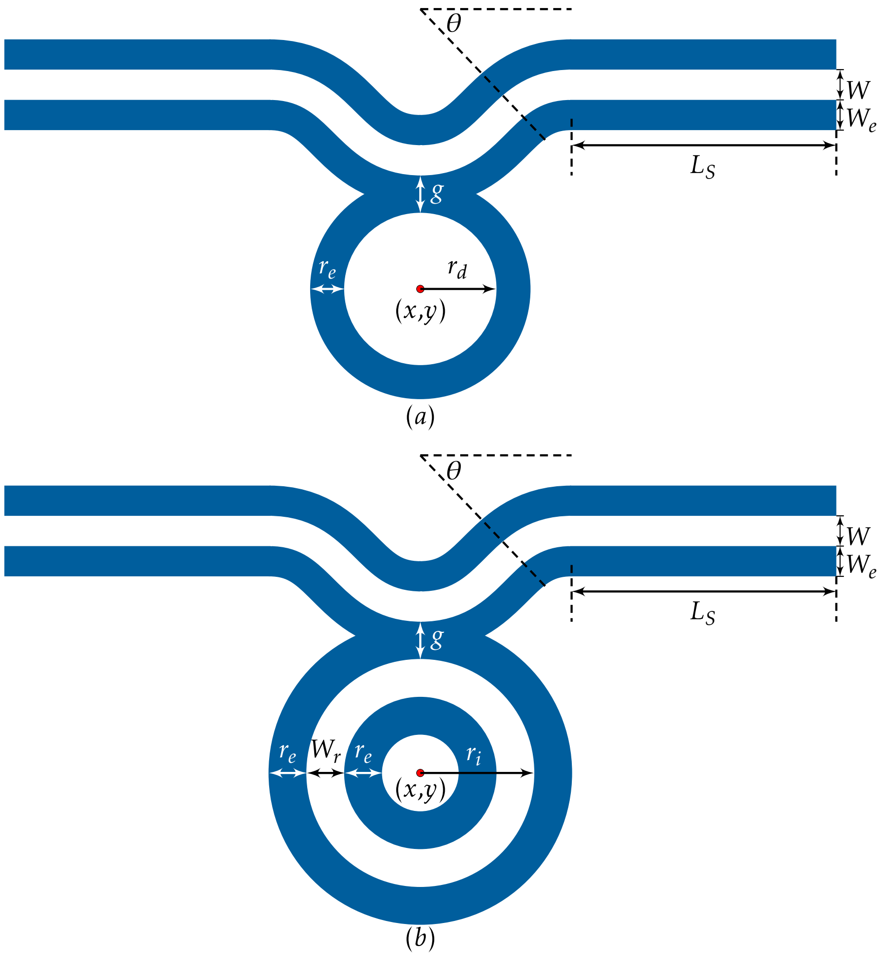


Figure 2.200: *Example shapes illustrating various parameters from the (a)* ***discSymmetricInvPosA*** *and (b)* ***ringSymmetricInvPosA*** *constructors.*

Disc symmetric inverse positive arc structure with an additional coupling waveguide.

<x y r_d r_e N g_1 θ N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **discSymInvPosADS**>

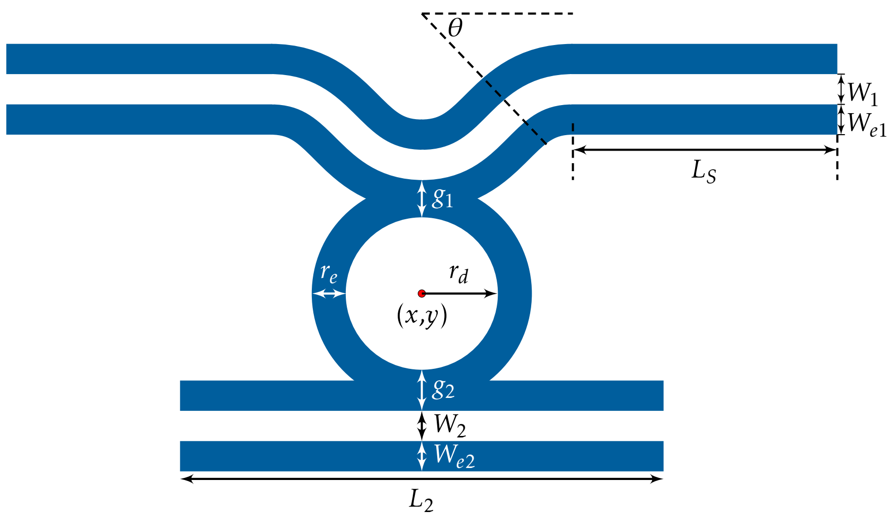


Figure 2.201: *Example shapes illustrating various parameters from the (a) **discSymInvPosADS** and (b) **ringSymInvPosADS** constructors.*

Disc symmetric inverse positive arc structure with an additional coupling pulley.

<x y r_d r_e N g_1 θ_1 N_{wg} W_1 W_{e1} L_{S1} g_2 θ_2 W_2 W_{e2} L_{S2} EC **discSymInvPosAPul**>

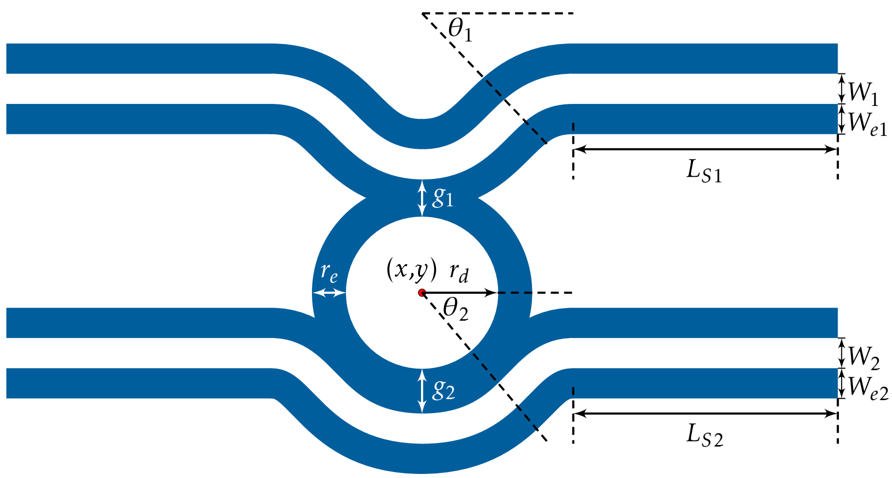


Figure 2.202: *Example shape illustrating various parameters from the **discSymInvPosAPul** constructor.*

Ring symmetric inverse positive arc structure with an additional coupling waveguide.

<x y r_i W_r r_e N g θ N_{wg} W W_e L_S g_2 W_2 W_{e2} L_2 EC **ringSymInvPosADS**>

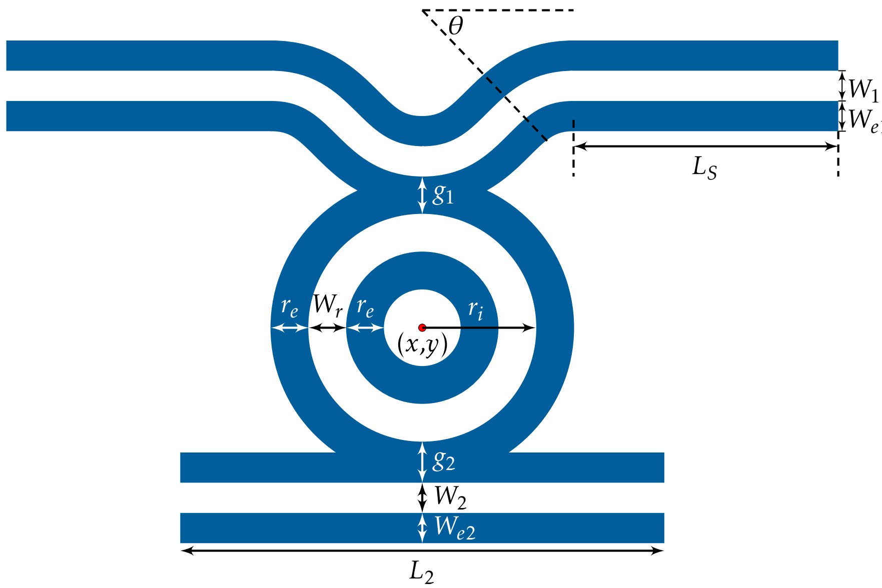


Figure 2.203: *Example shape illustrating various parameters from the* ***ringSymInvPosADS*** *constructor.*

Ring symmetric inverse positive arc structure with an additional coupling pulley.

<x y r_i W_r r_e N g_1 θ_1 N_{wg} W_1 W_{e1} L_{S1} g_2 θ_2 W_2 W_{e2} L_{S2} EC **ringSymInvPosAPul**>

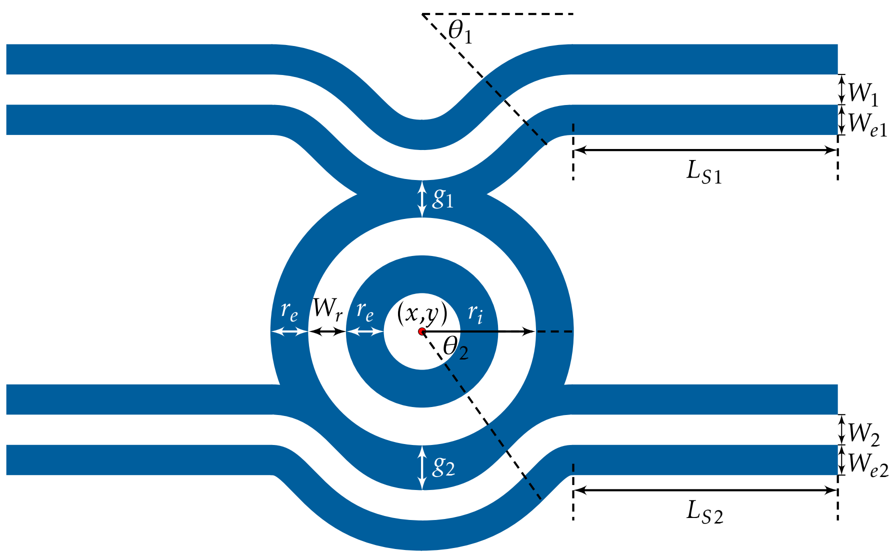
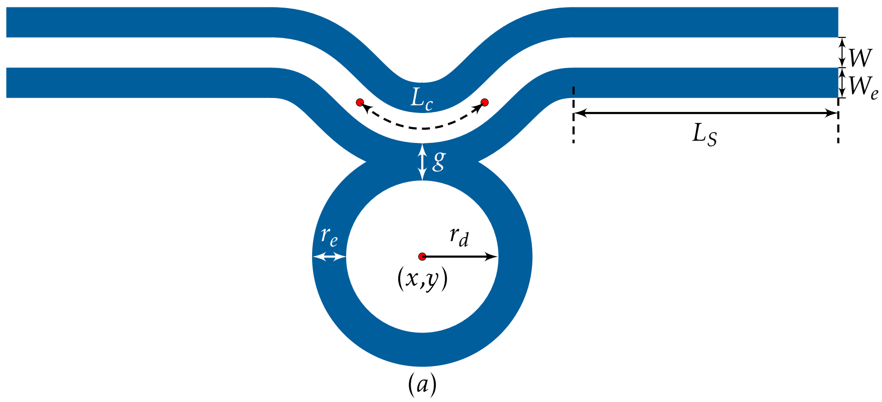


Figure 2.204: *Example shape illustrating various parameters from the* ***ringSymInvPos-APul*** *constructor.*

The following arc based, disc-ring waveguide symmetric inverse positive tone structures are defined by the coupling length parameter L_c.

<x y r_d r_e N g L_c N_{wg} W W_e L_S EC **discSymmetricInvPosLCA**>

<x y r_i W_r r_e N g L_c N_{wg} W W_e L_S EC **ringSymmetricInvPosLCA**>



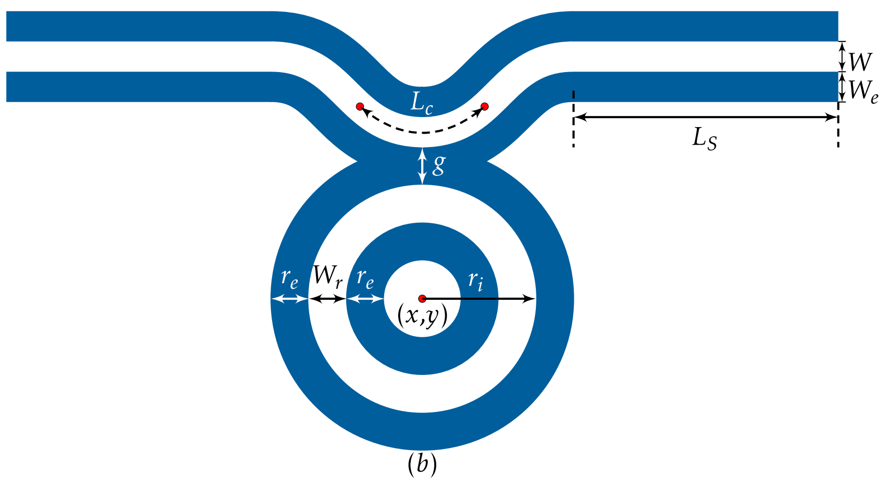


Figure 2.205: *Example shapes illustrating various parameters from the (a)* ***discSymmetricInvPosLCA*** *and (b)* ***ringSymmetricInvPosLCA*** *constructors.*

Disc symmetric inverse positive arc structure with an additional coupling waveguide.

<x y r_d r_e N g_1 L_c N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **discSymInvPosLCADS**>

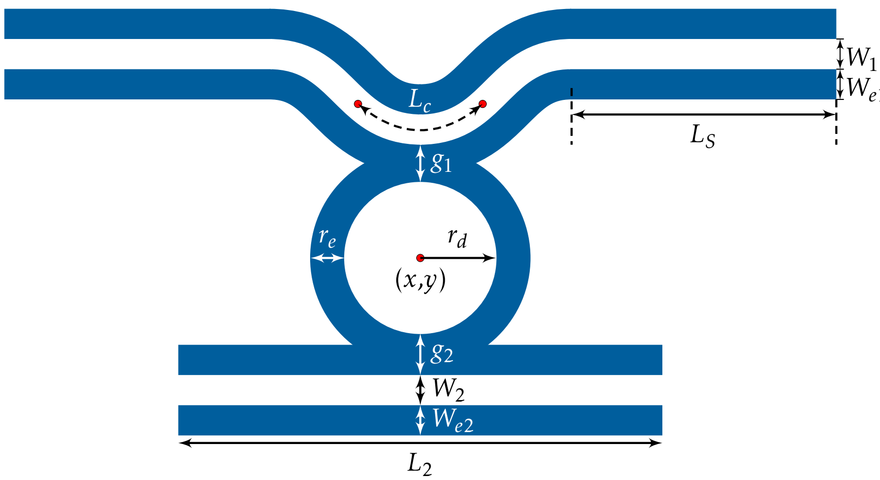


Figure 2.206: *Example shape illustrating various parameters from the **discSymInvPosLCADS** constructor.*

Disc symmetric inverse positive arc structure with an additional coupling pulley.

<x y r_d r_e N g_1 L_{c1} N_{wg} W_1 W_{e1} L_{S1} g_2 L_{c2} W_2 W_{e2} L_{S2} EC **discSymInvPosLCAPul**>

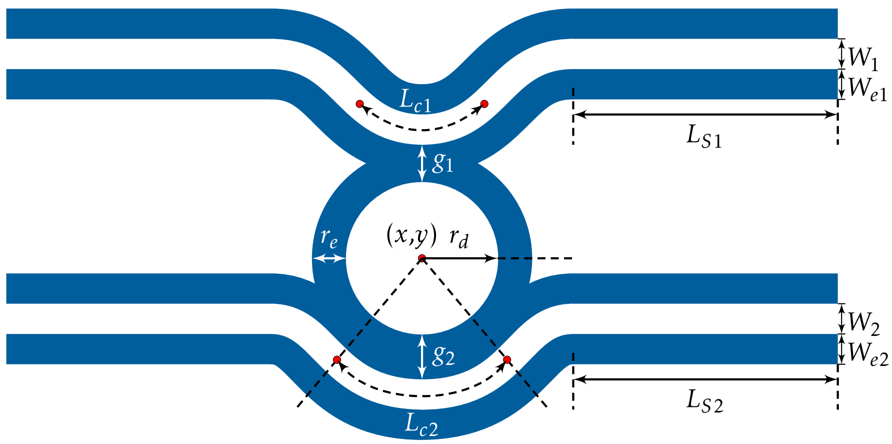


Figure 2.207: *Example shape illustrating various parameters from the* ***discSymInvPosLCAPul*** *constructor.*

Disc symmetric inverse positive arc structure with an additional coupling waveguide.

<x y r_i W_r r_e N g_1 L_c N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **ringSymInvPosLCADS**>

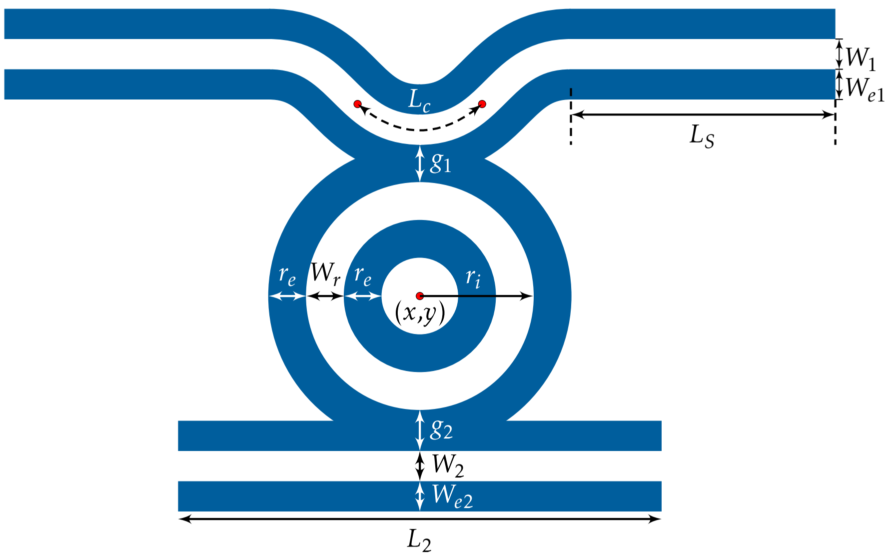


Figure 2.208: *Example shape illustrating various parameters from the* ***ringSymInvPosLCADS*** *constructor.*

Disc symmetric inverse positive arc structure with an additional coupling waveguide.

<x y r_i W_r r_e N g_1 L_{c1} N_{wg} W_1 W_{e1} L_{S1} g_2 L_{c2} W_2 W_{e2} L_{S2} EC **ringSymInvPosLCAPul**>

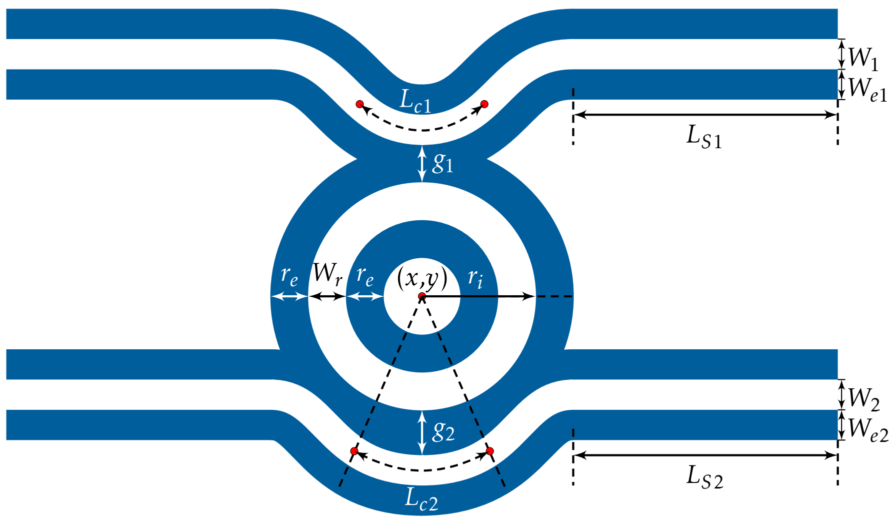


Figure 2.209: *Example shape illustrating various parameters from the* ***ringSymInvPosLCAPul*** *constructor.*

2.9.9.11 Disc-Ring Pulley Bezier

Shapes characterized by a curved waveguide around a disc ($R_{waveGuide} > -R_{Disc}$) and ring ($R_{waveGuide} > -R_{Ring}$)objects. Both objects (disc/ring) are described by the center coordinate (x, y), number of segments (N), gap between the object and waveguide (g), waveguide opening angle (θ), number of sides (N_{wg}), width (W), length (L) and height (H). Disc object is defined by a radius (r_d) and the ring is characterized by an inner radius (r_i) and ring width (W_r). $EC = 0$ and $EC = 1$ for waveguides without and with endcaps, respectively.

<x y r_d N g θ N_{wg} W L H EC **discPulley**>

<x y r_i W_r N g θ N_{wg} W L H EC **ringPulley**>

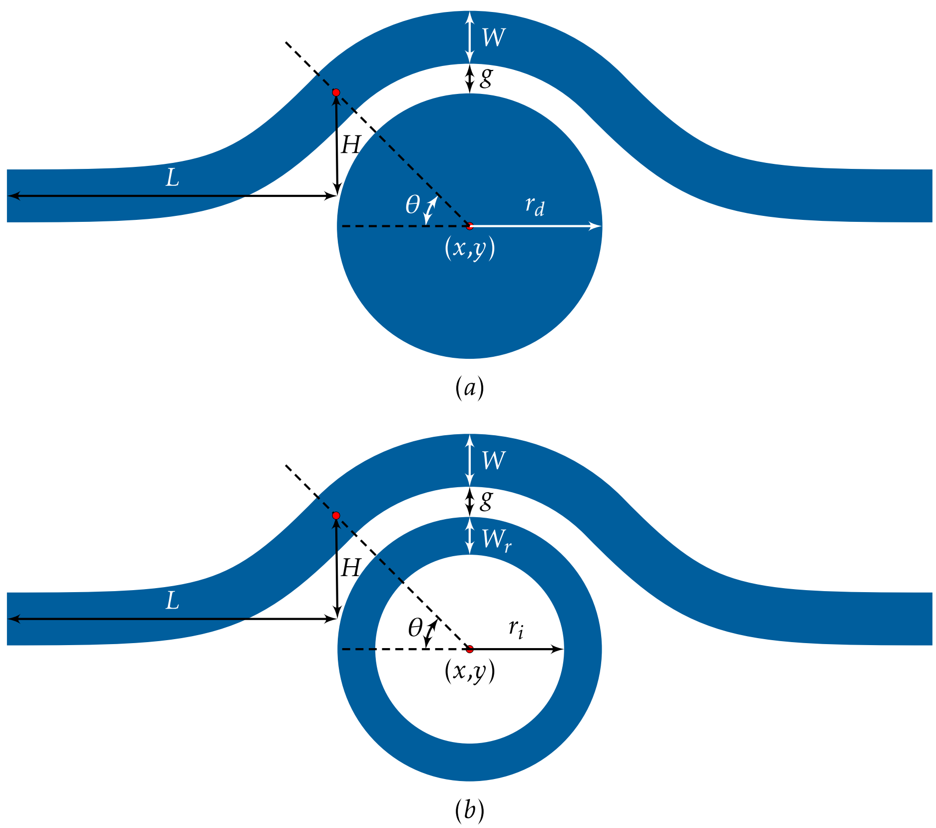


Figure 2.210: *Example shapes illustrating various parameters of the (a)* ***discPulley*** *and (b)* ***ringPulley*** *constructors.*

Disc pulley structure with an additional coupling waveguide.

<x y r_d N g_1 θ N_{wg} W_1 L_1 H g_2 W_2 L_2 EC **discPulDS**>

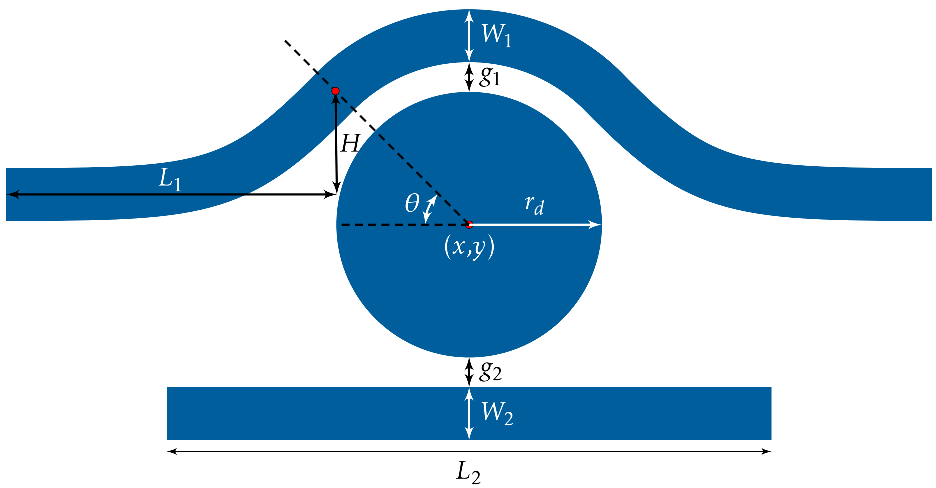


Figure 2.211: *Example shape illustrating various parameters of the* ***discPulDS*** *constructor.*

Disc pulley structure with an additional coupling pulley.

<x y r_d N g_1 θ_1 N_{wg} W_1 L_1 H_1 g_2 θ_2 W_2 L_2 H_2 EC **discPulPul**>

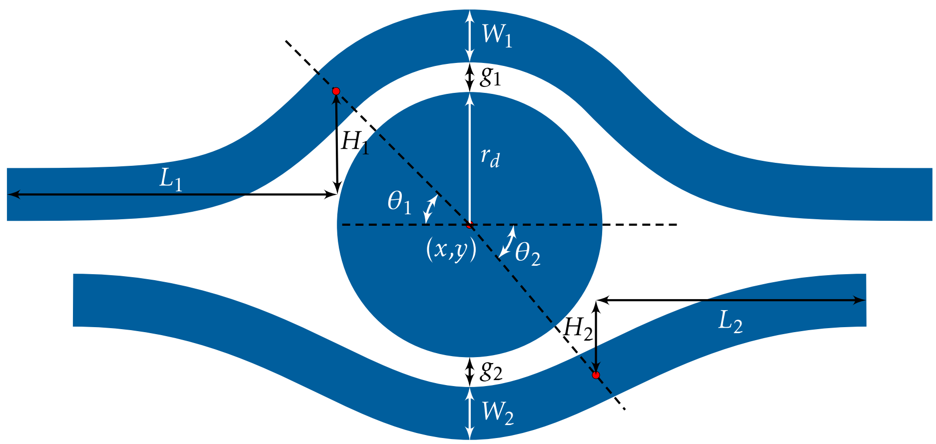


Figure 2.212: *Example shape illustrating various parameters of the* ***discPulPul*** *constructor.*

Ring pulley structure with an additional coupling waveguide.

<x y r_i W_r N g_1 θ N_{wg} W_1 L_1 H g_2 W_2 L_2 EC **ringPulDS**>

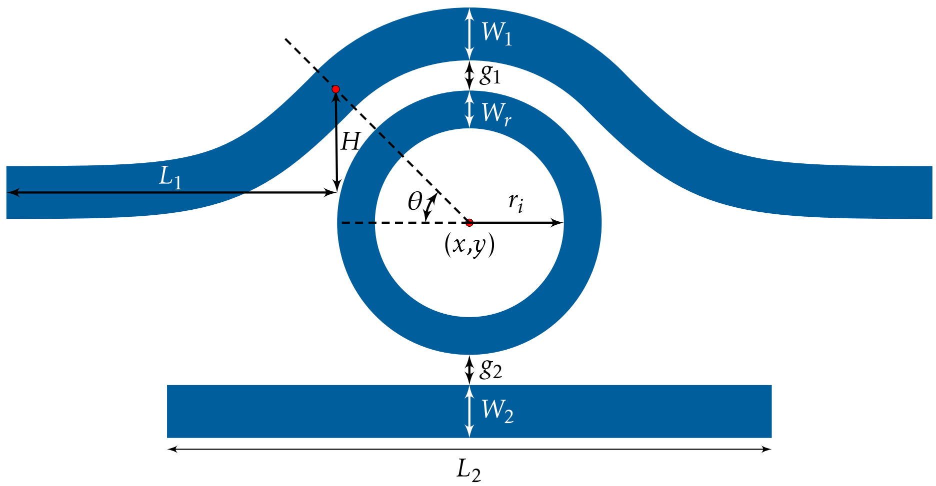


Figure 2.213: *Example shape illustrating various parameters of the* ***ringPulDS*** *constructor.*

Ring pulley structure with an additional coupling pulley.

<x y r_i W_r N g_1 θ_1 N_{wg} W_1 L_1 H_1 g_2 θ_2 W_2 L_2 H_2 EC **ringPulPul**>

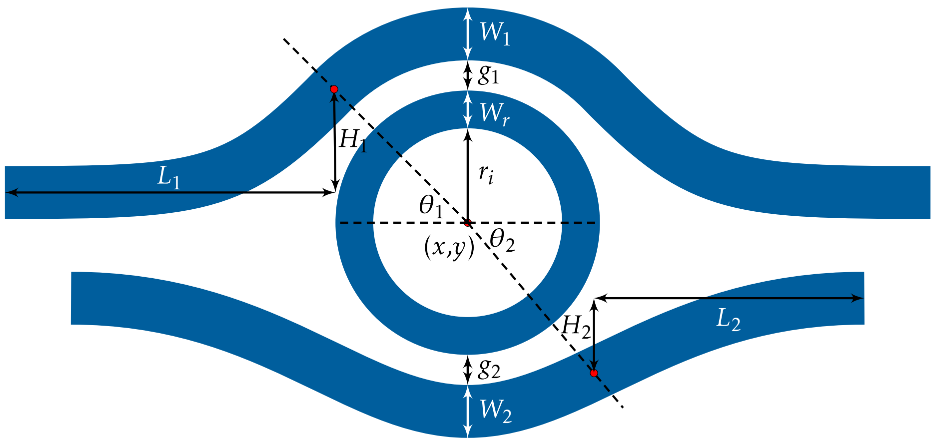


Figure 2.214: *Example shape illustrating various parameters of the ringPulPul constructor.*

The following disc-ring waveguide pulley structures are defined by the coupling length parameter L_c.

<x y r_d N g L_c N_{wg} W L H EC **discPulleyLC**>

<x y r_i W_r N g L_c N_{wg} W L H EC **ringPulleyLC**>

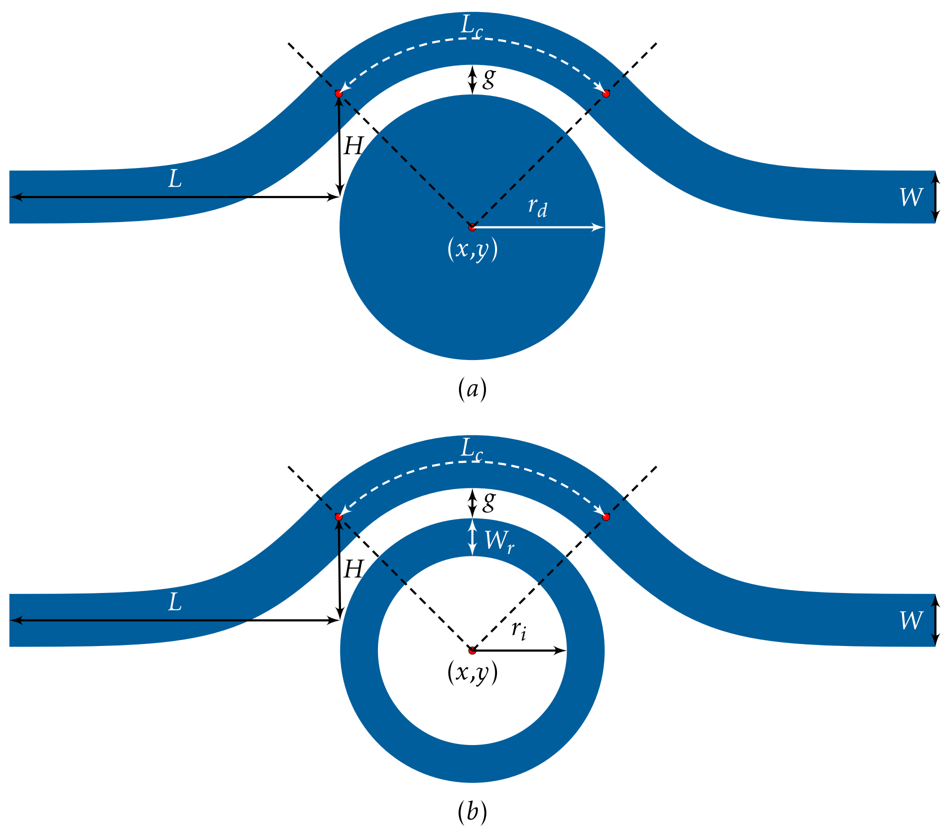


Figure 2.215: *Example shapes illustrating various parameters of the (a)* ***discPulleyLC*** *and (b)* ***ringPulleyLC*** *constructors.*

Disc pulley structure with an additional coupling waveguide.

<x y r_d N g_1 L_c N_{wg} W_1 L_1 H g_2 W_2 L_2 EC **discPulLCDS**>

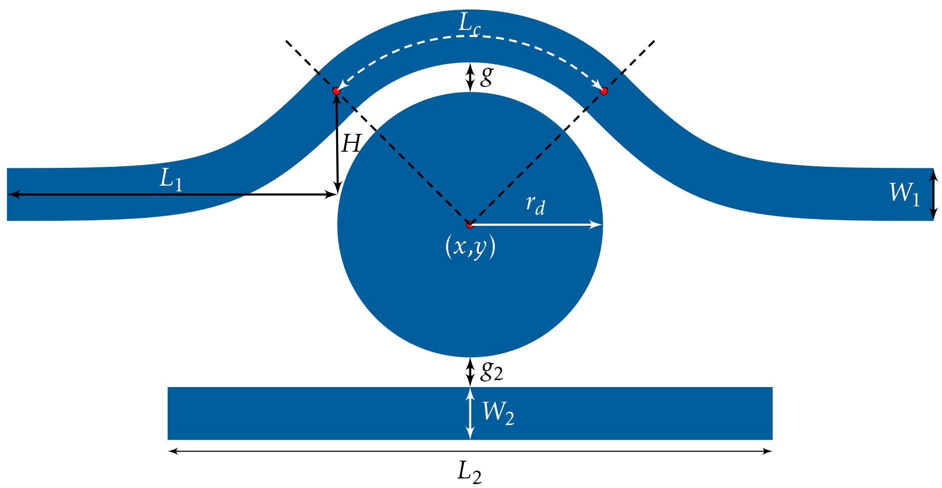


Figure 2.216: *Example shape illustrating various parameters of the **discPulLCDS** constructor.*

Disc pulley structure with an additional coupling pulley.

<x y r_d N g_1 L_{c1} N_{wg} W_1 L_1 H_1 g_2 L_{c2} W_2 L_2 H_2 EC **discPulLCPul**>

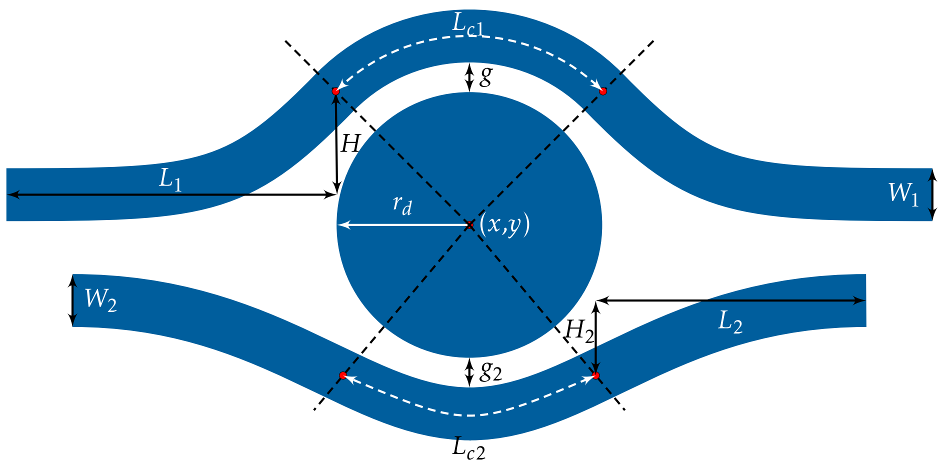


Figure 2.217: *Example shape illustrating various parameters of the* **discPulLCPul** *constructor.*

Ring pulley structure with an additional coupling waveguide.

<x y r_i W_r N g_1 L_c N_{wg} W_1 L_1 H g_2 W_2 L_2 EC **ringPulLCDS**>

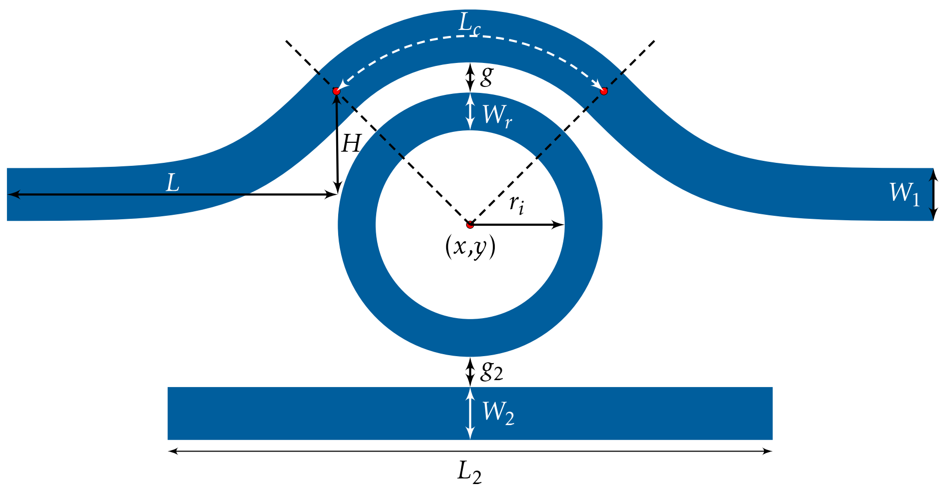


Figure 2.218: *Example shape illustrating various parameters of the* ***ringPulLCDS*** *constructor.*

Ring pulley structure with an additional coupling pulley.

<x y r_i W_r N g_1 L_{c1} N_{wg} W_1 L_1 H g_2 L_{c2} W_2 L_2 H_2 EC **ringPulLCPul**>

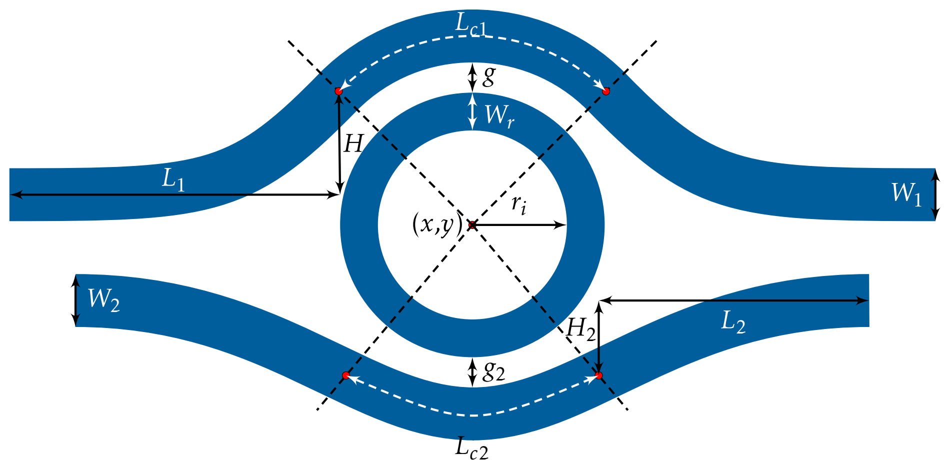


Figure 2.219: *Example shape illustrating various parameters of the* ***ringPulLCPul*** *constructor.*

2.9.9.12 Disc-Ring Pulley Arc

Symmetric structures constructed using arcs are similar to ones described in section 2.9.9.11. Both objects (disc/ring) are described by the center coordinate (x, y), number of segments (N), gap between the object and waveguide (g), waveguide opening angle (θ), number of sides (N_{wg}), width (W), and length of the connecting straight waveguide section (L_S). Disc object is defined by a radius (r_d) and the ring is characterized by an inner radius (r_i) and ring width (W_r). $EC = 0$ and $EC = 1$ for waveguides without and with endcaps, respectively.

<x y r_d N g θ N_{wg} W L_S EC **discPulleyA>**

<x y r_i W_r N g θ N_{wg} W L_S EC **ringPulleyA>**

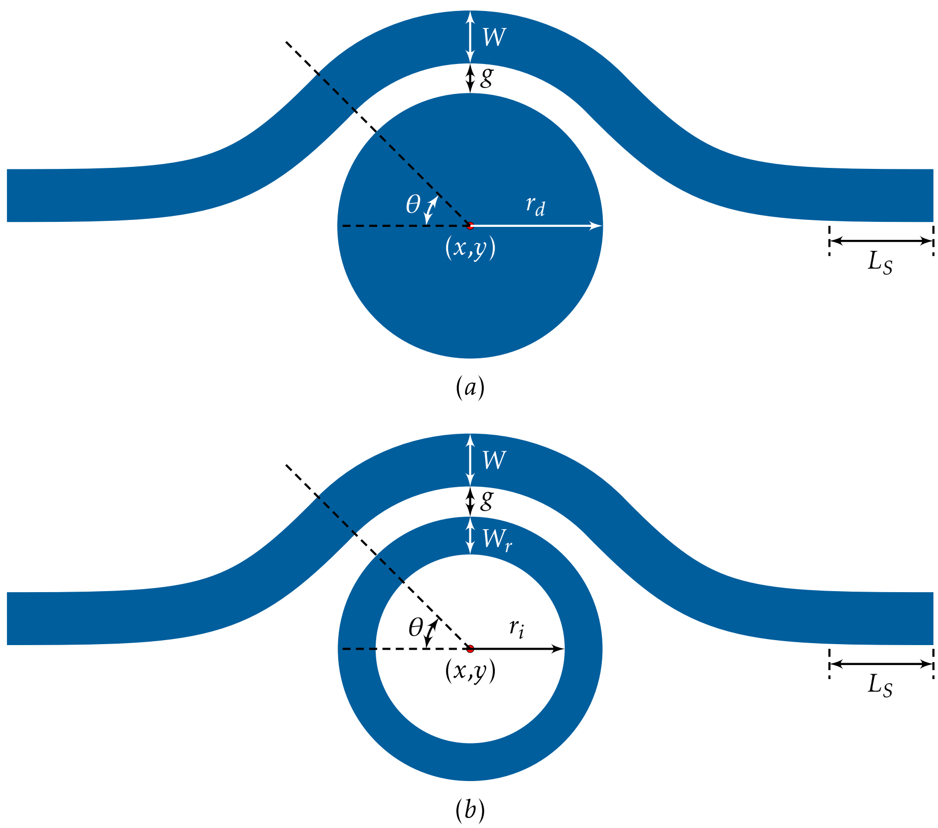


Figure 2.220: *Example shapes illustrating various parameters of the (a)* ***discPulleyA*** *and (b)* ***ringPulleyA*** *constructors.*

Disc pulley arc structure with an additional coupling waveguide.

<x y r_d N g_1 θ N_{wg} W_1 L_S g_2 W_2 L_2 EC **discPulADS**>

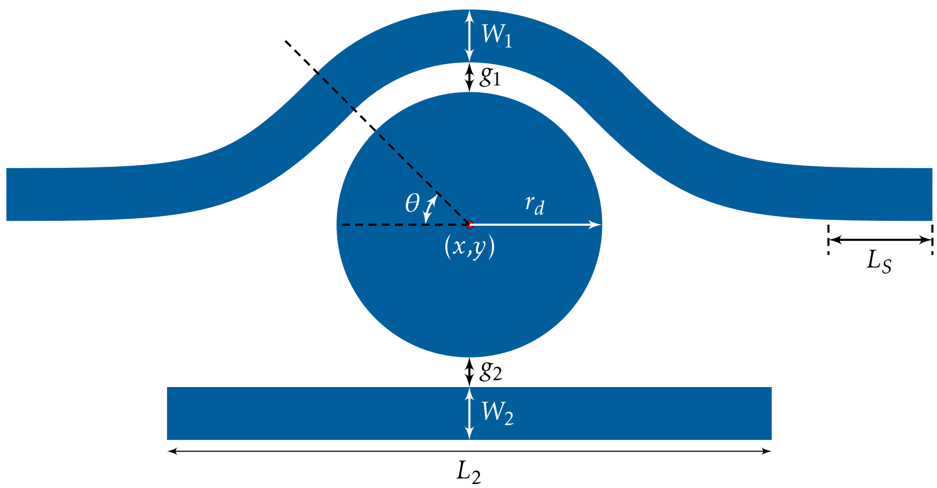


Figure 2.221: *Example shape illustrating various parameters of the **discPulADS** constructor.*

Disc pulley arc structure with an additional coupling pulley.

<x y r_d N g_1 θ_1 N_{wg} W_1 L_{S1} g_2 θ_2 W_2 L_{S2} EC **discPulAPul**>

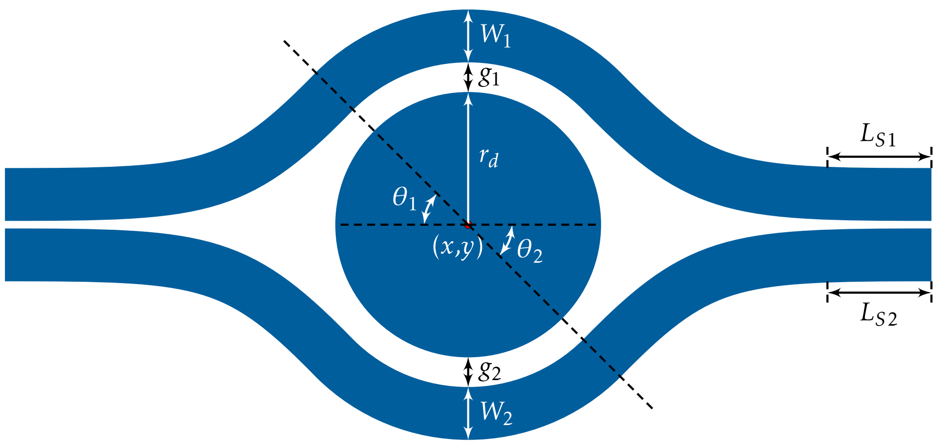


Figure 2.222: *Example shape illustrating various parameters of the* **discPulAPul** *constructor.*

Ring pulley arc structure with an additional coupling waveguide.

<x y r_i W_r N g_1 θ N_{wg} W_1 L_S g_2 W_2 L_2 EC **ringPulADS**>

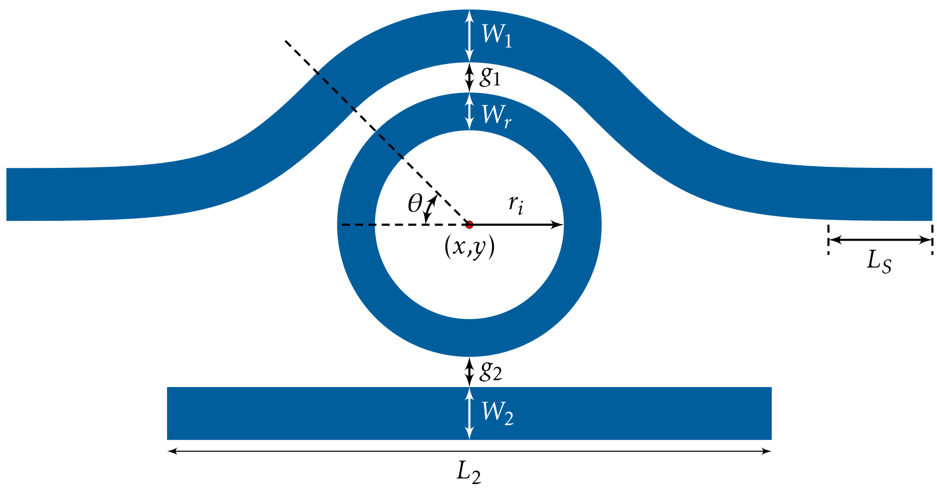


Figure 2.223: *Example shape illustrating various parameters of the* ***ringPulADS*** *constructor.*

Ring pulley arc structure with an additional coupling pulley.

<x y r_i W_r N g_1 θ_1 N_{wg} W_1 L_{S1} g_2 θ_2 W_2 L_{S2} EC **ringPulAPul**>

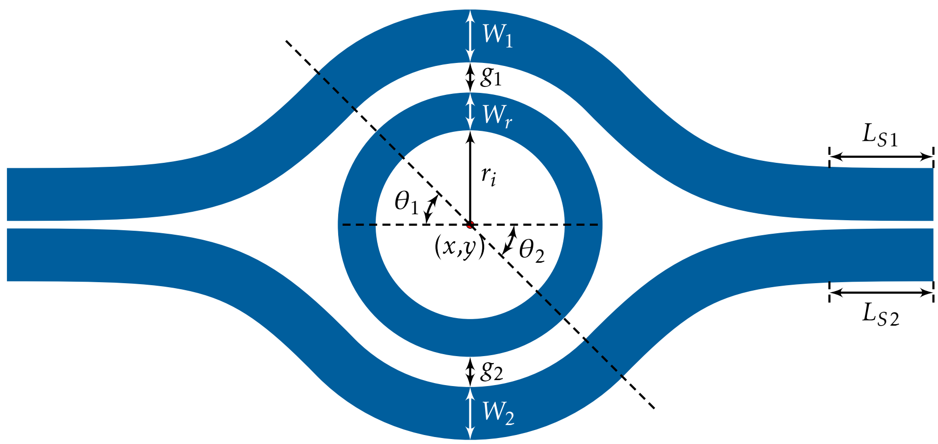


Figure 2.224: *Example shape illustrating various parameters of the* **ringPulAPul** *constructor.*

The following arc based, disc-ring waveguide pulley structures are defined by the coupling length parameter L_c.

<x y r_d N g L_c N_{wg} W L_S EC **discPulleyLCA**>

<x y r_i W_r N g L_c N_{wg} W L_S EC **ringPulleyLCA**>

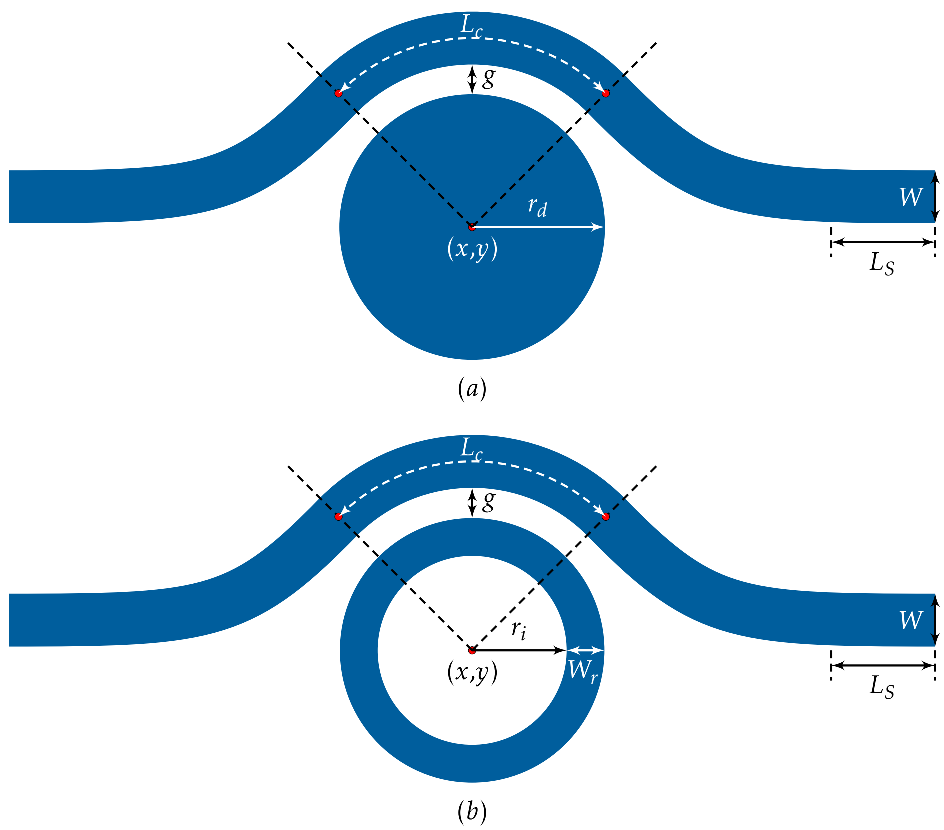


Figure 2.225: *Example shapes illustrating various parameters of the (a)* ***discPulleyLCA*** *and (b)* ***ringPulleyLCA*** *constructors.*

Disc pulley arc structure with an additional coupling waveguide.

<x y r_d N g_1 L_c N_{wg} W_1 L_S g_2 W_2 L_2 EC **discPulLCADS**>

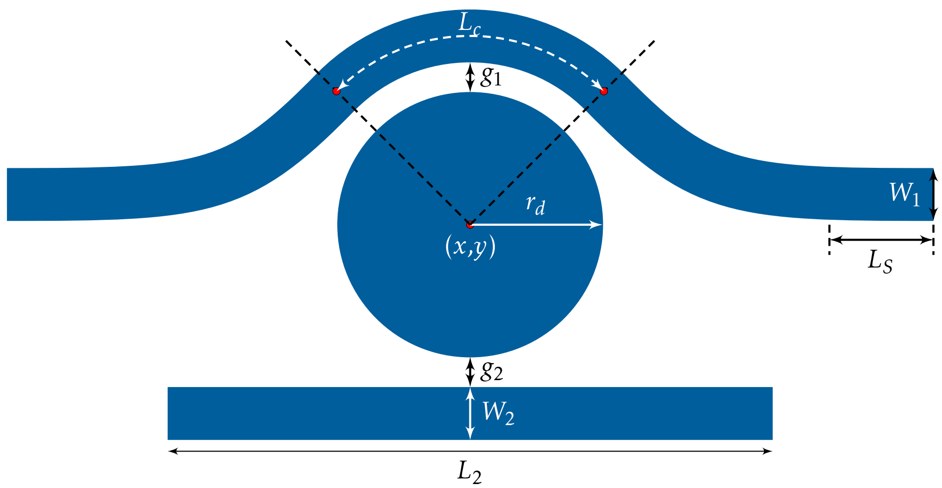


Figure 2.226: *Example shape illustrating various parameters of the (a)* ***discPulLCADS*** *constructor.*

Disc pulley arc structure with an additional coupling pulley.

<x y r_d N g_1 L_{c1} N_{wg} W_1 L_{S1} g_2 L_{c1} W_2 L_{S2} EC **discPulLCAPul**>

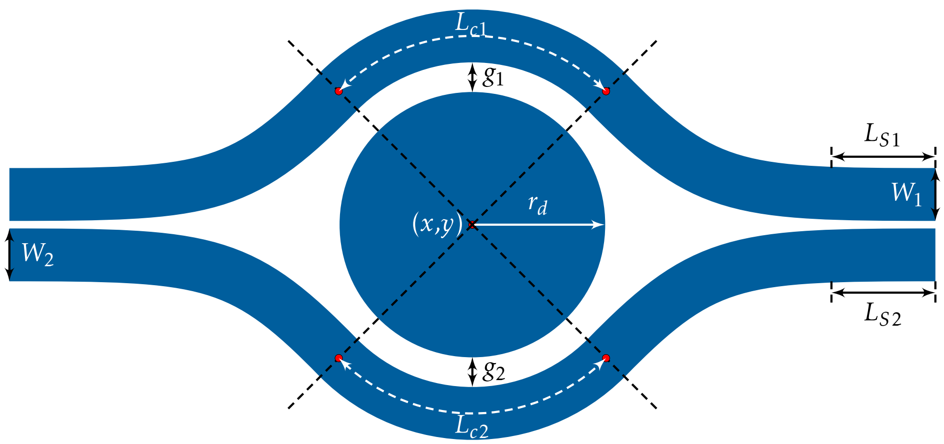


Figure 2.227: *Example shape illustrating various parameters of the (a)* ***discPulLCAPul*** *constructor.*

Ring pulley arc structure with an additional coupling waveguide.

<x y r_i W_r N g_1 L_c N_{wg} W_1 L_S g_2 W_2 L_2 EC **ringPulLCADS**>

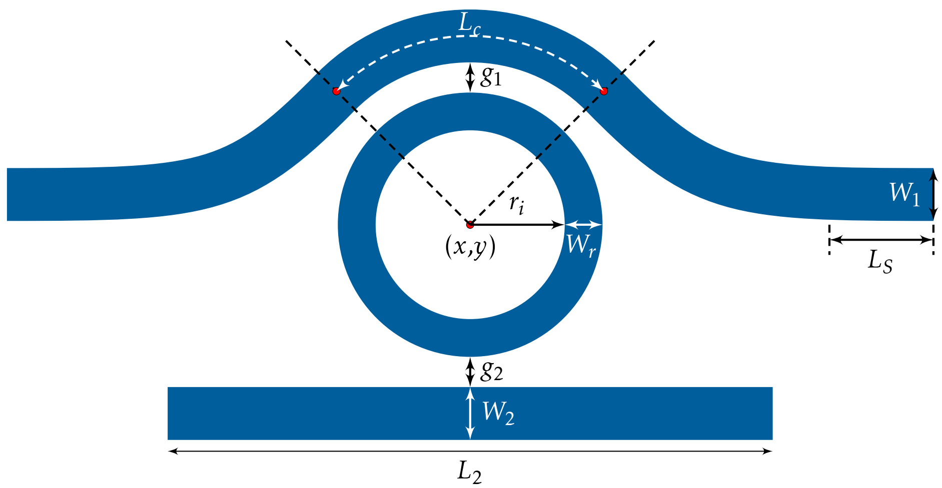


Figure 2.228: *Example shape illustrating various parameters of the* ***ringPulLCADS*** *constructor.*

Ring pulley arc structure with an additional coupling pulley.

<x y r_i W_r N g_1 L_{c1} N_{wg} W_1 L_{S1} g_2 L_{c1} W_2 L_{S2} EC **ringPulLCAPul**>

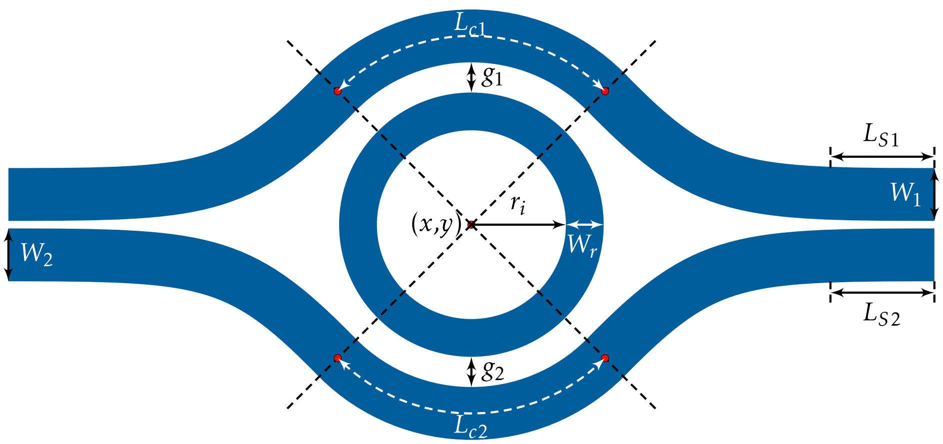


Figure 2.229: *Example shape illustrating various parameters of the* ***ringPulLCAPul*** *constructor.*

2.9.9.13 Disc-Ring Pulley Inverse Bezier

The structure is similar to the disc-ring waveguide symmetric structure defined in the previous section (2.9.9.11). Here, a slot waveguide of width W is formed by exposing a surrounding rectangular region of width W_e. Using a negative tone resist, the resulting structure would produce a disc or ring shape at a distance g to a slotted waveguide.

<$x \quad y \quad r_d \quad\quad N \quad g \quad \theta \quad N_{wg} \quad W \quad W_e \quad L \quad H \quad EC$ **discPulleyInv**>

<$x \quad y \quad r_i \quad W_r \quad N \quad g \quad \theta \quad N_{wg} \quad W \quad W_e \quad L \quad H \quad EC$ **ringPulleyInv**>

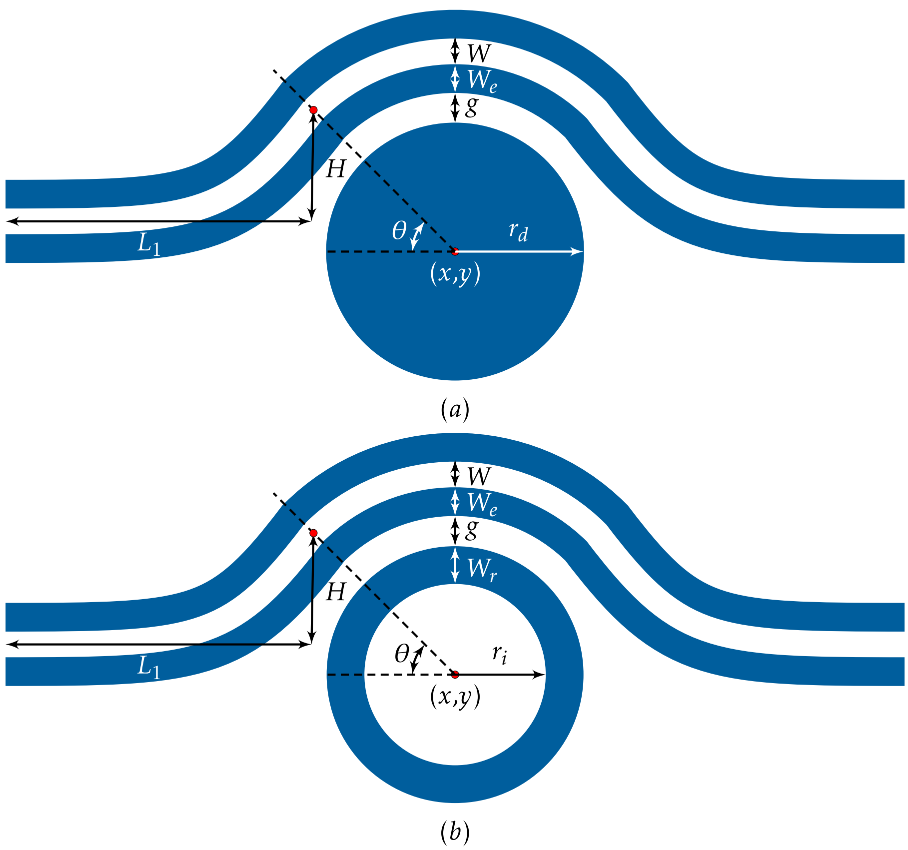


Figure 2.230: *Example shapes illustrating various parameters of the (a)* ***discPulleyInv*** *and (b)* ***ringPulleyInv*** *constructors.*

Disc pulley inverse structure with an additional coupling waveguide.

<x y r_d N g_2 θ N_{wg} W_2 W_{e2} L_2 H g_2 W_2 W_{e2} L_2 EC **discPulInvDS**>

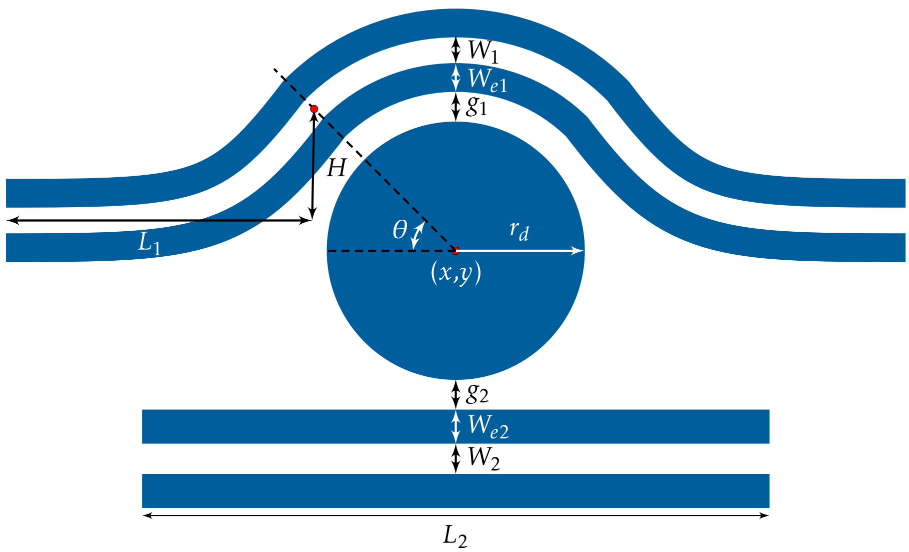


Figure 2.231: *Example shape illustrating various parameters of the* ***discPulInvDS*** *constructor.*

Disc pulley inverse structure with an additional coupling pulley.

<x y r_d N g_2 θ_1 N_{wg} W_2 W_{e2} L_2 H_2 g_2 θ_2 W_2 W_{e2} L_2 H_2 EC **discPulInvPul**>

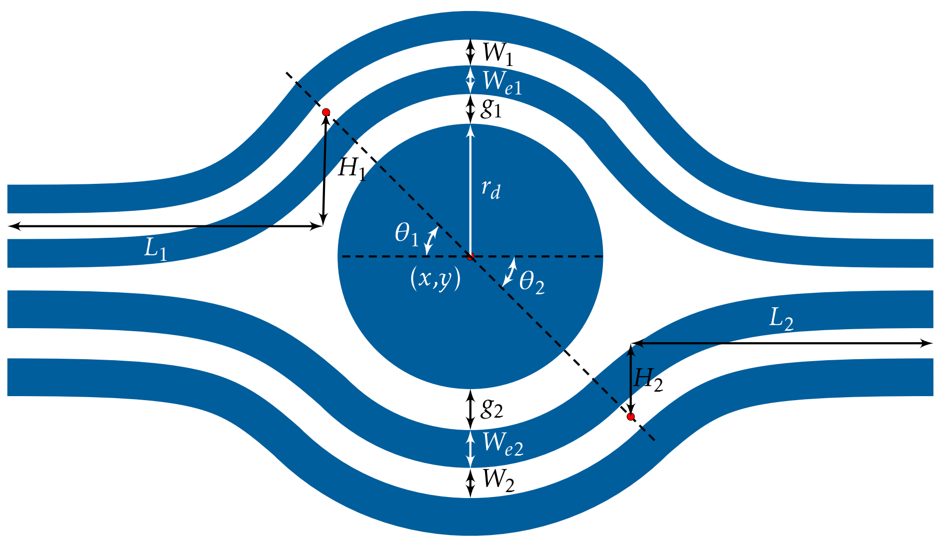


Figure 2.232: *Example shape illustrating various parameters of the* ***discPulInvPul*** *constructor.*

Ring pulley inverse structure with an additional coupling waveguide.

<$x \quad y \quad r_i \quad W_r \quad N \quad g_1 \quad \theta \quad N_{wg} \quad W_1 \quad W_{e1} \quad L_1 \quad H \quad g_2 \quad W_2 \quad W_{e2} \quad L_2 \quad EC$ **ringPulInvDS**>

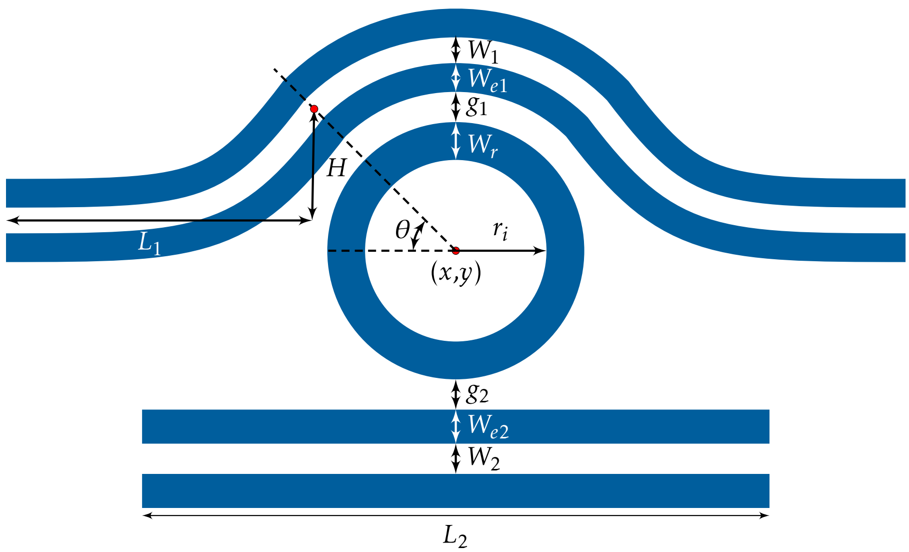


Figure 2.233: *Example shape illustrating various parameters of the* ***ringPulInvDS*** *constructor.*

Ring pulley inverse structure with an additional coupling pulley.

<x y r_i W_r N g_1 θ_1 N_{wg} W_1 W_{e1} L_1 H g_2 θ_2 W_2 W_{e2} L_2 H_2 EC **ringPulInvPul**>

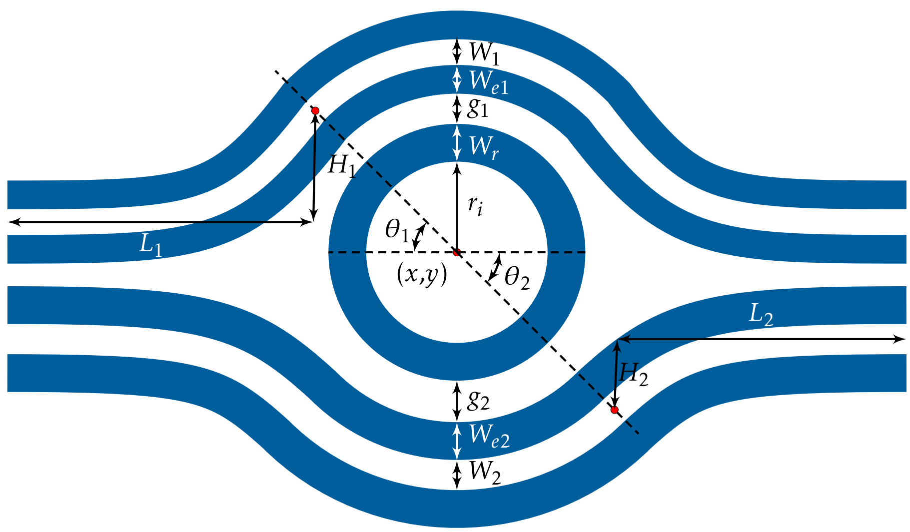


Figure 2.234: *Example shape illustrating various parameters of the* ***ringPulInvPul*** *constructor.*

The following disc-ring waveguide pulley inverse structures are defined by the coupling length parameter L_c.

<x y r_d N g L_c N_{wg} W W_e L H EC **discPulleyInvLC**>

<x y r_i W_r N g L_c N_{wg} W W_e L H EC **ringPulleyInvLC**>

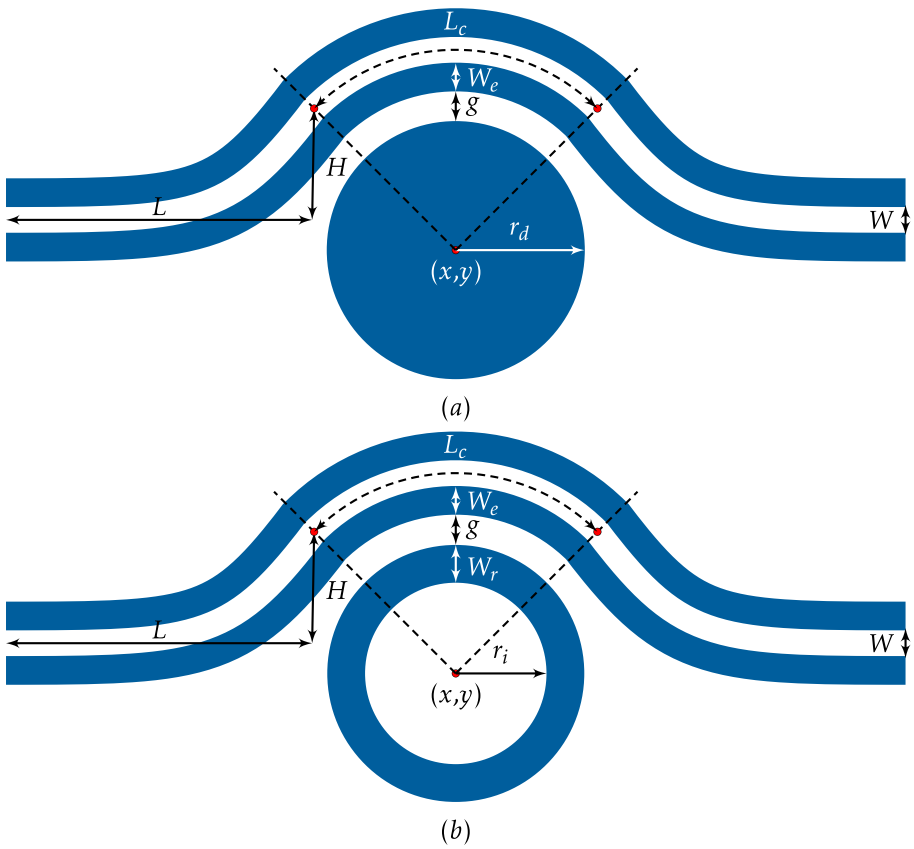


Figure 2.235: *Example shapes illustrating various parameters of the (a) **discPulleyInvLC** and (b) **ringPulleyInvLC** constructors.*

Disc pulley inverse structure with an additional coupling waveguide.

<x y r_d N g_1 L_c N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **discPulInvLCDS**>

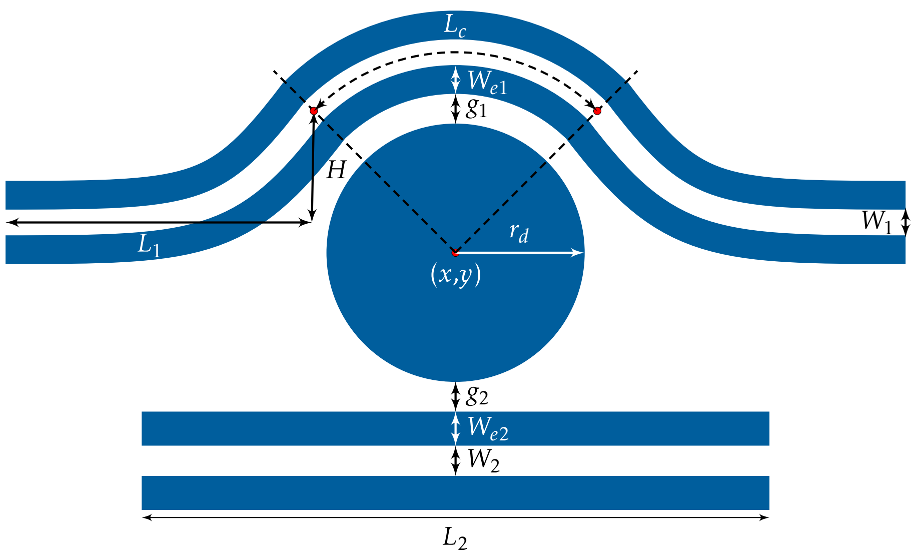


Figure 2.236: *Example shape illustrating various parameters of the* ***discPulInvLCDS*** *constructor.*

Disc pulley inverse structure with an additional coupling pulley.

<x y r_d N g_1 L_{c2} N_{wg} W_1 W_{e1} L_1 H_2 g_2 L_{c2} W_2 W_{e2} L_2 H_2 EC **discPulInvLCPul**>

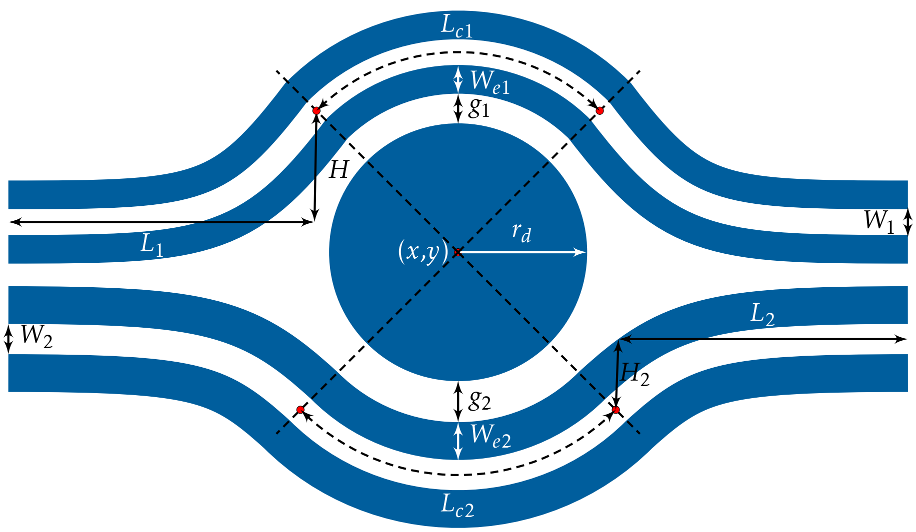


Figure 2.237: *Example shape illustrating various parameters of the* ***discPulInvLCPul*** *constructor.*

Ring pulley inverse structure with an additional coupling waveguide.

<x y r_i W_r N g_1 L_c N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **ringPulInvLCDS**>

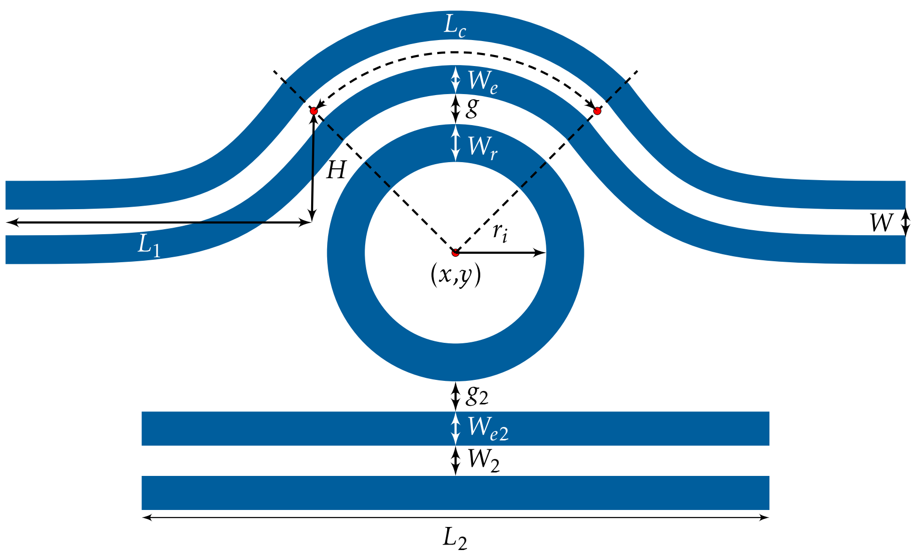


Figure 2.238: *Example shape illustrating various parameters of the ringPulInvLCDS constructor.*

Ring pulley inverse structure with an additional coupling pulley.

<x y r_i W_r N g_1 L_{c1} N_{wg} W_1 W_{e1} L_1 H_1 g_2 L_{c2} W_2 W_{e2} L_2 H_2 EC **ringPulInvLCPul**>

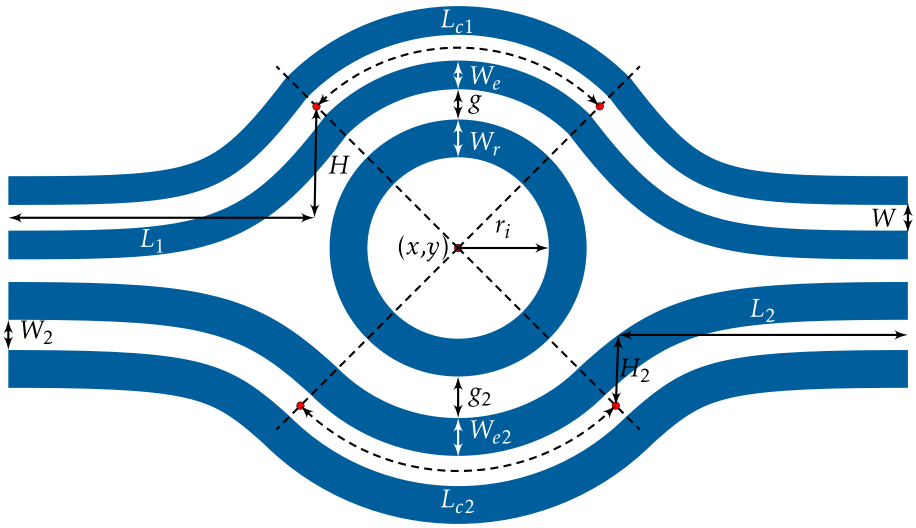


Figure 2.239: *Example shape illustrating various parameters of the* ***ringPulInvLCPul*** *constructor.*

2.9.9.14 Disc-Ring Pulley Inverse Arc

Pulley inverse structures constructed using arcs are similar to ones described in section 2.9.9.12. Here, a slot waveguide of width W is formed by exposing a surrounding rectangular region of width W_e. Using a negative tone resist, the resulting structure would produce a disc or ring shape at a distance g to a slotted waveguide.

<x y r_d N g θ N_{wg} W W_e L_S EC **discPulleyInvA**>

<x y r_i W_r N g θ N_{wg} W W_e L_S EC **ringPulleyInvA**>

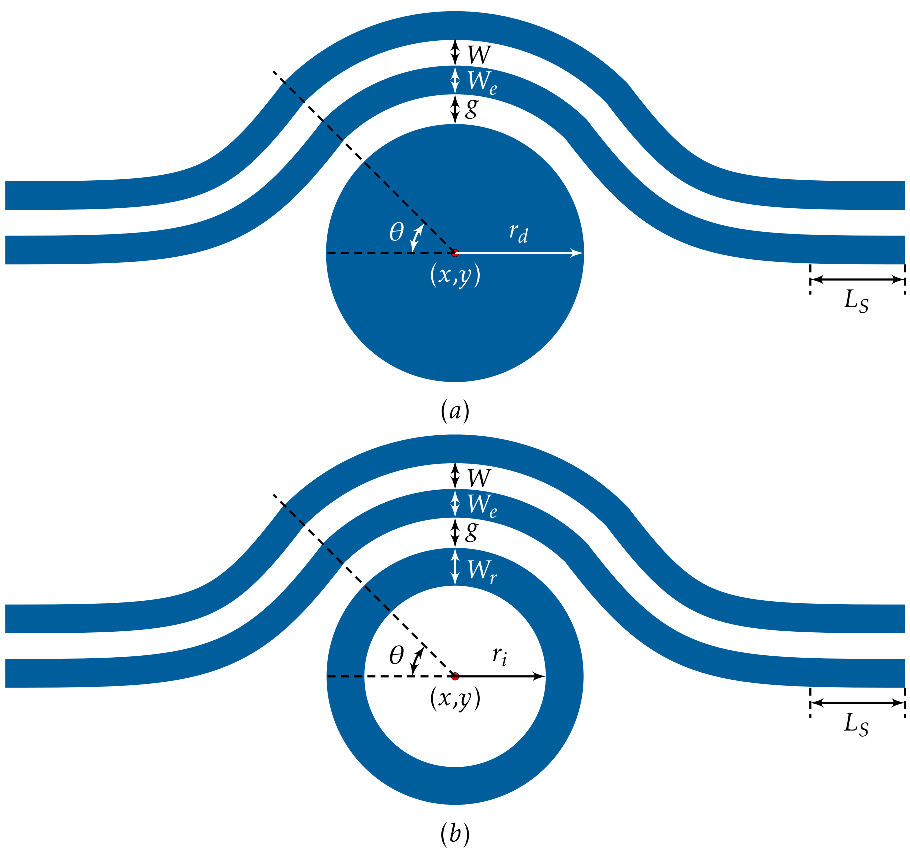


Figure 2.240: *Example shapes illustrating various parameters of the (a)* ***discPulleyInvA*** *and (b)* ***ringPulleyInvA*** *constructors.*

Disc pulley inverse arc structure with an additional coupling waveguide.

<x y r_d N g_1 θ N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **discPullnvADS**>

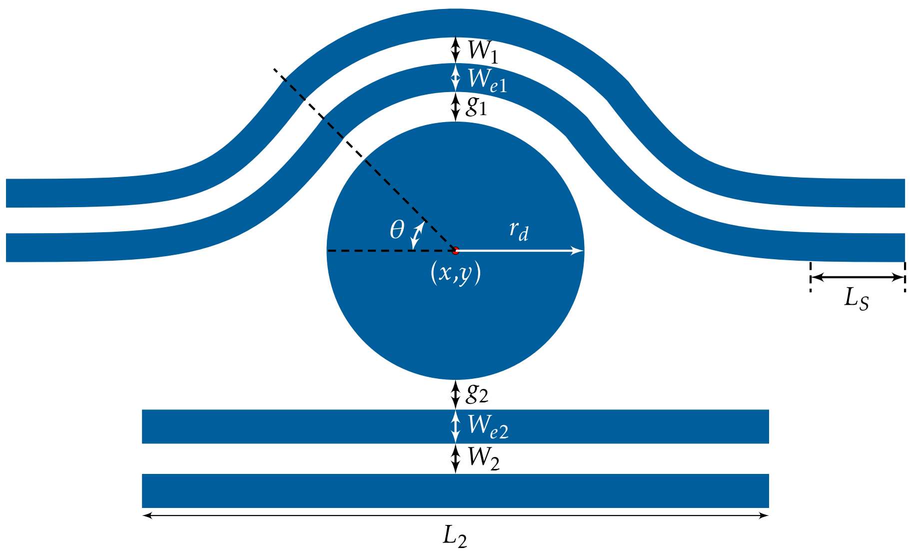


Figure 2.241: *Example shape illustrating various parameters of the* ***discPullnvADS*** *constructor.*

Disc pulley inverse arc structure with an additional coupling pulley.

<x y r_d N g_1 θ_1 N_{wg} W_1 W_{e1} L_{S1} g_2 θ_2 W_2 W_{e2} L_{S2} EC **discPulInvAPul**>

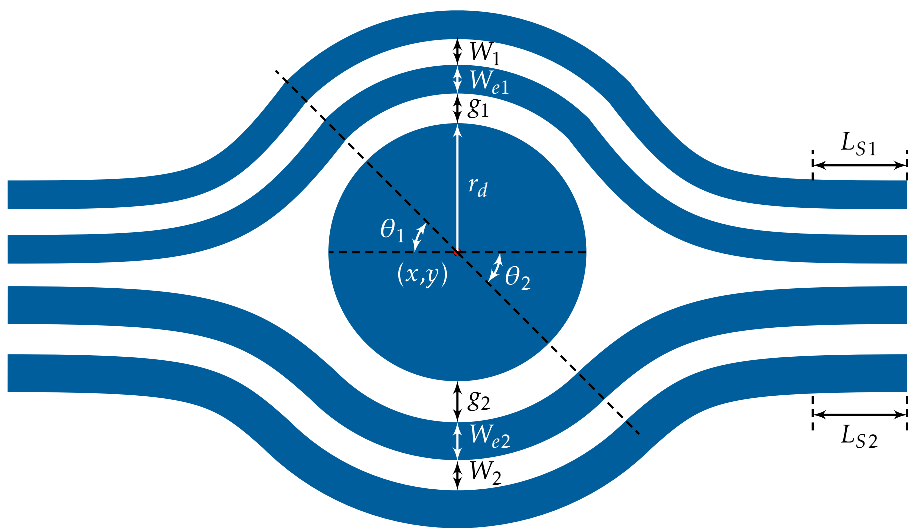


Figure 2.242: *Example shape illustrating various parameters of the* ***discPulInvAPul*** *constructor.*

Ring pulley inverse arc structure with an additional coupling waveguide.

<x y r_i W_r N g_1 θ N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **ringPulInvADS**>

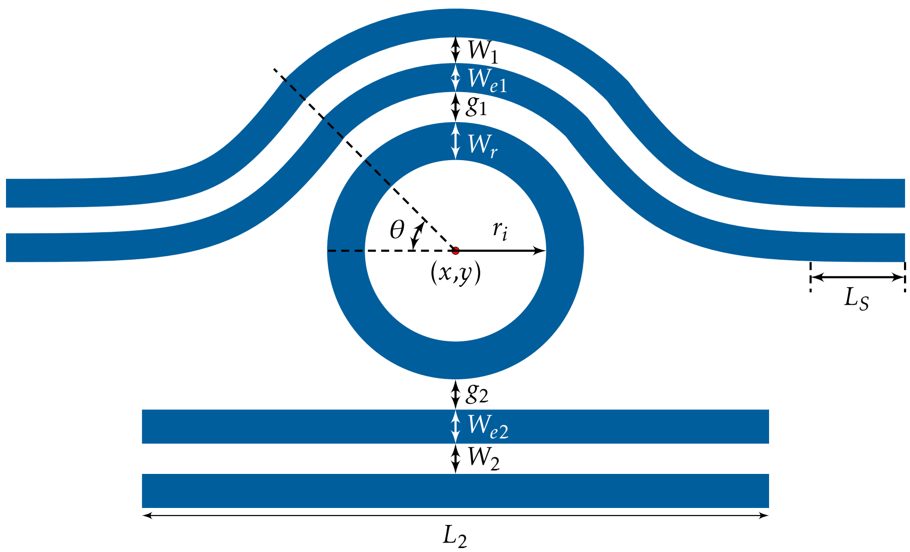


Figure 2.243: *Example shape illustrating various parameters of the* ***ringPulInvADS*** *constructor.*

Ring pulley inverse arc structure with an additional coupling pulley.

<x y r_i W_r N g_1 θ_1 N_{wg} W_1 W_{e1} L_S g_2 θ_2 W_2 W_{e2} L_2 EC **ringPulInvAPul**>

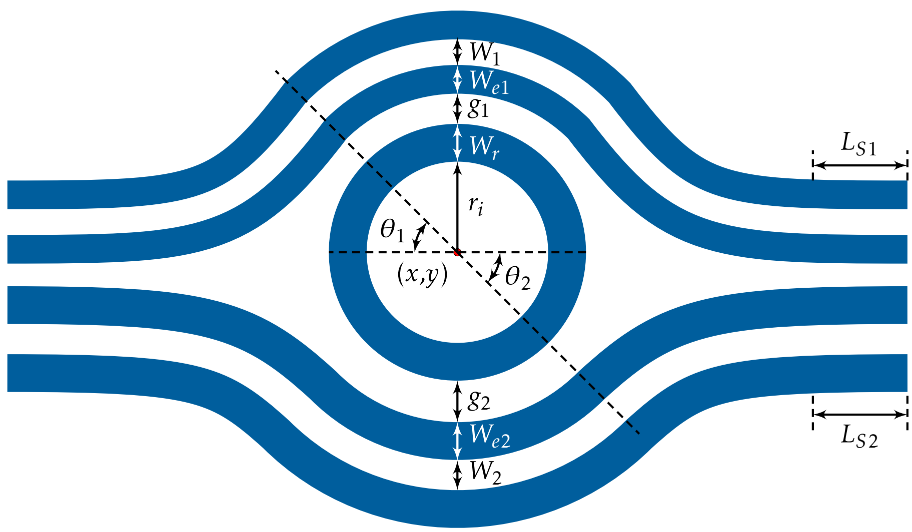


Figure 2.244: *Example shape illustrating various parameters of the* ***ringPulInvAPul*** *constructor.*

The following arc based, disc-ring waveguide pulley inverse structures are defined by the coupling length parameter L_c.

<x y r_d N g L_c N_{wg} W W_e L_S EC **discPulleyInvLCA**>

<x y r_i W_r N g L_c N_{wg} W W_e L_S EC **ringPulleyInvLCA**>

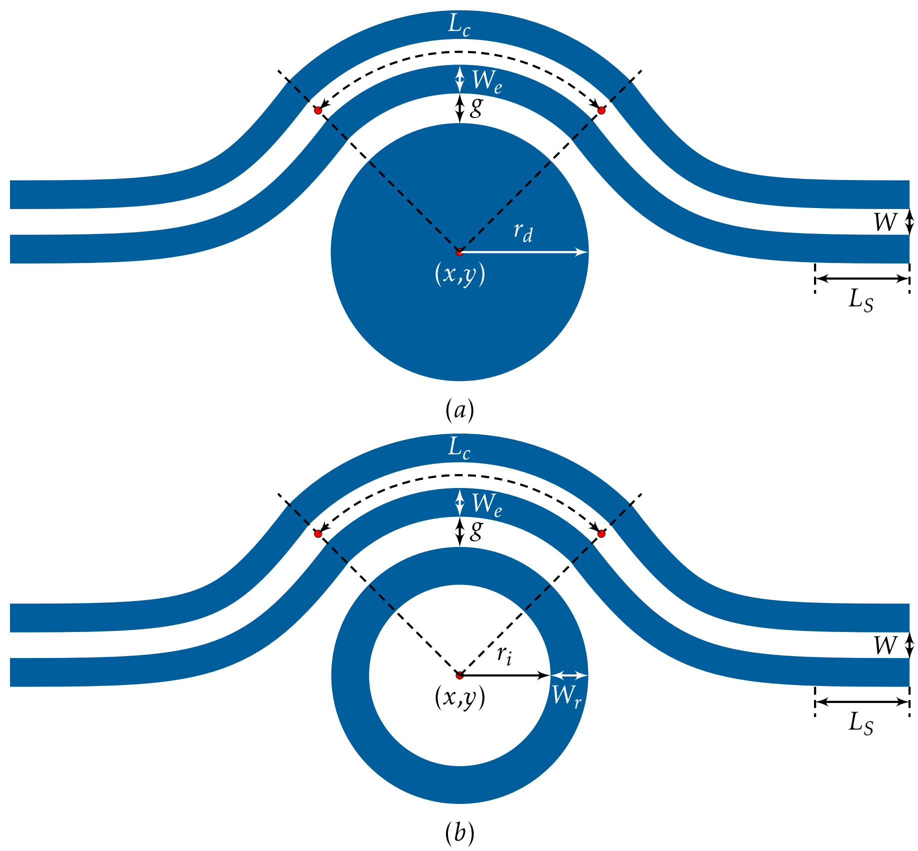


Figure 2.245: *Example shapes illustrating various parameters of the (a) **discPulleyInvLCA** and (b) **ringPulleyInvLCA** constructors.*

Disc pulley inverse arc structure with an additional coupling waveguide.

<x y r_d N g_1 L_c N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **discPulInvLCADS**>

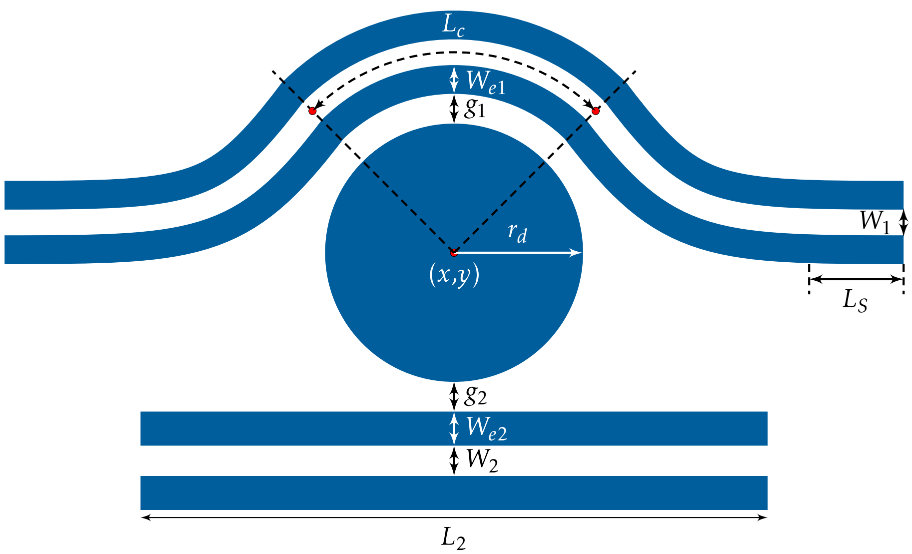


Figure 2.246: *Example shape illustrating various parameters of the* ***discPulInvLCADS*** *constructor.*

Disc pulley inverse arc structure with an additional coupling pulley.

<x y r_d N g_1 L_{c1} N_{wg} W_1 W_{e1} L_{S1} g_2 L_{c2} W_2 W_{e2} L_{S2} EC **discPulInvLCAPul**>

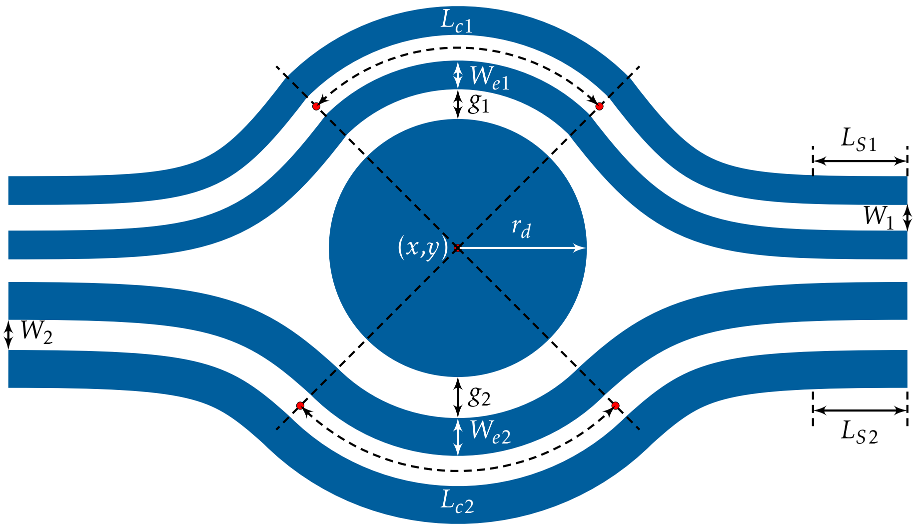


Figure 2.247: *Example shape illustrating various parameters of the* ***discPulInvLCAPul*** *constructor.*

Ring pulley inverse arc structure with an additional coupling waveguide.

<x y r_i W_r N g_1 L_c N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **ringPulInvLCADS**>

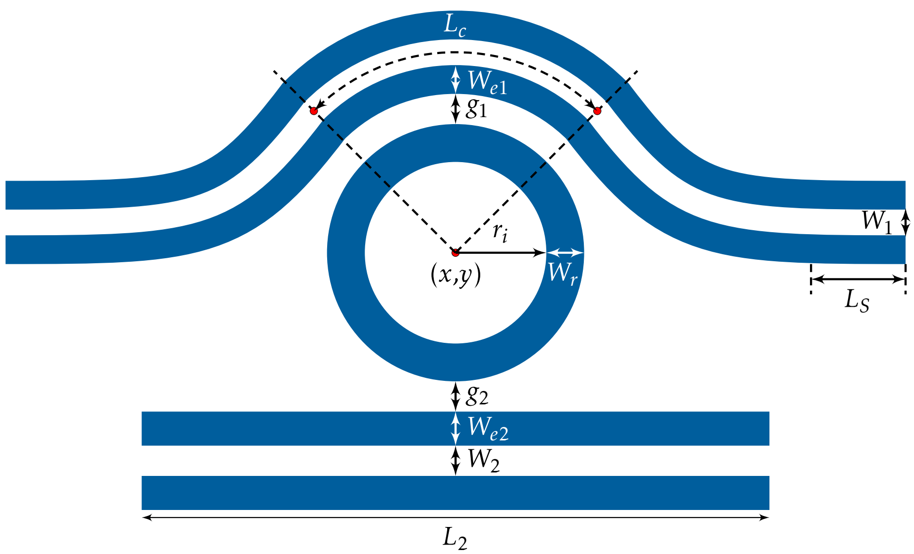


Figure 2.248: *Example shape illustrating various parameters of the ringPulInvLCADS constructor.*

Ring pulley inverse arc structure with an additional coupling pulley.

<$x\ y\ r_i\ W_r\ N\ g_1\ L_{c1}\ N_{wg}\ W_1\ W_{e1}\ L_{S1}\ g_2\ L_{c2}\ W_2\ W_{e2}\ L_{S2}\ EC$ ringPulInvLCADPul>

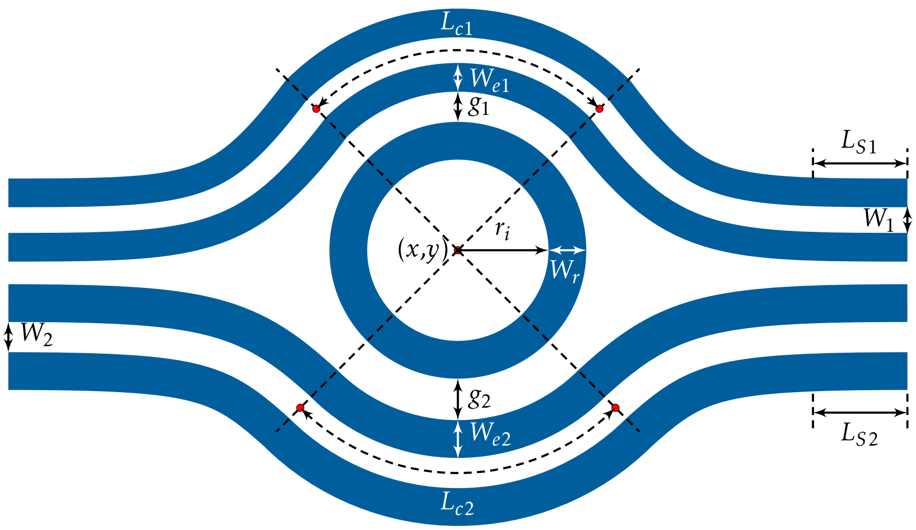


Figure 2.249: *Example shape illustrating various parameters of the* ringPulInvLCAPul *constructor.*

2.9.9.15 Disc-Ring Pulley Inverse Positive Tone Bezier

The structure is similar to the disc-ring waveguide symmetric structure defined in section 2.9.9.11. Here, a slot waveguide is formed at a distance g away from a disc or a ring structure using a positive resist exposure of the exposure sleeve elements W_e and r_e.

<x y r_d r_e N g_1 θ N_{wg} W_1 W_{e1} L_1 H EC **discPulleyInvPos**>

<x y r_i W_r r_e N g_1 θ N_{wg} W_1 W_{e1} L_1 H EC **ringPulleyInvPos**>

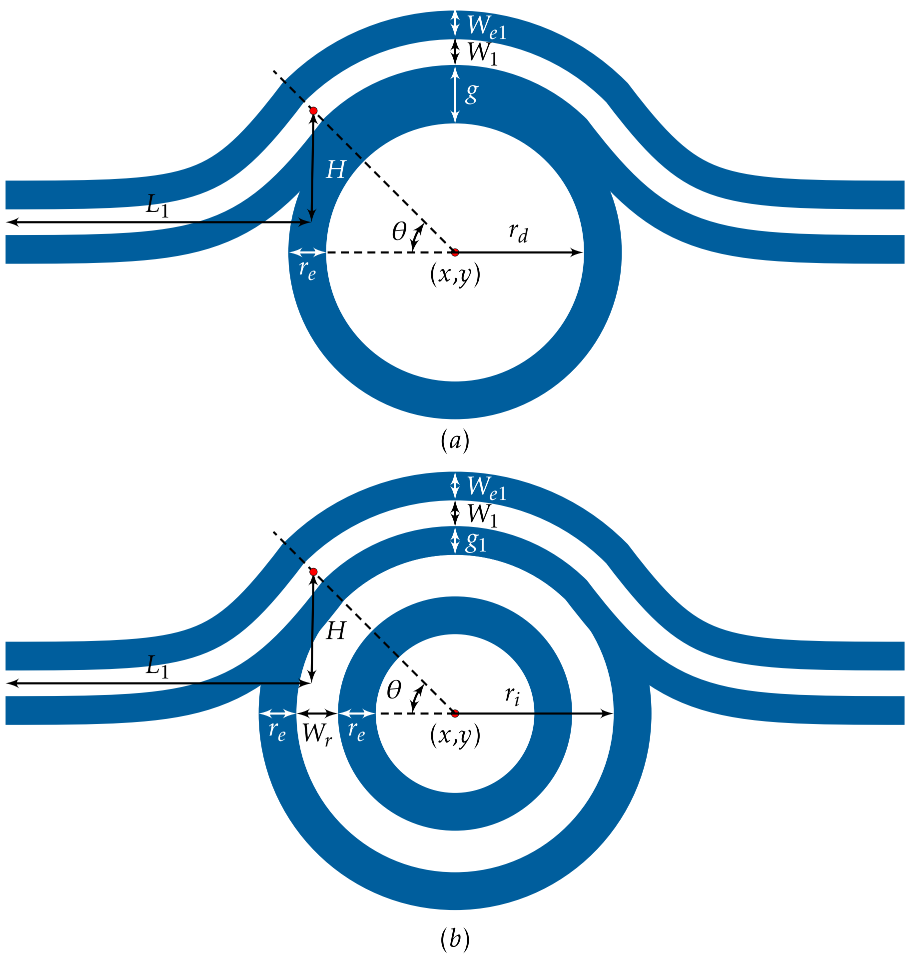


Figure 2.250: *Example shapes illustrating various parameters of the (a)* ***discPulleyInvPos*** *and (b)* ***ringPulleyInvPos*** *constructors.*

Disc pulley inverse positive structure with an additional coupling waveguide.

<x y r_d r_e N g_1 θ N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **discPullnvPDS**>

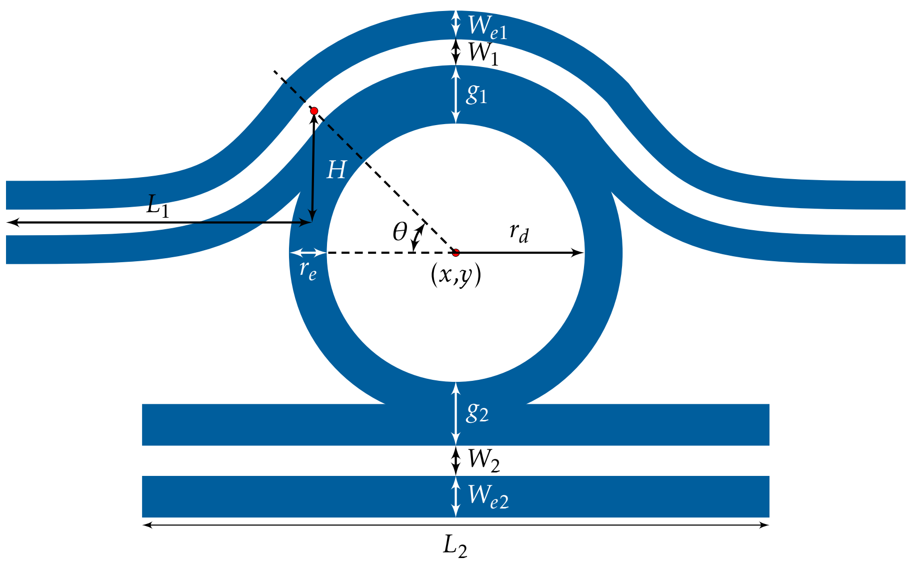


Figure 2.251: *Example shape illustrating various parameters of the* ***discPullnvPDS*** *constructor.*

Disc pulley inverse positive structure with an additional coupling pulley.

<$x\ y\ r_d\ r_e\ N\ g_1\ \theta_1\ N_{wg}\ W_1\ W_{e1}\ L_1\ H\ g_2\ \theta_2\ W_2\ W_{e2}\ L_2\ H_2\ EC$ **discPulInvPPul**>

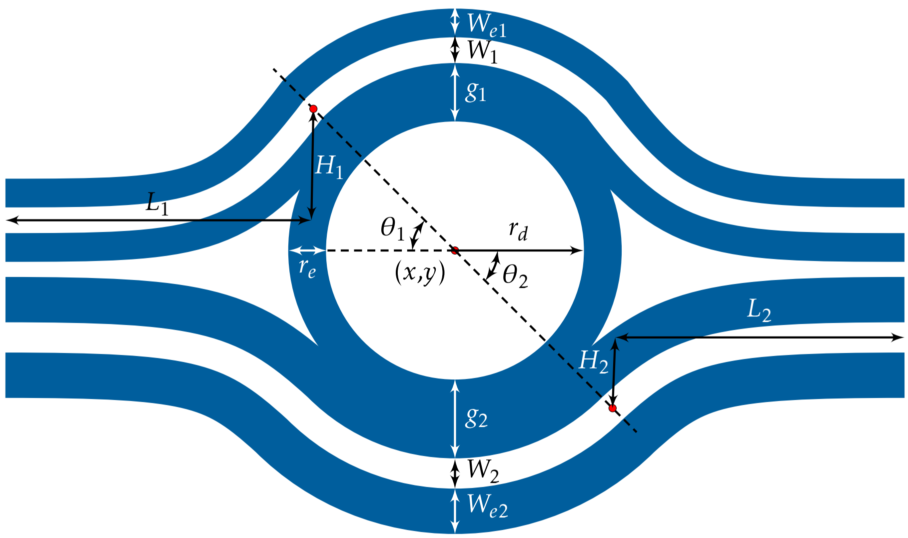


Figure 2.252: *Example shape illustrating various parameters of the* ***discPulInvPPul*** *constructor.*

Ring pulley inverse positive structure with an additional coupling waveguide.

<x y r_i W_r r_e N g_1 θ N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **ringPulInvPDS**>

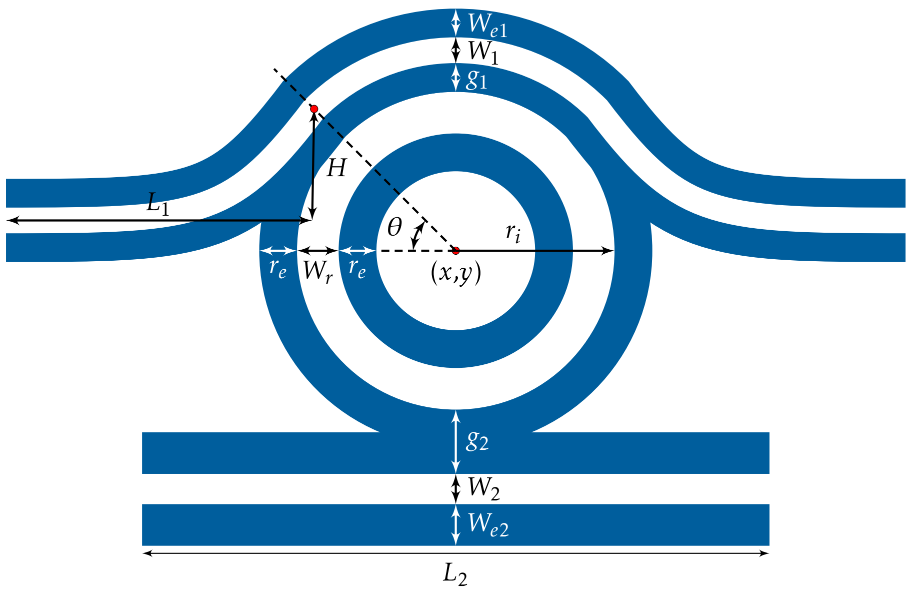


Figure 2.253: *Example shape illustrating various parameters of the* ***ringPulInvPDS*** *constructor.*

Ring pulley inverse positive structure with an additional coupling pulley.

<x y r_i W_r r_e N g_1 θ_1 N_{wg} W_1 W_{e1} L_1 H_1 g_2 θ_2 W_2 W_{e2} L_2 H_2 EC **ringPulInvPPul**>

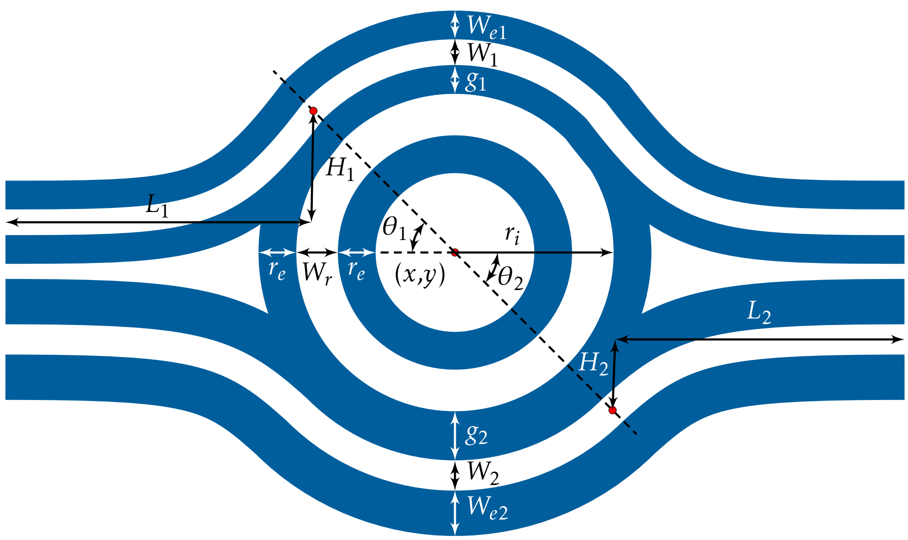


Figure 2.254: *Example shape illustrating various parameters of the* ***ringPulInvPPul*** *constructor.*

The following disc-ring waveguide pulley inverse positive tone structures are defined by the coupling length parameter L_c.

<x y r_d r_e N g L_c N_{wg} W W_e L H EC **discPulleyInvPosLC**>

<x y r_i W_r r_e N g L_c N_{wg} W W_e L H EC **ringPulleyInvPosLC**>

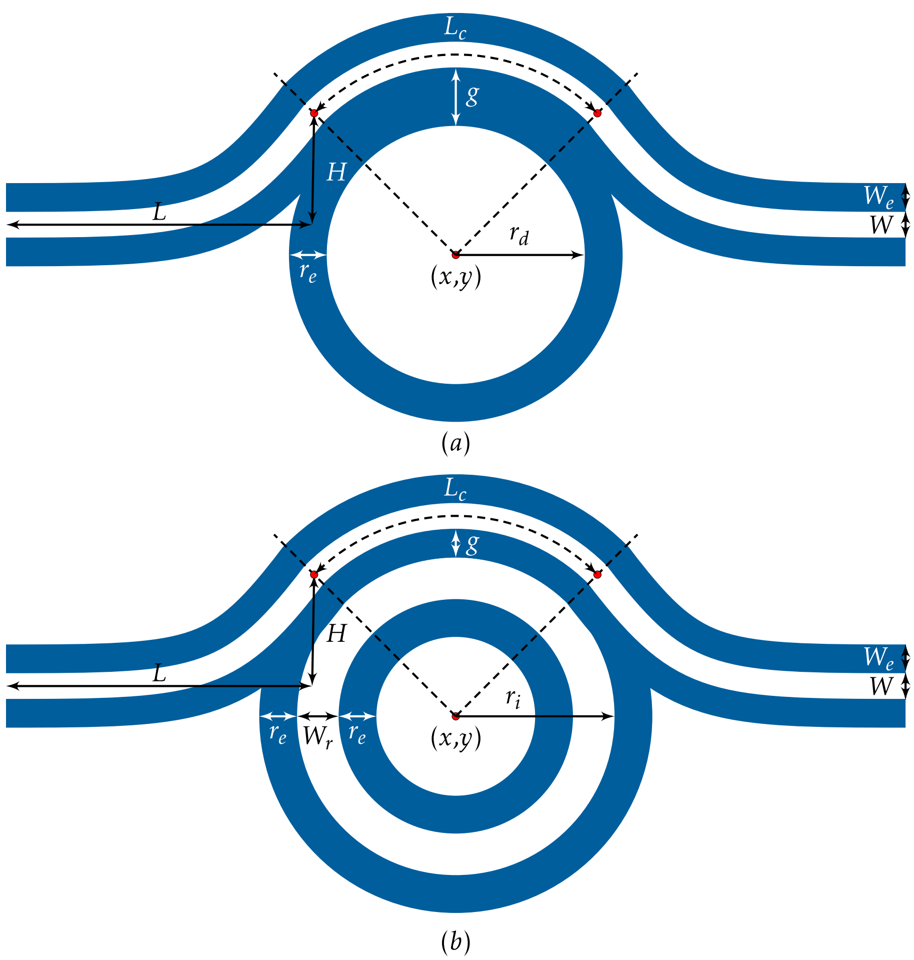


Figure 2.255: *Example shapes illustrating various parameters of the (a)* ***discPulleyInvPosLC*** *and (b)* ***ringPulleyInvPosLC*** *constructors.*

Disc pulley inverse positive structure with an additional coupling waveguide.

<x y r_d r_e N g_1 L_c N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **discPulInvPLCDS**>

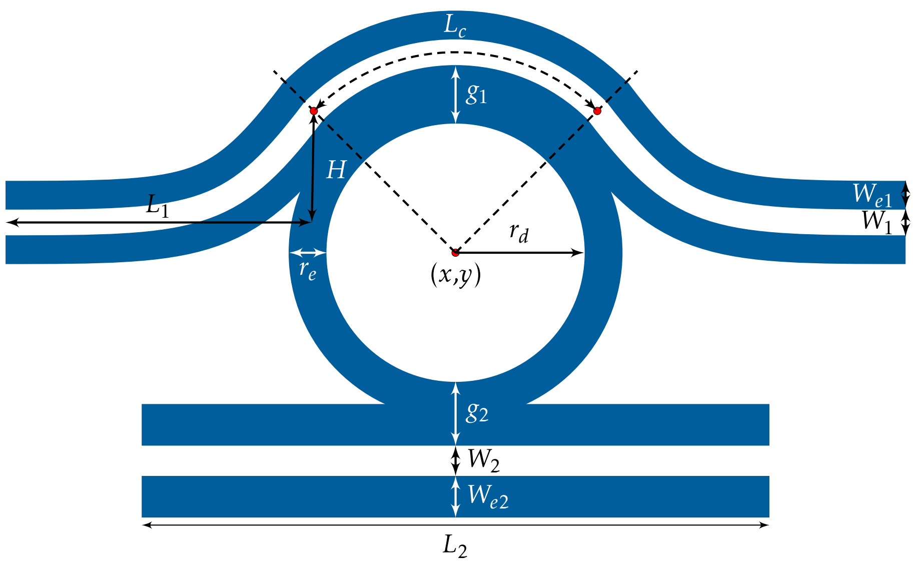


Figure 2.256: *Example shape illustrating various parameters of the* ***discPulInvPLCDS*** *constructor.*

Disc pulley inverse positive structure with an additional coupling pulley.

<x y r_d r_e N g_1 L_c N_{wg} W_1 W_{e1} L_1 H_1 g_2 L_{c2} W_2 W_{e2} L_2 H_2 EC **discPulInvPLCPul**>

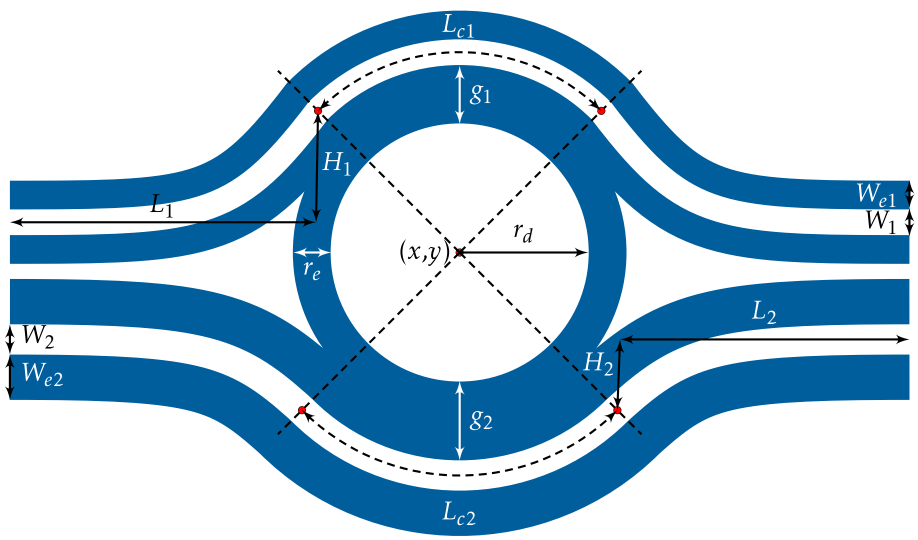


Figure 2.257: *Example shape illustrating various parameters of the* ***discPulInvPLCPul*** *constructor.*

Disc pulley inverse positive structure with an additional coupling waveguide.

<x y r_i W_r r_e N g_1 L_c N_{wg} W_1 W_{e1} L_1 H g_2 W_2 W_{e2} L_2 EC **ringPulInvPLCDS**>

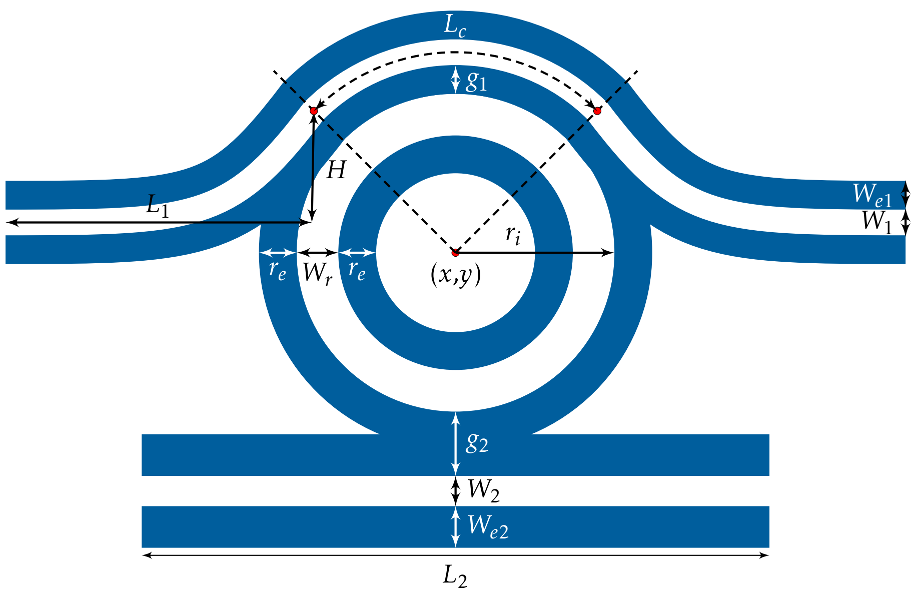


Figure 2.258: *Example shape illustrating various parameters of the* ***ringPulInvPLCDS*** *constructor.*

Disc pulley inverse positive structure with an additional coupling pulley.

<x y r_i W_r r_e N g_1 L_{c1} N_{wg} W_1 W_{e1} L_1 H_1 g_2 L_{c2} W_2 W_{e2} L_2 H_2 EC **ringPulInvPLCPul**>

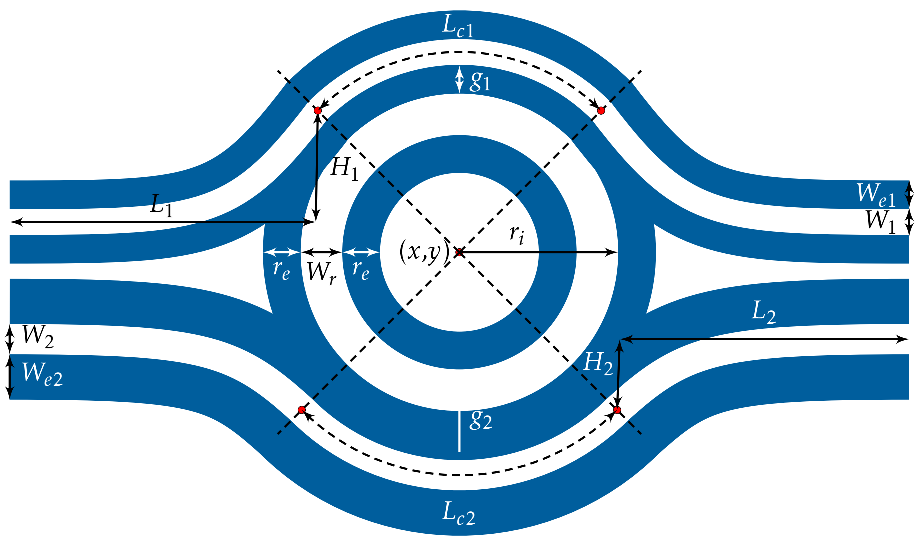


Figure 2.259: *Example shape illustrating various parameters of the* ***ringPulInvPLCPul*** *constructor.*

2.9.9.16 Disc-Ring Pulley Inverse Positive Tone Arc

Pulley inverse positive tone structures constructed using arcs are similar to ones described in section 2.9.9.12. Here, a slot waveguide is formed at a distance g away from a disc or a ring structure using a positive resist exposure of the exposure sleeve elements W_e and r_e.

<x y r_d r_e N g θ N_{wg} W W_e L_S EC **discPulleyInvPosA**>

<x y r_i W_r r_e N g θ N_{wg} W W_e L_S EC **ringPulleyInvPosA**>

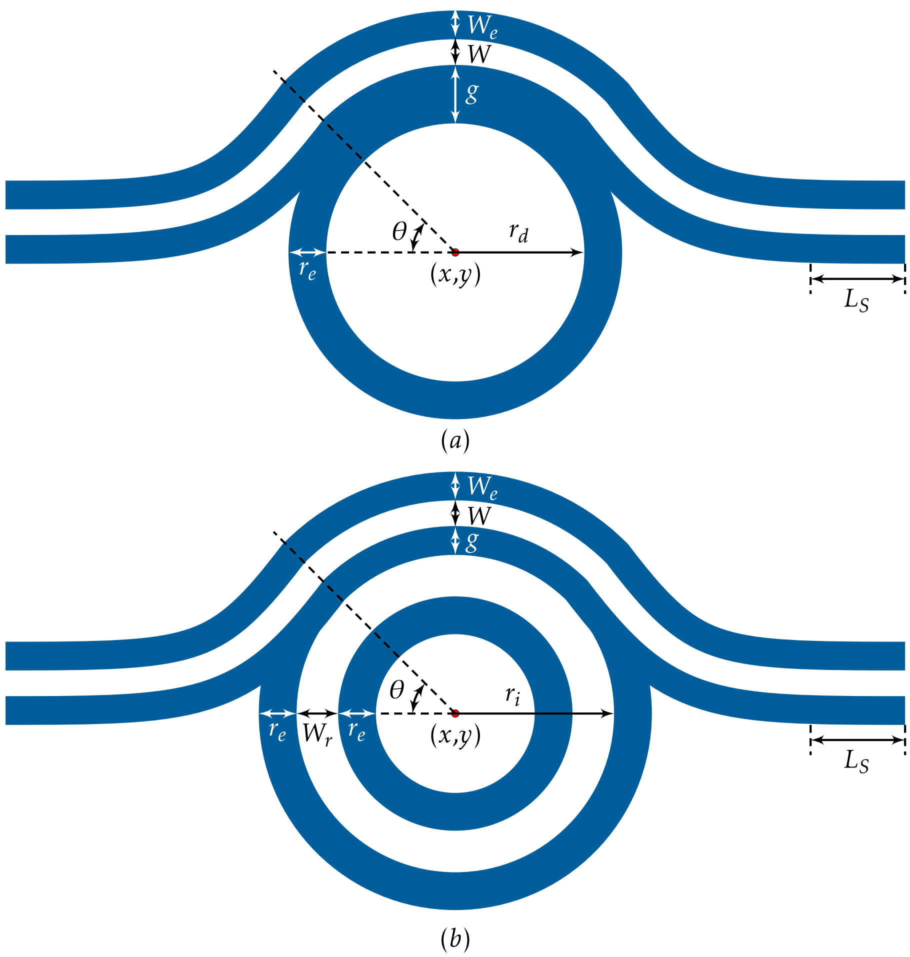


Figure 2.260: *Example shapes illustrating various parameters of the (a)* ***discPulleyInvPosA*** *and (b)* ***ringPulleyInvPosA*** *constructors.*

Disc pulley inverse positive arc structure with an additional coupling waveguide.

<x y r_d r_e N g_1 θ N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **discPullnvPADS**>

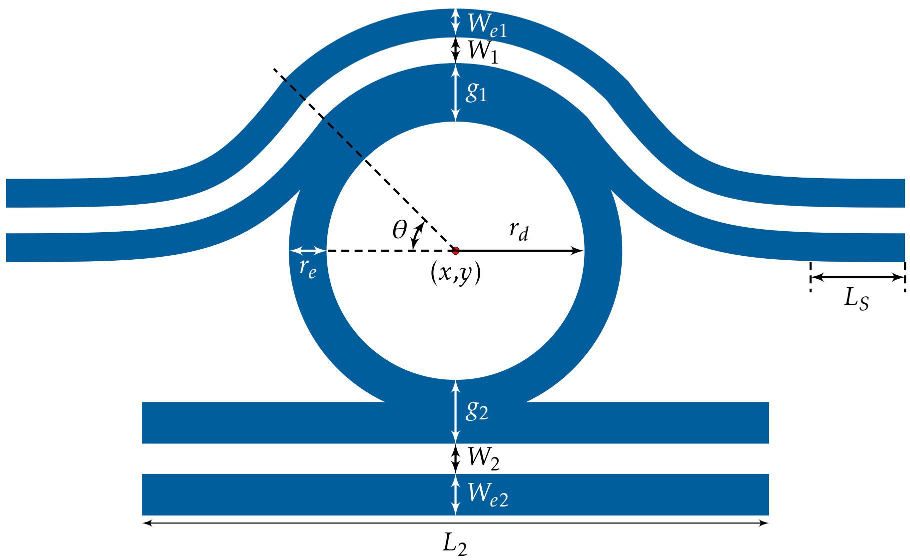


Figure 2.261: *Example shape illustrating various parameters of the* ***discPullnvPADS*** *constructor.*

Disc pulley inverse positive arc structure with an additional coupling pulley.

<x y r_d r_e N g_1 θ_1 N_{wg} W_1 W_{e1} L_{S1} g_2 θ_2 W_2 W_{e2} L_{S2} EC **discPulInvPAPul**>

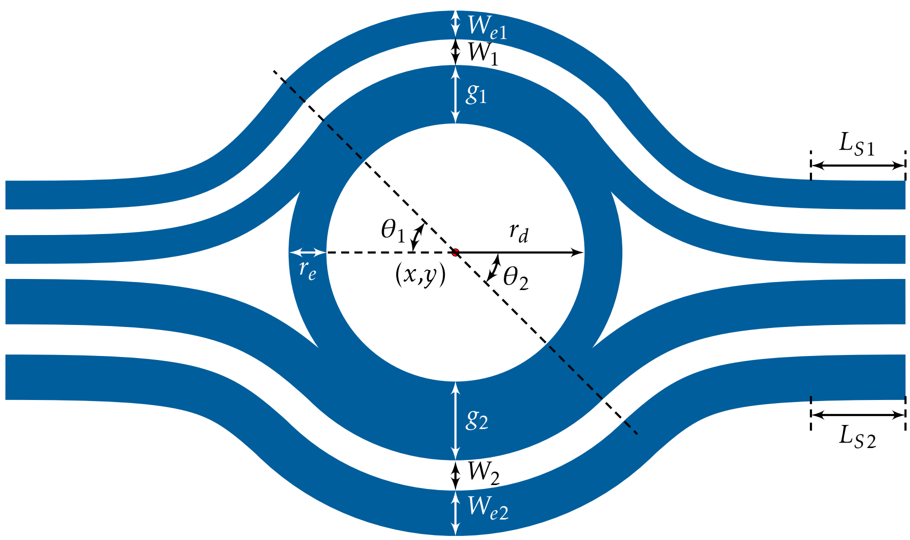


Figure 2.262: *Example shape illustrating various parameters of the* ***discPulInvPAPul*** *constructor.*

Ring pulley inverse positive arc structure with an additional coupling waveguide.

<x y r_i W_r r_e N g_1 θ N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **ringPullnvPADS**>

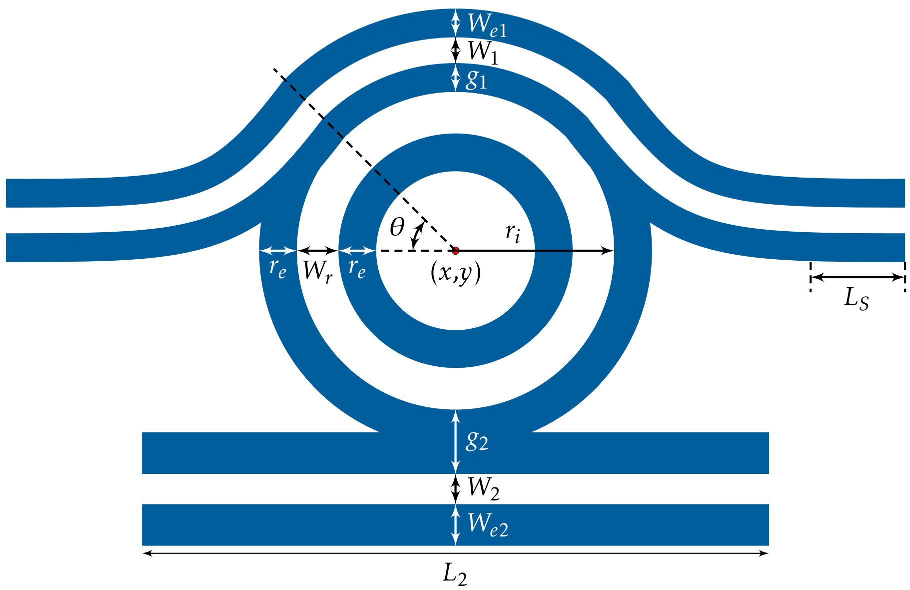


Figure 2.263: *Example shape illustrating various parameters of the* **ringPullnvPADS** *constructor.*

Ring pulley inverse positive arc structure with an additional coupling pulley.

<x y r_i W_r r_e N g_1 θ_1 N_{wg} W_1 W_{e1} L_{S1} g_2 θ_2 W_2 W_{e2} L_2 EC **ringPulInvPAPul**>

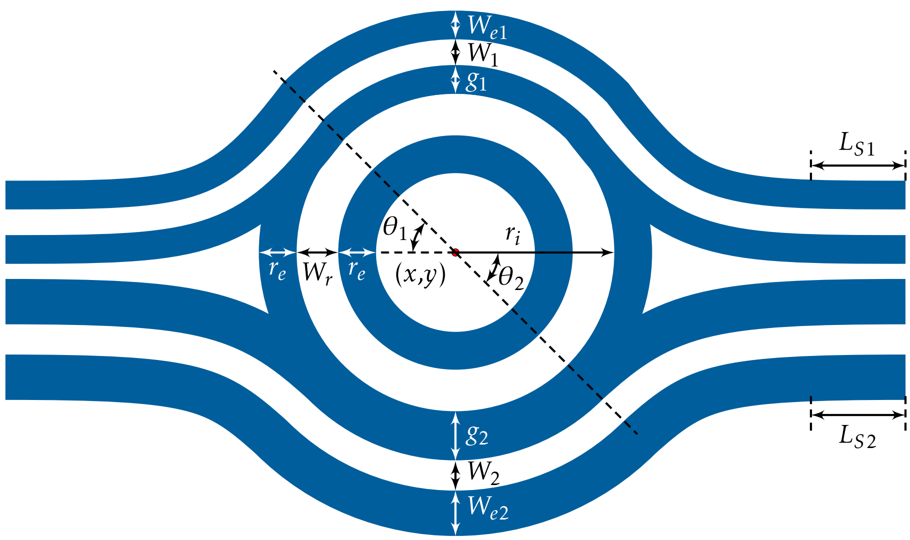
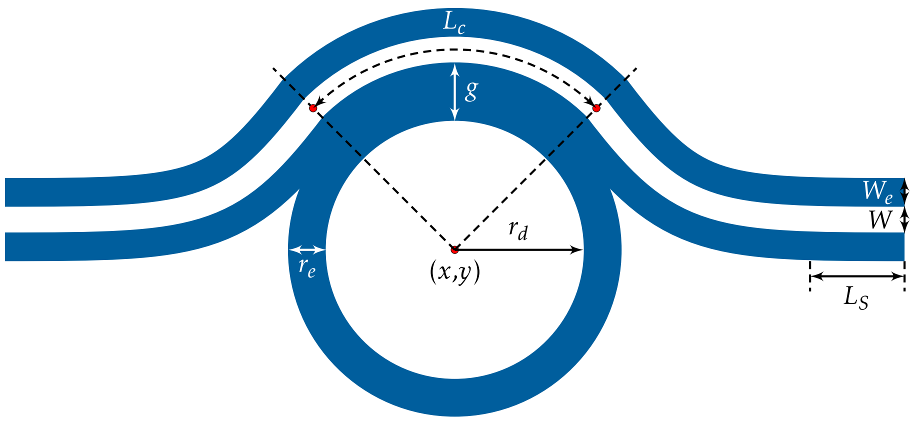


Figure 2.264: *Example shape illustrating various parameters of the* ***ringPulInvPAPul*** *constructor.*

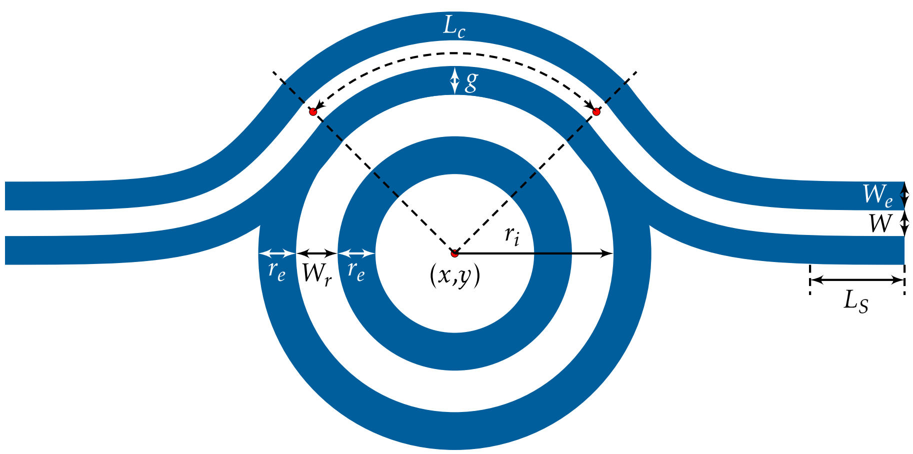
The following disc-ring waveguide pulley inverse positive tone structures are defined by the coupling length parameter L_c.

<x y r_d r_e N g L_c N_{wg} W W_e L_S EC **discPulleyInvPosLCA**>

<x y r_i W_r r_e N g L_c N_{wg} W W_e L_S EC **ringPulleyInvPosLCA**>



(a)



(b)

Figure 2.265: *Example shapes illustrating various parameters of the (a)* ***discPulleyInvPosLCA*** *and (b)* ***ringPulleyInvPosLCA*** *constructors.*

Disc pulley inverse positive arc structure with an additional coupling waveguide.

<x y r_d r_e N g_1 L_c N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **discPulInvPLCADS**>

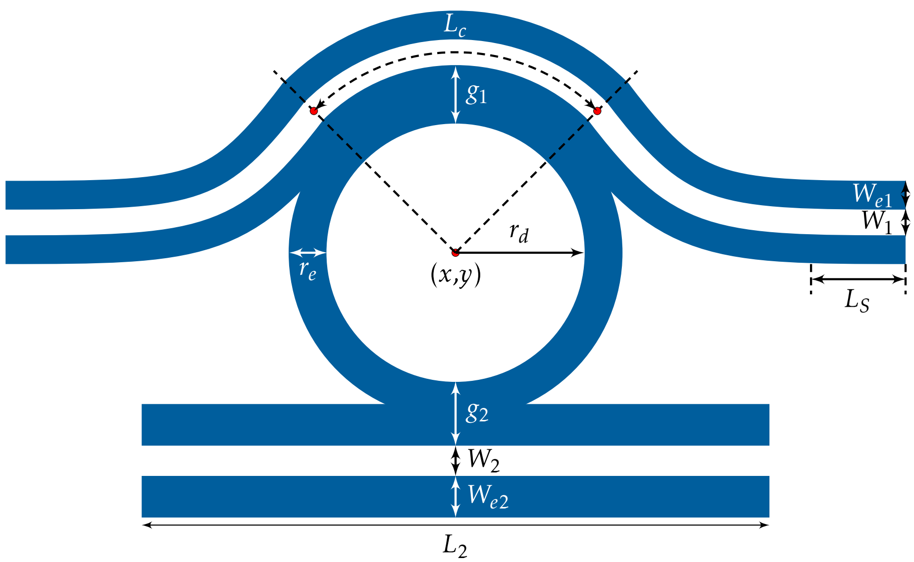


Figure 2.266: *Example shape illustrating various parameters of the* ***discPulInvPLCADS*** *constructor.*

Disc pulley inverse positive arc structure with an additional coupling pulley.

<x y r_d r_e N g_1 L_{c1} N_{wg} W_1 W_{e1} L_{S1} g_2 L_{c2} W_2 W_{e2} L_2 EC discPulInvPLCAPul>

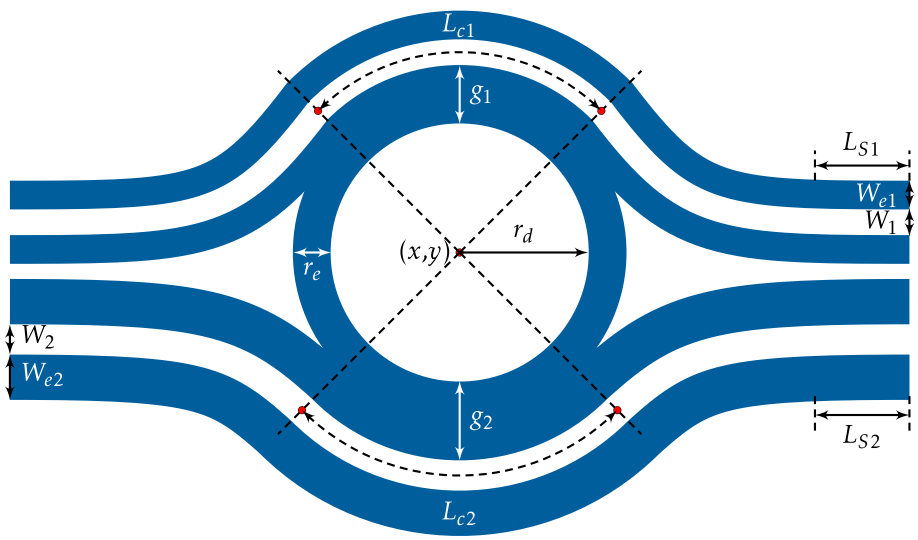


Figure 2.267: *Example shape illustrating various parameters of the* ***discPulInvPLCAPul*** *constructor.*

Ring pulley inverse positive arc structure with an additional coupling waveguide.

<x y r_i W_r r_e N g_1 L_c N_{wg} W_1 W_{e1} L_S g_2 W_2 W_{e2} L_2 EC **ringPulInvPLCADS**>

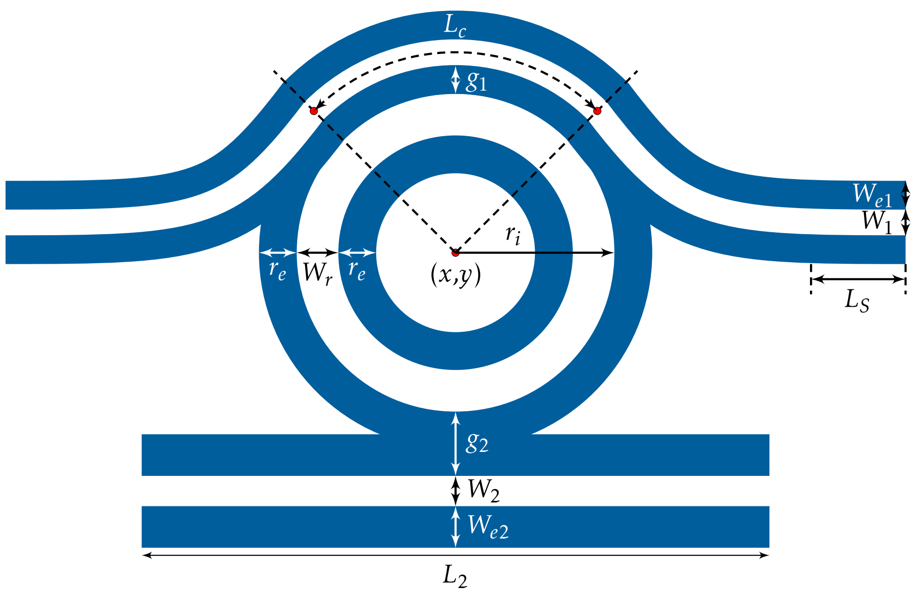


Figure 2.268: *Example shape illustrating various parameters of the* ***ringPulInvPLCADS*** *constructor.*

Ring pulley inverse positive arc structure with an additional coupling pulley.

<$x\ y\ r_i\ W_r\ r_e\ N\ g_1\ L_{c1}\ N_{wg}\ W_1\ W_{e1}\ L_{S1}\ g_2\ L_{c2}\ W_2\ W_{e2}\ L_{S2}\ EC$ ringPulInvPLCAPul>

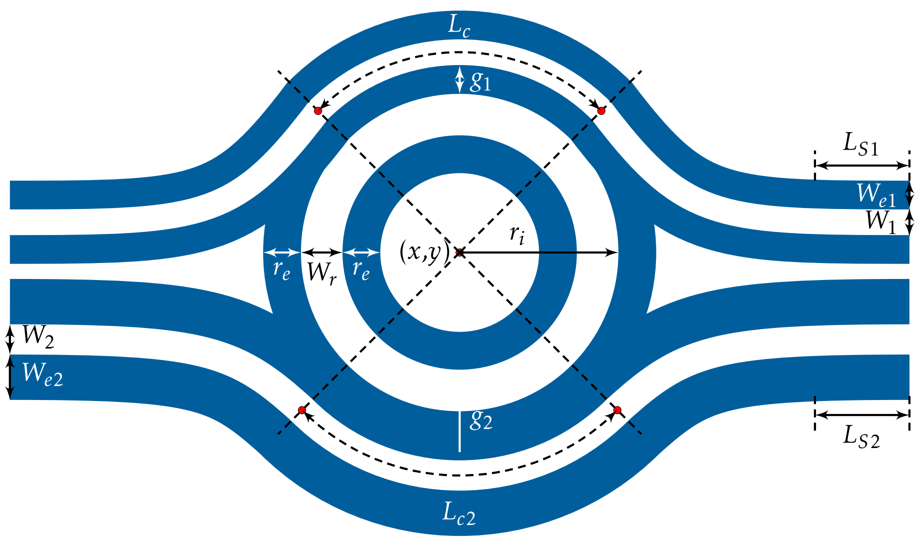


Figure 2.269: *Example shape illustrating various parameters of the* ***ringPulInvPLCAPul*** *constructor.*

2.9.10 Waveguide Inverse Photonic Crystals (Ellipse)

Waveguide shapes characterized by elliptical perforations on either a periodic ($a = constant$) or varying grid ($a_1, a_2, \ldots a_n$). Elliptical structures are defined by the two radii (r_x and r_y), the number of shape sides (N) and the waveguide width (W). The center waveguide position is (x, y). Indexed numbers ($1-7$ and $1-5$) correspond to the ellipse directly below.

r_{x_1} r_{y_1} N_1 r_{x_2} r_{y_2} N_2 $\ldots$ r_{x_n} r_{y_n} N_n x y a W **waveGuideInvPhC**

r_{x_1} r_{y_1} a_1 N_1 r_{x_2} r_{y_2} a_2 N_2 $\ldots$ r_{x_n} r_{y_n} a_n N_n x y W **waveGuideInvPhCvary**

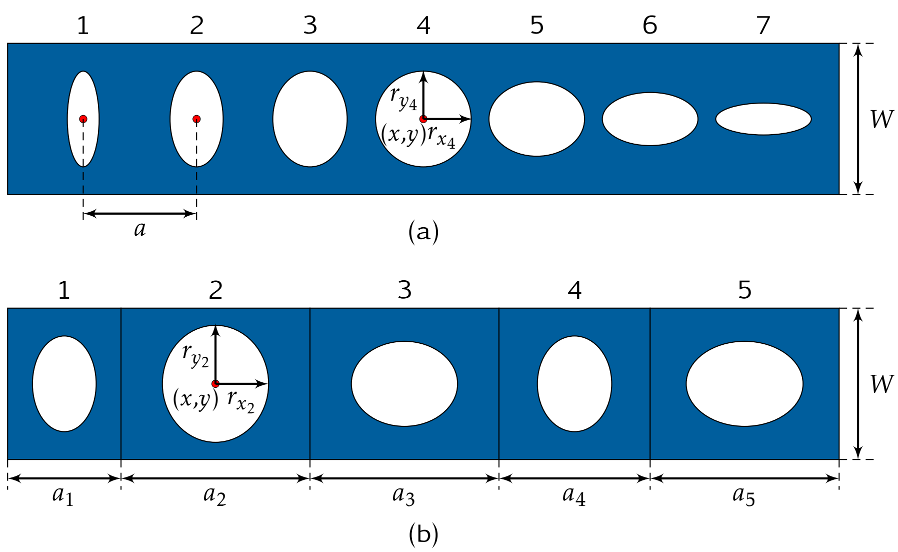


Figure 2.270: *Example shapes illustrating various parameters from the (a)* ***waveGuideInvPhC*** *and (b)* ***waveGuideInvPhCvary*** *constructor.*

2.9.11 Waveguide Photonic Crystals (Ellipse)

Waveguide shapes characterized by elliptical structures on either a periodic ($a = constant$) or varying grid ($a_1, a_2, \ldots a_n$). Elliptical structures are defined by the two radii (r_x and r_y), the number of shape sides (N) and the waveguide width (W). The center waveguide position is (x, y). The box defining the waveguide extends beyond the elliptical structures by the overhang (S_o) and is of height (S_h). Indexed numbers ($1-7$ and $1-5$) correspond to the ellipse directly below.

r_{x_1} r_{y_1} N_1 r_{x_2} r_{y_2} N_2 $\ldots$ r_{x_n} r_{y_n} N_n x y a W S_o S_h **waveGuidePhC**

r_{x_1} r_{y_1} a_1 N_1 r_{x_2} r_{y_2} a_2 N_2 $\ldots$ r_{x_n} r_{y_n} a_n N_n x y W S_o S_h **waveGuidePhCvary**

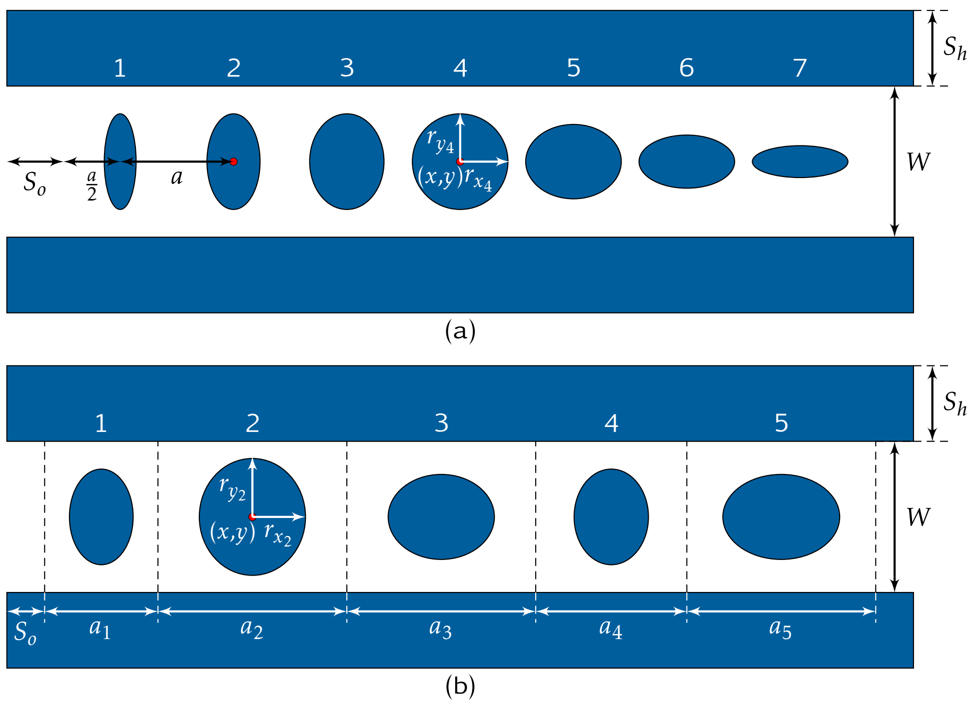


Figure 2.271: *Example shapes illustrating various parameters from the (a)* ***waveGuidePhC*** *and (b)* ***waveGuidePhCvary*** *constructor.*

2.9.12 Waveguide Inverse Photonic Crystals (Rectangle)

Waveguide shapes characterized by rectangular perforations on either a periodic ($a = constant$) or varying grid ($a_1, a_2, \dots a_n$). Rectangular structures are defined by the L_x and L_y, and the waveguide width (W). The center waveguide position is (x, y). Indexed numbers ($1-7$ and $1-5$) correspond to the rectangles directly below.

L_{x_1} L_{y_1} L_{x_2} L_{y_2} $\dots$ L_{x_n} L_{y_n} x y a W **waveGuideInvRectPhC**

L_{x_1} L_{y_1} a_1 L_{x_2} L_{y_2} a_2 $\dots$ L_{x_n} L_{y_n} a_n x y W **waveGuideInvRectPhCvary**

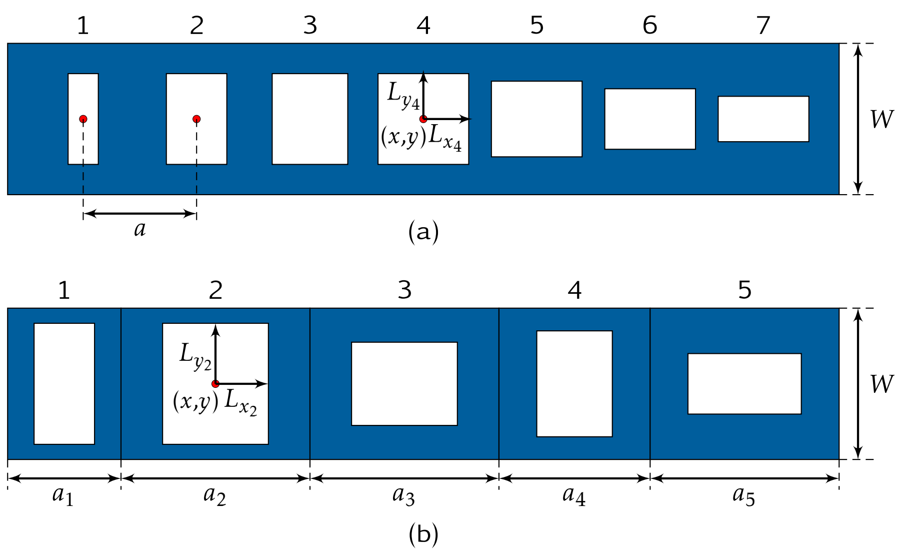


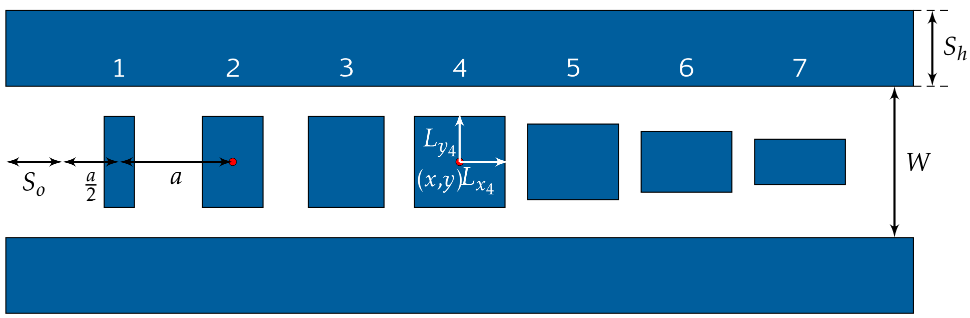
Figure 2.272: *Example shapes illustrating various parameters from the (a) **waveGuideInvRectPhC** and (b) **waveGuideInvRectPhCvary** constructor.*

2.9.13 Waveguide Photonic Crystals (Rectangle)

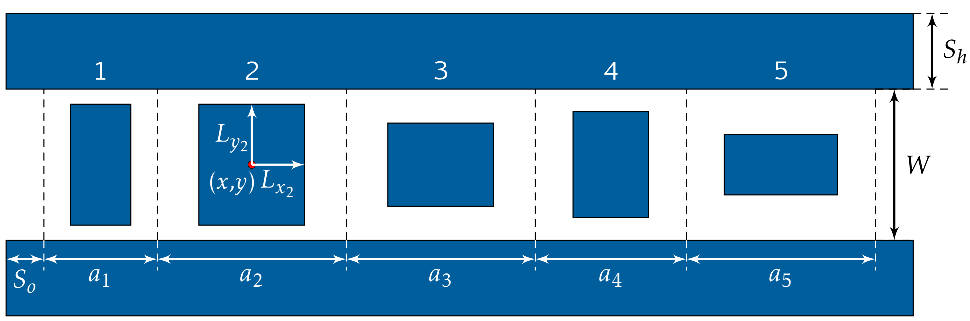
Waveguide shapes characterized by rectangular structures on either a periodic ($a = constant$) or varying grid ($a_1, a_2, \ldots a_n$). Rectangular structures are defined by the L_x and L_y, and the waveguide width (W). The center waveguide position is (x, y). The box defining the waveguide extends beyond the rectangular structures by the overhang (S_o) and is of height (S_h). Indexed numbers ($1-7$ and $1-5$) correspond to the rectangles directly below.

L_{x_1} L_{y_1} L_{x_2} L_{y_2} $\ldots$ L_{x_n} L_{y_n} x y a W S_o S_h **waveGuideRectPhC**

L_{x_1} L_{y_1} a_1 L_{x_2} L_{y_2} a_2 $\ldots$ L_{x_n} L_{y_n} a_n x y W S_o S_h **waveGuideRectPhCvary**



(a)



(b)

Figure 2.273: *Example shapes illustrating various parameters from the (a) **waveGuideRectPhC** and (b) **waveGuideRectPhCvary** constructor.*

2.9.14 Waveguide Photonic Crystals (Flush Rectangle)

Waveguide shapes characterized by rectangular structures on a varying grid $(a_1, a_2, \ldots a_n)$. Rectangular structures are defined by the L_x and L_y positioned flush at a distance d away from top of waveguide, and the waveguide width (W). The center waveguide position is (x, y). The box defining the waveguide (Figure 2.9.14) extends beyond the rectangular structures by the overhang (S_o) and is of height (S_h). Indexed numbers $(1-5)$ correspond to the rectangles directly below.

L_{x_1} L_{y_1} a_1 L_{x_2} L_{y_2} a_2 $\ldots$ L_{x_n} L_{y_n} a_n x y W d **waveGuideInvRectFlushPhCvary**

L_{x_1} L_{y_1} a_1 L_{x_2} L_{y_2} a_2 $\ldots$ L_{x_n} L_{y_n} a_n x y W d S_o S_h **waveGuideRectFlushPhCvary**

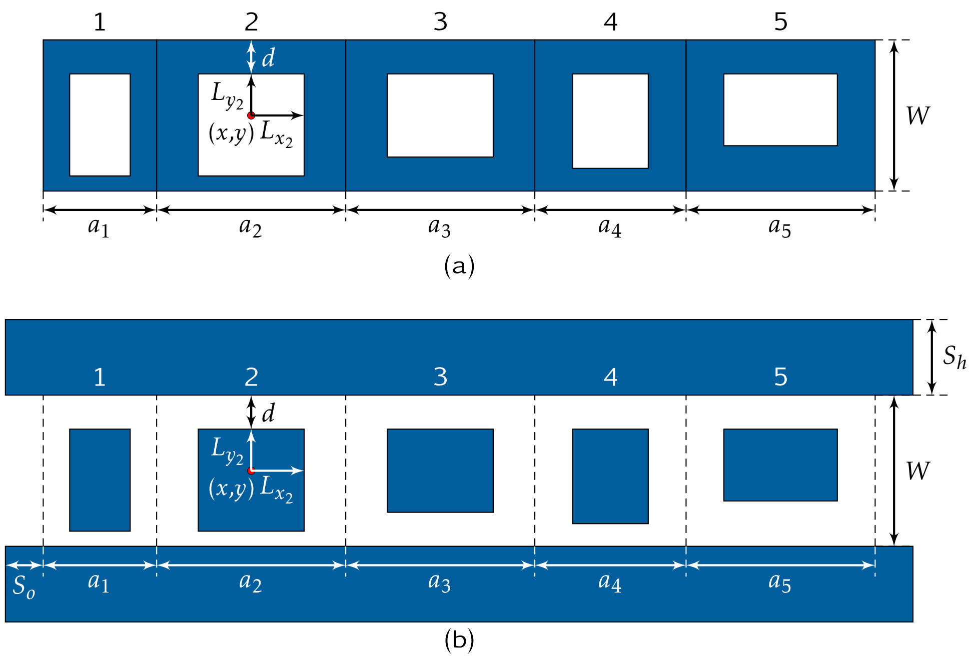


Figure 2.274: *Example shapes illustrating various parameters from the (a) **waveGuideInvRectFlushPhCvary** and (b) **waveGuideRectFlushPhCvary** constructor.*

2.9.15 Various Waveguide-Disc-Tip Coupled Structures

<x y r N_{sides} d_x d_y w L_{wg} r_{wg} s g r_e d_e c d_c $\theta_{(x,y)}$ **wgdcdV1**>

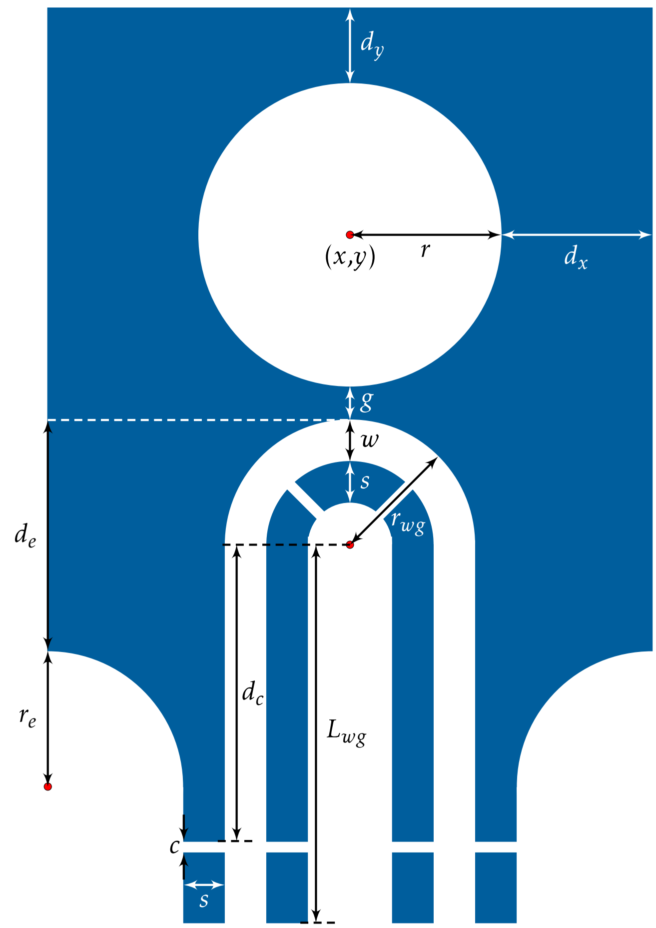


Figure 2.275: *wgdcdV1 constructor.*

<x y r N_{sides} d_x d_y H_1 W_1 t_H t_W t_S t_Y w L_{wg} r_{wg} s g c d_c $\theta_{(x,y)}$ **wgdcdV2**>

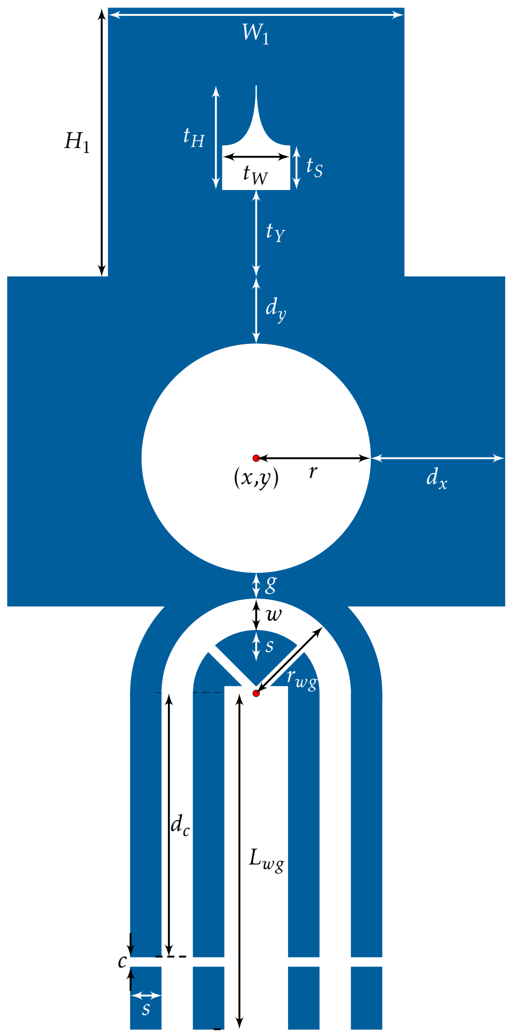


Figure 2.276: *wgdcdV2 constructor.*

<x y r N_{sides} d_x d_y d_g H_1 W_1 w L_{wg} r_{wg} s g c d_c D $\theta_{(x,y)}$ **wgdcdV3**>

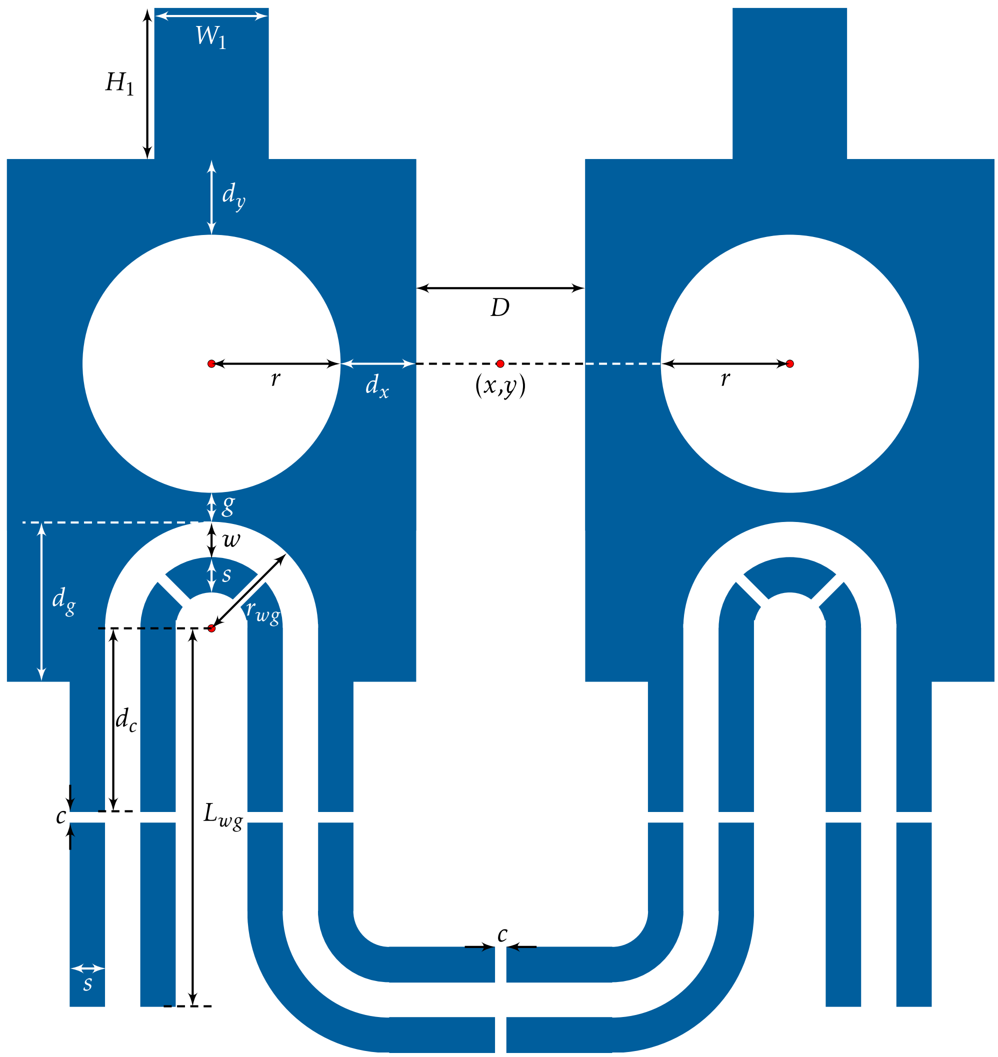


Figure 2.277: ***wgdcdV3*** *constructor.*

<x y r N_{sides} d_x d_y d_g H_1 t_H w L_{wg} r_{wg} s g c d_c D $\theta_{(x,y)}$ **wgdcdV4**>

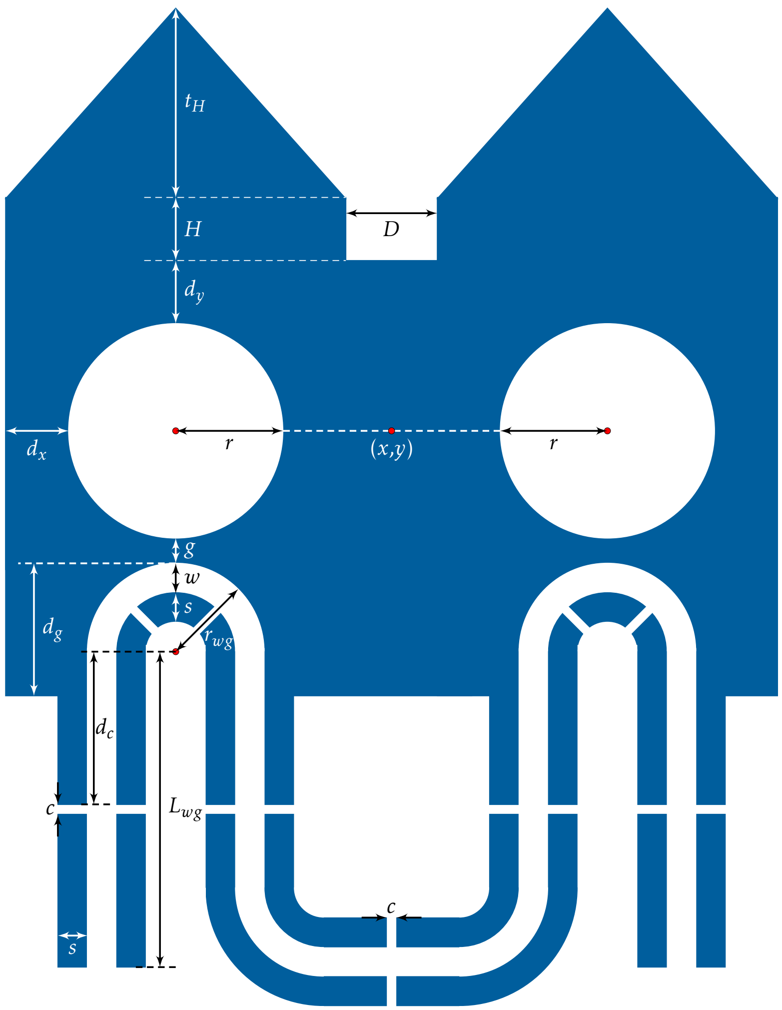


Figure 2.278: *wgdcdV4 constructor.*

<$x \quad y \quad r \quad N_{sides} \quad d_x \quad d_y \quad d_g \quad t_H \quad w \quad L_{wg} \quad r_{wg} \quad s \quad g \quad c \quad d_{c1} \quad d_{c2} \quad \theta_{(x,y)}$ **wgdcdV5**>

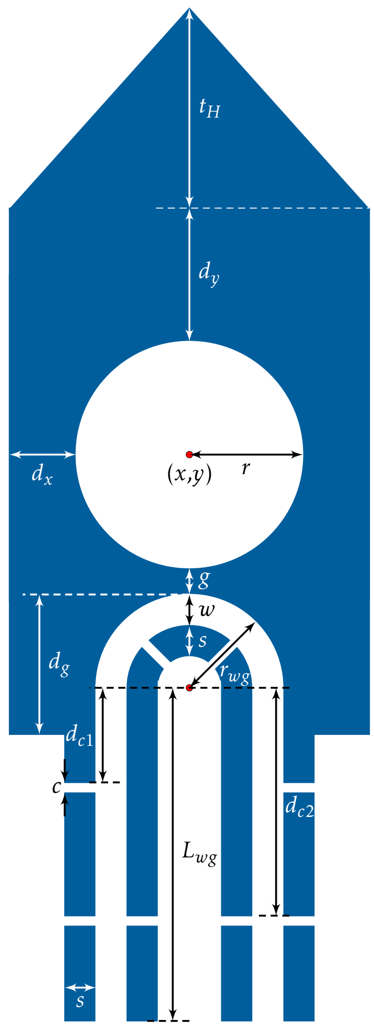


Figure 2.279: ***wgdcdV5*** *constructor.*

<$x \quad y \quad r \quad N_{sides} \quad d_x \quad d_y \quad d_g \quad H \quad t_H \quad w \quad L_{wg} \quad r_{wg} \quad s \quad g \quad c \quad d_{c1} \quad d_{c2} \quad \theta_{(x,y)}$ **wgdcdV6**>

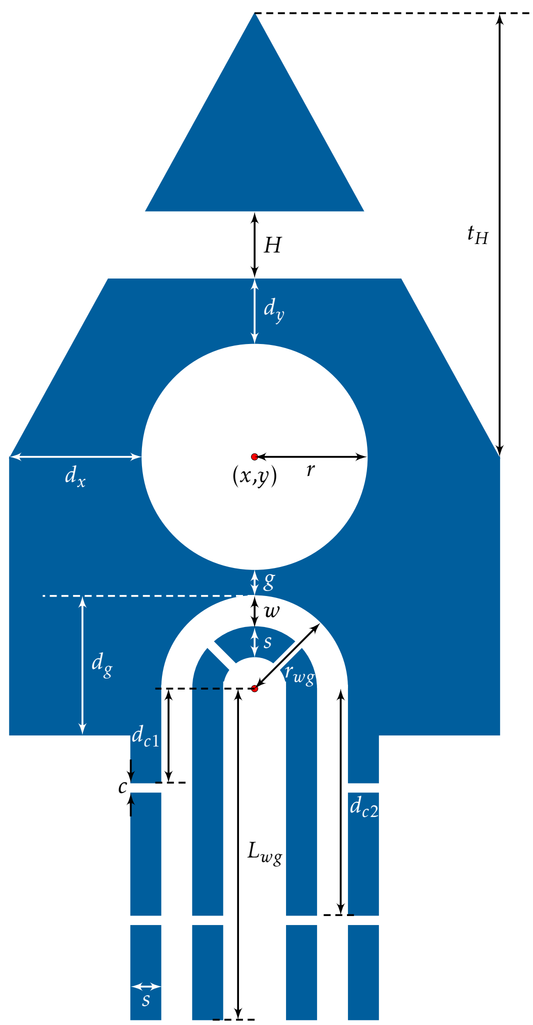


Figure 2.280: *wgdcdV6 constructor.*

<x y r r_2 N_{sides} d_y d_x w L_{wg} r_{wg} s g c d_c $\theta_{(x,y)}$ **wgdcdV7**>

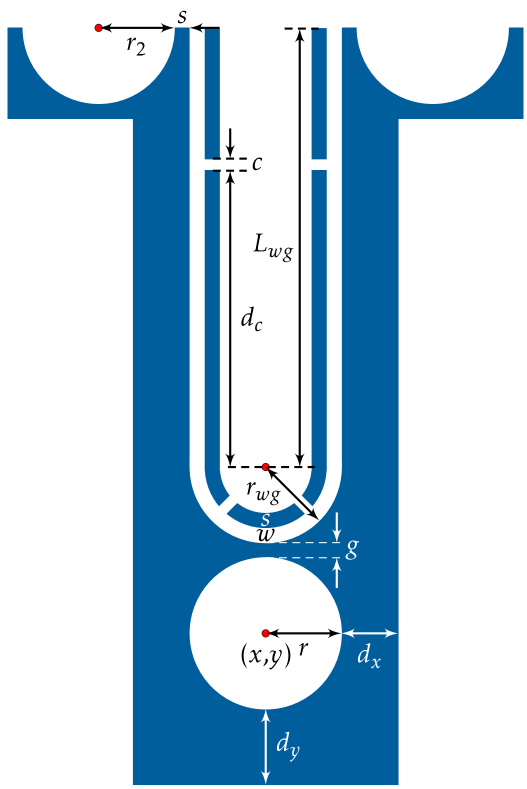


Figure 2.281: *wgdcdV7 constructor.*

<x y t b f s w_1 w_2 L_s L_t g c d_c W H L_1 L_2 L_3 $\theta_{(x,y)}$ **wgdcdV8**>

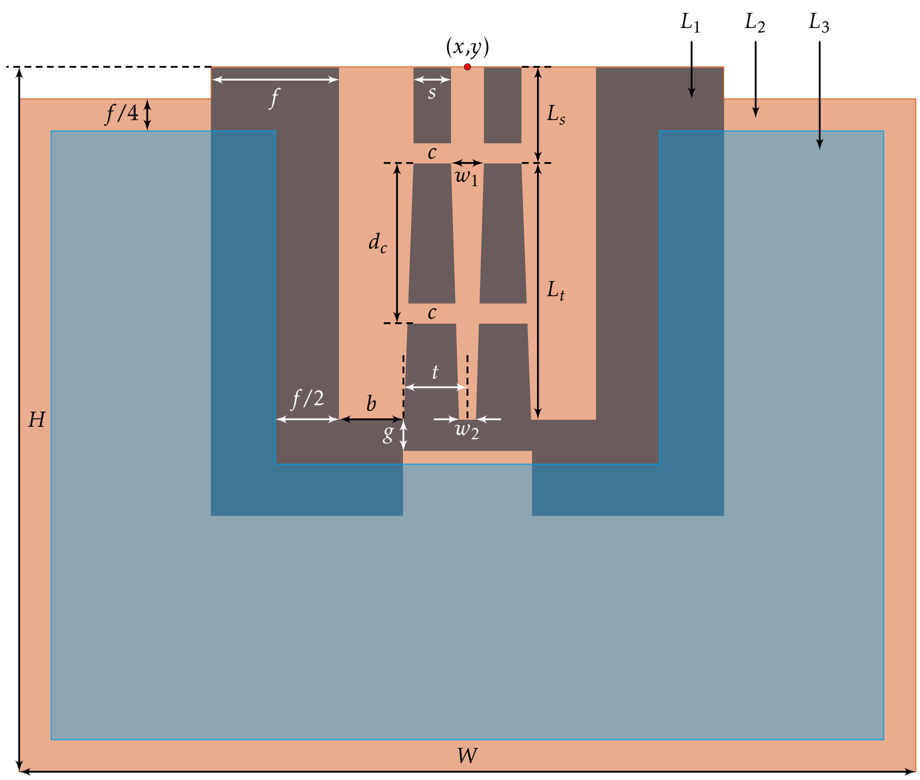


Figure 2.282: ***wgdcdV8*** *constructor.*

2.10 MEMS - NEMS Library

2.10.1 Actuators

2.10.1.1 Bent Beams

Bent beams form a class of linear displacement actuators. In this case, motion occurs via thermal expansion of the beam.

$x \quad y \quad w \quad l_1 \quad l_2 \quad l_3 \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **bentBeam**

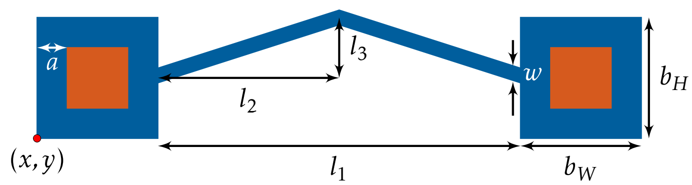


Figure 2.283: *Bent beam of width w suspended between two anchored electrodes. The anchor overlap and GDS layer parameters are defined by a and L_a.*

$x \quad y \quad w \quad l_1 \quad l_2 \quad l_3 \quad l_4 \quad h \quad p \quad N \quad c_W \quad d_H \quad d_W \quad L_d \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **bentBeamArray**

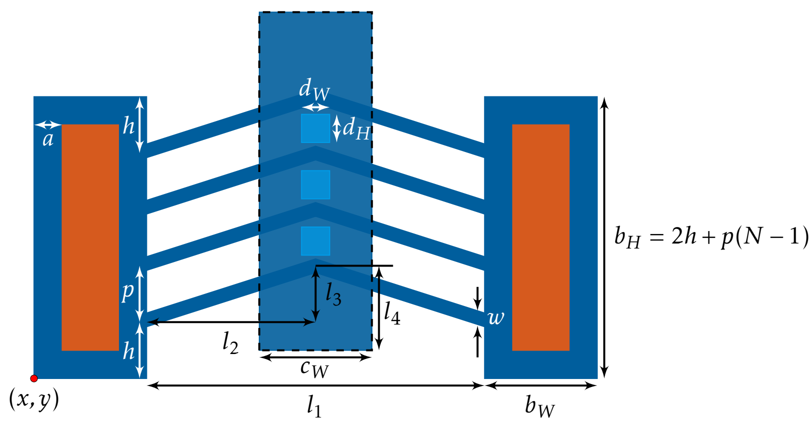


Figure 2.284: *Array of N bent beam elements with a central rectangular structure. The d_H and d_W parameter defines an extra GDS layer (L_d) that could be used to perforate the central structure.*

2.10.1.2 Bi-Morph Thermal Actuator

Differential thermal expansion of the bimorph actuator allows for in-plane motion. This occurs when a voltage is applied, wherein current induced Joule heating causes uneven thermal expansion within the two beams of differing widths.

$x \quad y \quad w_1 \quad w_2 \quad w_3 \quad w_4 \quad l_1 \quad l_2 \quad l_3 \quad p \quad s_H \quad s_W \quad L_s \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **biMorph**

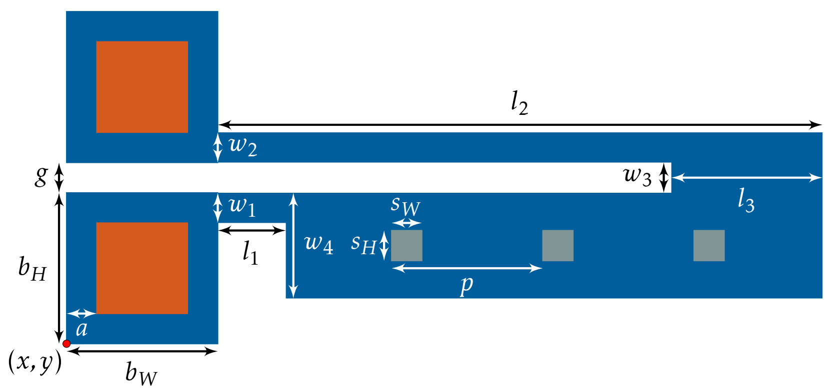


Figure 2.285: *Bimorph thermal actuator.*

2.10.1.3 Combs and Drive Elements

Linear comb drive created using three GDS layers. Lower and upper base electrodes are created using the initialized and L_b GDS layers respectively. The anchor overlap and GDS layers are correspondingly a and L_a.

x y w_1 w_2 l_1 l_2 N p b_H L_b a L_a $\theta_{(x,y)}$ **combDriveV1**

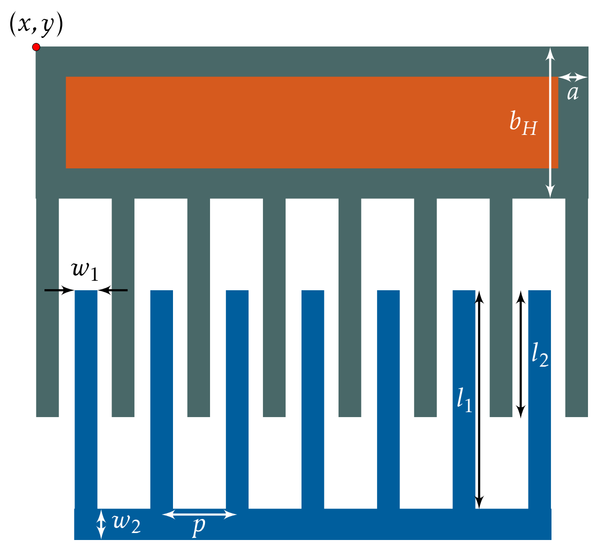


Figure 2.286: *Linear comb drive.*

Number of electrode elements (N) is used to calculate the number of rectangular rotor elements ($l_1 \times w_1$). The structure is composed from the initialized GDS layer (top and bottom electrodes), L_a (anchor) and L_b (rotor).

$x \quad y \quad w_1 \quad l_1 \quad l_2 \quad l_3 \quad g \quad N \quad p \quad b_H \quad b_W \quad p_b \quad L_b \quad a \quad L_a \quad \theta_{(x,y)}$ **linearDriveL1**

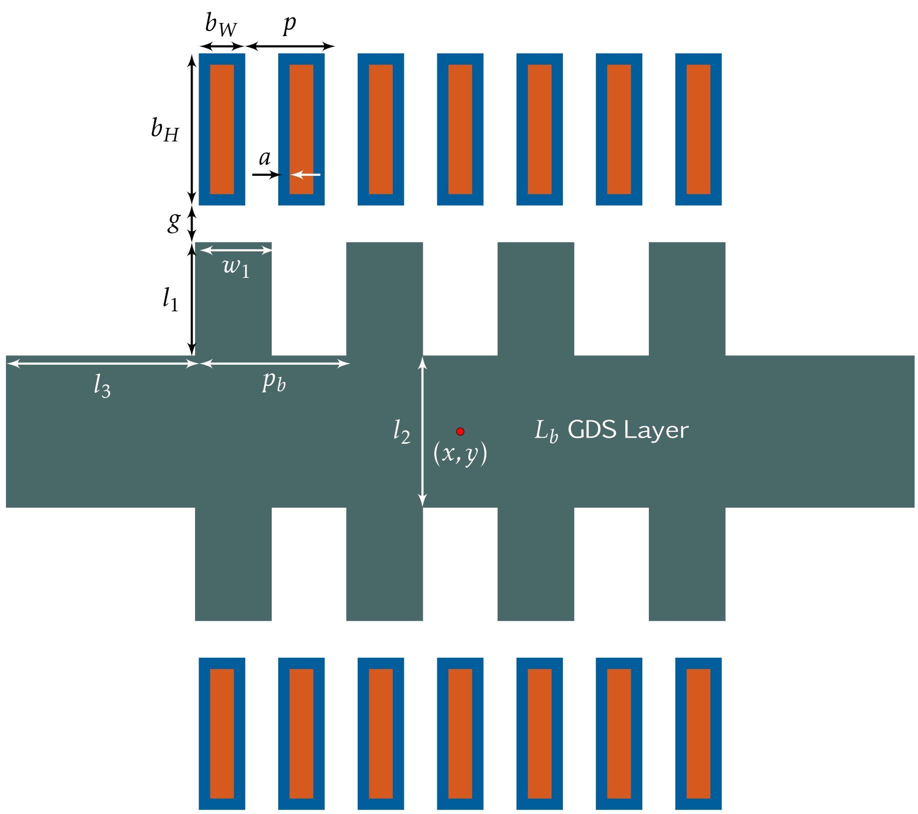
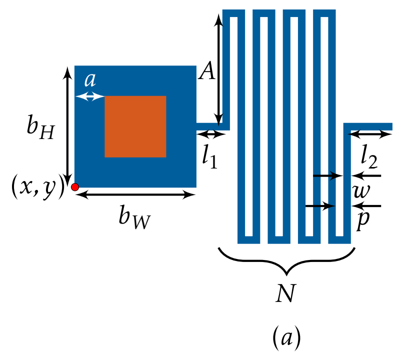


Figure 2.287: *Linear drive composed of anchored electrodes and a central rotor.*

2.10.1.4 Folded Springs

$x \quad y \quad w \quad l_1 \quad l_2 \quad p \quad A \quad N \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **foldedSpring1A**

$x \quad y \quad w \quad l_1 \quad l_2 \quad p \quad A \quad N \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **foldedSpring1B**



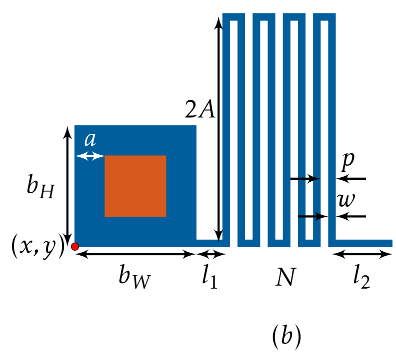
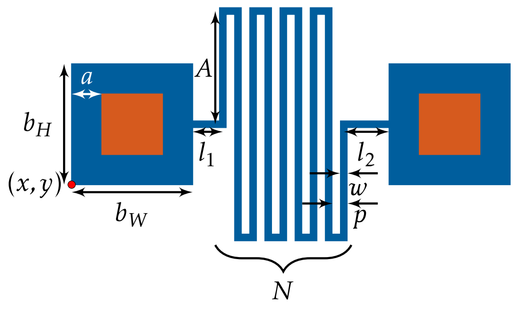


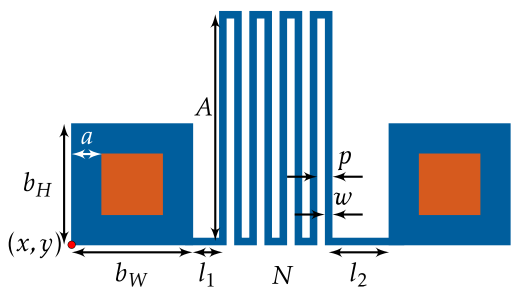
Figure 2.288: *Folded springs with a single anchored pad. The spring meander initiates at the (a) midpoint and (b) bottom of pads.*

$x \quad y \quad w \quad l_1 \quad l_2 \quad p \quad A \quad N \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **foldedSpring2A**

$x \quad y \quad w \quad l_1 \quad l_2 \quad p \quad A \quad N \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **foldedSpring2B**



(a)



(b)

Figure 2.289: *Folded springs with two anchored pads. The spring meander initiates at the (a) midpoint and (b) bottom of pads.*

$x \quad y \quad w \quad l_1 \quad l_2 \quad p \quad A \quad N \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **foldedSpring2C**

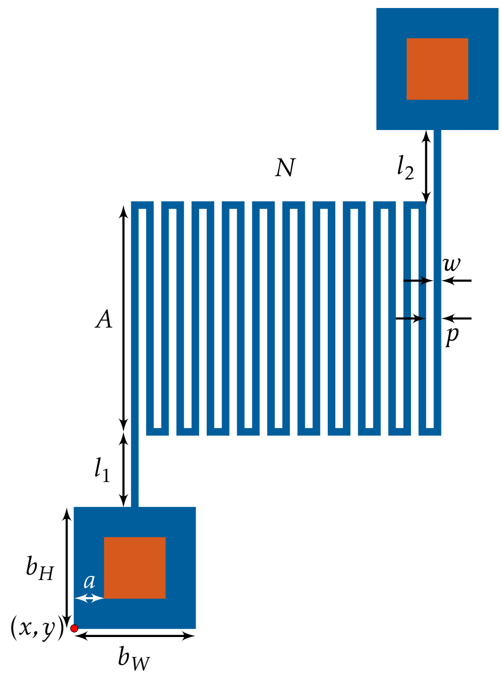


Figure 2.290: *Folded springs with two anchored pads V2C.*

$x \quad y \quad w \quad l_1 \quad l_2 \quad p \quad A \quad N \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **foldedSpring2D**

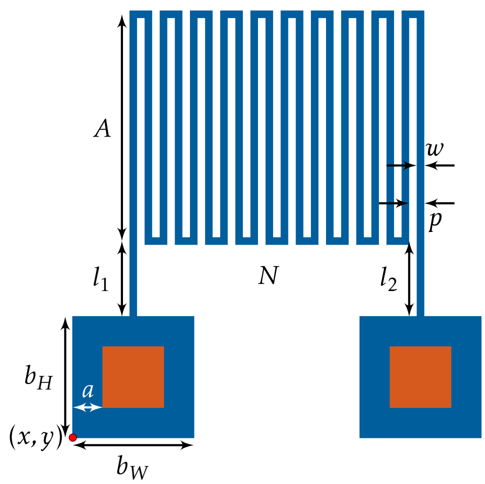
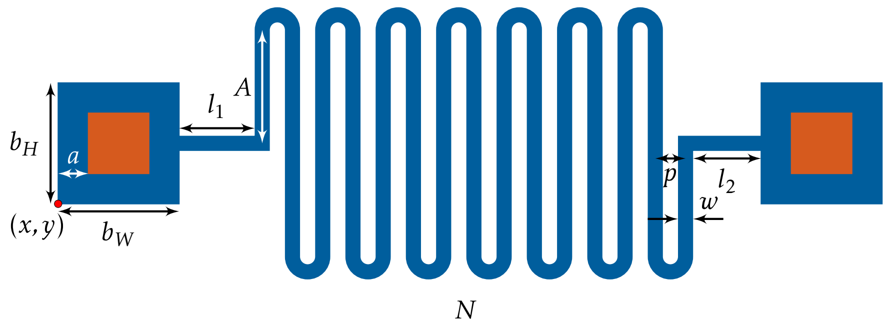


Figure 2.291: *Folded springs with two anchored pads V2D.*

$x \quad y \quad w \quad l_1 \quad l_2 \quad p \quad A \quad N \quad N_{sides} \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **foldedSpring2E**

$x \quad y \quad w \quad l_1 \quad l_2 \quad p \quad A \quad N \quad N_{sides} \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **foldedSpring2F**



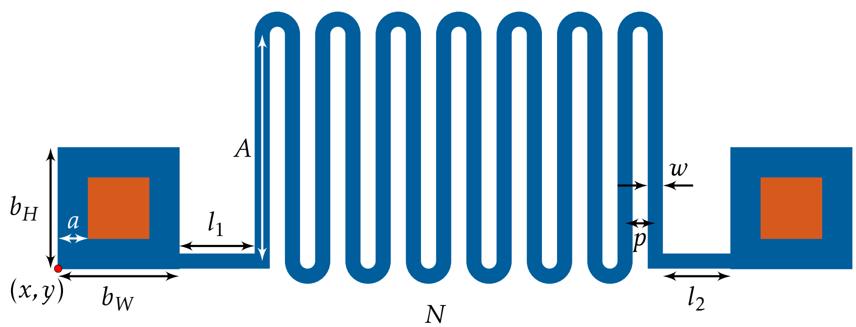


Figure 2.292: *Folded springs with two anchored pads V2E and V2F.*

$x \quad y \quad w \quad l_1 \quad l_2 \quad p \quad A \quad N \quad N_{sides} \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **foldedSpring2G**

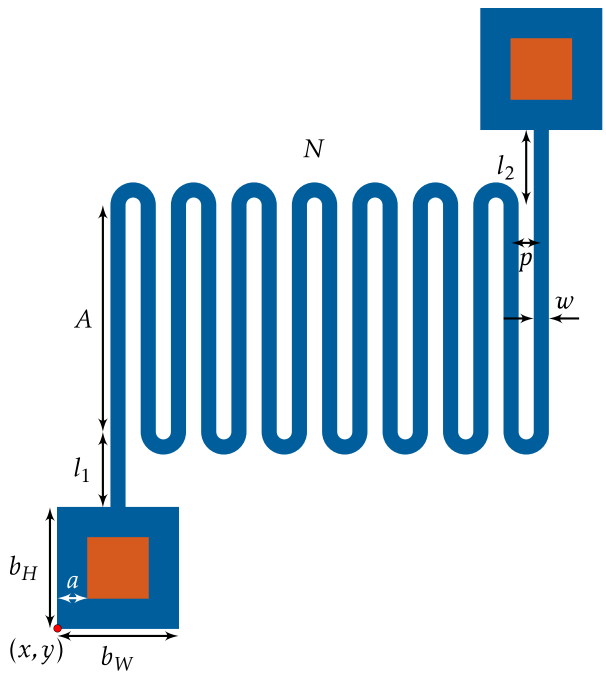


Figure 2.293: *Folded springs with two anchored pads V2G.*

$x \;\; y \;\; w \;\; l_1 \;\; l_2 \;\; p \;\; A \;\; N \;\; N_{sides} \;\; b_H \;\; b_W \;\; a \;\; L_a \;\; \theta_{(x,y)}$ **foldedSpring2H**

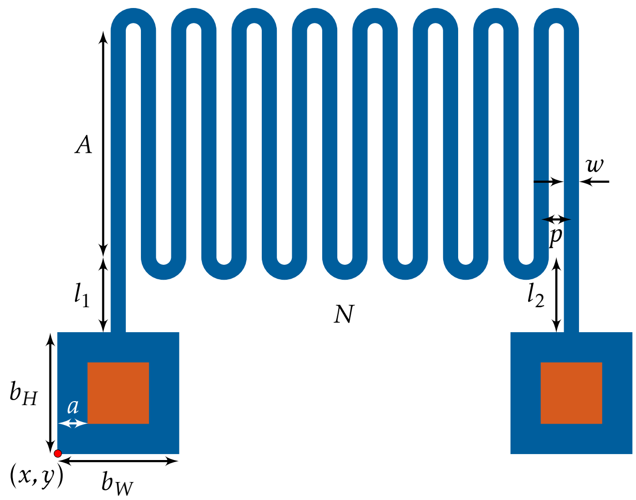


Figure 2.294: *Folded springs with two anchored pads V2H.*

$x \quad y \quad w \quad l_1 \quad l_2 \quad p \quad A \quad N \quad N_{sides} \quad r \quad a \quad L_a \quad \theta_{(x,y)}$ **foldedSpring2l**

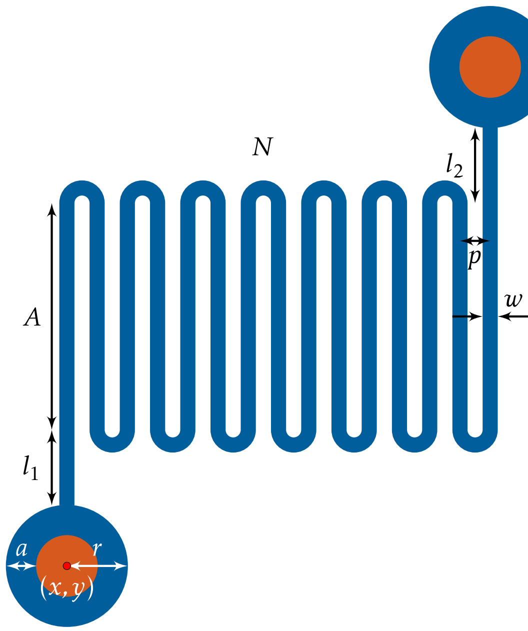


Figure 2.295: *Folded springs with two anchored pads V2l.*

$x \quad y \quad w \quad l_1 \quad l_2 \quad p \quad A \quad N \quad N_{sides} \quad r \quad a \quad L_a \quad \theta_{(x,y)}$ **foldedSpring2J**

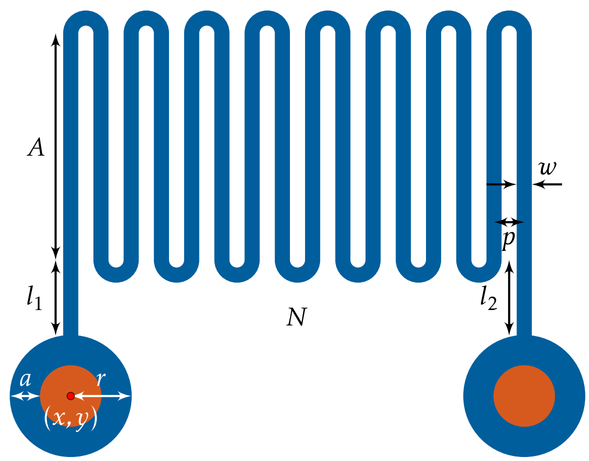


Figure 2.296: *Folded springs with two anchored pads V2J.*

2.10.2 Bolometers

Below L-Shaped bolometer is constructed from GDS layers L_a, L_b, L_c, L_d, L_e, and L_f using the below specified parameters. Rounded rectangles (layers L_d and L_e) are defined by a radius r_i. The number of points defining the curved region of the rounded rectangle is defined by the **shapeReso** parameter. Meandering curved region defined by radius r is constructed using N_{sides} number of points.

$x\ y\ w_1\ w_2\ w_3\ g_1\ g_2\ g_3\ L_1\ L_2\ r\ r_i\ N_{sides}\ a\ b\ c\ d\ e\ f\ L_a\ L_b\ L_c\ L_d\ L_e\ L_f\ \theta_{(x,y)}$ **bolometerL**

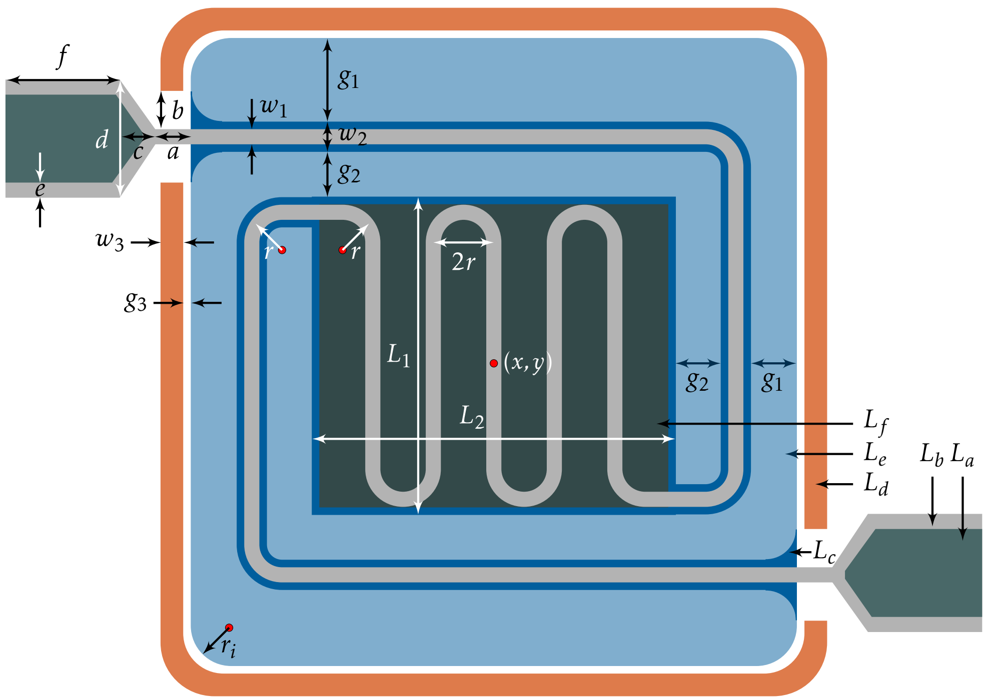


Figure 2.297: *L-shaped bolometer structure.*

$x\ y\ w_1\ w_2\ w_3\ g_1\ g_2\ g_3\ L_1\ L_2\ r\ r_i\ N_{sides}\ a\ b\ c\ d\ e\ f\ L_a\ L_b\ L_c\ L_d\ L_e\ L_f\ \theta_{(x,y)}$ **bolometerU**

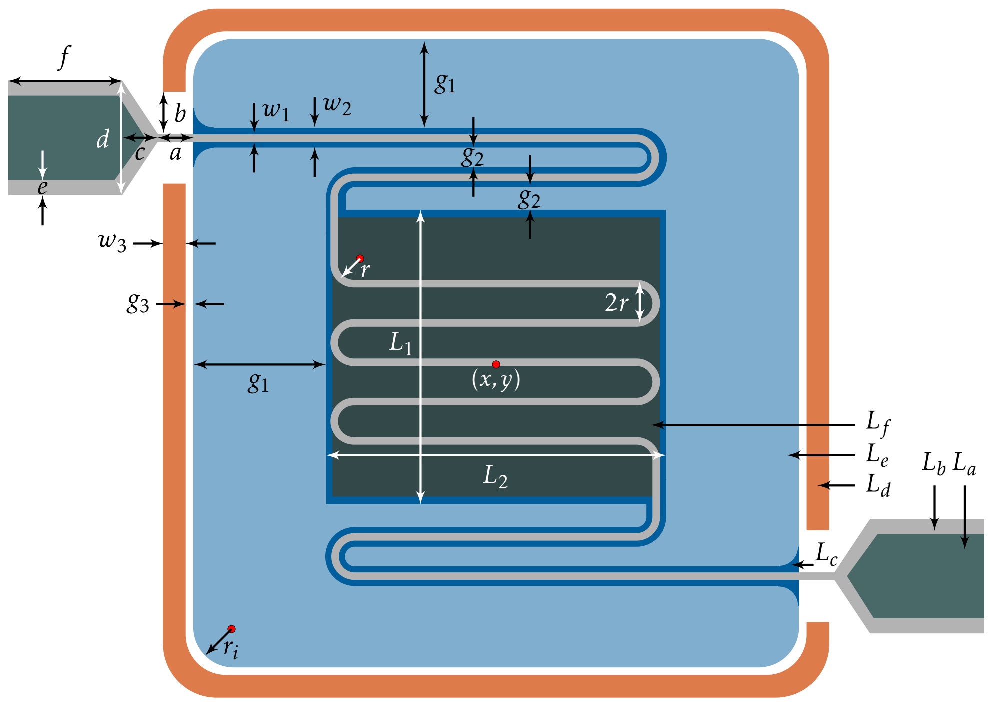


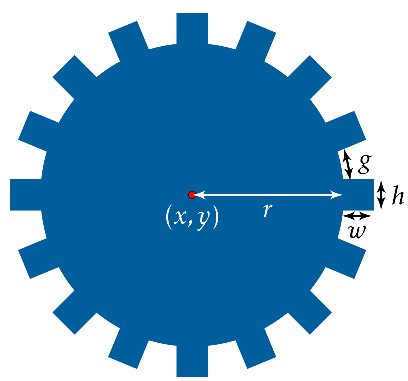
Figure 2.298: *U-shaped bolometer structure.*

2.10.3 Gears

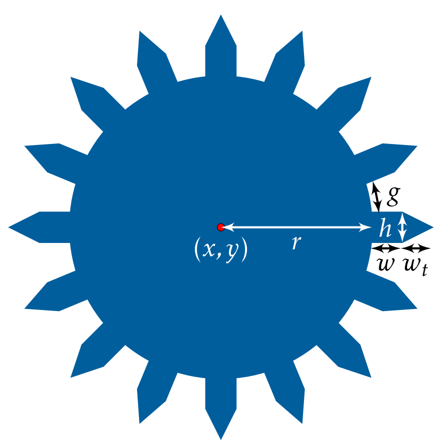
MEMS gear elements defined by the (x, y) position, radius r with N sides, gear width and height, w and h, respectively. Number of gear elements N_G are evenly distributed along the disc circumference.

$x \;\; y \;\; r \;\; w \;\; h \;\; N_G \qquad N \;\; \theta_{(x,y)}$ **gear**

$x \;\; y \;\; r \;\; w \;\; h \;\; N_G \;\; w_t \;\; N \;\; \theta_{(x,y)}$ **gearT**



(a)



(b)

Figure 2.299: *MEMS gear elements created using (a)* **gear** *and (b)* **gearT** *constructors.*

2.10.3.1 Hub With Straight and Circular Springs

$x \quad y \quad w \quad r_i \quad w_r \quad R \quad N_{sides} \quad N_{beams} \quad a \quad L_a \quad \theta_{(x,y)}$ **straightSpring**

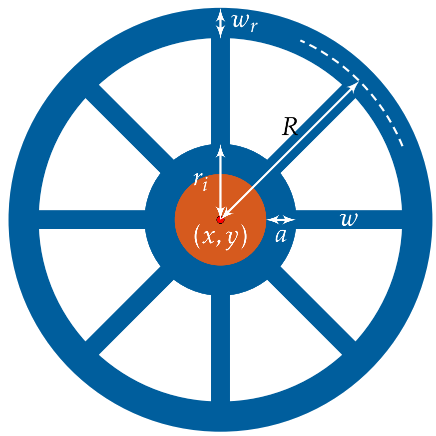


Figure 2.300: *Concentric hub with straight springs.*

$x \quad y \quad w \quad r_i \quad w_r \quad R \quad N_{sides} \quad N_{beams} \quad a \quad L_a \quad \theta_{(x,y)}$ **circularSpring**

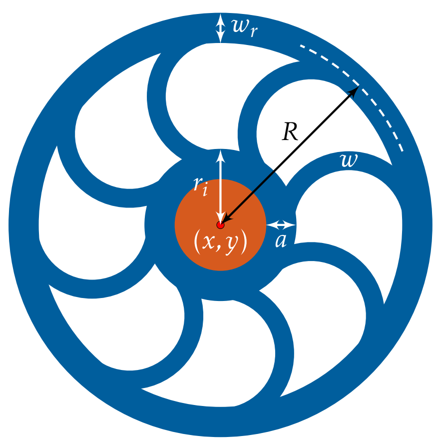


Figure 2.301: *Concentric hub with circular springs.*

In figure 2.302, size of the surrounding electrodes depends on the number of electrodes (N_e) and the dimensionless parameter β, where $0 < \beta < 1$. The gap between the electrodes is defined as βL_{es}, where the electrode length segment is defined as $L_{es} = C/N_e$. $C = 2\pi r^\star$ is the circumference of the innermost electrode, where $r^\star = R + w_r/2 + g$. Therefore, β defines the electrode gap as the fraction of the electrode segment. Number of sides N_s parameter is used to construct all circular objects.

$x \;\; y \;\; w \;\; r_i \;\; w_r \;\; R \;\; N_{sides} \;\; N_{beams} \;\; g \;\; W_e \;\; N_e \;\; \beta \;\; e_a \;\; a \;\; L_a \;\; \theta_{(x,y)}$ **straightSpringE**

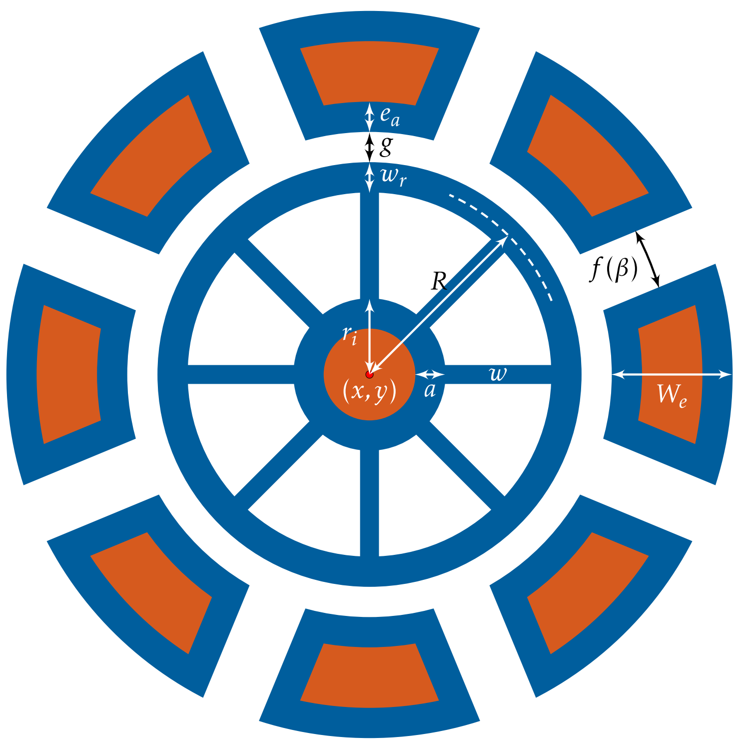


Figure 2.302: *Concentric hub with straight springs and surrounding electrodes.*

$x \;\; y \;\; w \;\; r_i \;\; w_r \;\; R \;\; N_{sides} \;\; N_{beams} \;\; g \;\; W_e \;\; N_e \;\; \beta \;\; e_a \;\; a \;\; L_a \;\; \theta_{(x,y)}$ **circularSpringE**

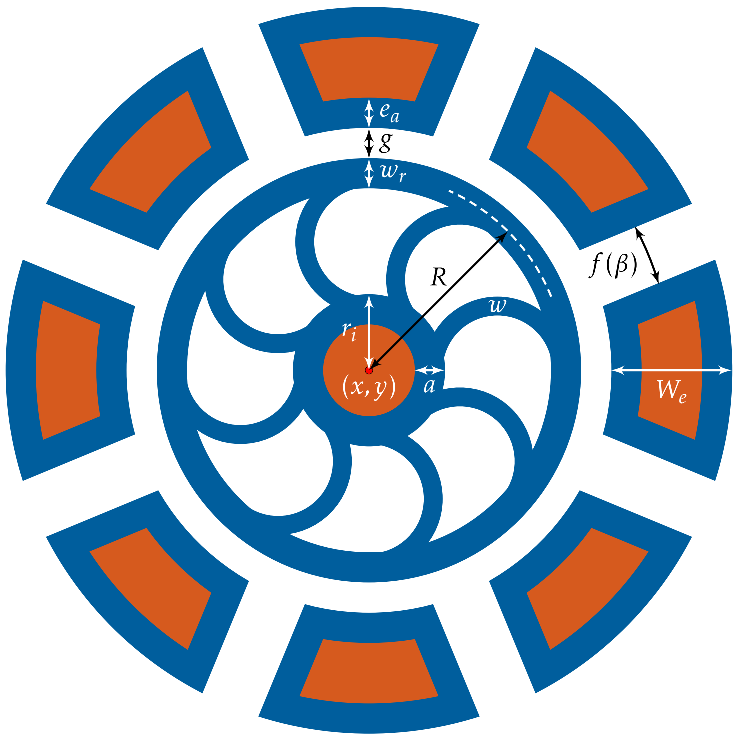


Figure 2.303: *Concentric hub with circular springs and surrounding electrodes.*

2.10.3.2 Radial Comb Drive

Below constructors create radial comb-drives defined by an opening angle (θ), overlap angle ($\theta_\circ$), electrode widths (w_1, w_2), comb width (w_c) and gap (g), number of combs (N_{combs}), number of sides for each comb arc segment (N_{sides}), anchor overlap (a) and anchor GDS layer (L_a).

x y w_1 r_1 w_2 r_2 w_c g N_{combs} N_{sides} θ $\theta_\circ$ a L_a $\theta_{(x,y)}$ **combRadialV1**

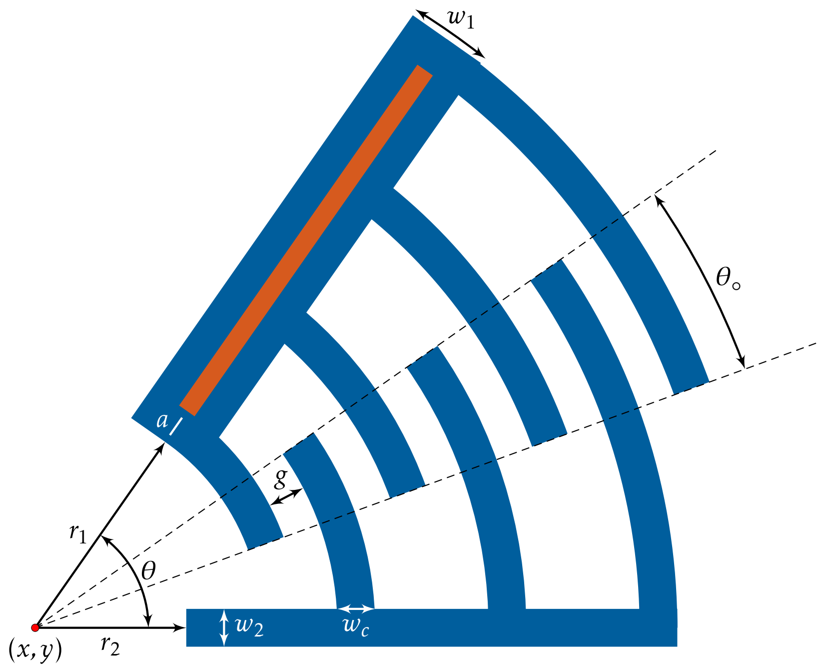


Figure 2.304: *Radial comb drive V1.*

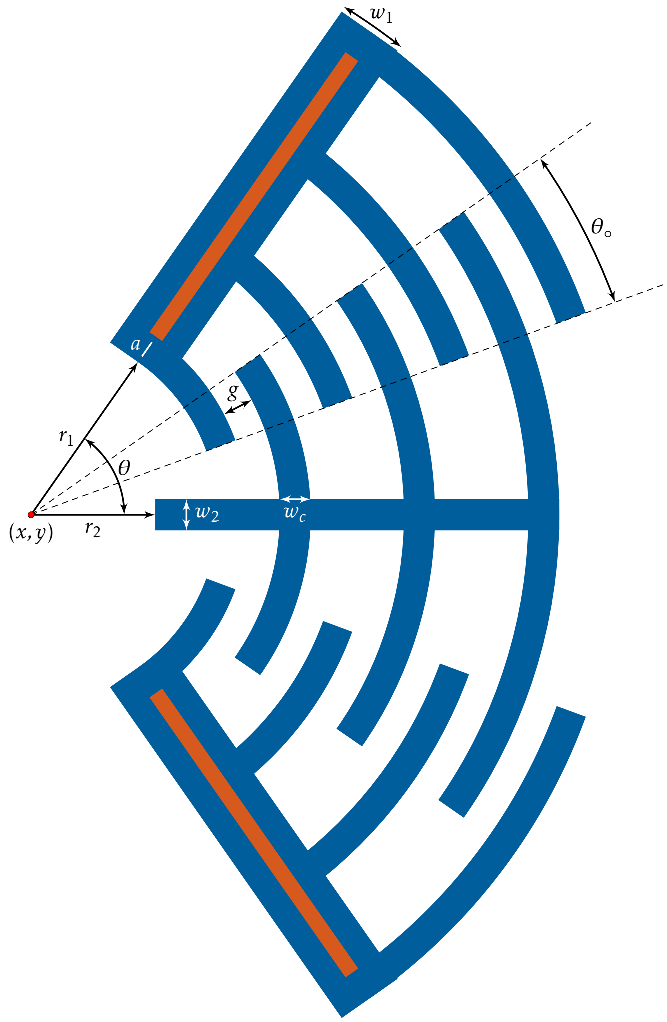


Figure 2.305: *Radial comb drive V2.*

2.10.4 Anchored Flexures

The following constructors create accelerometer type anchored flexures with a proof mass. In all of the cases, the rectangular base support anchor is defined by the anchor support width a and GDS layer L_a. Structural layer is defined by the active **layer**.

Anchored Flexure V2A

$x \quad y \quad w \quad l_1 \quad l_2 \quad w_m \quad l_m \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **flexure2A**

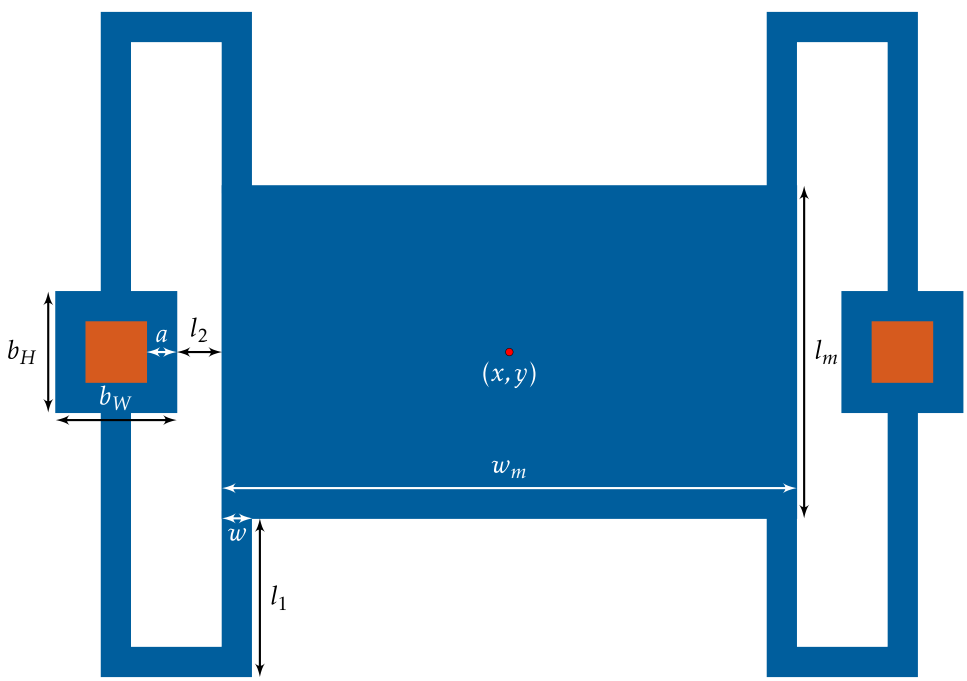


Figure 2.306: *Anchored Flexure V2A with two hinges supporting a proof mass.*

$x \quad y \quad w \quad l_1 \quad l_2 \quad w_m \quad l_m \quad c_H \quad c_W \quad s_H \quad s_W \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **flexure2B**

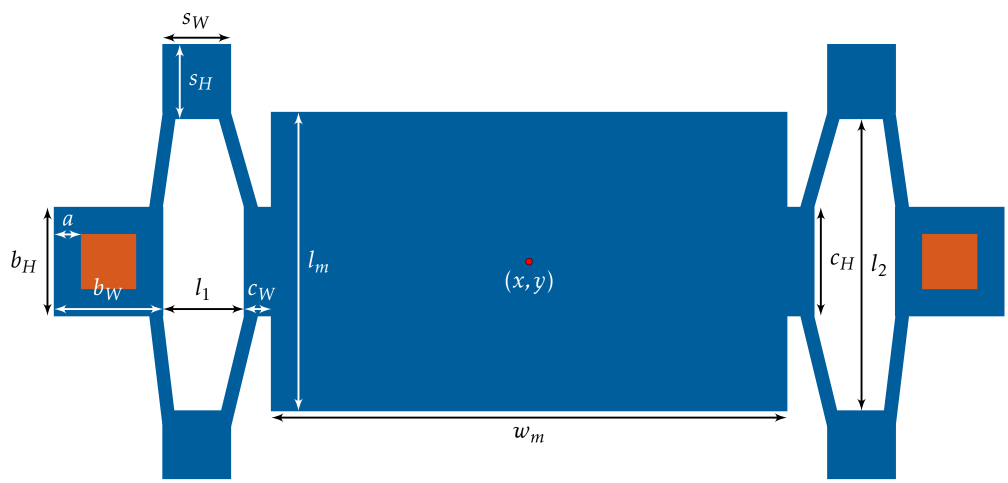


Figure 2.307: *Anchored Flexure V2B with two hinges supporting a proof mass.*

Anchored Flexure V2C

x y w l_1 l_2 l_3 w_m l_m A N_p b_H b_W a L_a $\theta_{(x,y)}$ **flexure2C**

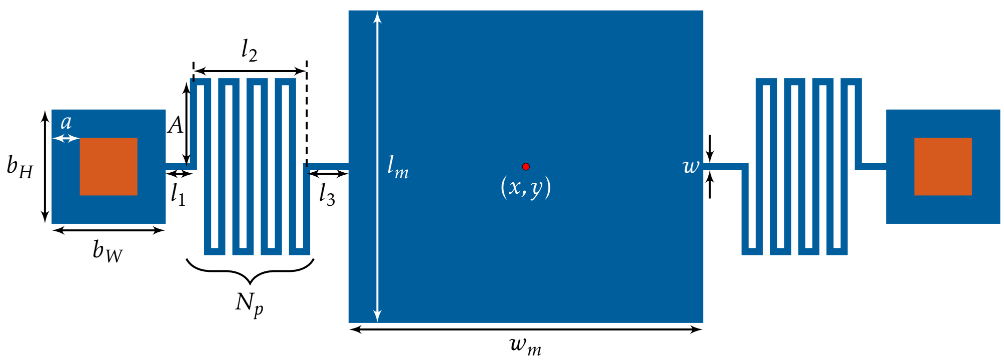


Figure 2.308: *Anchored Flexure V2C with a meander supporting a proof mass.*

x y w_1 w_2 w_3 w_4 l_1 l_2 l_3 l_4 l_5 l_6 b_W a L_a $\theta_{(x,y)}$ **flexure2D**

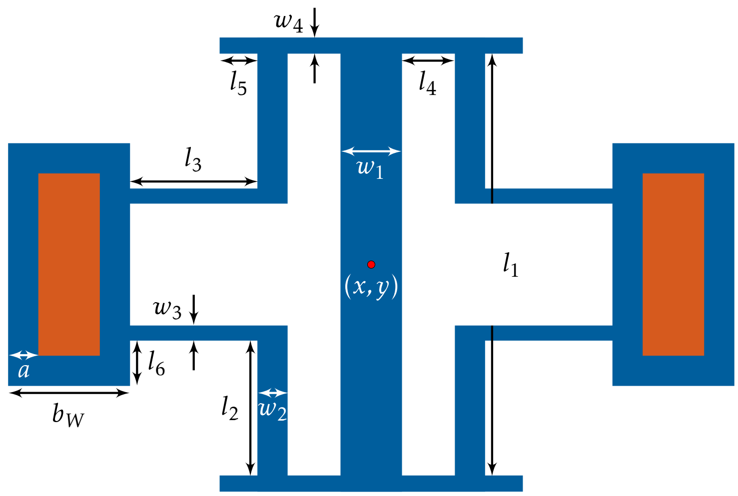


Figure 2.309: *Anchored Flexure V2D.*

Anchored Flexure V2E

x y w_1 w_2 w_3 w_4 w_5 l_1 l_2 l_3 l_4 g b b_H b_W a L_a $\theta_{(x,y)}$ **flexure2E**

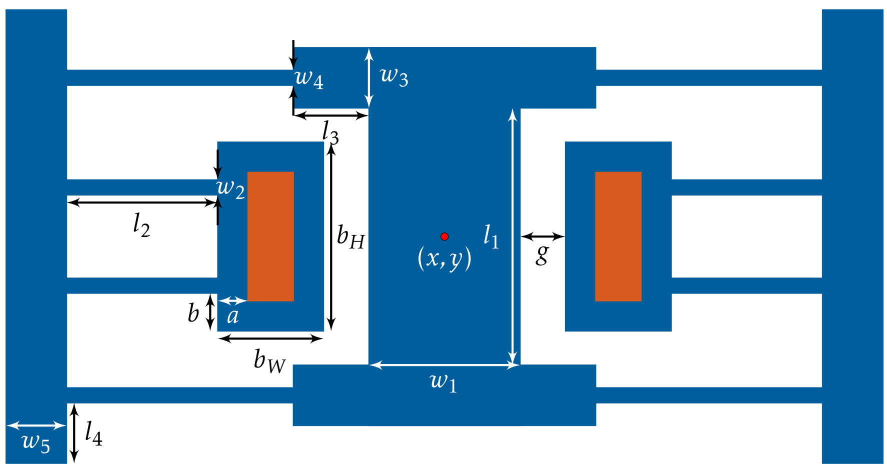


Figure 2.310: *Anchored Flexure V2E.*

Anchored Flexure V4A

$x \quad y \quad w \quad l_1 \quad l_2 \quad w_m \quad l_m \quad b_H \quad b_e \quad a \quad L_a \quad \theta_{(x,y)}$ **flexure4A**

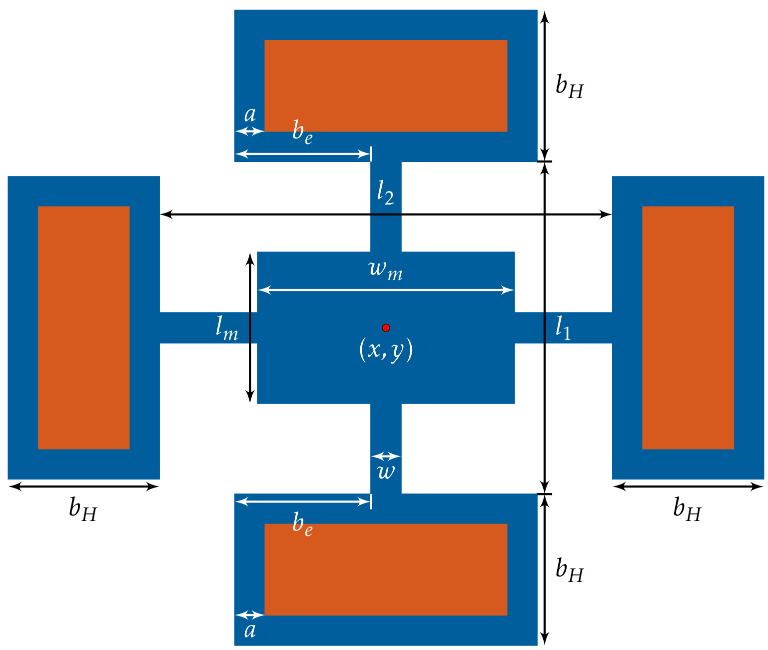


Figure 2.311: *Anchored Flexure V4A with four hinges supporting a proof mass.*

Anchored Flexure V4B

$x \quad y \quad w \quad l_1 \quad l_2 \quad w_m \quad g \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **flexure4B**

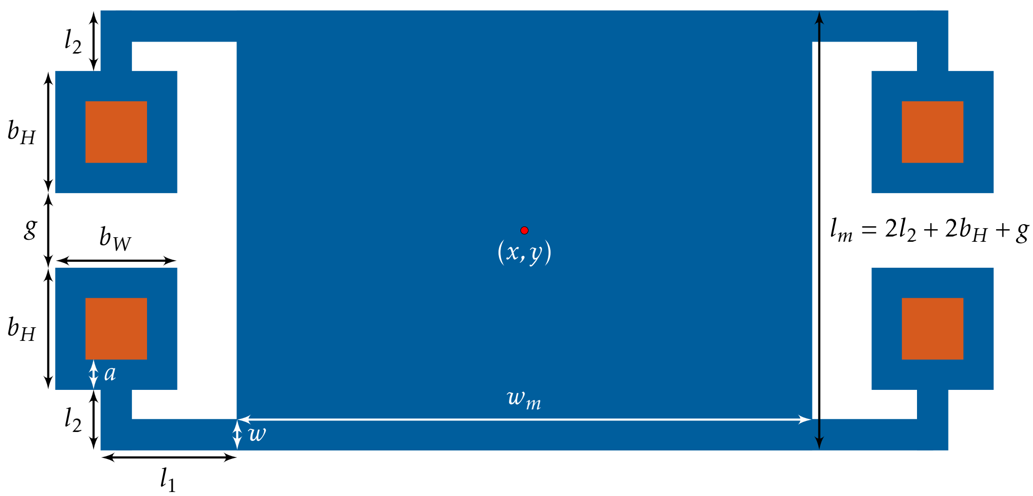


Figure 2.312: *Anchored Flexure V4B with four hinges supporting a proof mass.*

Anchored Flexure V4C

$x \quad y \quad w \quad l_1 \quad l_2 \quad l_3 \quad l_4 \quad w_m \quad g \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **flexure4C**

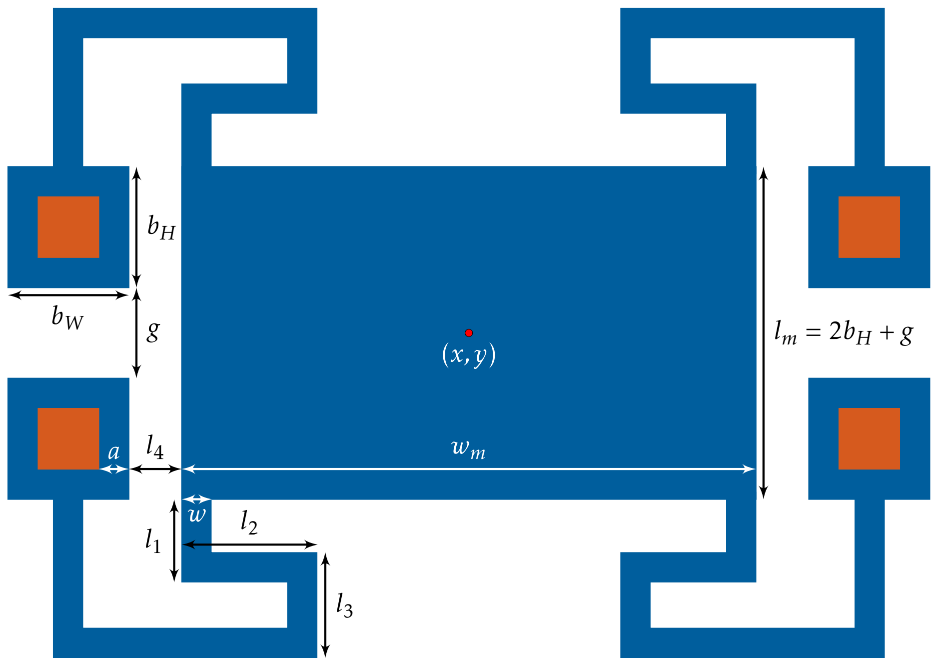


Figure 2.313: *Anchored Flexure V4C with four hinges supporting a proof mass.*

Anchored Flexure V4D

$x \quad y \quad w_1 \quad w_2 \quad l_1 \quad l_2 \quad w_m \quad l_m \quad g \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **flexure4D**

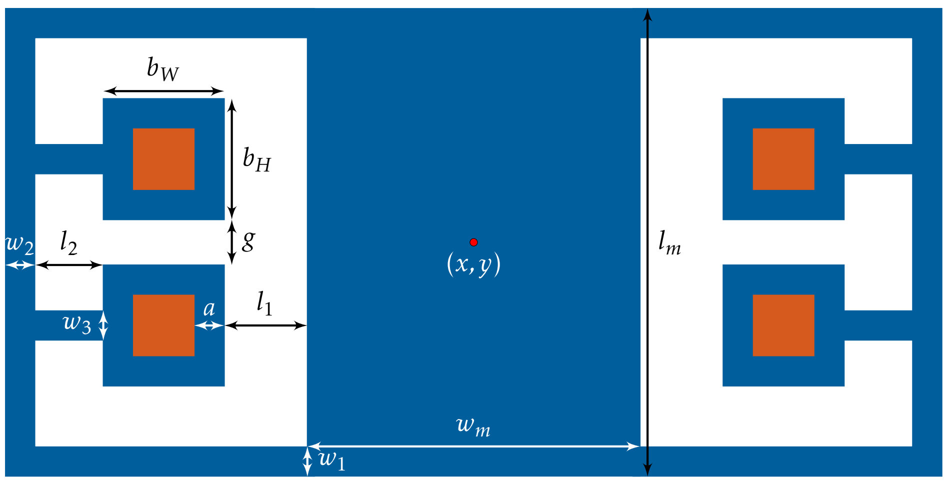


Figure 2.314: *Anchored Flexure V4D with four hinges supporting a proof mass.*

Anchored Flexure V4E

$x \quad y \quad w_1 \quad w_2 \quad w_3 \quad w_4 \quad l_1 \quad l_2 \quad l_3 \quad l_4 \quad l_5 \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **flexure4E**

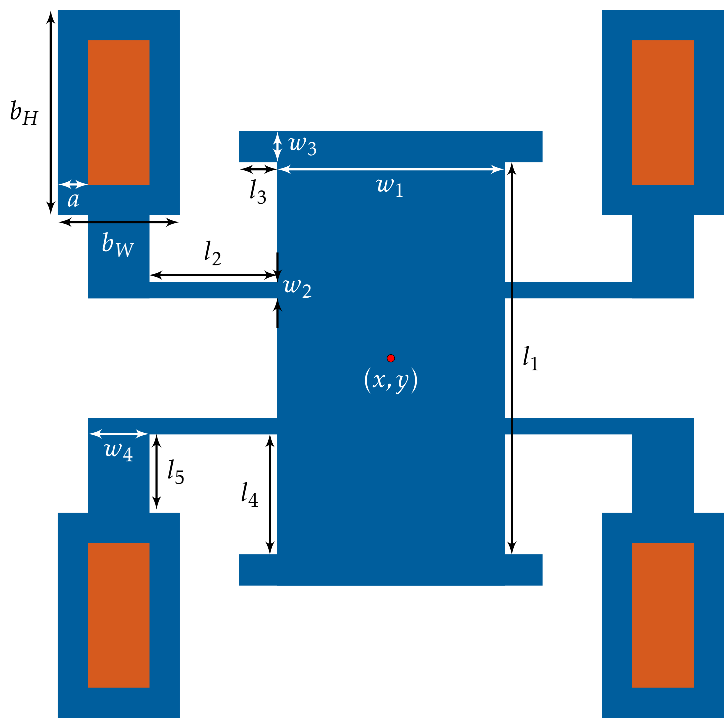


Figure 2.315: *Anchored Flexure V4E.*

2.10.5 Cantilevers

The following cantilever beam structures have a linear, percentage or sinusoidal length variation with respect to the starting length (s_L). The beams are periodically arranged on a base of height b_H and of width that is a function of the number of elements (n), beam width (w), pitch (p) and base extent (b_e).

x	y	w	s_L	p	n	b_H	b_e	ΔL	$\theta_{(x,y)}$	**cantileverL**
x	y	w	s_L	p	n	b_H	b_e	Percent	$\theta_{(x,y)}$	**cantileverP**
x	y	w	s_L	p	n	b_H	b_e	Amplitude	$\theta_{(x,y)}$	**cantileverSine**

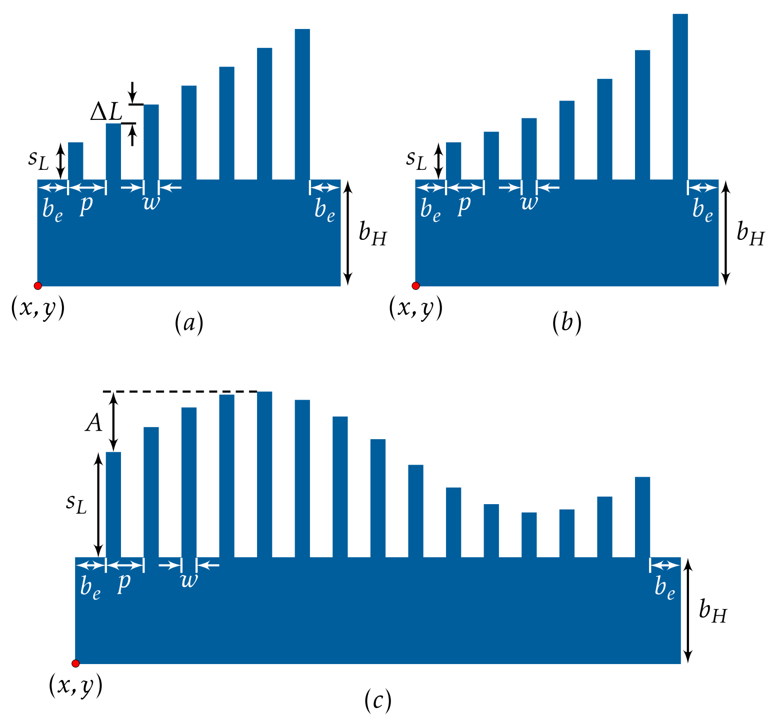


Figure 2.316: *Cantilever arrays of varying length. (a) Linear (**cantileverL**) variation from s_L with ΔL increments (b) Percentage (**cantileverP**) variation starting from s_L and (c) sinusoidal (**cantileverSine**) variation over one period with amplitude A.*

Similar to figure 2.316, the cantilever variation for the below constructors is bound between the starting length (s_L) and the end length (e_L). Here, the origin (x, y) is positioned at the lower left corner of the base, w, s_L, e_L and p are the cantilever width, start length, end lengths, and pitch, respectively. n is the number of cantilever beams, b_e and b_H are the base extent and height. $\theta_{(x,y)}$ is the rotation about the origin (x, y).

$x \quad y \quad w \quad s_L \quad e_L \quad p \quad n \quad b_H \quad b_e \quad \theta_{(x,y)}$ **cantileverLSE**

$x \quad y \quad w \quad s_L \quad e_L \quad p \quad n \quad b_H \quad b_e \quad \theta_{(x,y)}$ **cantileverNLSE**

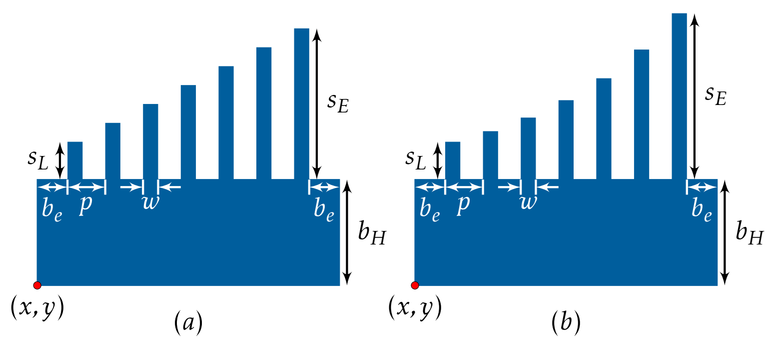


Figure 2.317: *Cantilever arrays of varying length. (a) Linear (**cantileverLSE**) and (b) nonlinear (**cantileverNLSE**) length variation from s_L to e_L.*

The following constructor creates cantilevers with custom parameters. Structural origin is defined by the lower left corner at (x, y). Cantilever length and widths are defined by the w_i and l_i values. Space between the adjacent cantilevers is defined by $s_1, s_2, \ldots, s_n$. The base rectangle extends beyond the n^{th} cantilever's right edge by the amount s_{end}.

$x \;\; y \;\; s_1 \;\; w_1 \;\; l_1 \;\; s_2 \;\; w_2 \;\; l_2 \;\; \ldots \;\; s_n \;\; w_n \;\; l_n \;\; s_{end} \;\; b_H \;\; \theta_{(x,y)}$ **cantileverCustom**

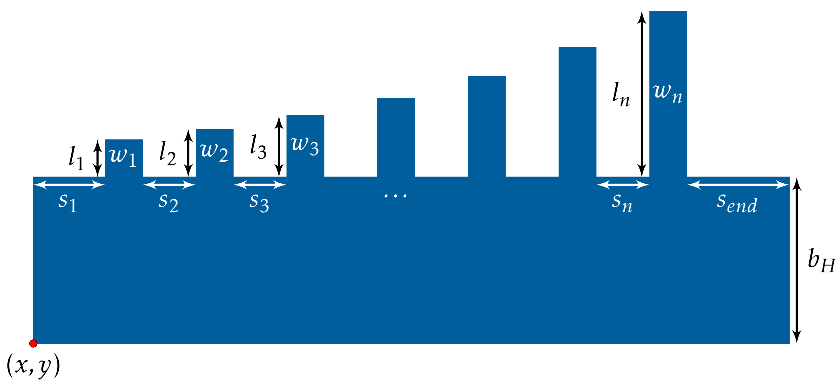


Figure 2.318: *Cantilever array constructed with custom, user defined beam dimensions.*

Below constructors create rectangular (with and without a triangular tip), trapezoidal and paddle cantilever structures. The rectangular base support anchor is defined by the anchor support width a and GDS layer L_a. Structural layer is defined by the active **layer**.

x	y	w	l			b_H	b_e	a	L_a	$\theta_{(x,y)}$	**cantileverSR**
x	y	w	l	t_H		b_H	b_e	a	L_a	$\theta_{(x,y)}$	**cantileverSTri**
x	y	w_a	w_b	l		b_H	b_e	a	L_a	$\theta_{(x,y)}$	**cantileverSTrap**
x	y	w_a	w_b	l_a	l_b	b_H	b_e	a	L_a	$\theta_{(x,y)}$	**cantileverSPaddle**

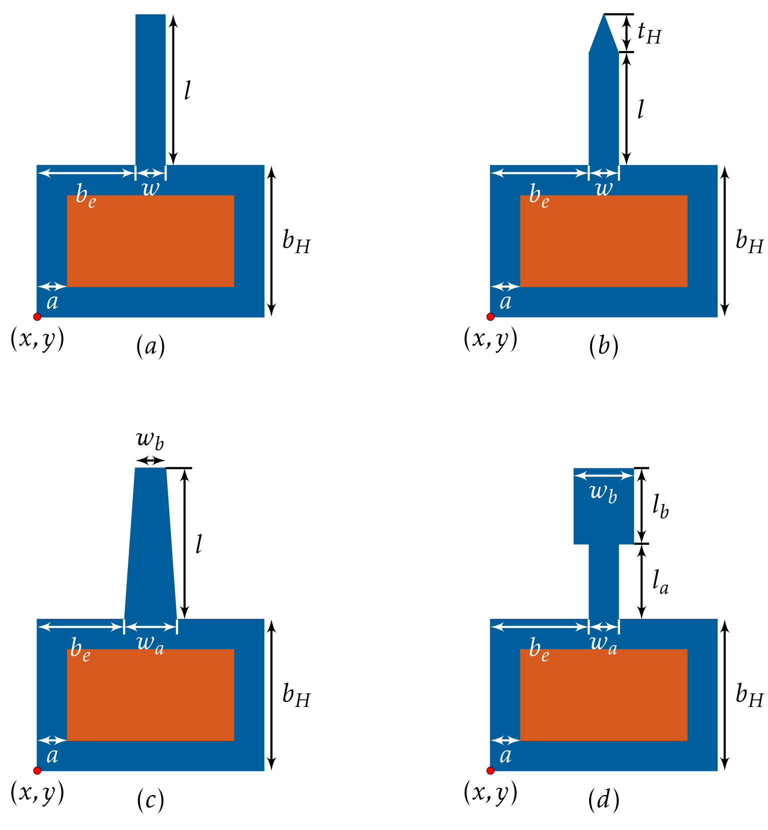


Figure 2.319: *(a) Rectangular, (b) rectangular with a triangular tip, (c) trapezoidal and (d) paddle cantilever structures stemming from a rectangularly anchored base.*

Curved and straight-circular beams where the curved segment is defined by the number of vertices N_{sides} and radius R.

x	y	w	R	N_{sides}		b_H	b_e	a	L_a	$\theta_{(x,y)}$	cantileverSCH
x	y	w	R	N_{sides}	l	b_H	b_e	a	L_a	$\theta_{(x,y)}$	cantileverSCF

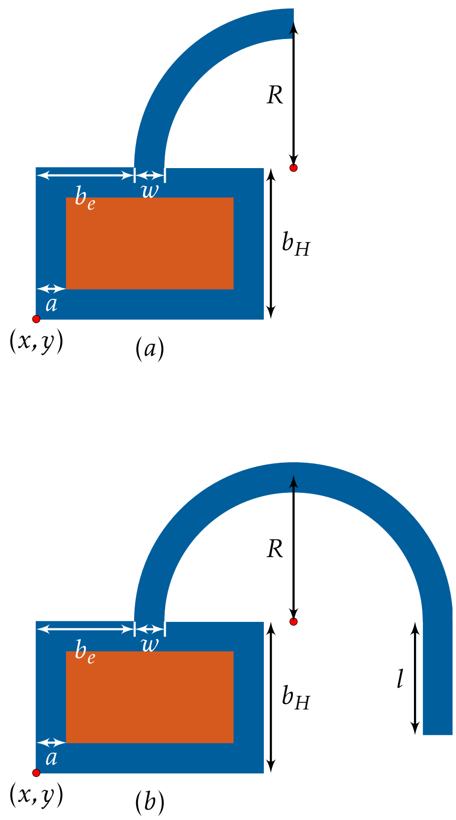


Figure 2.320: *(a) Curved and (b) straight-circular beams stemming from a rectangularly anchored base.*

Below constructors create rectangular (with and without a triangular tip), trapezoidal and paddle cantilever structures. Constraints on parameter h are $h < w/2$ and $h < w_a/2$.

x	y	w	l			h	b_H	b_e	a	L_a	$\theta_{(x,y)}$	cantileverHR
x	y	w	l	t_H		h	b_H	b_e	a	L_a	$\theta_{(x,y)}$	cantileverHTri
x	y	w_a	w_b	l		h	b_H	b_e	a	L_a	$\theta_{(x,y)}$	cantileverHTrap
x	y	w_a	w_b	l_a	l_b	h	b_H	b_e	a	L_a	$\theta_{(x,y)}$	cantileverHPaddle

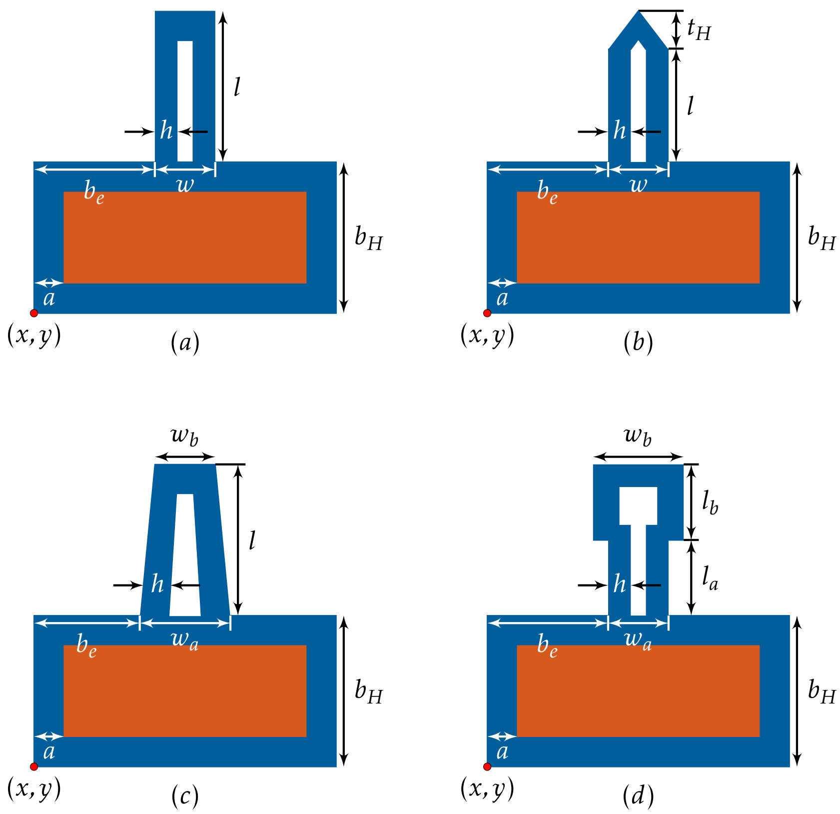


Figure 2.321: *Hollow (a) rectangular, (b) rectangular with a triangular tip, (c) trapezoidal and (d) paddle cantilever structures stemming from a rectangularly anchored base.*

The following two constructors create hollow curved and straight-circular beams. In both cases $h < w/2$

$x \quad y \quad w \quad R \quad N_{sides} \quad h \quad b_H \quad b_e \quad a \quad L_a \quad \theta_{(x,y)}$ **cantileverHCH**

$x \quad y \quad w \quad R \quad N_{sides} \quad l \quad h \quad b_H \quad b_e \quad a \quad L_a \quad \theta_{(x,y)}$ **cantileverHCF**

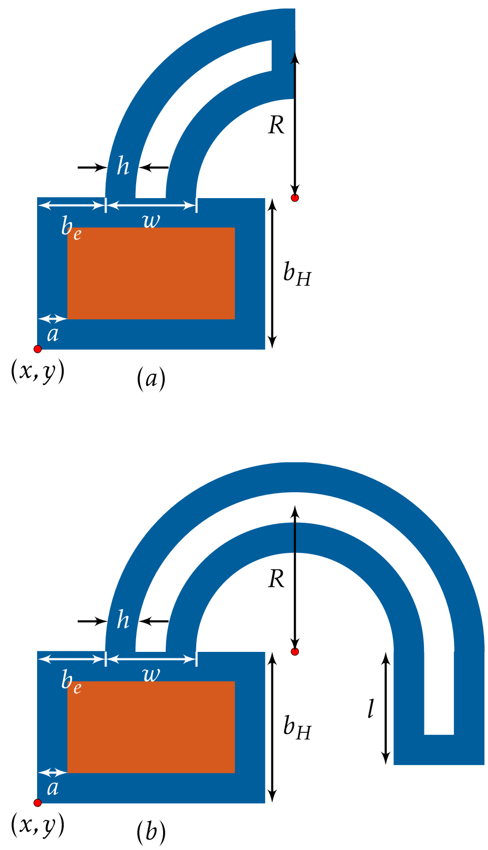


Figure 2.322: *Hollow (a) curved and (b) straight-circular beams stemming from a rectangularly anchored base.*

Below constructors create connected parallel beams. The gap (g) between the electrodes has the following constraint:

$$g \leq \frac{l_B}{2} - 2w \qquad \text{2 parallel beams}$$

$$g \leq l_B - 2w \qquad \text{3 parallel beams}$$

x y w l_1 l_2 l_B g b_H b_e a L_a $\theta_{(x,y)}$ **cantileverPB2**

x y w l_1 l_2 l_3 l_B g b_H b_e a L_a $\theta_{(x,y)}$ **cantileverPB3**

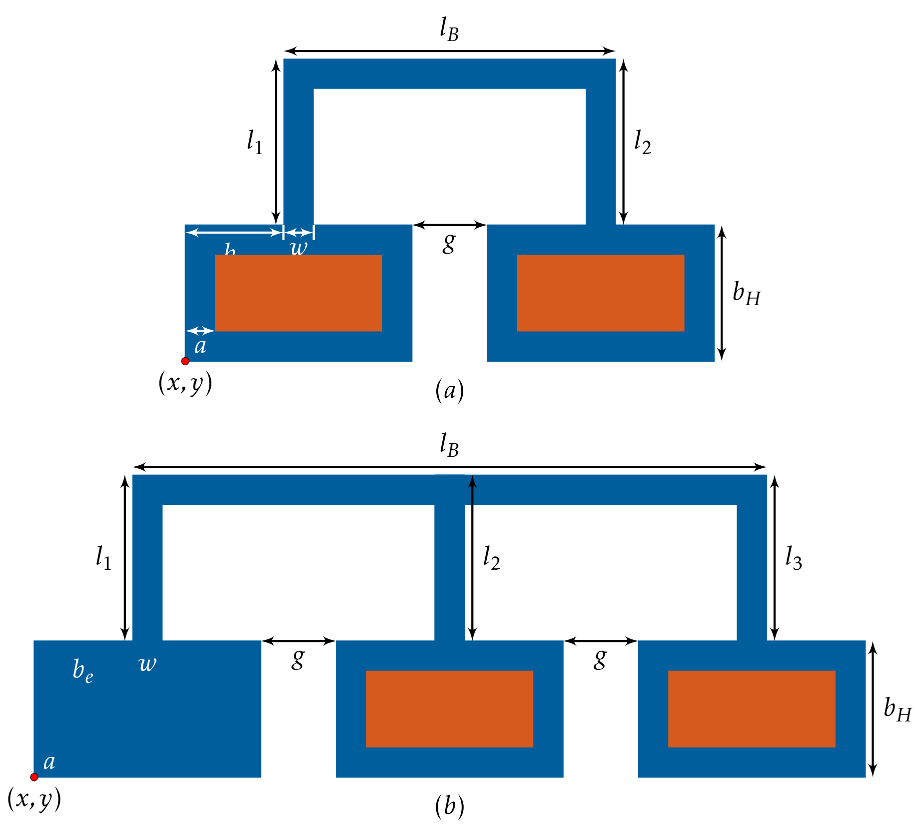


Figure 2.323: *(a) Two and (b) three parallel, interacting beams.*

U-Shaped spring designs with sharp rectangular, circularly filleted and circular links. Parameters a and L_a are anchor overlap and anchor GDS layer respectively.

x	y	w	l_1	l_2	l_B			b_H	b_e	a	L_a	$\theta_{(x,y)}$	cantileverUR
x	y	w	l_1	l_2	l_B	r	N_{sides}	b_H	b_e	a	L_a	$\theta_{(x,y)}$	cantileverUCF
x	y	w	l_1	l_2	D	N_{sides}		b_H	b_e	a	L_a	$\theta_{(x,y)}$	cantileverUC

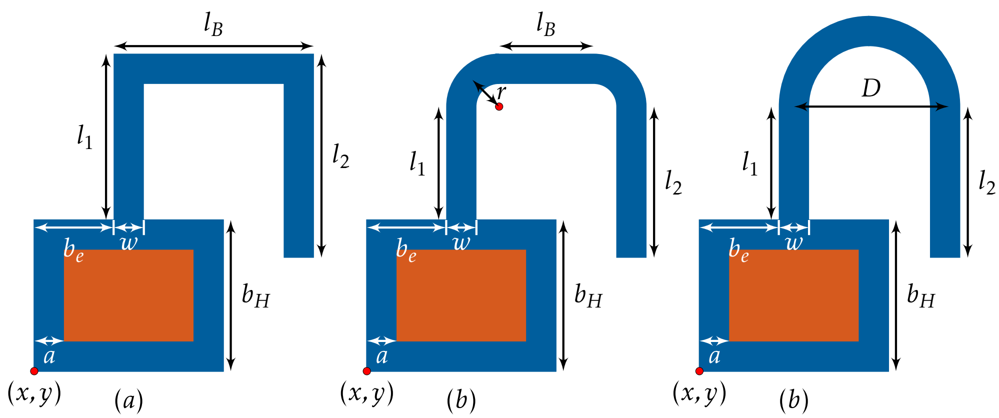


Figure 2.324: *U-shaped (a) rectangular, (b) circularly filleted corners and (c) circular cantilever structures.*

U-shaped structures with a central cantilever and a central paddle. Parameters a and L_a are anchor overlap and anchor GDS layer, respectively. Central cantilever length l_2 can be either positive of negative, respectively yielding a cantilever of width w_2 below or above the top link.

x	y	w_1	w_2	l_1	l_2		l_3	l_B	b_H	b_e	a	L_a	$\theta_{(x,y)}$	**cantileverUCC**
x	y	w_1	w_2	l_1	l_{2a}	l_{2b}	l_3	l_B	b_H	b_e	a	L_a	$\theta_{(x,y)}$	**cantileverUCP**

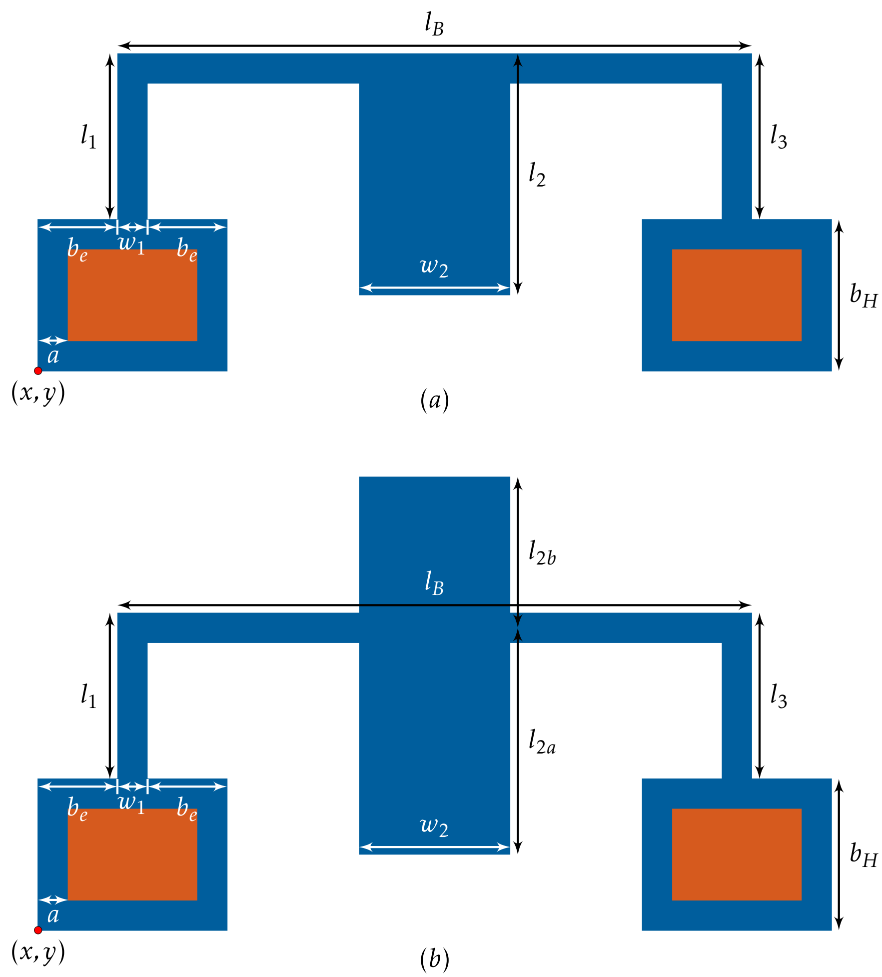


Figure 2.325: *U-shaped structure with a center (a) cantilever and (b) paddle.*

Below constructors create curved cantilever structures. The rectangular base support anchor is defined by the anchor support width a and GDS layer L_a. Structural layer is defined by the active layer. Curved segments of the upper and lower paddle oscillators are defined by ellipses with radii (r_{x_1}, r_{y_1}) and (r_{x_2}, r_{y_2}), respectively.

$x \;\; y \;\; w \;\; l \;\; r_x \;\; r_y \;\; N_{sides} \;\; b_H \;\; b_e \;\; a \;\; L_a \;\; \theta_{(x,y)}$ **cantileverCE**

$x \;\; y \;\; w \;\; l \;\; r_{x_1} \;\; r_{y_1} \;\; r_{x_2} \;\; r_{y_2} \;\; N_{sides} \;\; w_p \;\; l_p \;\; b_H \;\; b_e \;\; a \;\; L_a \;\; \theta_{(x,y)}$ **cantileverCEPaddle**

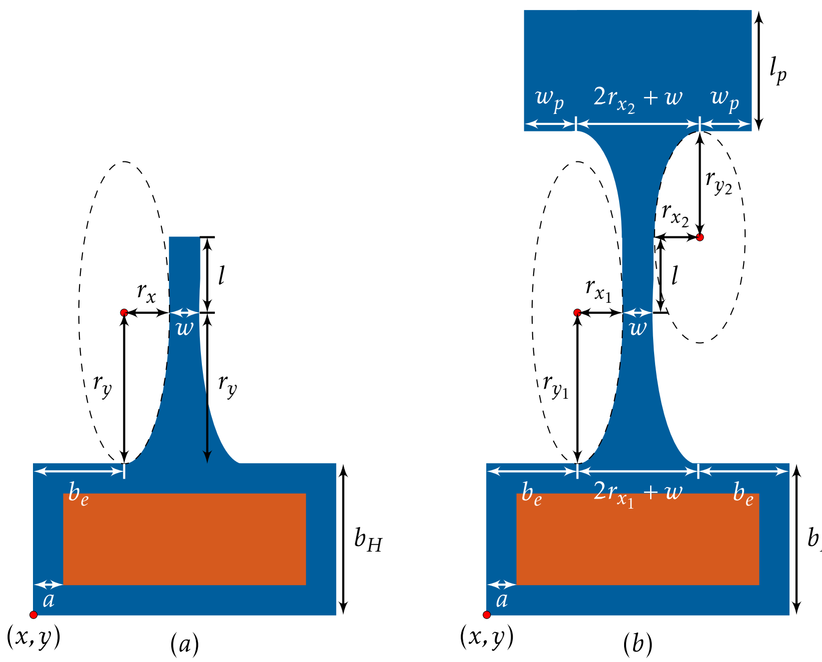


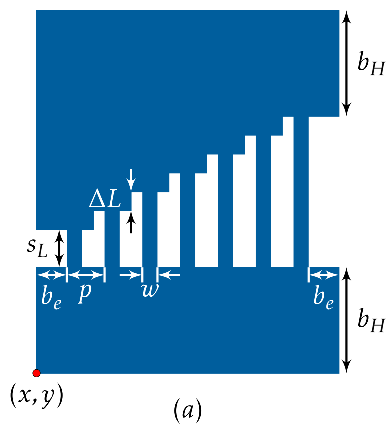
Figure 2.326: *(a) Curved cantilever and (b) curved cantilever with a paddle.*

2.10.6 Doubly Clamped Beams

Similar to the cantilever structures in figures 2.316a and 2.316b, these are doubly clamped beams with a linear and percentage variation with respect to the starting length (s_L).

$x \quad y \quad w \quad s_L \quad p \quad n \quad b_H \quad b_e \quad \Delta L \qquad \theta_{(x,y)}$ **dcBeamL**

$x \quad y \quad w \quad s_L \quad p \quad n \quad b_H \quad b_e$ Percent $\theta_{(x,y)}$ **dcBeamP**



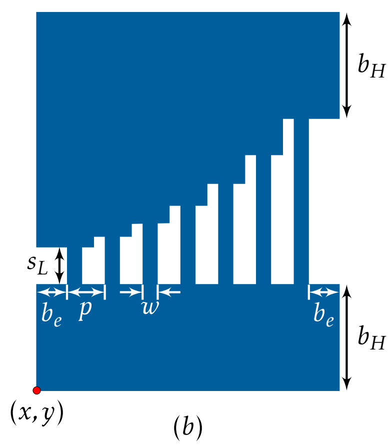


Figure 2.327: *Doubly clamped beam arrays of varying length. (a) Linear (**dcBeamL**) variation from s_L with ΔL increments and (b) Percentage (**dcBeamP**) length variation starting from s_L.*

Similar to the cantilever arrays in figure 2.317, these are doubly clamped beams with length variation bound between the starting (s_L) and the end length (e_L) values.

$x \quad y \quad w \quad s_L \quad e_L \quad p \quad n \quad b_H \quad b_e \quad \theta_{(x,y)}$ **dcBeamLSE**

$x \quad y \quad w \quad s_L \quad e_L \quad p \quad n \quad b_H \quad b_e \quad \theta_{(x,y)}$ **dcBeamNLSE**

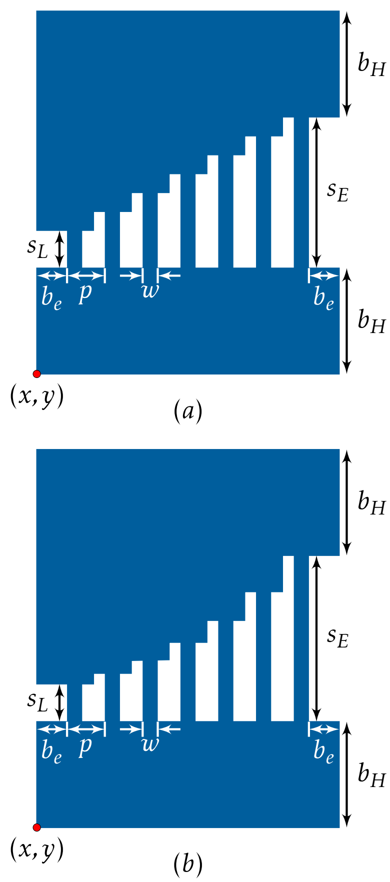


Figure 2.328: *Doubly clamped beam arrays of length varying between s_L and s_E. (a) Linear (**dcBeamLSE**) and (b) nonlinear (**dcBeamNLSE**) length variation from s_L to e_L.*

The following constructor creates doubly clamped beams with used defined parameters. The structure is similar to custom cantilevers in Figure 2.318.

$x \;\; y \;\; s_1 \;\; w_1 \;\; l_1 \;\; s_2 \;\; w_2 \;\; l_2 \;\; \ldots \;\; s_n \;\; w_n \;\; l_n \;\; s_{end} \;\; b_H \;\; \theta_{(x,y)}$ **dcBeamCustom**

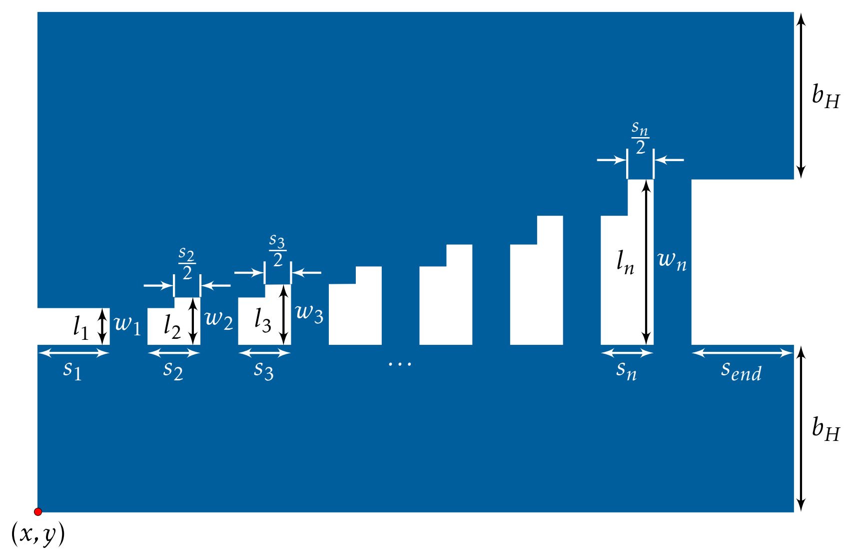


Figure 2.329: *Doubly clamped array of beams constructed with custom, user defined dimensions.*

Below constructors create rectangular and torsional doubly clamped beam structures. The rectangular base support anchor is defined by the anchor support width a and GDS layer L_a. Structural layer is defined by the active **layer**.

$x \;\; y \;\; w \;\; l \;\; b_H \;\; b_e \;\; a \;\; L_a \;\; \theta_{(x,y)}$ **dcBeamR**

$x \;\; y \;\; w_1 \;\; l_1 \;\; w_2 \;\; l_2 \;\; b_H \;\; b_e \;\; a \;\; L_a \;\; \theta_{(x,y)}$ **dcBeamT**

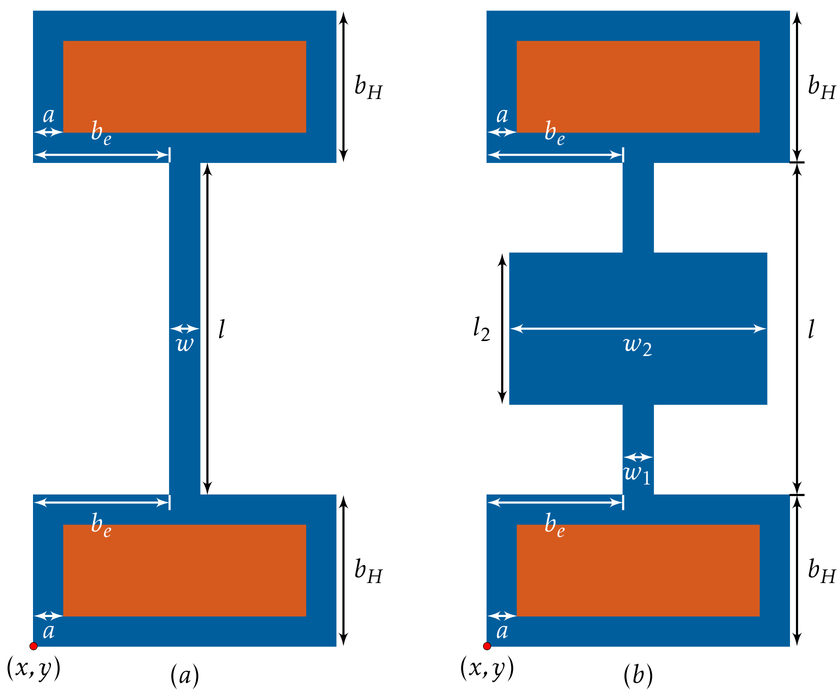


Figure 2.330: *(a) Rectangular and (b) torsional doubly clamped beams.*

Doubly clamped torsional beam.

$x \quad y \quad w_1 \quad w_2 \quad w_3 \quad w_4 \quad l_1 \quad l_2 \quad l_3 \quad g \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **dcBeamT2**

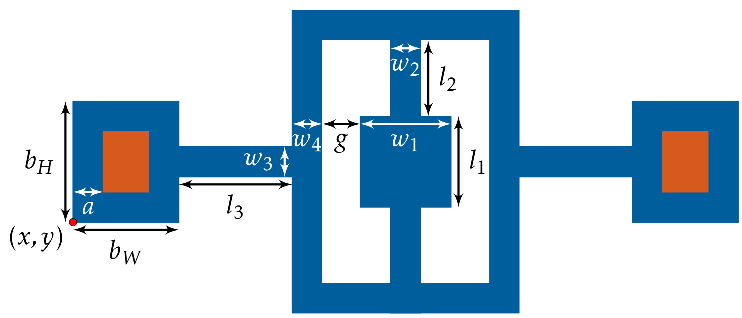


Figure 2.331: *Doubly clamped torsional beam.*

Doubly clamped array of N interacting beams with lengths ranging linearly from L_s to L_e.

$x \quad y \quad w \quad L_s \quad L_e \quad N \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **dcBeamCB**

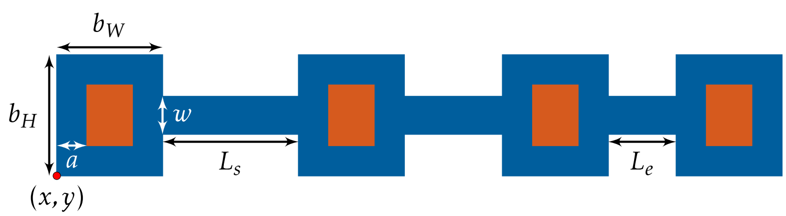


Figure 2.332: *Doubly clamped coupled beams.*

Below constructor creates a curved doubly clamped beam structures. The rectangular base support anchor is defined by the anchor support width a and GDS layer L_a. Structural layer is defined by the active **layer**. Curved segments of the upper and lower beams are defined by ellipses with radii (r_{x_1}, r_{y_1}) and (r_{x_2}, r_{y_2}), respectively.

$x \;\; y \;\; w \;\; l \;\; r_{x_1} \;\; r_{y_1} \;\; r_{x_2} \;\; r_{y_2} \;\; N_{sides} \;\; b_H \;\; b_e \;\; a \;\; L_a \;\; \theta_{(x,y)}$ **dcBeamC**

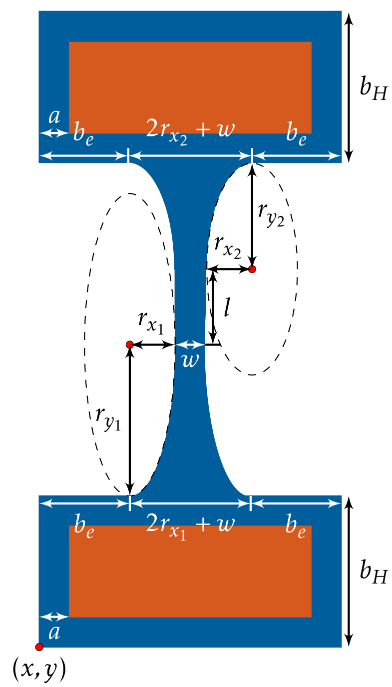


Figure 2.333: *curved doubly clamped beams.*

2.10.7 Interacting Arrays

The following objects each have two constructors. The bracketed constructor (<id parameters ... constructor>) creates hierarchical structures that are instantiated within the current structure. The id parameter is a string prefix all generated structures for the particular object. This parameter is a unique continuous string of characters (no spaces or tabs). To ensure compatibility with the GDSII standard, the allowed structure character names are $A-Z$, $a-z$, $0-9$, underscore (_), question mark (?) and dollar sign ($). Furthermore, the id parameter should be limited to no more than 15 characters, otherwise under certain circumstances, it's possible to overwriting existing structures. Two major benefits of this constructor are that processing is faster and smaller files are generated. Both are a consequence of GDS structural hierarchy.

The second constructor is nearly identical with the exception of not having brackets, the string id parameter and the constructor suffix s. Furthermore, the constructor does not create any additional structures, hence resulting structures entirely are generated within the initialized structure. Consequently, the resulting files are bigger and take longer to generate.

In both cases, structures are generated with the following 3 GDS layers:

Ly_F - front side beam layer
Ly_B - back side release layer
Ly_M - front side circular metal dot layer

<$id\ x\ y\ N\ L_1\ W_1\ L_2\ W_2\ s\ H_\circ\ L_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MARAs>

$x\ y\ N\ L_1\ W_1\ L_2\ W_2\ s\ H_\circ\ L_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MARA

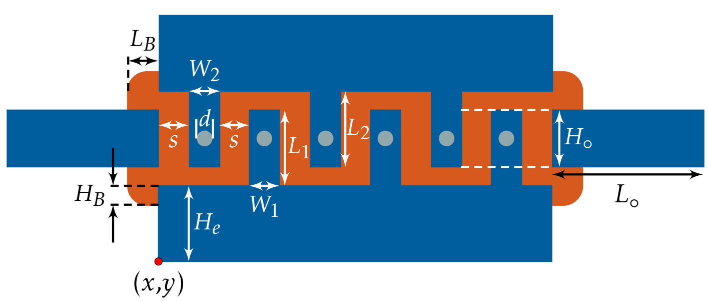


Figure 2.334: *Two rectangular arrays of N interacting beams created using MARAs and MARA constructors.*

Two trapezoidal array of N interacting beams with identical parameters,

<$id\ x\ y\ N\ L\ W_a\ W_b\ s\ H_\circ\ L_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MATALWs>

$x\ y\ N\ L\ W_a\ W_b\ s\ H_\circ\ L_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MATALW

and with varying length (L) and widths (W_a and Wb) between the two arrays.

<$id\ x\ y\ N\ L_1\ W_{1a}\ W_{1b}\ L_2\ W_{2a}\ W_{2b}\ s\ H_\circ\ L_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MATAs>

$x\ y\ N\ L_1\ W_{1a}\ W_{1b}\ L_2\ W_{2a}\ W_{2b}\ s\ H_\circ\ L_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MATA

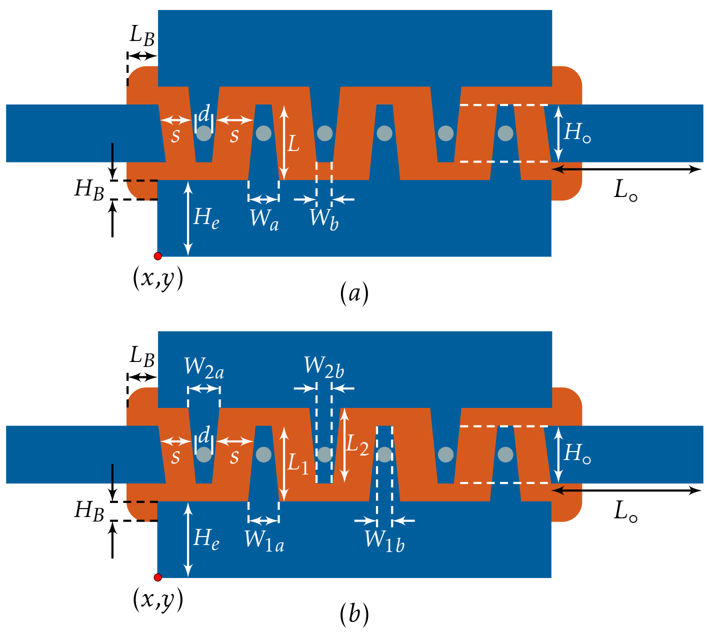


Figure 2.335: *Two interacting trapezoidal beam arrays with (a) identical (MATALWs, MATALW) and (b) varying (MATAs, MATA) length and width parameters.*

Array of two interacting rectangular beams.

<$id\ x\ y\ N\ L_1\ W_1\ L_2\ W_2\ s\ e\ H_{\circ}\ H_e\ L_s\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MAR2s>

$x\ y\ N\ L_1\ W_1\ L_2\ W_2\ s\ e\ H_{\circ}\ H_e\ L_s\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MAR2

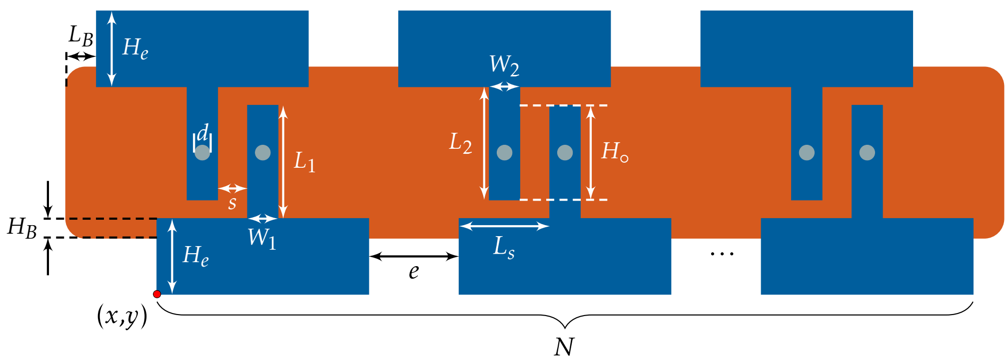


Figure 2.336: *Array of two interacting rectangular beams created using the MAR2s and MAR2, constructors.*

Array of three interacting rectangular beams.

<$id\ x\ y\ N\ L_1\ W_1\ L_2\ W_2\ s\ e\ H_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MAR3s>

$x\ y\ N\ L_1\ W_1\ L_2\ W_2\ s\ e\ H_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MAR3

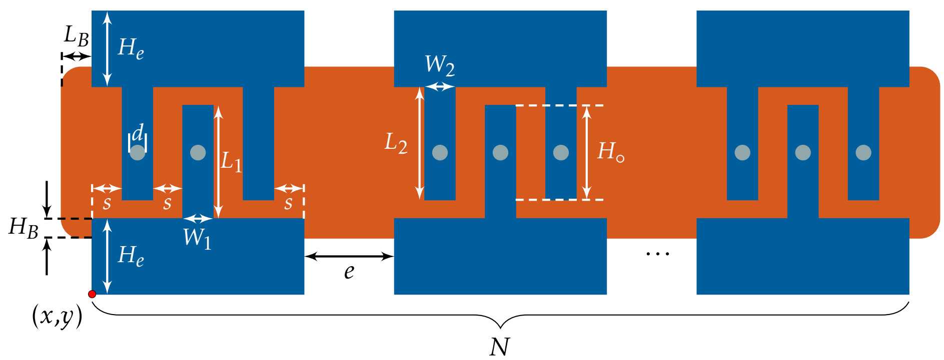


Figure 2.337: *Array of three interacting rectangular beams created using the MAR3s and MAR3 constructors.*

Rectangular top array of elements interacting with single beams. The lower single beam elements are individually addressable via electrodes of width $H_w = W_1 + 2W_2 + 4s$ and height H_e.

<$id\ x\ y\ N\ L_1\ W_1\ L_2\ W_2\ s\ e\ H_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MARCs>

$x\ y\ N\ L_1\ W_1\ L_2\ W_2\ s\ e\ H_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MARC

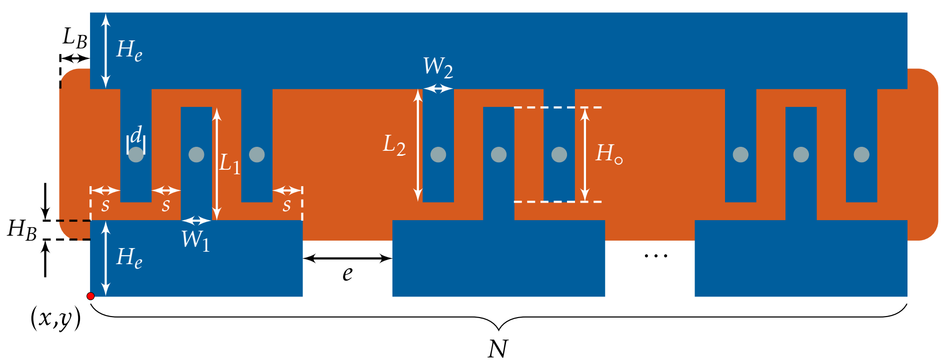


Figure 2.338: *Array of $2N$ rectangular beams interacting with N single beams created using the MARCs and MARCconstructors.*

Array of two interacting trapezoidal beams.

<$id\ x\ y\ N\ L_1\ W_{1a}\ W_{1b}\ L_2\ W_{2a}\ W_{2b}\ s\ e\ H_\circ\ H_e\ L_s\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MAT2s>

$x\ y\ N\ L_1\ W_{1a}\ W_{1b}\ L_2\ W_{2a}\ W_{2b}\ s\ e\ H_\circ\ H_e\ L_s\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MAT2

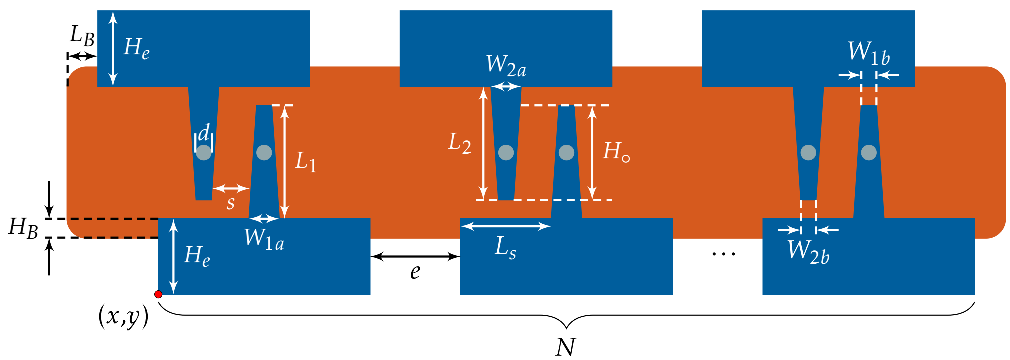


Figure 2.339: *Array of two interacting trapezoidal beams created using the MAT2s and MAT2 constructors.*

Array of three interacting trapezoidal beams.

<$id\ x\ y\ N\ L_1\ W_{1a}\ W_{1b}\ L_2\ W_{2a}\ W_{2b}\ s\ e\ H_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MAT3s>

$x\ y\ N\ L_1\ W_{1a}\ W_{1b}\ L_2\ W_{2a}\ W_{2b}\ s\ e\ H_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MAT3

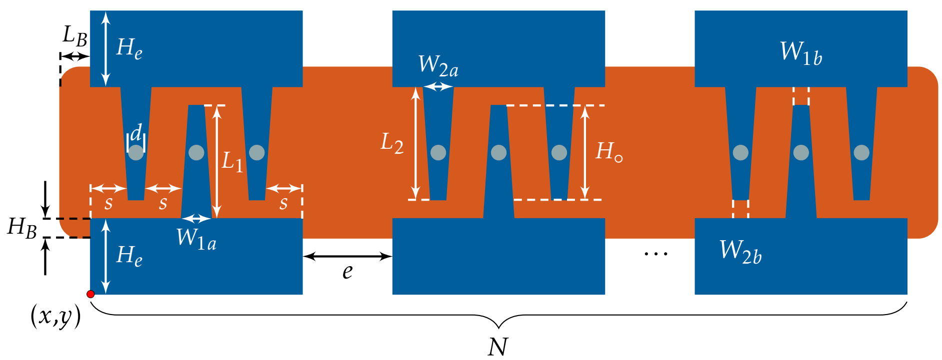


Figure 2.340: *Array of three interacting trapezoidal beams created using the MAT3s and MAT3s constructors.*

Trapezoidal top array of elements interacting with single beams. The lower single beam elements are individually addressable via electrodes of width $H_w = W_{1a} + 2W_{2b} + 4s$ and height H_e.

<$id\ x\ y\ N\ L_1\ W_{1a}\ W_{1b}\ L_2\ W_{2a}\ W_{2b}\ s\ e\ H_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MATCs>

$x\ y\ N\ L_1\ W_{1a}\ W_{1b}\ L_2\ W_{2a}\ W_{2b}\ s\ e\ H_\circ\ H_e\ L_B\ H_B\ d\ N_s\ Ly_F\ Ly_B\ Ly_M\ \theta_{(x,y)}$ MATC

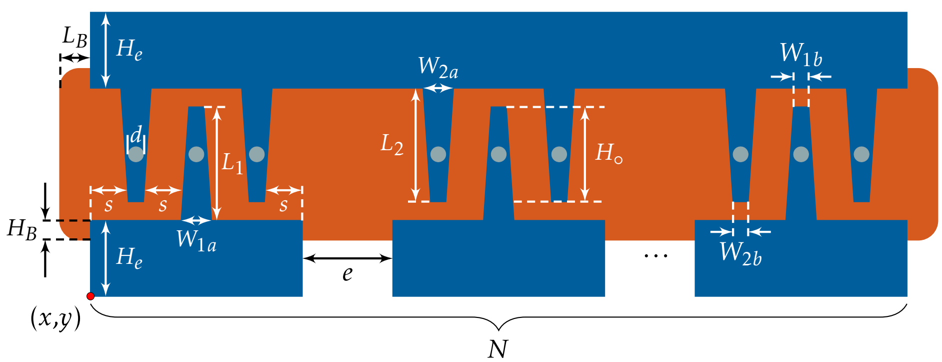


Figure 2.341: *Array of $2N$ trapezoidal beams interacting with a N single beams created using the MATCs and MATC constructors.*

Two interacting rectangular arrays between elements of differing lengths. The electrode base varies linearly from the value of H_e to $He + \Delta$.

<$id\ \ x\ \ y\ \ N\ \ L\ \ \Delta\ \ W\ \ s\ \ H_\circ\ \ L_\circ\ \ H_e\ \ L_B\ \ H_B\ \ d\ \ N_s\ \ L_1\ \ L_2\ \ L_3\ \ \theta_{(x,y)}$ **MARALINEARs**>

$x\ \ y\ \ N\ \ L\ \ \Delta\ \ W\ \ s\ \ H_\circ\ \ L_\circ\ \ H_e\ \ L_B\ \ H_B\ \ d\ \ N_s\ \ L_1\ \ L_2\ \ L_3\ \ \theta_{(x,y)}$ **MARALINEAR**

Figure 2.342: *Two interacting rectangular arrays between elements of differing lengths. Beam lengths vary linearly across the electrode base. Structures are generated using the* ***MARALINEARs*** *and* ***MARALINEAR*** *constructors.*

Two rectangular arrays between elements of differing lengths. The electrode base has a slow non-linear variation from of H_e to $H_e + \Delta$. The non-linear element was constructed using a Bezier curve.

<id x y N L Δ W s $H_\circ$ $L_\circ$ H_e L_B H_B d N_s L_1 L_2 L_3 $\theta_{(x,y)}$ MARACURVEs>

x y N L Δ W s $H_\circ$ $L_\circ$ H_e L_B H_B d N_s L_1 L_2 L_3 $\theta_{(x,y)}$ MARACURVE

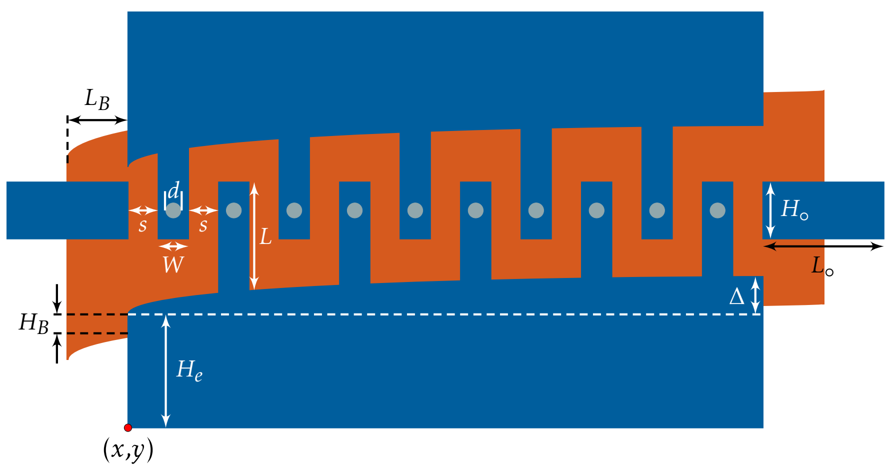


Figure 2.343: *Two interacting rectangular arrays between elements of differing lengths. Beam lengths vary non-linearly across the electrode base. Structures are generated using the MARACURVEs and MARACURVE constructors.*

2.10.8 Stress, Strain Measurement Structures

2.10.8.1 Guckel Rings

Guckel ring structures are used to estimate residual stress in structural layers.

$x \quad y \quad r_W \quad R \quad N_{sides} \quad b_W \quad b \quad L_c \quad W_c \quad a \quad L_a \quad \theta_{(x,y)}$ **GuckelRing**

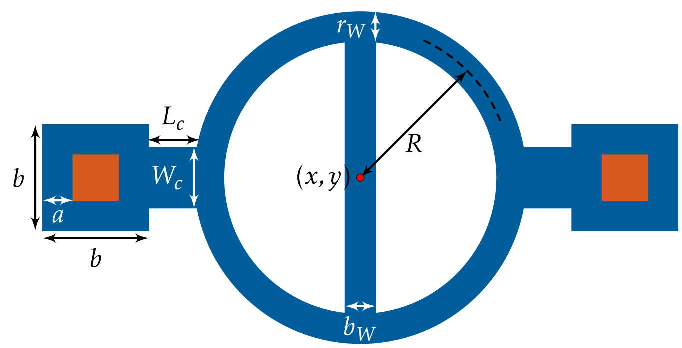


Figure 2.344: *Schemaric of a Guckel ring structure used for measuring residual stress.*

Below is a Guckel ring array structure. The varying radii range from R_s to R_e in increments of ΔR.

$x \quad y \quad r_W \quad R_s \quad R_e \quad \Delta R \quad N \quad b_W \quad b \quad L_c \quad W_c \quad a \quad L_a \quad \theta_{(x,y)}$ **GuckelRingArray**

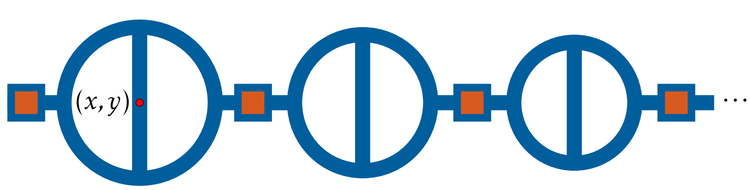


Figure 2.345: *Schemaric of a Guckel ring array structure with varying radius.*

2.10.8.2 Diamond Ring

$x \quad y \quad w_1 \quad w_2 \quad w_3 \quad l_1 \quad l_2 \quad l_3 \quad b_H \quad b_W \quad a \quad L_a \quad \theta_{(x,y)}$ **diamondRing**

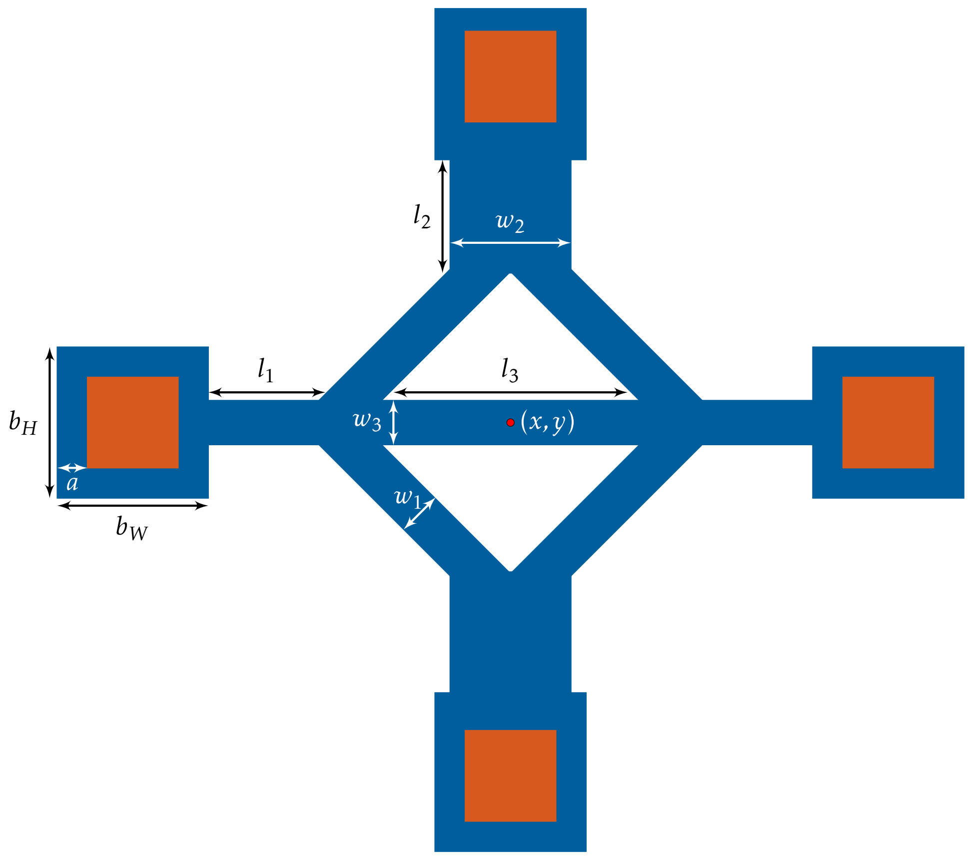


Figure 2.346: *Stress measurement diamond ring.*

2.10.9 Suspended Fluid Cell

Fluid cell (L_c) with a suspended region defined by radius r_3 and a spiral delay line heater (L_b). Central red dot indicated coordinate (x, y). The fluid input funnel shape are defined by the **shapeReso** parameter.

$x\ y\ w_1\ w_2\ w_{2T}\ w_3\ w_4\ L_1\ L_2\ r\ r_1\ r_2\ r_3\ N_{sides}\ a\ b\ c\ d\ e\ f\ g\ h\ i\ L_a\ L_b\ L_c\ L_d\ L_e\ L_f\ \theta_{(x,y)}$ **fluidCell**

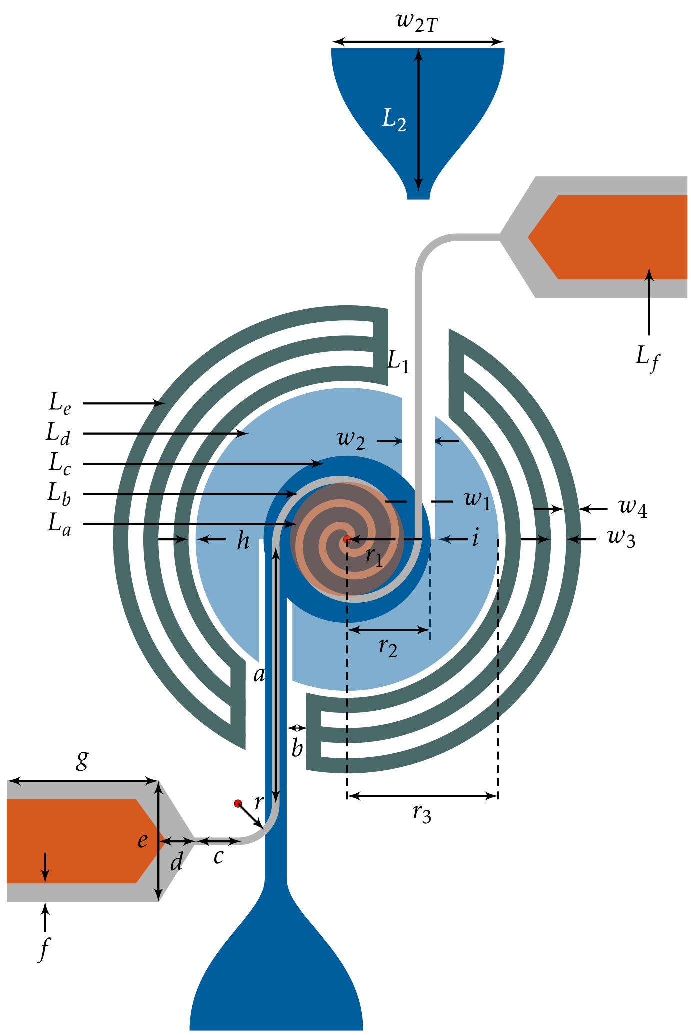


Figure 2.347: *Fluid cell (L_c) with an integrated spiral delay line heater (L_b) and release trenches (L_e).*

Email: Nanolithography.Toolbox@nist.gov

3.1 Basic Shapes

3.1.1 Pillar-Hole (Square/Hex) Array

Within in this module, polygons are created and arrayed. User defined parameters consist of number of sides, size and rotation of individual elements, the GDS layer number, and lower left position, number of elements, and pitch between the arrayed structures. This module creates cells for individual elements used to create pillars and holes. Pillars are created by performing a boolean operation between a box of dimensions $(Pitch_x \times Pitch_y)$ and the specified shape. The shapes are then instantiated within 4 arrayed cells consisting of square and hexagonal arrays of both polarities. Figures 3.348$(a-h)$ show several examples of the pillar hole array.

3.1.2 Torus

This module creates arc shapes defined by the start (θ_s) and end (θ_e) sweep angles of the individual elements. Torus is created by sweeping an arc over 2π radians, i.e. $\theta_e - \theta_s = 360$degrees. Default parameters for the torus module are $\theta_s = 0$degrees and $\theta_e = 360$degrees. Generated features are defined by the number of sides for the inner and outer arc segments, the GDS layer number, and rotation of individual shapes. Position, elements and pitch parameters define square and hexagonal array elements. Figures 3.348$(i-j)$ show 4 examples of various arcs.

3.1.3 Grating Coupler - Bulls Eye

The module creates concentric arcs to form grating couplers or bulls-eye patterns. The arc section is defined by a sweep angle and arc width. The arrayed elements are located at the specified (x, y) position. First element is placed at a distance defined by the radius midpoint. Parameter $Rings$ defines the number of arrayed elements instantiated at the specified pitch. Figures 3.348$(k-l)$ show several examples of grating coupler structures.

3.1.4 Spirals

Spirals are defined by their center position, GDS layer number, shape width, and number of turns. Shape resolution is specified by the $Increment$ parameter. Choosing many turns with a small increment (high resolution) will increase the GDS file generation time. Spiral structures are generated and placed into a GDS structure named top.

We offer three types of spirals, Archimedes, Fermat and Logarithmic (Figures 3.348($m-o$)). Archimedes spiral has a uniform spacing between turns (s) and is defined as

$$r = m\theta \tag{3.23}$$

where

$$m = \frac{s + width}{2\pi} \tag{3.24}$$

Fermat spiral is defined as

$$r = \sqrt{a^2\theta} \tag{3.25}$$

and Logarithmic spiral is defined as

$$r = ae^{b\theta} \tag{3.26}$$

3.1.5 Gratings

Gratings module generates user-defined lines arrayed at a predefined pitch. Each line of the table will create two cells, one for the line and the other for the grating array. Generated structure names will have a prefix RX where X represents the table row number. The load table button allows users to upload text files. Values from loaded text files will populate the table. Top cell will have an instance of each array separated by the $TopCellSpacing$ value. Figures 3.348(p) shows an example of a grating structure. An example of a grating text file is located \loadFiles\gratingTable.

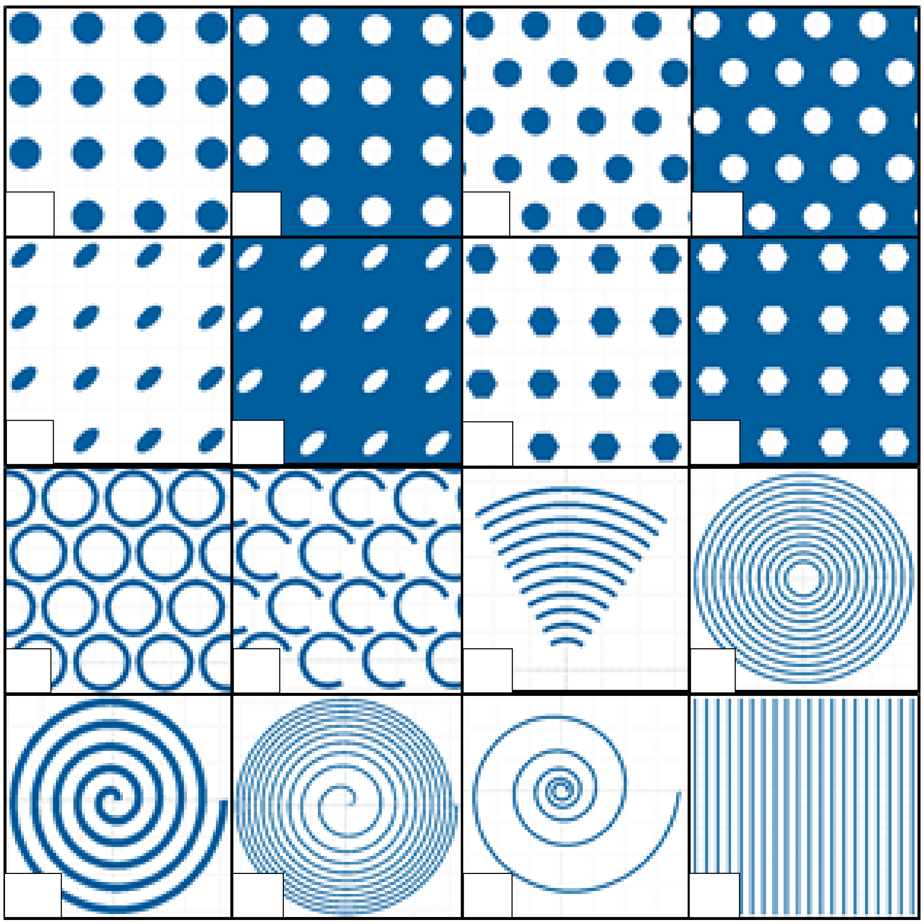


Figure 3.348: *Various examples from the BasicShapes branch. Rectangular arrays of (a,e,g) holes and (b,f,h) pillars. Hexagonal array of (c) holes, (d) pillars, (i) torii and (j) arcs. (k) Grating coupler and (l) bulls-eye pattern. Spirals created using various parameters (m) Archimedes, (n) Fermat, (o) and Logarithmic. (p) Grating structure.*

3.2 Lithography Machine Resources

3.2.1 CNST Reticle Frame Generator

This module creates reticle frames for the CNST Nanofab ASML-PAS5500 i-line stepper and contact aligners. Default stepper option will print reticle marks, user defined label and barcode, NIST and CNST logos. ASML barcode and label are limited to 12 and 14 characters respectively. Two remaining options are for 5 inch and 7 inch contact masks. In both cases, label, along with NIST and CNST logos are printed near the periphery of the mask. Contact labels are limited to 22 characters.

3.2.2 Generic Reticle Frames

Within this module, reticle marks, label and barcode are generated for several steppers.

3.2.3 Ebeam Lithography - Job and Schedule File Generator

This module generates job and schedule files for the CNST JEOL 6300 electron beam lithography tool. The module offers a number of graphical features that help ensure proper pattern and alignment mark placement. Additionally, it features a wide variety of dose variation features including base dose matrices, single and multi-shot rank modulation, user defined dose table modulation, and several dose ramping functions. This node has 4 sections accessible using the tabs located at the top of the panel named $Main$, $Align$, $Pattern$ and $DoseMatrix$.

3.2.3.1 Default Values Initialization File

Many features within the CNST JEOL 6300 JDF-SDF module are customizable using the provided $CNSTdefaultValues.xml$ initialization file. For example, position size, auto-loader (ALD) position, paths, calibration parameters, alignment marks represent a few parameters that are stored within the initialization file. If this file is missing, hardcoded values will be displayed within the toolbox. Also, directly to the left of the $About$ button within the $Main$ tab, a string will indicate if values were loaded from the initialization file.

3.2.3.2 Main

Within the $Main$ panel material parameters, jdf and sdf file names, alignment schemes, paths and calibration parameters are preset. The $PATH$ and

$CALPRM$ variables are editable. Most of these parameters are predefined within the $CNSTdefaultValues.xml$ initialization file. Figure 3.349 shows parameters under the $Main$ panel.

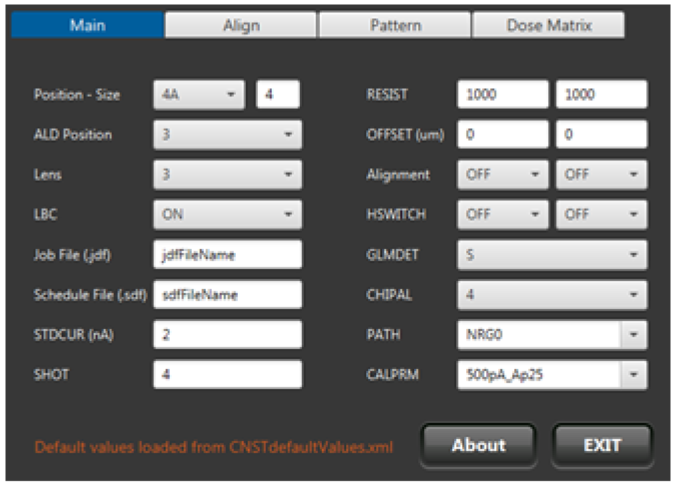


Figure 3.349: *Main panel showing various available options under Main tab.*

3.2.3.3 Align

The alignment panel allows users to define position and size of global (P and Q) and local (M_1, M_2, M_3, and M_4) alignment marks. The positions are in wafer coordinates in units of micrometers. Under mark definition, mark width and length values are specified in micrometers for the the global P ($GLMP$), global Q ($GLMQRS$) and chip ($CHMARK$) alignment marks. The $Align$ section is only used if global and local marks are selected under the $Alignment$ field within the $Main$ tab. The left-most alignment option activates the global marks, while the right-most option controls local (chip) alignment. The options are by default inactive as indicated by the OFF state. Figure 3.350 shows parameters under the $Align$ JEOL 6300 panel.

3.2.3.4 Pattern

This section defines pattern arrays within the job definition file. Pattern files specified, arrays are generated from those pattern files and stored into a vector array is accessed when job and schedule definition files are created. To add a pattern file to the database, type in a pattern file name then click the $AddFile$ button. A string label will appear and indicate that the entered .v30 file was added to the pattern file list. More files are added by repeating the previous process. Entered pattern names will appear in the pull down selection box.

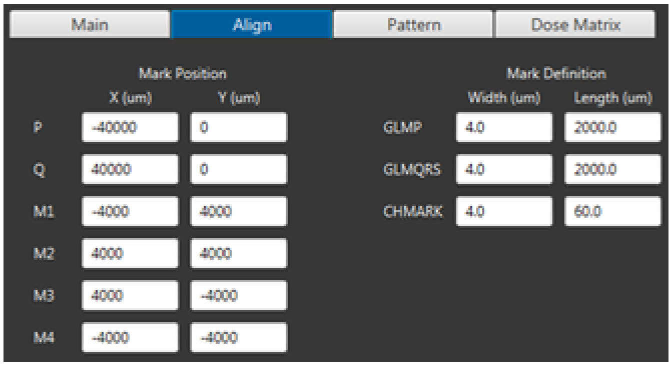


Figure 3.350: *Alignment panel showing various alignment mark definitions under Align tab.*

Select a pattern, then type underneath the $ARRAY$ section, type in the starting coordinates of the first element of the array, then number of elements and the pitch between elements, then type in the dose modulation for the pattern file. For a single element leave both Element values at 1. Click the Generate Array button. The value of the generated array will appear in a selection box directly to the left of the Generates Arrays field. Repeat the process, i.e. choose file name, then pattern position, number of array elements, pitch between elements, enter a dose modulation and click the $GenerateArray$ button. $Delete$ button to the right of the selection box within Generates Arrays field allows users to delete previously generated arrays stored within the selection box. Also, generated arrays can be modified by choosing an array from the saved list. Following parameter modifications, clicking the $UpdateArray$ button overwrites the previous entry. Figure 3.351 shows parameters under the $Pattern$ panel.

To view the arrays as well as the job and schedule files at any point during the array creation, click the Show SDF JDF button. A new frame will pop-up with a text area containing the contents of the jdf and sdf files. Another frame will pop-up and will show graphically where patterns are placed (Figure 3.352). The feature is similar to the JEOL Array Check program. Following any alteration of the generated array elements, clicking the Show SDF JDF button will update the job and schedule file panel as well as the array check panel.

3.2.3.5 Dose Matrix

Dose matrix module is a means to create complex dose and base dose matrices. The procedure initiates by choosing a pattern file name, the position, number of elements and pitch between the elements of the resulting dose array (Figure 3.353). There are various options under the $DoseMethod$ tab. Standard $DoseMatrix$ is the default method for executing a dose matrix on the chosen V30 file. Method $BaseDose$ is used to determine a proper base dose for

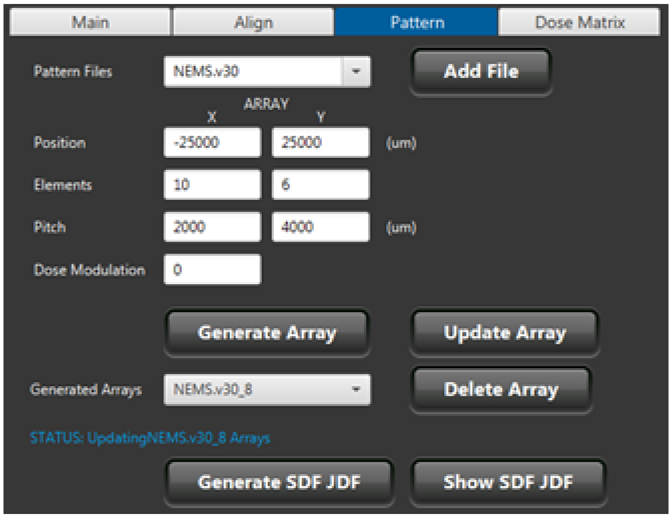


Figure 3.351: *Pattern panel showing user-defined pattern files, array definitions, and generated arrays.*

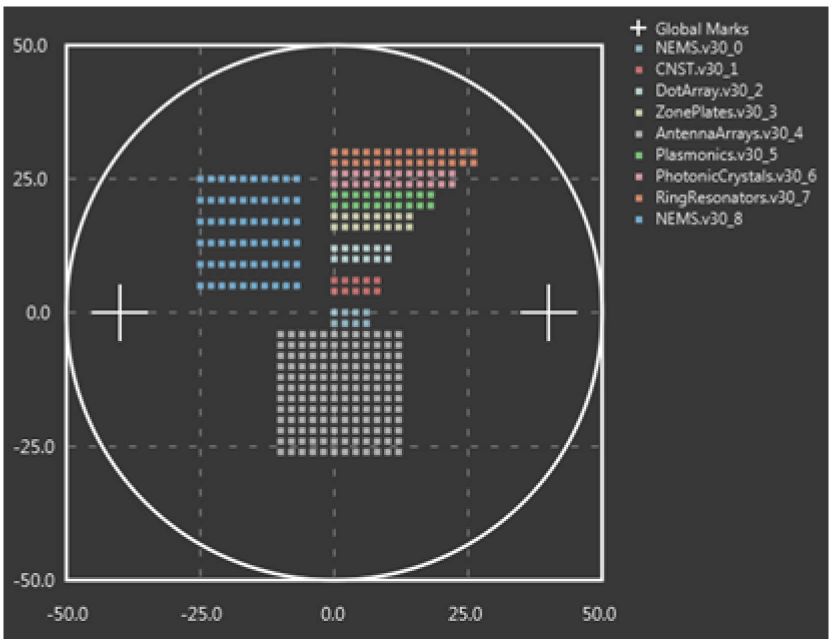


Figure 3.352: *Display showing user generated pattern arrays and global mark positions (P and Q).*

a proximity effect corrected pattern. Here base dose ($RESIST$ parameter) is modified within the schedule file, the pitch in the two directions will represent the $OFFSET$ parameter, with the $RESIST$ value derived from the $Start$ text field within this tabbed panel. There are 4 options within the $Ramp$ selection menu. $Linear$ and $Percent$ options use respective right-most text-field values of $Linear$ and $Percentage$ to increment the dose array from the starting value represented by the $Start$ text field. For instance, choosing $Linear$ with a value of 10 within the Linear text field in conjunction with a $Start$ value of 100 for an array of 4 elements, percentage modulation dose values will be 100, 110, 120 and 130. Analogously, with an active $Percent$ ramp option and a value of 10 within the $Percentage$ text field in conjunction with a $Start$ value of 100 for an array of 8 elements,percentage modulation dose values will be 100, 110, 121, 133.1, 146.41, 161.05, 177.16 and 194.87. $LinearSE$ and $NonlinearSE$ are two ramp methods that utilize number of arrayed elements, the $Start$ and End text field values to determine the percentage dose modulation.

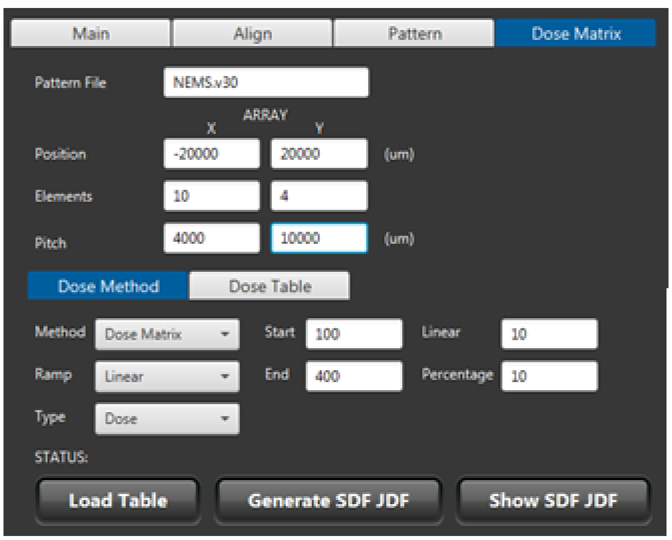


Figure 3.353: *Dose matrix panel showing various user defined pattern, array and dose parameters.*

$Dose$ represents the default value of the $Type$ selection. $DoseTable$ option under $Type$ uses values from the $DoseTable$ tabbed panel. Within the Dose Table tabbed panel, values for the shot rank and modulation are either manually entered or uploaded from a text file (Figure 3.354). The method assumes the standard dose modulation table format, as seen in the layout beamer proximity effect corrected output file with extension JDI. An example dose matrix JDI file is located in the \loadFiles\jeol6300DoseTable directory. When using the table method, ramp can either be the default $Linear$ or $Percent$ option. Depending on which method is chosen, the respective $Linear$ and $Percentage$ text fields are used to modify the individual modulation values from the table. The sdf and jdf files could be shown or generated using the respective buttons at the bottom of the panel.

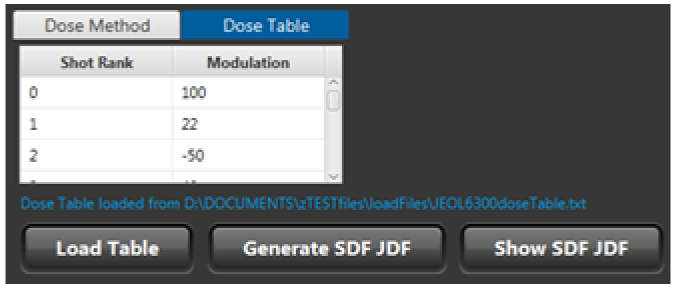


Figure 3.354: *Dose matrix panel showing various user defined pattern, array and dose parameters.*

3.2.4 EBL Alignment Offset

The JEOL alignment module calculates the offsets between the designed and observed wafer positions. Type in the designed mark positions of the P (or Q) marks. This value is specified in material (or wafer) coordinates with micrometer units. Check the substrate holder center position and type in those values for the wafer center. Once the marks are located in the scanning electron microscope (SEM) of either of the CNST ebeam tools, type in the stage coordinates of this observed mark position, then press $Enter$ or click the $Calculate$ button. Within the $OFFSET$ text field, calculated values will appear. These values should be used within the SETWFR routine to manually check global alignment. Furthermore, these values are placed within the schedule file (.sdf file) as:

$$OFFSET(X_{offset}, Y_{offset})$$

3.2.5 EBL Max Clock

This module calculates the maximum writing frequency and the minimum shot time for the 4^{th} and 5^{th} lens electron beam lithography tools. Calculation is based on beam current, writing dose, shot pitch and tool type.

3.2.6 EBL Write Time Estimation

This module calculates an estimated electron beam lithography write time. Calculation is based on beam current, die area (written die area in micrometers squared - a value easily obtained from various CAD and fracturing tools), writing dose, fields per die and the number of die. Stage time is ′estimated′ at 1second per stage move. This is not quite correct (′estimate′) since stage motion depends upon distance traveled and the EBL tool. The estimated calculation does not take into account tool calibration time.

3.3 Advanced CAD Resources

Many of the modules in the advanced CAD resources are implemented within CNST scripting. Therefore, many modules refer to sections and figures within the scripting command reference chapter. Users should note that scripting offers more flexibility with many more features not implemented within its GUI counterpart.

3.3.1 Label Maker

Label Maker module is used to generate chip labels into a GDS file that could then be instanced into a user defined pattern. There are 4 label type options. The automated $Outer$ and $Row-Column$ will generate number arrays, whereas the custom variants are more versatile allowing imported tab delimited data to be cast as labels. Two test label files are included in \loadFiles\labels example directory. The files were generated in Excel and exported as plain text tab delimited.

Within the label maker module, first, number of elements, pitch between the elements, font specifications and label type are specified. Font resolution is the rendering resolution of the Bezier curves that construct font shapes. This parameter is defined as **shapeReso** within CNST scripting (see Section 2.2.6 and Figure 2.16). The four label types are described within the label maker scripting command reference guide. This module does not implement automatic letter labeling. Scripting section 2.6.3 further illustrates automatically generated $Outer$ and $Row-Column$ (Figure 2.45a,b) and the respective custom, user-defined labels (Figure 2.45c,d).

3.3.2 Text To GDS

Text to GDS module renders strings composed of vector fonts to GDS shapes. Font resolution parameter controls the rendered shape resolution. Example of font resolution and generated text are shown respectively in Figure 2.2.6 and 2.43.

3.3.3 Arbitrary Function Generator

Arbitrary Function Generator module will create a GDS file with a shape defined by a mathematical equation. User will input a lower and upper bound, an increment and line width for the function. Within this module, users define a function $f(x)$ using the lower case variable x. Functional definitions follow the Java $Math$ class. Scripting section 2.7.4 offers a more efficient function generator. This section also describes how functions are represented.

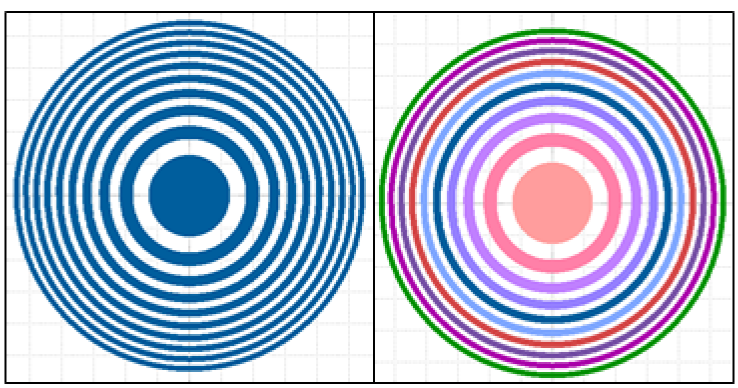
Functions constructed with a large number of points could take a considerable amount of time to cast the resulting GDS file. Label indicator above the module buttons will display the path and file name once it's finished writing data to file. Also, casting a curved function defined by a large width could result in a shape with looped interiors.

3.3.4 Binary Zone Plate

In a binary zone plate, zones switch from opaque to transparent at radii,

$$r_n = \sqrt{n\lambda f + \frac{n^2\lambda^2}{4}} \tag{3.27}$$

where n is an integer, λ is the wavelength and f is the focal distance measured from the center of the zone plate. Each shape is constructed with double the number of prescribed sides (interior and exterior) whereas the central element (circle) vertices are equal to the $Sides$ module parameter. Figure 3.355 shows two examples of binary zone plates. Zones are either composed of a single user defined GDS layer, or cast into zone-respective GDS layers. This implies that zone at a radius r_n is rendered to GDS layer number n where $n = 0, 1, 2, \ldots 255$. Due to 8-bit layer GDS standard restrictions, zone numbers above the upper bound (255) reset the counter back to GDS layer number 0. Consequently, zones at radii $r_{256}, r_{257}, r_{258}, \ldots$ would respectively have GDS layer numbers $0, 1, 2, \ldots$.



(a) (b)

Figure 3.355: *GDS output of a zone plate with 10 zones, 88 sides per zone, $\lambda = 632.0nm$, and $f = 0.001m$. (a) Single layer zone plate. (b) Enabling the different layers option casts each zone to a respective GDS layer number.*

3.3.5 Photonic Crystals

Photonic crystals module creates two hexagonal arrays of circles. Circles are defined by a diameter (d), number of sides and GDS layer number parameters. Within the array circular elements are defined by the spacing proximity to the nearest neighbor (h). Hexagonal arrays are defined by the separation between the two arrays (s), and the array size S_x and S_y along the corresponding x and y directions (Figure 3.356). Table of values are either manually populated or data is loaded from a text file. Example photonic crystal table file is included in the \loadFiles\photonicCrystalTable directory. Each table value is tab separated, each table row starts on a new line. Figure 3.356 shows various parameters from the photonic crystal module.

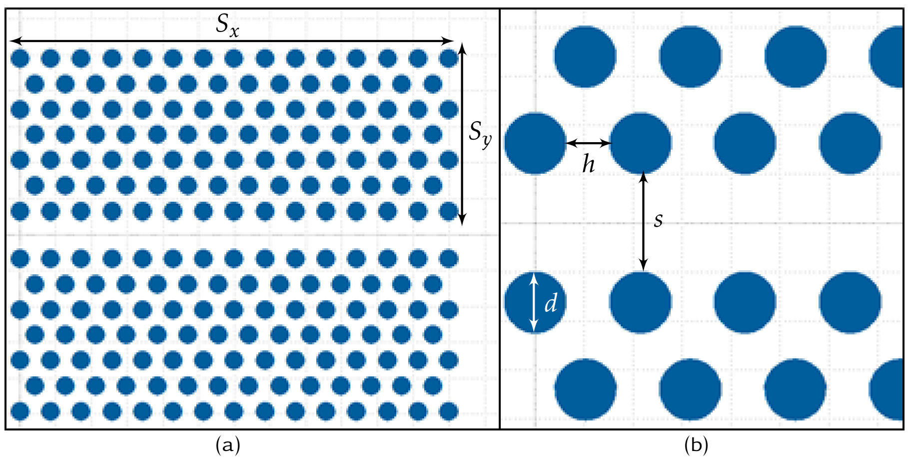


Figure 3.356: *Photonic crystal example of a rendered GDS structure labeled with module parameters.*

3.3.6 Random Polygons

Random Polygons module will randomly place polygons into a user defined area. Separation parameter defines the minimum separation between the outer radial perimeter of the objects. Polygons are defined by the outer radius and number of sides. The polygon placement area is defined by the $Width$ and $Length$ parameters. If the randomly generated coordinate violates the minimum separation distance, the module will keep generating random coordinates until the maximum number of failures (defined by the parameter $Iteration$) is reached.

By clicking the $RandomRotation$ checkbox, each shape will be randomly rotated within the top cell. Enabling the option for features with many sides is not useful, however, with $Sides = 3$ and random rotation produces randomly oriented triangles within the array (see Figure 2.78 in section 2.7.11).

This shape could be generated using the scripting constructor **randomPolygons**, as described in section 2.7.11.

3.3.7 Random Rectangular Array

Random rectangular array module will randomly place squares or rectangles into a user-defined area specified by the number of elements and pitch (in x and y directions). The shape size (square or rectangular) as well as the probability that a lattice point is occupied are user-defined parameters. Furthermore, user can load x and y coordinate pairs and cast them to lattice sites. This module was suggested by a researcher and used for generating disordered metamaterial structures.

This module allows users to load x and y coordinates where objects will be drawn. The ASCII file should be arranged with x and y pairs tab or space separated, with one pair per line. The first line of the data file is defined as a header and is consequently skipped. An example file is located under the \loadFiles\randomRectangularArray directory. To use the module, first choose the size of the square or rectangular object, then check the Load File check box, then click Load File , navigate to a directory with the text file, click on the file, then click OK. The chosen filename will be displayed in the label field directly below. Then click Create GDS to cast the shapes into a GDS file. NOTE: when loading from file, this module ignores the number of elements field, and will not display the total number of drawn shapes, skipped shapes, etc, within the results label field.

3.3.8 Cantilever Arrays

Cantilever Arrays module will create a GDS file with a modulated (linearly, non-linearly, percentage, sinusoidally, etc) cantilever array structures. Number of resulting structures is defined by the $Elements$ parameter. Levers are characterized by a width, pitch and variable length values. Cantilevers are connected to a rectangular base of a user specified height. The width of the base rectangle is defined by the number of elements, pitch and the base extent.

By choosing `Linear` or `Percentage` type variation, the generator will utilize the `Length start` value and will increment the length using the linear or percentage parameters respectively. Type `Linear SE` and `non-linear SE` use the `Length start` and `Length end` values and respectively vary the cantilever lengths linearly and non-linearly. Type `Sinusoid` will use the `Length start` value as the initial length value and will vary the cantilever lengths sinusoidally over a 2π period with an amplitude defined by the `sin Amplitude` value.

The MEMS-NEMS library offers identical elements (section 2.10.5) as well as many other shapes with enhanced functionality. Figure 2.316 illustrates cantilevers with linear, percentage, and sinusoidal length modulation. Figure 2.317 shows examples of a linear and exponential length variation using start and end length values.

3.3.9 Verniers

This module generates verniers between two specified alignment layers. User defined parameters consist of GDS layer numbers for layer A and B, vernier resolution, number of vernier tick lines, text labels for the two layers, vernier line width, length and pitch. Table of values are either manually populated or data is loaded from a text file. Example vernier table file is included in the \loadFiles\vernierTable directory. Each table value is tab separated, each table row starts on a new line. Vernier example is shown in the scripting command reference section 2.8.5 and figure 2.94.

3.3.10 Fractals

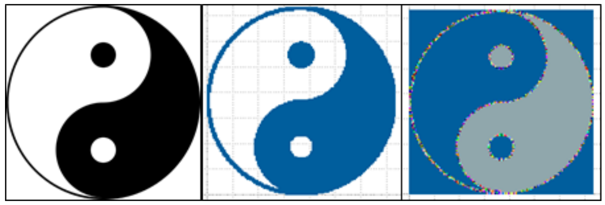
This module contains Sierpinski triangle and carpet, curved tree, and the Vicsek saltire and cross fractals. Each fractal iteration is stored into a GDS structure with a prefix cell name concatenated with the iteration number. The extent of the final structure is defined by the module length and width parameters. Fractal examples are defined in the scripting command reference section 2.7.3 (see also Figure 2.58).

3.3.11 Grayscale Image To GDS

Grayscale Image to GDS module will convert a 8-bit gray scale BMP (PNG or JPG) and cast it to a GDS file where each level of gray (values 0 to 255) will be mapped to corresponding GDS layer numbers (GDS layers 0 to 255). This mapping is important for grayscale electron beam lithography. In this case, the generated file can be used in conjunction with a resist contrast curve to print three dimensional structures [104].

Resulting data is stored into a GDS structure named top. Within the module, data is read and converted line by line. Adjacent pixels of same value are merged together in order to minimize the resulting GDS file size. Also note that data within the top cell is not centered around the origin. The lower left hand corner of the image is mapped to the origin of the GDS file (point $(0,0)$). The image is mapped within the first quadrant $(+x,+y)$ of the GDS file.

If the BW option is checked, then all color values other than white (pixel value 255) will be cast to GDS layer 1. In this case, adjacent pixels are merged, however, if 2 pixels are of different value, they will be both cast to GDS layer 1, as 2 different GDS layer 1 pixels. To have pixels merged, use a graphic editing software package to cast image to black and white BMP, then change the mode to RGB 8-bit gray scale. Figure 3.357 shows an image and the resulting GDS files.



(a) (b) (c)

Figure 3.357: *Grayscale to GDS. (a) 8-bit gray scale image (in this case black and white). The resulting GDS file (b) without and (c) with the BW option enabled.*

Programming Reference

Email: Nanolithography.Toolbox@nist.gov

4.1 Programming Examples

The nanolithography toolbox distribution includes a NetBeans 8.0.2 project entitled `CNSTprogrammingExamples`. The `src` directory contains a package with source .java example files. These files could be used with any integrated development environment (IDE) in conjunction with Java 8. Furthermore the nanolithography toolbox `jar` file must be included within the project compile-time libraries. The following examples illustrate access to existing scripting methods through programming. Furthermore, the project directory includes the output GDS example files.

The following is a procedure for setting up the included Netbeans example project:

1. Start NetBeans -> File -> Open Project ... -> navigate to \EXAMPLES\Programming and open the CNSTprogrammingExamples project

2. To fix the broken library link, right click on the project and choose Properties, click Libraries and remove the red-error highlighted compile-time library. Click the "Add JAR/Folder" button, then choose the CNST Nanolithography Toolbox JAR file and click OK.

4.1.1 Template

```java
package cnstprogrammingexamples;

import CNST.Scripting;
import JGDS2.*;
import java.io.File;

/**
 *
 * @author rob
 */
public class Example01Template {

    public static void main(String[] args) {
        Lib lib = new Lib();

        // Insert Code Here

        File f = lib.GDSOut("Example01Template.gds");
```

```
19         System.out.println(" Saved to " + f.getAbsolutePath());
20     }
21
22     // Insert class methods here
23
24 }
```

The above example is a template for java files accessing the CNST nanolithography toolbox. Lines 3 and 4 import all the objects needed to access scripting methods and create the GDS file. Line 5 import statement allows file input-output access. The example class contains a main method. Line 14 initializes the GDS library. Line 18 sets the GDS output file. The print statement (line 19) is optional but helpful since it displays the full path of the saved GDS file.

4.1.2 Script Method Access

The programming reference provides method headers for the available scripting methods within the toolbox. These methods either return a GDS Area object (`GArea`) and vector array of these objects (`ArrayList<GArea>`), or are void in which case the the areas are placed within a particular GDS structure.

```
package cnstprogrammingexamples;

import CNST.Scripting;
import JGDS2.*;
import java.io.File;

/**
 *
 * @author rob
 */
public class Example02ScriptingMethodAccess {

    public static void main(String[] args) {
        Lib lib = new Lib();
        //
        // create a GDS struct SingleEllipse
        Struct ellipse = new Struct("ellipseSingle");
        // add a GArea of an ellipse from the nanolithography toolbox scripting method
        ellipse.add(Scripting.createEllipse(0, 0, 0.2, 0.5, 44, 50,
        4));
        // create a GDS struct to store many instantiated ellipses
        Struct manyEllipses = new Struct("InstantiatedEllipses");
        // instantiate ellipses along a circular path
        double circleRadius = 20; // units in micrometers
        int numberOfInstances = 100;
        double increment = 2 * Math.PI / numberOfInstances;
        for (int i = 0; i < numberOfInstances; i++) {
            manyEllipses.add(new Ref(ellipse, circleRadius * Math.cos(i*increment), circleRadius * Math.sin(i*increment)));
        }
```

```
30         // adding structures to GDS library
31         lib.add(new Ref(ellipse, 0, 0));
32         lib.add(new Ref(manyEllipses, 0, 0));
33         //
34         File f = lib.GDSOut("Example02Template.gds");
35         System.out.println(" Saved to " + f.getAbsolutePath());
36     }
37 }
```

The above example creates a GDS structure object `ellipse` (line 17) with a structure name `ellipseSingle`. Line 19 adds a GDS area of an ellipse into the structure object. Here, the ellipse is created by one of the available nanolithography toolbox scripting methods using the following method header (Reference Methods section shows all the available methods)

```
public static GArea createEllipse(double x, double y, double radiusX,
    double radiusY, int numSides, double THETA, int gdsLayer)
```

Line 22 creates a GDS structure object `manyEllipses`. Using a `for` loop the `ellipse` object is instantiated along a circular path using the `Ref` constructor (line line 27). Figure 4.358 shows the output of the instantiated `ellipse` object. Lines 31 and 32 add the two structures to the GDS library. The following are `Ref` constructors

```
Ref(Struct structure, double x, double y)
Ref(Struct structure, double x, double y, int mirror)
Ref(Struct structure, double x, double y, int mirror, double angle)
Ref(Struct structure, double x, double y, int mirror, double mag,
    double angle)
```

To use mirroring within `Ref` the existing class must implement an interface `Const`, then set `int mirror` to `MIRROR`. Please consult the JGDS user manual for examples and more information on GDS structure instantiation [76].

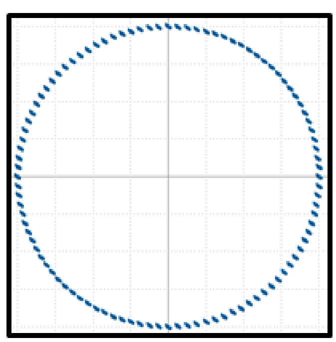


Figure 4.358: *Programming example illustrating instantiation of objects created using the nanolithography scripting methods.*

4.1.3 Boolean Operations and Affine Transformations

The following example illustrates affine transformations of GDS areas and boolean operation between GDS areas. The code first generates a GDS structure (line 18) to store boolean substraction between a circle and a circle wave object. Lines 19 and 20 show instantiation of GDS areas using the available nanolithography toolbox methods. Line 21 subtracts the circle wave from the circle object. Subsequently the result (circle) is stored in the `booleanCCW` GDS structure. Figure 4.359 shows the rendered GDS shapes.

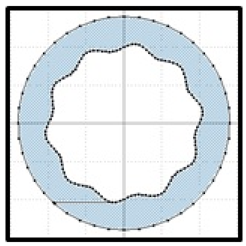
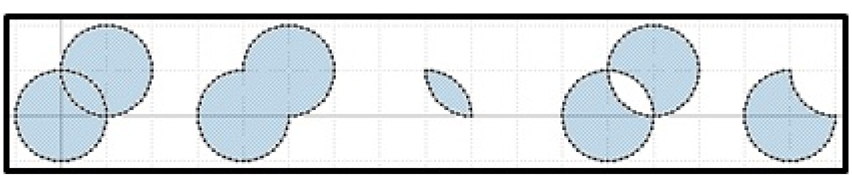


Figure 4.359: *Rendered GDS output shape resulting from a subtraction between a circle and a circle wave object. The black dots represent shape vertices.*

Lines 25-30 create a GDS structure and two circular areas, then add the areas to the structure. A copy of `circle1` into a `temp` area object occurs in line 34. Directly following, in line 35 a boolean `OR` operation with `circle2` occurs. Line 37 shows a GDS area translation using built in Java affine transformations. In a similar fashion, the areas could be scaled, rotated and sheared. Lines 40 to 59 repeat the process for a boolean `AND`, `XOR`, and `SUBTRACT` operations. Figure 4.360 shows the output of the rendered structures.



(*a*) (*b*) (*c*) (*d*) (*e*)

Figure 4.360: *Rendered GDS output shape of the (a) original two circles and various boolean operations between the areas (b) `OR`, (c) `AND`, (d) `XOR` and (e) `SUBTRACT`.*

```
1 package cnstprogrammingexamples;
2
```

```
import CNST.Scripting;
import JGDS2.*;
import java.awt.geom.AffineTransform;
import java.io.File;

/**
 *
 * @author rob
 */
public class Example03BooleanOperationsTransformations {

    public static void main(String[] args) {
        Lib lib = new Lib();
        //
        // Subtraction of 2 GAreas - circle - circleWave
        Struct booleanCCW = new Struct("BooleanCircleCircleWave");
        GArea circle = Scripting.createEllipse(0, 0, 14, 14, 44, 0, 4);
        GArea circWave = Scripting.createCircleWave(0, 0, 10, 10, 0.5,
            128, 0, 4);
        circle.subtract(circWave);
        booleanCCW.add(circle);

        // boolean examples between 2 circles
        Struct booleanCircles = new Struct("BooleanCircles");
        GArea circle1 = Scripting.createEllipse(0, 0, 1, 1, 44, 0, 4);
        GArea circle2 = Scripting.createEllipse(1, 1, 1, 1, 44, 0, 4);
        // add both circles to the struct
        booleanCircles.add(circle1);
        booleanCircles.add(circle2);

        // OR Example
        // create a temporary copy of circle1
        GArea temp = new GArea(circle1);
        temp.or(circle2);
        // affine transform - translation 4um in x
        temp.transform(AffineTransform.getTranslateInstance(4, 0));
        booleanCircles.add(temp);

        // AND Example
        temp = new GArea(circle1);
        temp.and(circle2);
        // affine transform - translation 8um in x
        temp.transform(AffineTransform.getTranslateInstance(8, 0));
        booleanCircles.add(temp);

        // XOR Example
        temp = new GArea(circle1);
        temp.xor(circle2);
        // affine transform - translation 12um in x
        temp.transform(AffineTransform.getTranslateInstance(12, 0));
        booleanCircles.add(temp);

        // SUBTRACT Example
        temp = new GArea(circle1);
        temp.subtract(circle2);
        // affine transform - translation 16um in x
        temp.transform(AffineTransform.getTranslateInstance(16, 0));
```

```
        booleanCircles.add(temp);

        lib.add(new Ref(booleanCCW, 0, 0));
        lib.add(new Ref(booleanCircles, 0, 0));
        //
        File f = lib.GDSOut("Example03BooleanOperationsTransformations.
            gds");
        System.out.println(" Saved to " + f.getAbsolutePath());
    }
}
```

4.1.4 Labeled Arrays

Labeled arrays could be created in a variety of ways using the nanolithography toolbox scripting methods. For instance, general areas could be instantiated using any of the available array methods. The following example uses a for loop to iterate through various diameters and separations with

```
public static void createSqrHoleC(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, int
    numSides, double pitchX, double pitchY, int numElementsX, int
    numElementsY, double THETA, int gdsLayer)
```

to create an array of circular objects, centered at position (x, y). Within the loop, labels for each array are created using the centered text method

```
public static GArea createTextGdsC(String textString, String fontName,
    double fontSize, double x, double y, double THETA, int gdsLayer,
    double shapeReso)
```

The program starts by initializing a GDS structure `top` (line 16). This structure will be used to hold instantiated arrays of various circular apertures. Lines 18-29 initialize a variety of variables used to create the arrayed structures. The nested `for` loop (lines 31-40) iterates through diameters and separations between circular array elements. In the inner loop, a pitch is calculated in line 33. Directly following, a string defining the GDS structure name of individual arrays is established (line 34). Number of array elements, based on the array extent and pitch, are calculated (line 35). Then `createSqrHoleC` method is used to create and instantiate the hole array patterns within the GDS structure `top` (line 36). A string label is defined using the diameter and pitch values (line 37) and a GDS area containing the text label is added to the GDS structure `top` (line 38). Figure 4.361 shows the rendered GDS output.

```
1 package cnstprogrammingexamples;
2
3 import CNST.Scripting;
4 import JGDS2.*;
5 import java.io.File;
6
7 /**
8  *
9  * @author rob
10  */
```

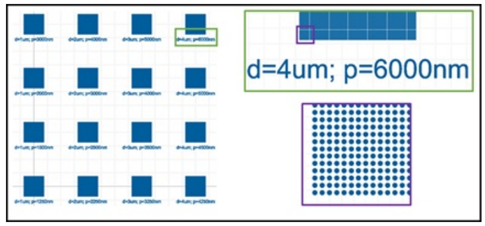


Figure 4.361: *Programming example of labeled arrays.*

```
public class Example04LabeledArrays {

    public static void main(String[] args) {
        Lib lib = new Lib();
        //
        Struct top = new Struct("top");
        // initialize variables
        double[] diameter = new double[]{1, 2, 3, 4};
        double[] separation = new double[]{0.25, 0.5, 1, 2};
        double arrayExtent = 750;
        double arrayPitch = 2000;
        String s, lbl;
        double pitch;
        int numSides = 44;
        int numElements;
        int gdsLayer = 4;
        double labelOffset = 200;
        double fontSize = 170;
        double shapeReso = 0.1;
        // for loop to create arrays and labels
        for (int i = 0; i < diameter.length; i++) {
            for (int j = 0; j < separation.length; j++) {
                pitch = (diameter[i] + separation[j]);
                s = "circle_d" + (int) diameter[i] + "um_p" + (int) (
                    pitch * 1000) + "nm";
                numElements = (int) (arrayExtent / pitch);
                Scripting.createSqrHoleC(s, top, i * arrayPitch, j *
                    arrayPitch, diameter[i] / 2, diameter[i] / 2,
                    numSides, pitch, pitch, numElements, numElements,
                    0, gdsLayer);
                lbl = "d=" + (int) diameter[i] + "um; p=" + (int) (
                    pitch * 1000) + "nm";
                top.add(Scripting.createTextGdsC(lbl, "Arial", fontSize
                    , i * arrayPitch, j * arrayPitch - labelOffset -
                    arrayExtent / 2, 0, gdsLayer, shapeReso));
            }
        }
        lib.add(new Ref(top, 0, 0));
        //
        File f = lib.GDSOut("Example04LabeledArrays.gds");
        System.out.println(" Saved to " + f.getAbsolutePath());
    }
}
```

4.1.5 MEMS Perforated Flexures

The following code creates a perforated MEMS flexure. The scripting element is called flexure2C and described in subsection 2.10.4. The code describes storing vector array elements into a GDS structure, then extracting various layers from a `Struct` and storing them into `GArea` objects. The stored flexure and circle array GDS areas are then used to construct a perforated structure via boolean subtraction.

Lines 17 and 19 create two GDS structures. Line 21 stores the flexure2C element into an `ArrayList<GArea>`. Using the `createStruct` method, the vector array al is stored into a GDS structure (line 24). Line 27 stores an array of circles with GDS layer 7 into a GDS structure. Figure 4.362a shows the GDS rendered output.

Lines 30 and 32 extract GDS areas with particular GDS layer numbers and stores the shapes into the instantiated `GArea` objects. Line 34 performs a boolean subtraction between the flexure and the circle array. The resulting perforated area is stored into the `top` structure (line 37). Line 40 extracts the anchors and stores them into the `top` structure. Figure 4.362b shows the GDS rendered output.

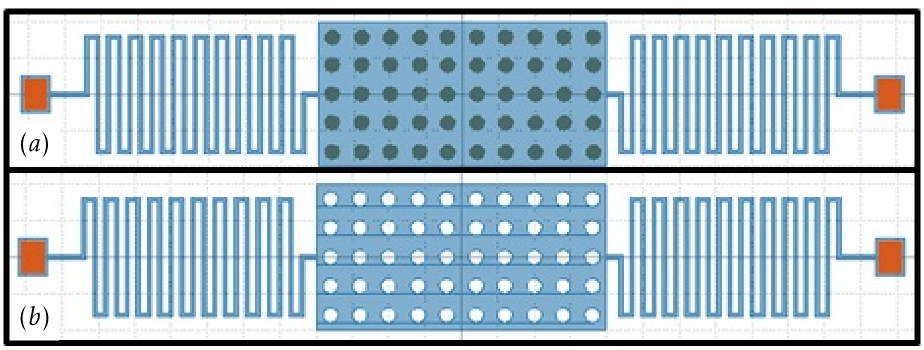


Figure 4.362: *Perforated flexures example showing GDS structures (a) flexureWithCircles and (b) top.*

```
1 package cnstprogrammingexamples;
2
3 import CNST.Scripting;
4 import JGDS2.*;
5 import java.io.File;
6 import java.util.ArrayList;
7
```

```java
/**
 *
 * @author rob
 */
public class Example05MEMSperforatedFlexure {

    public static void main(String[] args) {
        Lib lib = new Lib();
        //
        Struct top = new Struct("top");
        //
        Struct flexureWithCircles = new Struct("flexureWithCircles");
        // creating element flexure2C, structural layer = 4, anchor
            layer = 1
        ArrayList<GArea> al = Scripting.createFlexure2C(0, 0, 0.5, 5,
            30, 2, 40, 20, 8, 10, 5.2, 4, 0.4, 1, 0, 4);

        // store ArrayList<GArea> into Struct
        Scripting.createStruct(flexureWithCircles, al);

        // creating an array of circles (circle layer = 7) in
            flexureWithCircles Struct
        Scripting.createSqrHoleC("circleArray", flexureWithCircles, 0,
            0, 1, 1, 16, 4, 4, 10, 5, 0, 7);

        // extracting all objects with flexure layer 4
        GArea flexure = new GArea(flexureWithCircles.getArea(4), 4);
        // extracting all objects with circle layer 7
        GArea circle = new GArea(flexureWithCircles.getArea(7), 7);
        // boolean subtraction to create perforated flexure
        flexure.subtract(circle);

        // store boolean structure
        top.add(flexure);

        // extract and store anchors
        top.add(new GArea(flexureWithCircles.getArea(1), 1));
        //
        lib.add(new Ref(top, 0, 0));
        lib.add(new Ref(flexureWithCircles, 0, 0));
        //
        File f = lib.GDSOut("Example05MEMSperforatedFlexure.gds");
        System.out.println(" Saved to " + f.getAbsolutePath());
    }
}
```

4.1.6 Custom Class Methods

The following example creates three methods identical to ones that generate **yBend**, **yBendInv** and **yBendInvSlot** structures described in corresponding sections 2.9.3.10, 2.9.3.11 and 2.9.3.12. Figure 4.363 shows the three 90 degree y-bend structures.

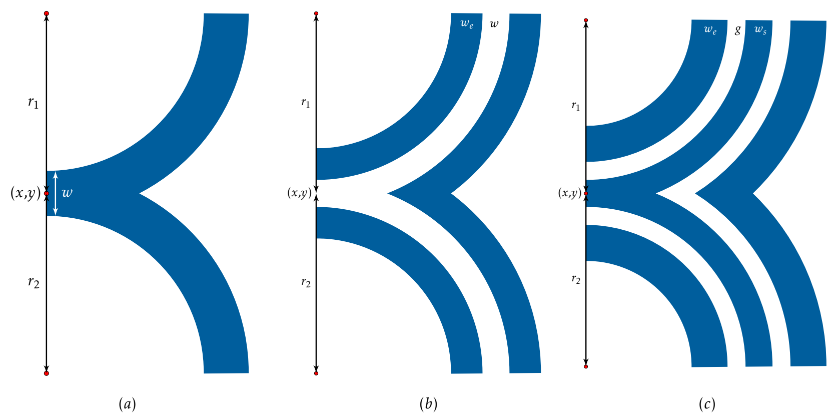


Figure 4.363: *Programming example of creating 90 degree (a) y-bend, (b) y-bend inverse and (c) y-bend inverse slot structures.*

The following code has four methods, `main`, `createYBend90`, `createYBendInv90` and `createYBendInvSlot90`. Within the main method, line 14 initializes the GDS library and lines 16 to 20 initialize variables used to define the 90 degree y-bend structures. Lines 22 to 24 create GDS structures to store shapes created by the respective methods. Here we use the following constructor

```
Struct(String structName, GDS2Element shape)
```

Line 22 creates a 90 degree y-bend (figure 4.363a) by implementing the `createYBend90` method defined by lines 37-41. The method simply creates upper arc using the `Scripting.createTorusW` method (line 38). The GDS area ga undergoes a Boolean `OR` with the lower arc. The arc shape is defined by the constructor **torusW** in section 2.3.15.

Similarly, line 23 and 24 creates the remaining two 90 degree y-bend structures (figure 4.363b and 4.363c). The methods `createYBendInv90` and `createYBendInvSlot90` reuse the defined `createYBend90` method to create the resulting shapes. For instance, `createYBendInv90` first creates a 90 degree y-bend of width $w+2w_e$ (line 47) and then subtracts a similar structure of width w (line 48) to create a 90 degree y-bend inverse GDS area. Analogously, lines 54-58 define a method that creates a 90 degree y-bend inverse slot structure.

```java
package cnstprogrammingexamples;

import CNST.Scripting;
import JGDS2.*;
import java.io.File;

/**
 *
 * @author rob
 */
public class Example06CustomClassMethods {

    public static void main(String[] args) {
        Lib lib = new Lib();
        // define variables
        double x = 0, y = 0;
        double r1 = 20, r2 = 20;
        double w = 1.4, we = 1, ws = 1, g = 0.25;
        int numSides = 44, gdsLayer = 4;
        double THETA = 0;
        //
        Struct yBend90 = new Struct("yBend90Test", createYBend90(x, y,
            r1, r2, w, numSides, THETA, gdsLayer));
        Struct yBendInv90 = new Struct("yBendInv90Test",
            createYBendInv90(x, y, r1, r2, w, we, numSides, THETA,
            gdsLayer));
        Struct yBendInvSlot90 = new Struct("yBendInvSlot90Test",
            createYBendInvSlot90(x, y, r1, r2, ws, g, we, numSides,
            THETA, gdsLayer));
        //
        lib.add(new Ref(yBend90, 0, 0));
        lib.add(new Ref(yBendInv90, 0, 0));
        lib.add(new Ref(yBendInvSlot90, 0, 0));
        //
        File f = lib.GDSOut("Example06CustomClassMethods.gds");
        System.out.println(" Saved to " + f.getAbsolutePath());
    }

    //
    // yBend90
    //
    public static GArea createYBend90(double x, double y, double r1,
        double r2, double w, int numSides, double THETA, int gdsLayer)
        {
        GArea ga = new GArea(Scripting.createTorusW(0, r1, r1, w, 270,
            360, numSides, 0, gdsLayer));
        ga.or(Scripting.createTorusW(0, -r2, r2, w, 0, 90, numSides, 0,
             gdsLayer));
        return Scripting.transformGArea(ga, THETA, x, y);
    }

    //
    // yBendInv90
    //
    public static GArea createYBendInv90(double x, double y, double r1,
         double r2, double w, double we, int numSides, double THETA,
        int gdsLayer) {
```

```
        GArea ga = createYBend90(x, y, r1, r2, w + 2 * we, numSides,
            THETA, gdsLayer);
        return ga.subtract(createYBend90(x, y, r1, r2, w, numSides,
            THETA, gdsLayer));
    }

    //
    // yBendInvSlot90
    //
    public static GArea createYBendInvSlot90(double x, double y, double
         r1, double r2, double ws, double g, double we, int numSides,
        double THETA, int gdsLayer) {
        GArea ga = createYBend90(x, y, r1, r2, ws + 2 * we + 2 * g,
            numSides, THETA, gdsLayer);
        ga.subtract(createYBend90(x, y, r1, r2, ws + 2 * g, numSides,
            THETA, gdsLayer));
        return ga.or(createYBend90(x, y, r1, r2, ws, numSides, THETA,
            gdsLayer));
    }

}
```

4.1.7 GDS Area Objects - Layers and Data-types

GDS layer definitions are typically defined within the method constructor. Layer data-types are either defined globally for subsequent GDS objects or GDS area objects are assigned to a data-type. For instance, within the following 4 lines, a structure is created, layer data-type 44 is set for subsequent shapes, the GDS area `ellipse` acquires the data-type value, and is added to the `Struct`.

```
Struct top = new Struct("top");
Scripting.setDataType(44);
GArea ellipse = Scripting.createEllipse(0, 0, 0.4, 0.8, 44, 0, 4);
top.add(singleEllipse);
```

The following is an equivalent strategy that casts the GDS area object onto a particular datatype.

```
Struct top = new Struct("top");
GArea ellipse = Scripting.createEllipse(0, 0, 0.4, 0.8, 44, 0, 4);
singleEllipse.setDataType(44);
top.add(singleEllipse);
```

4.1.8 Centering GDS Area Objects

The following code will find a centroid of a GDS shape. This procedure is useful for centering features around a specified origin or to create symmetric pattern extents. Lines 18 and 19 define a GDS structure and area, respectively. The GDS area is then added to the structure (line 20). In line 22, a new structure is formed that will store the resulting centered GDS area. The GDS area is extracted and stored into a Java `Area` (line23). Using the built-in Java `Rectangle2D` class, the area boundary is extracted in line 24. The GDS structure containing the GDS area is then instantiated with offsets determined by the `getCenterX()` and `getCenterY()` methods from the `Rectangle2D` class. Instead of instantiating, the GDS area object could be added directly to a GDS structure using affine translational transforms with `(-rec.getCenterX(), -rec.getCenterY())`.

```
1  package cnstprogrammingexamples;
2
3  import CNST.Scripting;
4  import JGDS2.*;
5  import java.awt.geom.Area;
6  import java.awt.geom.Rectangle2D;
7  import java.io.File;
8
9  /**
10  *
11  * @author rob
12  */
13 public class Example07AreaExtents {
14
15     public static void main(String[] args) {
16         Lib lib = new Lib();
17         // creating and storing a y-bend
18         Struct yBendTest = new Struct("yBendExample");
19         GArea yBend = Scripting.createYbend(0, 0, 10, 10, 20, -40, 1,
               0, 7, 0.01);
20         yBendTest.add(yBend);
21         // extracting pattern extents
22         Struct yBendCentered = new Struct("yBendCenteredShape");
23         Area a = new Area(yBend.getArea());
24         Rectangle2D rec = a.getBounds2D();
25         yBendCentered.add(new Ref(yBendTest, -rec.getCenterX(), -rec.
               getCenterY()));
26         //
27         lib.add(new Ref(yBendTest, 0, 0));
28         lib.add(new Ref(yBendCentered, 0, 0));
29         File f = lib.GDSOut("Example07AreaExtents.gds");
30         System.out.println(" Saved to " + f.getAbsolutePath());
31     }
32 }
```

4.1.9 PostScript to GDS

The below code creates a GDS area using a string containing postscript commands. Unlike scripting, where the the number of postscript commands is practically unlimited, with the programming interface it is limited. This limitation stems from the Java `String` length limit. As defined by the Java specifications, a `String` has a maximum character length of `Integer.MAX_VALUE` $= (2^{31} - 1)$. A host of memory dilemmas will be encountered prior reaching this limit, hence instead of holding all postscript commands in one `String`, the commands could be distributed over multiple Strings.

Example 8 implements an interface (Example08PSinterface.java) that contains a string `s` with postscript paths (line 11). Variables are defined and a GDS structure is created (lines 16 to 21) in a similar manner to previous programming examples. Line 22 uses a method **createPostScript** in conjunction with a `String psString` to generate output GDS shapes. String variable `psString` is defined in the Example08PSinterface.java interface file. The following two methods are available for creating GDS shapes from vectorized objects:

```
public static ArrayList<GArea> createPostScript(double x, double y,
    String s, int fractureSegments, double THETA, double shapeReso,
    double pixelValue, int gdsLayer)
```

```
public static void createPostScript(Struct currentStruct, double x,
    double y, String s, int fractureSegments, double THETA, double
    shapeReso, double pixelValue, int gdsLayer)
```

In our example we used the `void` method (line 22), that directly stores generated shapes into a specified (`currentStruct`) GDS structure. The lower left corner of the structure is positioned at (x, y). The resulting structure is fractured into a number of equal segments defined by the integer value of `fractureSegments`. Parameters `THETA, shapeReso, pixelValue` and `gdsLayer` are rotation about (x, y), rendering resolution of the vectorized shape(section 2.2.6), pixel scaling value of the postscript coordinates (section 2.6.5.1) and GDS layer number, respectively.

```
1  package cnstprogrammingexamples;
2
3  import CNST.Scripting;
4  import JGDS2.*;
5  import java.io.File;
6
7  /**
8   *
9   * @author rob
10  */
11 public class Example08PostScriptFracturing implements
       Example08PSinterface {
```

```java

    public static void main(String[] args) {
        Lib lib = new Lib();
        // variables
        int gdsLayer = 44;
        double shapeReso = 0.001;
        double pixelValue = .1;
        int fractureSegments = 10;
        //
        Struct ps2gds = new Struct("postScript2GDS");
        Scripting.createPostScript(ps2gds, 0, 0, psString,
            fractureSegments, 0, shapeReso, pixelValue, gdsLayer);
        //
        lib.add(new Ref(ps2gds, 0, 0));
        File f = lib.GDSOut("Example08PostScriptFracturing.gds");
        System.out.println(" Saved to " + f.getAbsolutePath());
    }
}
```

4.1.10 Curved Fluidic Channels

The following example creates two sets of labeled fluidic channels using pre-defined scripting methods. Straight segments were constructed using the waveguide method that defines a rectangular shape between points (x_1, y_1) and (x_2, y_2). The curved segments were created using either bezier curves or 90 degree torus bends.

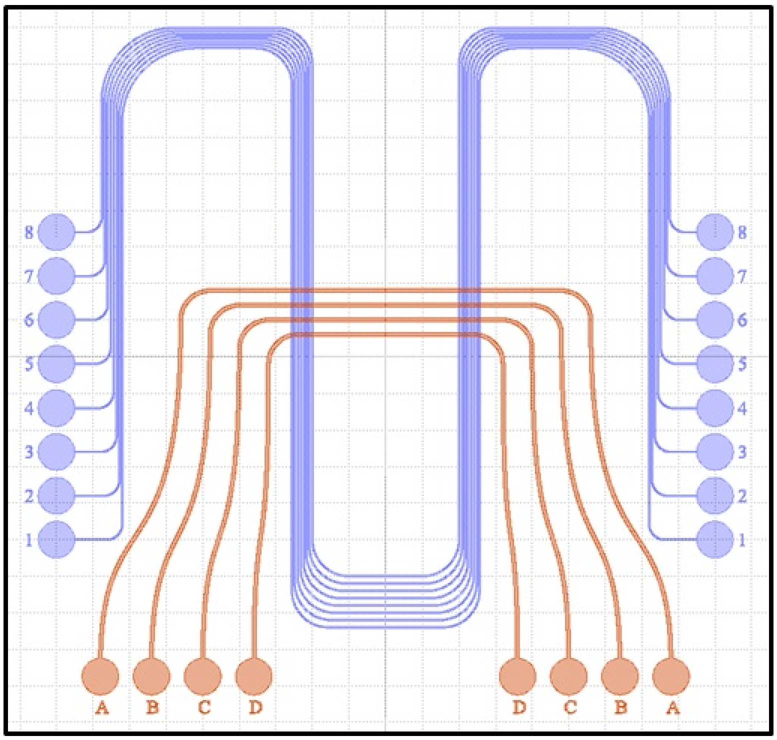


Figure 4.364: *Programming example of labeled fluidic channels.*

```
package cnstprogrammingexamples;

import CNST.Scripting;
import JGDS2.*;
import java.awt.geom.AffineTransform;
import java.io.File;

/**
 *
 * @author rob
 */
public class Example09CurvedFluidicChannels {
    public static void main(String[] args) {
        Lib lib = new Lib();
```

```
        //
        int layerChannel = 4, layerChannel2 = 7, numElectrodes = 8;
        double shapeReso = 0.1, fontSize = 250;
        double chipSize = 10000, electrodeRadius = 250,
            electrodeSpacing = 100, channelWidth = 20;
        GArea electrode = Scripting.createEllipse(0, 0, electrodeRadius
            , electrodeRadius, 100, 0, layerChannel);
        Struct chip = new Struct("chip");
        AffineTransform at = new AffineTransform(new double[]{-1.0,
            0.0, 0.0, 1.0});
        // side channels 1-8
        for (int i = 0; i < numElectrodes; i++) {
            GArea channels = new GArea(electrode);
            GArea label = Scripting.createTextGdsC("" + (i + 1), "Serif
                ", fontSize, -electrodeRadius - fontSize / 2, 0, 0,
                layerChannel, shapeReso);
            double x = 2 * electrodeRadius;
            double y = chipSize / 4 + i * (2 * electrodeRadius +
                electrodeSpacing);
            double x2 = x + 200 - i * channelWidth * 2;
            double x3 = 200, y3 = chipSize - 1500 - (numElectrodes - i
                - 1) * 40 - y;
            channels.or(Scripting.createWaveGuide(0, 0, x2, 0,
                channelWidth, 0, 0, 0, layerChannel));
            channels.or(Scripting.create90degreeBendLH(x2, 0, x3, 200,
                channelWidth, 0, layerChannel, shapeReso));
            channels.or(Scripting.createWaveGuide(x2 + x3, 200, x2 + x3
                , y3, channelWidth, 0, 0, 0, layerChannel));
            double radiusChannel = 1000;
            double x4 = x2 + x3 + radiusChannel;
            channels.or(Scripting.createTorusW(x4, y3, radiusChannel,
                channelWidth, 90, 180, 100, 0, layerChannel));
            double y4 = y3 + radiusChannel;
            double x5 = chipSize / 2 - 2000 - (numElectrodes - i - 1) *
                 40;
            channels.or(Scripting.createWaveGuide(x4, y4, x5, y4,
                channelWidth, 0, 0, 0, layerChannel));
            radiusChannel = 500;
            double y5 = y4 - radiusChannel;
            channels.or(Scripting.createTorusW(x5, y5, radiusChannel,
                channelWidth, 0, 90, 100, 0, layerChannel));
            double x6 = x5 + radiusChannel;
            double y6 = -y + 2500 - (numElectrodes - i - 1) * 100;
            channels.or(Scripting.createWaveGuide(x6, y5, x6, y6,
                channelWidth, 0, 0, 0, layerChannel));
            radiusChannel = 500;
            double x7 = x6 + radiusChannel;
            channels.or(Scripting.createTorusW(x7, y6, radiusChannel,
                channelWidth, 180, 270, 100, 0, layerChannel));
            double y7 = y6 - radiusChannel;
            double x8 = chipSize / 2 - x;
            channels.or(Scripting.createWaveGuide(x7, y7, x8, y7,
                channelWidth, 0, 0, 0, layerChannel));
            channels.transform(AffineTransform.getTranslateInstance(-
                chipSize / 2 + x, -chipSize / 2 + y));
            GArea channelsMirror = new GArea(channels);
            channelsMirror.transform(at); // mirror around y-axis
```

```
            chip.add(channels);
            chip.add(channelsMirror);
            chip.add(label.transform(AffineTransform.
                getTranslateInstance(-chipSize / 2 + x, -chipSize / 2 +
                 y)));
            GArea temp = new GArea(label);
            chip.add(temp.transform(AffineTransform.
                getTranslateInstance(chipSize - x / 2, 0)));
        }
        // bottom channels
        electrodeSpacing = 200;
        channelWidth = 50;
        double offsetX = 400;
        for (int i = 0; i < numElectrodes / 2; i++) {
            GArea channels = new GArea(electrode);
            double x = (i + 1) * (2 * electrodeRadius +
                electrodeSpacing) + offsetX;
            double y = 2.5 * electrodeRadius;
            double x2 = x - i * channelWidth * 20;
            double y2 = 0.55 * chipSize - y - i * channelWidth * 4;
            channels.or(Scripting.createBezierCurve(0, electrodeRadius
                / 2, 0, chipSize / 4, x2, chipSize / 8, x2, y2,
                channelWidth, shapeReso, 0, layerChannel2));
            double radiusChannel = 400;
            double x3 = x2 + radiusChannel;
            channels.or(Scripting.createTorusW(x3, y2, radiusChannel,
                channelWidth, 90, 180, 100, 0, layerChannel2));
            double y3 = y2 + radiusChannel;
            double x4 = chipSize / 2 - x;
            channels.or(Scripting.createWaveGuide(x3, y3, x4, y3,
                channelWidth, 0, 0, 0, layerChannel));
            channels.transform(AffineTransform.getTranslateInstance(-
                chipSize / 2 + x, -chipSize / 2 + y));
            channels.setLayer(layerChannel2);
            GArea channelsMirror = new GArea(channels);
            channelsMirror.transform(at); // mirror around y-axis
            chip.add(channels);
            chip.add(channelsMirror);
        }
        // Labels for the bottom electrodes
        double x = -chipSize / 2 + (2 * electrodeRadius +
            electrodeSpacing) + offsetX - fontSize / 4;
        double y = -chipSize / 2 + fontSize / 2;
        double pitch = (2 * electrodeRadius + electrodeSpacing);
        Scripting.createLabelMakerAutoOutLett(0, 4, "Serif", fontSize,
            x, y, 0, 0, pitch, 1, chip,
                layerChannel2, shapeReso); // label A B C D
        x = Math.abs(x)-fontSize/2;
        Scripting.createLabelMakerAutoOutLett(0, 4, "Serif", fontSize,
            x, y, 0, 0, -pitch, 1, chip, layerChannel2, shapeReso); //
            label D C B A
        //
        lib.add(new Ref(chip, 0, 0));
        File f = lib.GDSOut("fluidics.gds");
        System.out.println(" Saved to " + f.getAbsolutePath());
    }
}
```

4.2 Reference Methods

The following subsection contain method headers that create complex GDS objects. These shapes are fully described in the GDS scripting chapter. Excluding access, mutator and miscellaneous methods, the shape methods names have the `create` followed by the script constructor name with the first letter capitalized. For instance, the **ellipse** scripting constructor (also shown in the previous comment line) would have a method entitled **createEllipse**

```
// ellipse
public static GArea createEllipse(double x, double y, double radiusX,
    double radiusY, int numSides, double THETA, int gdsLayer)
```

Directly following the method name are a set of parameters. All methods have a parameter list with the exception of accessor methods that have empty parameter lists. Methods return types are either `void`, `GArea` or `ArrayList<GArea>`. Since `Struct` objects add `GArea` objects but not array lists of these objects, each vector array return types also have a void method. The void method stores the `ArrayList<GArea>` into the passed `Struct currentStruct`. Section 4.2.2 contains methods for dealing with `GArea` or `ArrayList<GArea>` objects. These are useful for controlling GDS area objects in custom user defined methods.

4.2.1 Accessor and Mutator Methods

```
public static double getFontOutline()
```

```
public static int getFracElements()
```

```
public static double getGDSreso()
```

```
public static int getLayer()
```

```
public static int getDataType()
```

```
public static double getPixelValue()
```

```
public static double getShapeReso()
```

```
public static void setFontOutline(double fontOutlineWidth)
```

```
public static void setFracElements(int fracElements)
```

```
public static void setGDSreso(double gdsReso)
```

```
public static void setLayer(int layer)
```

```
public static void setDataType(int layer)
```

```
public static void setPixelValue(double pixelValue)
```

```
public static void setShapeReso(double shapeReso)
```

4.2.2 Miscellaneous GDS Area and Struct Methods

These methods are used for affine transformations of single and vector array GDS area objects. Furthermore, the void methods place constructed vector arrays of `GArea` objects into a GDS structure.

```
// createStruct - place ga into currentStruct
public static void createStruct(Struct currentStruct, ArrayList<GArea>
    ga)


// createStruct - mirror ga then place ga into currentStruct
public static void createStruct(Struct currentStruct, ArrayList<GArea>
    ga, boolean MIRROR)


// createStructRotate - rotation only - then place ga into
    currentStruct
public static void createStructRotate(Struct currentStruct, ArrayList<
    GArea> ga, double THETA, double x, double y)


// createStructTranslateRotate - translate then rotate ga then place ga
     into currentStruct
public static void createStructTranslateRotate(Struct currentStruct,
    ArrayList<GArea> ga, double THETA, double x, double y)


// rotateGArea - rotate GArea v about a point (x,y)
public static GArea rotateGArea(GArea v, double THETA, double x, double
     y)


// transformGArea - translate v to (x,y) then rotate about (x,y)
public static GArea transformGArea(GArea v, double THETA, double x,
    double y)


// rotateArrayListGArea - rotate ArrayList ga about (x,y)
public static ArrayList<GArea> rotateArrayListGArea(ArrayList<GArea> ga
    , double THETA, double x, double y) {


// transormArrayListGArea - ArrayList ga translate to (x,y) then rotate
     about (x,y)
public static ArrayList<GArea> transformArrayListGArea(ArrayList<GArea>
     ga, double THETA, double x, double y)
```

4.2.3 Shape Methods

```
// ellipse
public static GArea createEllipse(double x, double y, double radiusX,
    double radiusY, int numSides, double THETA, int gdsLayer)


// ellipseVector
public static GArea createEllipseVector(double x, double y, double
    radiusX, double radiusY, double THETA, int gdsLayer, double
    shapeReso)


// circlethree
public static GArea createCircleThree(double x1, double y1, double x2,
    double y2, double x3, double y3, int numSides, double THETA, int
    gdsLayer)


// circleWave
public static GArea createCircleWave(double x, double y, double r, int
    n, double A, int numSides, double THETA, int gdsLayer)


// cross
public static GArea createCross(double x, double y, double W, double L,
     double THETA, int gdsLayer)


// Lshape
public static GArea createLshape(double x, double y, double W1, double
    L1, double W2, double L2, double THETA, int gdsLayer)


// arc
public static GArea createArc(double x, double y, double rX, double rY,
     double angleStart, double angleEnd, int numSides, double THETA,
    int gdsLayer)


// arcVector
public static GArea createArcVector(double x, double y, double rX,
    double rY, double angleStart, double angleEnd, double THETA, int
    gdsLayer, double shapeReso)


// polygon
public static GArea createPolygon(double x, double y, double r, int
    numSides, double THETA, int gdsLayer, double shapeReso)


// rectangle
public static GArea createRectangle(double xLL, double yLL, double xUR,
     double yUR, double THETA, int gdsLayer)
```

```
// rectangleLH
public static GArea createRectangleLH(double xLL, double yLL, double L,
     double H, double THETA, int gdsLayer)


// rectangleC
public static GArea createRectangleC(double xC, double yC, double L,
    double H, double THETA, int gdsLayer)


// roundrect
public static GArea createRoundRect(double xLL, double yLL, double L,
    double H, double rX, double rY, double THETA, int gdsLayer, double
    shapeReso)


// rectSUshape
public static GArea createRectSUshape(double x, double y, double L1,
    double L2, double L3, double W, double THETA, int gdsLayer)


// rectTaper
public static GArea createRectTaper(double x, double y, double w1,
    double L1, double w2, double L2, double THETA, int gdsLayer)


// star
public static GArea createStar(double x, double y, double rIn, double
    rOut, int numPoints, double THETA, int gdsLayer, double shapeReso)


// torus
public static GArea createTorus(double x, double y, double rIn, double
    rOut, double angleStart, double angleEnd, int numPoints, double
    THETA, int gdsLayer)


// torusW
public static GArea createTorusW(double x, double y, double r, double
    width, double angleStart, double angleEnd, int numPoints, double
    THETA, int gdsLayer)


// torusVector
public static GArea createTorusVector(double x, double y, double rIn,
    double rOut, int gdsLayer, double shapeReso)


// torusWaveIn
public static GArea createTorusWaveIn(double x, double y, double rIn,
    double rOut, int n, double A, int numSides, double THETA, int
    gdsLayer)

// torusWaveOut
public static GArea createTorusWaveOut(double x, double y, double rIn,
    double rOut, int n, double A, int numSides, double THETA, int
    gdsLayer)
```

4.2.4 Array Methods

```
// arrayRectV1
public static void createArrayRectV1(Struct structToBeArrayed, Struct
    currentStruct, double x, double y, int numColumns, int numRows,
    double dx, double dy)


// arrayRectV2
public static void createArrayRectV2(Struct structToBeArrayed, Struct
    currentStruct, double x, double y, int numColumns, int numRows,
    double xE, double yE)


// arrayHex
public static void createArrayHex(Struct structToBeArrayed, Struct
    currentStruct, double x, double y, int numColumns, int numRows,
    double ds)


// arrayPolarV1
public static void createArrayPolarV1(Struct structToBeArrayed, Struct
    currentStruct, double angleStart, double angleEnd, double
    deltaAngle, double radiusStart, double radiusEnd, double
    deltaRadius)


// arrayPolarV1R
public static void createArrayPolarV1R(Struct structToBeArrayed, Struct
     currentStruct, double angleStart, double angleEnd, double
    deltaAngle, double radiusStart, double radiusEnd, double
    deltaRadius)


// arrayPolarV2
public static void createArrayPolarV2(Struct structToBeArrayed, Struct
    currentStruct, double angleStart, double angleEnd, double
    numberOfAngles, double radiusStart, double radiusEnd, double
    numberOfRadii)


// arrayPolarV2R
public static void createArrayPolarV2R(Struct structToBeArrayed, Struct
     currentStruct, double angleStart, double angleEnd, double
    numberOfAngles, double radiusStart, double radiusEnd, double
    numberOfRadii)
```

Instantiation using **instance**, **instanceSym** and **points2instance** can be accomplished using the JGDS reference (`Ref`) constructor. Refer to the JGDS manual for information on `Ref`.

```
// sqrPillar
public static void createSqrPillar(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, int
    numSides, double pitchX, double pitchY, int numElementsX, int
    numElementsY, double THETA, int gdsLayer)


// hexPillar
public static void createHexPillar(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, int
    numSides, double pitchX, int numElementsX, int numElementsY, double
     THETA, int gdsLayer)


// sqrHole
public static void createSqrHole(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, int
    numSides, double pitchX, double pitchY, int numElementsX, int
    numElementsY, double THETA, int gdsLayer)


// hexHole
public static void createHexHole(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, int
    numSides, double pitchX, int numElementsX, int numElementsY, double
     THETA, int gdsLayer)


// sqrPillarC
public static void createSqrPillarC(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, int
    numSides, double pitchX, double pitchY, int numElementsX, int
    numElementsY, double THETA, int gdsLayer)


// hexPillarC
public static void createHexPillarC(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, int
    numSides, double pitchX, int numElementsX, int numElementsY, double
     THETA, int gdsLayer)


// sqrHoleC
public static void createSqrHoleC(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, int
    numSides, double pitchX, double pitchY, int numElementsX, int
    numElementsY, double THETA, int gdsLayer)


// hexHoleC
public static void createHexHoleC(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, int
    numSides, double pitchX, int numElementsX, int numElementsY, double
     THETA, int gdsLayer)
```

```java
// sqrPillarV
public static void createSqrPillarV(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, double
    pitchX, double pitchY, int numElementsX, int numElementsY, double
    THETA, int gdsLayer, double shapeReso)


// hexPillarV
public static void createHexPillarV(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, double
    pitchX, int numElementsX, int numElementsY, double THETA, int
    gdsLayer, double shapeReso)


// sqrHoleV
public static void createSqrHoleV(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, double
    pitchX, double pitchY, int numElementsX, int numElementsY, double
    THETA, int gdsLayer, double shapeReso)


// hexHoleV
public static void createHexHoleV(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, double
    pitchX, int numElementsX, int numElementsY, double THETA, int
    gdsLayer, double shapeReso)


// sqrPillarVC
public static void createSqrPillarVC(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, double
    pitchX, double pitchY, int numElementsX, int numElementsY, double
    THETA, int gdsLayer, double shapeReso)


// hexPillarVC
public static void createHexPillarVC(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, double
    pitchX, int numElementsX, int numElementsY, double THETA, int
    gdsLayer, double shapeReso)


// sqrHoleVC
public static void createSqrHoleVC(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, double
    pitchX, double pitchY, int numElementsX, int numElementsY, double
    THETA, int gdsLayer, double shapeReso)


// hexHoleVC
public static void createHexHoleVC(String uniqueStructName, Struct
    currentStruct, double x, double y, double rX, double rY, double
    pitchX, int numElementsX, int numElementsY, double THETA, int
    gdsLayer, double shapeReso)
```

4.2.5 Text, Labels, PostScript and Logo Methods

```
// textgds
public static GArea createTextGds(String textString, String fontName,
    double fontSize, double x, double y, double THETA, int gdsLayer,
    double shapeReso)


// textgdsC
public static GArea createTextGdsC(String textString, String fontName,
    double fontSize, double x, double y, double THETA, int gdsLayer,
    double shapeReso)


// textOutline
public static ArrayList<GArea> createTextOutline(String textString,
    String fontName, double fontSize, double x, double y, double THETA,
     double fontOutlineWidth, int gdsLayer, double shapeReso)


// textOutline
public static void createTextOutline(Struct currentStruct, String
    textString, String fontName, double fontSize, double x, double y,
    double fontOutlineWidth, int gdsLayer, double shapeReso, double
    THETA)


// textOutlineC
public static ArrayList<GArea> createTextOutlineC(String textString,
    String fontName, double fontSize, double x, double y, double THETA,
     double fontOutlineWidth, int gdsLayer, double shapeReso)


// textOutlineC
public static void createTextOutlineC(Struct currentStruct, String
    textString, String fontName, double fontSize, double x, double y,
    double fontOutlineWidth, int gdsLayer, double shapeReso, double
    THETA)


// labelMaker autoOut
public static void createLabelMakerAutoOut(int rows, int columns,
    String fontName, double fontSize, double x, double y, double xRow,
    double yRow, double pitchX, double pitchY, Struct currentStruct,
    int gdsLayer, double shapeReso)


// labelMaker autoRowCol
public static void createLabelMakerAutoRowCol(int rows, int columns,
    String fontName, double fontSize, double x, double y, double pitchX
    , double pitchY, Struct currentStruct, int gdsLayer, double
    shapeReso)

// labelMaker autoOutLett
public static void createLabelMakerAutoOutLett(int rows, int columns,
    String fontName, double fontSize, double x, double y, double xRow,
```

```java
    double yRow, double pitchX , double pitchY , Struct currentStruct ,
    int gdsLayer , double shapeReso)


// labelMaker autoRowColLett
public static void createLabelMakerAutoRowColLett(int rows , int columns
    , String fontName , double fontSize , double x , double y , double
    pitchX , double pitchY , Struct currentStruct , int gdsLayer , double
    shapeReso)


// labelMaker CUSTOM OUTER
public static void createLabelMakerCustomOuter(String[] stringArray ,
    int rows , int columns , String fontName , double fontSize , double x ,
    double y , double xRow , double yRow , double pitchX , double pitchY ,
    Struct str , int gdsLayer , double shapeReso)


// labelMaker CUSTOM ROW COLUMN label
public static void createLabelMakerCustomRowColumn(String[] stringArray
    , int rows , int columns , String fontName , double fontSize , double x
    , double y , double pitchX , double pitchY , Struct str , int gdsLayer ,
     double shapeReso)


// labelOutline autoOut
public static void createLabelOutlineAutoOut(int rows , int columns ,
    String fontName , double fontSize , double x , double y , double xRow ,
    double yRow , double pitchX , double pitchY , Struct currentStruct ,
    double fontOutlineWidth , int gdsLayer , double shapeReso)


// labelOutline autoRowCol
public static void createLabelOutlineAutoRowCol(int rows , int columns ,
    String fontName , double fontSize , double x , double y , double pitchX
    , double pitchY , Struct currentStruct , double fontOutlineWidth , int
     gdsLayer , double shapeReso)


// labelOutline autoOutLett
public static void createLabelOutlineAutoOutLett(int rows , int columns ,
     String fontName , double fontSize , double x , double y , double xRow ,
     double yRow , double pitchX , double pitchY , Struct currentStruct ,
    double fontOutlineWidth , int gdsLayer , double shapeReso)


// labelOutline autoRowColLett
public static void createLabelOutlineAutoRowColLett(int rows , int
    columns , String fontName , double fontSize , double x , double y ,
    double pitchX , double pitchY , Struct currentStruct , double
    fontOutlineWidth , int gdsLayer , double shapeReso)


// labelOutline CUSTOM OUTER
public static void createLabelOutlineCustomOuter(String[] stringArray ,
    int rows , int columns , String fontName , double fontSize , double x ,
    double y , double xRow , double yRow , double pitchX , double pitchY ,
```

```
    Struct str, double fontOutlineWidth, int gdsLayer, double shapeReso
    )


// labelOutline CUSTOM ROW COLUMN label
public static void createLabelOutlineCustomRowColumn(String[]
    stringArray, int rows, int columns, String fontName, double
    fontSize, double x, double y, double pitchX, double pitchY, Struct
    str, double fontOutlineWidth, int gdsLayer, double shapeReso)


// postScript
public static ArrayList<GArea> createPostScript(double x, double y,
    String s, int fractureSegments, double THETA, double shapeReso,
    double pixelValue, int gdsLayer)


// postScript
public static void createPostScript(Struct currentStruct, double x,
    double y, String s, int fractureSegments, double THETA, double
    shapeReso, double pixelValue, int gdsLayer)


// cnstEmblem
public static GArea createCnstEmblemLogo(double x, double y, double
    scale, double THETA, double shapeReso, int gdsLayer) throws
    FileNotFoundException


// cnstLogo
public static GArea createCnstLogo(double x, double y, double scale,
    double THETA, double shapeReso, int gdsLayer) throws
    FileNotFoundException


// nistLogo
public static GArea createNistLogo(double x, double y, double scale,
    double THETA, double shapeReso, int gdsLayer) throws
    FileNotFoundException


// nistCnstLogo
public static GArea getNistCnstLogo(double x, double y, double scale,
    double THETA, double shapeReso, int gdsLayer) throws
    FileNotFoundException
```

4.2.6 Miscellaneous Object Methods

```java
// arcSquareFill
public static void createArcSquareFill(Struct currentStruct, String
    uniqueStructName, double x, double y, double rIn, double rOut,
    double angleStart, double angleEnd, int numSides, double THETA,
    double rSmallObject, int numSidesSmallObject, double pitchX, int
    gdsLayer)


// arcSquareFillV
public static void createArcSquareFillV(Struct currentStruct, String
    uniqueStructName, double x, double y, double rIn, double rOut,
    double angleStart, double angleEnd, int numSides, double THETA,
    double rSmallObject, double pitchX, double shapeReso, int gdsLayer)


// arcHexFill
public static void createArcHexFill(Struct currentStruct, String
    uniqueStructName, double x, double y, double rIn, double rOut,
    double angleStart, double angleEnd, int numSides, double THETA,
    double rSmallObject, int numSidesSmallObject, double pitchX, int
    gdsLayer)


// arcSquareFillV
public static void createArcHexFillV(Struct currentStruct, String
    uniqueStructName, double x, double y, double rIn, double rOut,
    double angleStart, double angleEnd, int numSides, double THETA,
    double rSmallObject, double pitchX, double shapeReso, int gdsLayer)


// bezierCurve
public static GArea createBezierCurve(double x1, double y1, double cx1,
     double cy1, double cx2, double cy2, double x2, double y2, double
    width, double shapeReso, double THETA, int gdsLayer)


// bezierCurveInv
public static GArea createBezierCurveInv(double x1, double y1, double
    cx1, double cy1, double cx2, double cy2, double x2, double y2,
    double sleeveWidth, double slotWidth, double shapeReso, double
    THETA, int gdsLayer)


// bezierCurveInvSlot
public static GArea createBezierCurveInvSlot(double x1, double y1,
    double cx1, double cy1, double cx2, double cy2, double x2, double
    y2, double sleeveWidth, double slotWidth, double gap, double
    shapeReso, double THETA, int gdsLayer)


// sierpinskiTriangle
public static void createSierpinskiTriangle(Struct currentStruct,
    String shortStructName, double x, double y, int iterations, double
    length, int gdsLayer)
```

```
// sierpinskiCarpet
public static void createSierpinskiCarpet(Struct currentStruct, String
    shortStructName, double x, double y, int iterations, double length,
     int gdsLayer)


// vicsekSaltire
public static void createVicsekSaltire(Struct currentStruct, String
    shortStructName, double x, double y, int iterations, double length,
     int gdsLayer)


// vicsekCross
public static void createVicsekCross(Struct currentStruct, String
    shortStructName, double x, double y, int iterations, double length,
     int gdsLayer)


// curvedTree
public static void createCurvedTree(Struct currentStruct, String
    shortStructName, double x, double y, double length, double width,
    int iterations, int gdsLayer)


// anotherTree fractal - undocumented Fractal
public static void createAnotherTree(Struct currentStruct, String
    shortStructName, double x, double y, int iterations, int gdsLayer)


// complex tree fractal - undocumented Fractal - vary parameters
public static void createTree(Struct currentStruct, String
    shortStructName, double x, double y, double d, double ang, double
    ratio, int depth, int gdsLayer)


// functionXY
public static ArrayList<GArea> createFunctionXY(String function, double
     xLowerLimit, double xUpperLimit, int N, double W, int CAP, int
    JOIN, int gdsLayer) throws ScriptException


// functionXY
public static void createFunctionXY(Struct currentStruct, String
    function, double x, double y, double xLowerLimit, double
    xUpperLimit, int N, double W, int CAP, int JOIN, double THETA)
    throws ScriptException


// functionRTheta
public static ArrayList<GArea> createFunctionRTheta(String function,
    double x, double y, double thetaLowerLimit, double thetaUpperLimit,
     int N, double W, int CAP, int JOIN, int gdsLayer) throws
    ScriptException
```

```
// functionRTheta
public static void createFunctionRTheta(Struct currentStruct, String
    function, double x, double y, double thetaLowerLimit, double
    thetaUpperLimit, int N, double W, int CAP, int JOIN, double THETA)
    throws ScriptException


// grayERamp
public static ArrayList<GArea> createGrayERamp(double x, double y,
    double dX, double dY, int numberOfSegments, double THETA)


// grayERamp
public static void createGrayERamp(Struct currentStruct, double x,
    double y, double dX, double dY, int numberOfSegments, double THETA)


// grayENgon
public static ArrayList<GArea> createGrayENgon(double x, double y,
    double radX, double radY, int numberOfSegments, int numSides,
    double THETA)


// grayENgon
public static void createGrayENgon(Struct currentStruct, double x,
    double y, double radX, double radY, int numberOfSegments, int
    numSides, double THETA)



// grayUDR - al contains dx and dy coordinate pairs
public static ArrayList<GArea> createGrayUDR(double x, double y,
    ArrayList<Double> al, double THETA)


// grayUDR - al contains dx and dy coordinate pairs
public static void createGrayUDR(Struct currentStruct, double x, double
     y, ArrayList<Double> al, double THETA)


// grayUDNgon - al contains dx and dy coordinate pairs
public static ArrayList<GArea> createGrayUDNgon(double x, double y,
    ArrayList<Double> al, int numSides, double THETA)


// grayUDNgon - al contains dx and dy coordinate pairs
public static void createGrayUDNgon(Struct currentStruct, double x,
    double y, ArrayList<Double> al, int numSides, double THETA)


// grayERamp - UP = true or false
public static ArrayList<GArea> createGrayERamp(double x, double y,
    double dX, double dY, int numberOfSegments, boolean UP, double
    THETA)


// grayERamp - UP = true or false
```

```java
public static void createGrayERamp(Struct currentStruct, double x,
    double y, double dX, double dY, int numberOfSegments, boolean UP,
    double THETA)


// grayERamp2
public static ArrayList<GArea> createGrayERamp2(double x, double y,
    double dX, double dY, int numberOfSegments, double THETA)


// grayERamp2
public static void createGrayERamp2(Struct currentStruct, double x,
    double y, double dX, double dY, int numberOfSegments, double THETA)


// grayUDRamp - al contains x1, x2, .... xn
public static ArrayList<GArea> createGrayUDRamp(double x, double y,
    ArrayList<Double> al, double dY, boolean UP, double THETA)


// grayUDRamp - al contains x1, x2, .... xn
public static void createGrayUDRamp(Struct currentStruct, double x,
    double y, ArrayList<Double> al, double dY, boolean UP,double THETA)


// grayUDRamp2 - al contains x1, x2, .... xn
public static ArrayList<GArea> createGrayUDRamp2(double x, double y,
    ArrayList<Double> al, double dY, double THETA)


// grayUDRamp2 - al contains x1, x2, .... xn
public static void createGrayUDRamp2(Struct currentStruct, double x,
    double y, ArrayList<Double> al, double dY, double THETA)


// graySpiralStairOverlap - create grayscale OVERLAPPING ARCs
public static void createGraySpiralStairOverlap(Struct currentStruct,
    double x, double y, double rIn, double rOut, int numSegments, int
    numSides, double THETA)


// graySpiralStair - create grayscale NON-Overlapping ARCs
public static ArrayList<GArea> createSpiralStair(double x, double y,
    double rIn, double rOut, int numSegments, int numSides, double
    THETA)


// graySpiralStair - create grayscale NON-Overlapping ARCs
public static void createGraySpiralStair(Struct currentStruct, double x
    , double y, double rIn, double rOut, int numSegments, int numSides,
     double THETA)


// intElec1
public static ArrayList<GArea> createIntElec1(double x, double y,
    double width1, double width2, double length1, double length2,
    double overlap, int numElectrodes, double pitch, double baseHeight,
```

```
     double baseWidth, double THETA, int gdsLayer)


// intElec1
public static void createIntElec1(Struct currentStruct, double x,
    double y, double width1, double width2, double length1, double
    length2, double overlap, int numElectrodes, double pitch, double
    baseHeight, double baseWidth, double THETA, int gdsLayer)


// intElec2
public static ArrayList<GArea> createIntElec2(double x, double y,
    double width1, double width2, double length1, double length2,
    double overlap, int numElectrodes, double pitch, double baseHeight,
     double baseWidth, double THETA, int gdsLayer)


// intElec2
public static void createIntElec2(Struct currentStruct, double x,
    double y, double width1, double width2, double length1, double
    length2, double overlap, int numElectrodes, double pitch, double
    baseHeight, double baseWidth, double THETA, int gdsLayer)


// intElec3
public static ArrayList<GArea> createIntElec3(double x, double y,
    double width1, double width2, double length1, double length2,
    double overlap, int numElectrodes, double pitch, double baseHeight,
     double baseWidth, double THETA, int gdsLayer)


// intElec3
public static void createIntElec3(Struct currentStruct, double x,
    double y, double width1, double width2, double length1, double
    length2, double overlap, int numElectrodes, double pitch, double
    baseHeight, double baseWidth, double THETA, int gdsLayer)


// intElec4
public static ArrayList<GArea> createIntElec4(double x, double y,
    double width1, double width2, double length1, double length2,
    double overlap, int numElectrodes, double pitch, double baseHeight,
     double baseWidth, double THETA, int gdsLayer)


// intElec4
public static void createIntElec4(Struct currentStruct, double x,
    double y, double width1, double width2, double length1, double
    length2, double overlap, int numElectrodes, double pitch, double
    baseHeight, double baseWidth, double THETA, int gdsLayer)


// intElec5
public static ArrayList<GArea> createIntElec5(double x, double y,
    double width1, double width2, double length1, double length2,
    double overlap, int numElectrodes, double pitch, double baseHeight,
     double baseWidth, double THETA, int gdsLayer)
```

```
// intElec5
public static void createIntElec5(Struct currentStruct, double x,
    double y, double width1, double width2, double length1, double
    length2, double overlap, int numElectrodes, double pitch, double
    baseHeight, double baseWidth, double THETA, int gdsLayer)


// tJunction
public static ArrayList<GArea> createTjunction(double x, double y,
    double w1, double w2, double L1, double L2, double rad, int
    numSides, double THETA, int gdsLayer)


// tJunction
public static void createTjunction(Struct currentStruct, double x,
    double y, double w1, double w2, double L1, double L2, double rad,
    int numSides, double THETA, int gdsLayer)


// hJunction
public static ArrayList<GArea> createHjunction(double x, double y,
    double w1, double w2, double L1, double L2, double rad, int
    numSides, double THETA, int gdsLayer)

// hJunction
public static void createHjunction(Struct currentStruct, double x,
    double y, double w1, double w2, double L1, double L2, double rad,
    int numSides, double THETA, int gdsLayer)


// arrowJunction
public static ArrayList<GArea> createArrowJunction(double x, double y,
    double w1, double w2, double L1, double L2, double rad, int
    numSides, double junctionAngle, double THETA, int gdsLayer)


// arrowJunction
public static void createArrowJunction(Struct currentStruct, double x,
    double y, double w1, double w2, double L1, double L2, double rad,
    int numSides, double junctionAngle, double THETA, int gdsLayer)


// meanderSin
public static ArrayList<GArea> createMeanderSin(double x, double y,
    double L1, double H1, double L2, double H2, double width, double
    amplitude, int numPeriods, int numCurveSegments, double a, double b
    , double c, double THETA, int gdsLayer)


// meanderSin
public static void createMeanderSin(Struct currentStruct, double x,
    double y, double L1, double H1, double L2, double H2, double width,
     double amplitude, int numPeriods, int numCurveSegments, double a,
    double b, double c, double THETA, int gdsLayer)
```

```
// meanderSqr
public static ArrayList<GArea> createMeanderSqr(double x, double y,
    double L1, double H1, double L2, double H2, double width, double
    amplitude, int numPeriods, double a, double b, double c, double
    THETA, int gdsLayer)


// meanderSqr
public static void createMeanderSqr(Struct currentStruct, double x,
    double y, double L1, double H1, double L2, double H2, double width,
     double amplitude, int numPeriods, double a, double b, double c,
    double THETA, int gdsLayer)


// meanderRamp
public static ArrayList<GArea> createMeanderRamp(double x, double y,
    double L1, double H1, double L2, double H2, double width, double
    amplitude, int numPeriods, double a, double b, double c, double
    THETA, int gdsLayer)


// meanderRamp
public static void createMeanderRamp(Struct currentStruct, double x,
    double y, double L1, double H1, double L2, double H2, double width,
     double amplitude, int numPeriods, double a, double b, double c,
    double THETA, int gdsLayer)



// meanderTri
public static ArrayList<GArea> createMeanderTri(double x, double y,
    double L1, double H1, double L2, double H2, double width, double
    amplitude, int numPeriods, double a, double b, double c, double
    THETA, int gdsLayer)


// meanderTri
public static void createMeanderTri(Struct currentStruct, double x,
    double y, double L1, double H1, double L2, double H2, double width,
     double amplitude, int numPeriods, double a, double b, double c,
    double THETA, int gdsLayer)


// points2shape
public static GArea createPoints2Shape(double x, double y, ArrayList<
    Double> al, double THETA, int gdsLayer)


// polypath
public static GArea createPolyPath(double x, double y, ArrayList<Double
    > al, double width, int CAP, int JOIN, double THETA, int gdsLayer)


// randomPolygons
public static void createRandomPolygons(Struct currentStruct, String
    uniqueStructName, double x, double y, double width, double height,
```

```
    double radius, int numSides, double separation, int numElements,
    int iterations, boolean RANDOMROTATION, int gdsLayer)


// randomEllipses
public static void createRandomEllipses(Struct currentStruct, String
    uniqueStructName, double x, double y, double width, double height,
    double radiusX, double radiusY, int numSides, double separation,
    int numElements, int iterations, boolean RANDOMROTATION, int
    gdsLayer)


// randomEllipsesV
public static void createRandomEllipsesV(Struct currentStruct, String
    uniqueStructName, double x, double y, double width, double height,
    double radiusX, double radiusY, double separation, int numElements,
     int iterations, boolean RANDOMROTATION, int gdsLayer, double
    shapeReso)


// resoPattern
public static ArrayList<GArea> createResoPattern(double x, double y,
    double rad, double width, double THETA, int gdsLayer)


// resoPattern
public static void createResoPattern(Struct currentStruct, double x,
    double y, double rad, double width, double THETA, int gdsLayer)


// resoPatternPi
public static ArrayList<GArea> createResoPatternPi(double x, double y,
    double rad, double width, int n, double THETA, int gdsLayer)


// resoPatternPi
public static void createResoPatternPi(Struct currentStruct, double x,
    double y, double rad, double width, int n, double THETA, int
    gdsLayer)


// resoPatternRS
public static GArea createResoPatternRS(double x, double y, double W,
    double H, int numberOfLines, double THETA, int gdsLayer, double
    shapeReso)


// resoPatternRS
public static void createResoPatternRS(Struct currentStruct, double x,
    double y, double W, double H, int numberOfLines, double THETA, int
    gdsLayer, double shapeReso)


// resoPatternRSA
public static ArrayList<GArea> createResoPatternRSA(double x, double y,
     double startW, double endW, double delta, double H, int
    numberOfLines, double space, double THETA, int gdsLayer, double
```

```
    shapeReso)


// resoPatternRSA
public static void createResoPatternRSA(Struct currentStruct, double x,
     double y, double startW, double endW, double delta, double H, int
    numberOfLines, double space, double THETA, int gdsLayer, double
    shapeReso)


// resoPatternLS
public static GArea createResoPatternLS(double x, double y, double W,
    double H, int numberOfLines, double THETA, int gdsLayer, double
    shapeReso)


// resoPatternLS
public static void createResoPatternLS(Struct currentStruct, double x,
    double y, double W, double H, int numberOfLines, double THETA, int
    gdsLayer, double shapeReso)


// resoPatternLSA
public static ArrayList<GArea> createResoPatternLSA(double x, double y,
     double startW, double endW, double delta, double H, int
    numberOfLines, double space, double THETA, int gdsLayer, double
    shapeReso)


// resoPatternLSA
public static void createResoPatternLSA(Struct currentStruct, double x,
     double y, double startW, double endW, double delta, double H, int
    numberOfLines, double space, double THETA, int gdsLayer, double
    shapeReso)


// spiralArch
public static ArrayList<GArea> createSpiralArch(double x, double y,
    double width, int turns, double separation, double inc, double
    THETA, int gdsLayer)


// spiralArch
public static void createSpiralArch(Struct currentStruct, double x,
    double y, double width, int turns, double separation, double inc,
    double THETA, int gdsLayer)


// spiralFermat
public static ArrayList<GArea> createSpiralFermat(double x, double y,
    double width, int turns, double a, double inc, double THETA, int
    gdsLayer)


// spiralFermat
public static void createSpiralFermat(Struct currentStruct, double x,
    double y, double width, int turns, double a, double inc, double
```

```
    THETA, int gdsLayer)


// spiralLog
public static ArrayList<GArea> createSpiralLog(double x, double y,
    double width, int turns, double a, double b, double inc, double
    THETA, int gdsLayer)


// spiralLog
public static void createSpiralLog(Struct currentStruct, double x,
    double y, double width, int turns, double a, double b, double inc,
    double THETA, int gdsLayer)


// spiralRect
public static ArrayList<GArea> createSpiralRect(double x, double y,
    double width, double len, double pitch, int numTurns, double THETA,
     int gdsLayer)

// spiralRect
public static void createSpiralRect(Struct currentStruct, double x,
    double y, double width, double len, double pitch, int numTurns,
    double THETA, int gdsLayer)
```

4.2.7 Alignment and Reticle Element Methods

```java
// alignFFFB1
public static ArrayList<GArea> createAlignFFFB1(double x, double y, int
     layerCross, int layerSquare, double THETA)

// alignFFFB1
public static void createAlignFFFB1(Struct currentStruct, double x,
    double y, int layerCross, int layerSquare, double THETA)

// alignFFFB2
public static ArrayList<GArea> createAlignFFFB2(double x, double y, int
     layerCross, int layerSquare, double THETA)

// alignFFFB2
public static void createAlignFFFB2(Struct currentStruct, double x,
    double y, int layerCross, int layerSquare, double THETA)

// align3Level
public static ArrayList<GArea> createAlign3Level(double x, double y,
    int layerA, int layerB, int layerC, double THETA)

// align3Level
public static void createAlign3Level(Struct currentStruct, double x,
    double y, int layerA, int layerB, int layerC, double THETA)

// alignVern
public static ArrayList<GArea> createAlignVern(double x, double y, int
    layer1, int layer2, double vernReso, boolean L1INV, boolean L2INV,
    double invL, double invW, double THETA)

// alignVern
public static void createAlignVern(Struct currentStruct, double x,
    double y, int layer1, int layer2, double vernReso, boolean L1INV,
    boolean L2INV, double invL, double invW, double THETA)

// alignVernLb1
public static ArrayList<GArea> createAlignVernLb1(double x, double y,
    int layer1, int layer2, double vernReso, double THETA)

// alignVernLb1
public static void createAlignVernLb1(Struct currentStruct, double x,
    double y, int layer1, int layer2, double vernReso, double THETA)
```

```
// alignVernLb2
public static ArrayList<GArea> createAlignVernLb2(double x, double y,
    int layer1, int layer2, double vernReso, double THETA)


// alignVernLb2
public static void createAlignVernLb2(Struct currentStruct, double x,
    double y, int layer1, int layer2, double vernReso, double THETA)


// alignCustC1
public static GArea createCustomCrossC1(double x, double y, double L1,
    double W1, double L2, boolean INVERSE, double IL, double IW, int
    TYPE, double THETA, int gdsLayer)


// alignCustC2
public static GArea createCustomCrossC2(double x, double y, double L1,
    double W1, double PL, double PW, boolean INVERSE, double IL, double
     IW, int TYPE, double THETA, int gdsLayer)


// alignCustC3
public static GArea createCustomCrossC3(double x, double y, double L1,
    double W1, double PL, double PW, double LX, boolean INVERSE, double
     IL, double IW, int TYPE, double THETA, int gdsLayer)


// alignCustC4
public static GArea createCustomCrossC4(double x, double y, double L1,
    double W1, double L2, double d, double BL, double BW, boolean
    INVERSE, double IL, double IW, int TYPE, double THETA, int gdsLayer
    )


// cnstASML
public static ArrayList<GArea> createCnstASML(String label, String
    barcode, int gdsLayer) throws FileNotFoundException


// cnstASML
public static void createCnstASML(Struct currentStruct, String label,
    String barcode, boolean MIRROR, int gdsLayer) throws
    FileNotFoundException


// cnstContact5
public static ArrayList<GArea> createCnstContact5(String label, int
    gdsLayer) throws FileNotFoundException


// cnstContact5
public static void createCnstContact5(Struct currentStruct, String
    label, boolean MIRROR, int gdsLayer) throws FileNotFoundException


// cnstContact7
```

```java
public static ArrayList<GArea> createCnstContact7(String label, int
    gdsLayer) throws FileNotFoundException


// cnstContact7
public static void createCnstContact7(Struct currentStruct, String
    label, boolean MIRROR, int gdsLayer) throws FileNotFoundException


// alignCustVern
public static ArrayList<GArea> createCustomVerniers(double x, double y,
     int layer1, int layer2, double L, double W, double pitch, double
    vernReso, double spacing, boolean INVERSE1, boolean INVERSE2,
    double IL, double IW, double THETA, double shapeReso)


// alignCustVern
public static void createCustomVerniers(Struct currentStruct, double x,
     double y, int layer1, int layer2, double L, double W, double pitch
    , double vernReso, double spacing, boolean INVERSE1, boolean
    INVERSE2, double IL, double IW, double THETA, int gdsLayer, double
    shapeReso)


// verniers - custom verniers with text labels
public static ArrayList<GArea> createVerniers(double x, double y, int
    layer1, int layer2, double vernierReso, int ticks, String label1,
    String label2, double fontSize, double fontReso, double lineWidth,
    double lineLength, double pitch, double THETA)


// verniers - custom verniers with text labels
public static void createVerniers(Struct currentStruct, double x,
    double y, int layer1, int layer2, double vernierReso, int ticks,
    String label1, String label2, double fontSize, double fontReso,
    double lineWidth, double lineLength, double pitch, double THETA)


// arrowHead
public static GArea createArrowHead(double x, double y, double arrowW,
    double arrowL, double width, double THETA, int gdsLayer)


// arrow
public static GArea createArrow(double x, double y, double arrowW,
    double arrowL, double width, double length, double THETA, int
    gdsLayer)


// arrowArray
public static GArea createArrowLinearArray(double x, double y, double
    arrowW, double arrowL, double width, double length, int
    numberOfArrows, double THETA, int gdsLayer)
```

4.2.8 Nanophotonics Library Methods

```
// waveguide
public static GArea createWaveGuide(double x1, double y1, double x2,
    double y2, double w, double THETA, int ENDCAPLEFT, int ENDCAPRIGHT,
     int gdsLayer)


// waveguideSlot
public static GArea createWaveGuideSlot(double x1, double y1, double x2
    , double y2, double w, double slotWidth, double THETA, int
    ENDCAPLEFT, int ENDCAPRIGHT, int gdsLayer)


// waveguideInv
public static GArea createWaveGuideInv(double x1, double y1, double x2,
     double y2, double w, double invWidth, double THETA, int ENDCAPLEFT
    , int ENDCAPRIGHT, int gdsLayer)


// waveguideInvSlot
public static GArea createWaveGuideInvSlot(double x1, double y1, double
     x2, double y2, double w, double slotWidth, double invWidth, double
     THETA, int ENDCAPLEFT, int ENDCAPRIGHT, int gdsLayer)


// wgExpander
public static GArea createWaveGuideExpander(double x, double y, double
    width, double length, double deltaLength, double a, double b,
    double angle, double w0, double lambda, double baseHeight, double
    THETA, int gdsLayer)


// linearTaper
public static GArea createLinearTaper(double x1, double y1, double x2,
    double y2, double w1, double w2, double THETA, int gdsLayer)


// linearTaperSlot
public static ArrayList<GArea> createLinearTaperSlot(double x1, double
    y1, double x2, double y2, double w1, double w2, double slotWidth1,
    double slotWidth2, double THETA, int gdsLayer)


// linearTaperSlot
public static void createLinearTaperSlot(Struct currentStruct, double
    x1, double y1, double x2, double y2, double w1, double w2, double
    slotWidth1, double slotWidth2, double THETA, int gdsLayer)


// linearTaperInvSlot
public static ArrayList<GArea> createLinearTaperInvSlot(double x1,
    double y1, double x2, double y2, double w1, double w2, double gap,
    double slotWidth1, double slotWidth2, double THETA, int gdsLayer)
```

```
// linearTaperInvSlot
public static void createLinearTaperInvSlot(Struct currentStruct,
    double x1, double y1, double x2, double y2, double w1, double w2,
    double gap, double slotWidth1, double slotWidth2, double THETA, int
     gdsLayer)


// exponentialTaper
public static GArea createExponentialTaper(double x1, double y1, double
     L, double W1, double W2, int numPoints, double THETA,int gdsLayer,
     double shapeReso)


// exponentialTaperInv
public static ArrayList<GArea> createExpTaperInv(double x1, double y1,
    double length, double wStart, double wEnd, int nPoints, double
    widthAround, double THETA, int gdsLayer, double shapeReso)


// exponentialTaperInv
public static void createExpTaperInv(Struct currentStruct, double x1,
    double y1, double length, double wStart, double wEnd, int nPoints,
    double widthAround, double THETA, int gdsLayer, double shapeReso)


// exponentialTaperInvSlot
public static ArrayList<GArea> createExpTaperInvSlot(double x1, double
    y1, double length, double wStart, double wEnd, int nPoints, double
    inverseWidth, double slotW1, double slotW2, double THETA, int
    gdsLayer, double shapeReso)


// exponentialTaperInvSlot
public static void createExpTaperInvSlot(Struct currentStruct, double
    x1, double y1, double length, double wStart, double wEnd, int
    nPoints, double inverseWidth, double slotW1, double slotW2, double
    THETA, int gdsLayer, double shapeReso)


// customTaper
public static GArea createCustomTaper(ArrayList<Double> al, double Tx,
    double Ty, double THETA, int gdsLayer)


// directionalCoupler1
public static GArea createDirectionalCoupler1(double x, double y,
    double L1, double w1, double we1, double L2, double L3, double w2,
    double we2, double g, double r, int numSides, double THETA, int
    gdsLayer)


// directionalCoupler2
public static GArea createDirectionalCoupler2(double x, double y,
    double L1, double w1, double we1, double L2, double L3, double w2,
    double we2, double g, double r, int numSides, double THETA, int
    gdsLayer)
```

```java
// directionalCoupler3
public static GArea createDirectionalCoupler3(double x, double y,
    double w, double wE, double g, double L1, double L2, double r, int
    numSides, double THETA, int gdsLayer)


// directionalCoupler4
public static GArea createDirectionalCoupler4(double x, double y,
    double w, double wE, double g, double L1, double LB, double HB,
    double THETA, int gdsLayer)


// sBendTaper
public static GArea createSbendTaper(double x, double y, double L,
    double H, double wStart, double wEnd, double THETA, int gdsLayer,
    double shapeReso)


// sBendFunnel
public static GArea createSbendFunnel(double x, double y, double L,
    double H, double W, double THETA, int gdsLayer, double shapeReso)


// sBend
public static GArea createSbend(double x1, double y1, double x2, double
     y2, double width, double THETA, int gdsLayer, double shapeReso)


// sBendLH
public static GArea createSbendLH(double x1, double y1, double length,
    double height, double width, double THETA, int gdsLayer, double
    shapeReso)


// sBendInv
public static GArea createSbendInv(double x1, double y1, double length,
     double height, double width, double sleeve, double THETA, int
    gdsLayer, double shapeReso)


// sBendInvSlot
public static GArea createSbendInvSlot(double x, double y, double
    length, double height, double slotWidth, double gap, double sleeve,
     double THETA, int gdsLayer, double shapeReso)


// yBend
public static GArea createYbend(double x1, double y1, double x2, double
     y2, double x3, double y3, double width, double THETA, int gdsLayer
    , double shapeReso)


// yBendLH
public static GArea createYbendLH(double x1, double y1, double length2,
     double height2, double length3, double height3, double width,
    double THETA, int gdsLayer, double shapeReso)
```

```java
// yBendInv
public static GArea createYbendInv(double x1, double y1, double length2
    , double height2, double length3, double height3, double width,
    double sleeve, double THETA, int gdsLayer, double shapeReso)

// yBendInvSlot
public static GArea createYbendInvSlot(double x1, double y1, double
    length2, double height2, double length3, double height3, double
    slotWidth, double gap, double sleeve, double THETA, int gdsLayer,
    double shapeReso)


// yBend90
public static GArea createYBend90(double x, double y, double r1, double
     r2, double w, int numSides, double THETA, int gdsLayer)


// yBendInv90
public static GArea createYBendInv90(double x, double y, double r1,
    double r2, double w, double we, int numSides, double THETA, int
    gdsLayer)


// yBendInvSlot90
public static GArea createYBendInvSlot90(double x, double y, double r1,
     double r2, double ws, double g, double we, int numSides, double
    THETA, int gdsLayer)


// 90degreeBend
public static GArea create90degreeBend(double x1, double y1, double x2,
     double y2, double width, double THETA, int gdsLayer, double
    shapeReso)


// 90degreeBendLH
public static GArea create90degreeBendLH(double x1, double y1, double
    length, double height, double width, double THETA, int gdsLayer,
    double shapeReso)


// 90degreeBendInv
public static GArea create90degreeInv(double x1, double y1, double
    length, double height, double width, double sleeve, double THETA,
    int gdsLayer, double shapeReso)


// 90degreeBendInvSlot
public static GArea create90degreeInvSlot(double x1, double y1, double
    length, double height, double slotWidth, double gap, double sleeve,
     double THETA, int gdsLayer, double shapeReso)


// 180degreeBend
public static GArea create180bend(double x, double y, double L1, double
```

```java
    L2, double D, double W, int numSides, double THETA, int gdsLayer)

// 180degreeBendInv
public static GArea create180bendInv(double x, double y, double L1,
    double L2, double D, double W, double We, int numSides, double
    THETA, int gdsLayer)

// 180degreeBendInvSlot
public static GArea create180bendInvSlot(double x, double y, double L1,
     double L2, double D, double W, double gap, double We, int numSides
    , double THETA, int gdsLayer)


// raceTrack
public static GArea createRaceTrack(double x, double y, double length,
    double width, double radiusInner, double THETA, int numSides, int
    gdsLayer)


// spiralDelayLineArch
public static ArrayList<GArea> createSpiralDelayLineArch(double x,
    double y, double width, int turns, double separation, double deltaR
    , double length, double THETA, int ENDCAP, int gdsLayer)


// spiralDelayLineArch
public static void createSpiralDelayLineArch(Struct currentStruct,
    double x, double y, double width, int turns, double separation,
    double deltaR, double length, double THETA, int ENDCAP, int
    gdsLayer)


// spiralDelayLineFermat
public static ArrayList<GArea> createSpiralDelayLineFermat(double x,
    double y, double width, int turns, double a, double deltaR, double
    length, double THETA, int ENDCAP, int gdsLayer)


// spiralDelayLineFermat
public static void createSpiralDelayLineFermat(Struct currentStruct,
    double x, double y, double width, int turns, double a, double
    deltaR, double length, double THETA, int ENDCAP, int gdsLayer)


// spiralDelayLineArchV2
public static void createSpiralDelayLineArchV2(Struct currentStruct,
    double x, double y, double width, int turns, double pitch, int
    stepsPerTurn, int skippedTurns, double length, double THETA, int
    ENDCAP, int gdsLayer)


// spiralDelayLineArchInv
public static ArrayList<GArea> createSpiralDelayLineArchInv(double x,
    double y, double width, double sleeveWidth, int turns, double
    separation, double deltaR, double length, double THETA, int ENDCAP,
     int gdsLayer)
```

```
// spiralDelayLineArchInv
public static void createSpiralDelayLineArchInv(Struct currentStruct,
    double x, double y, double width, double sleeveWidth, int turns,
    double separation, double deltaR, double length, double THETA, int
    ENDCAP, int gdsLayer)

// spiralDelayLineFermatInv
public static ArrayList<GArea> createSpiralDelayLineFermatInv(double x,
     double y, double width, double sleeveWidth, int turns, double a,
    double deltaR, double length, double THETA, int ENDCAP, int
    gdsLayer)


// spiralDelayLineFermatInv
public static void createSpiralDelayLineFermatInv(Struct currentStruct,
     double x, double y, double width, double sleeveWidth, int turns,
    double a, double deltaR, double length, double THETA, int ENDCAP,
    int gdsLayer)


// spiralDelayLineArchV2Inv
public static void createSpiralDelayLineArchV2Inv(Struct currentStruct,
     double x, double y, double width, double sleeveWidth, int turns,
    double pitch, int stepsPerTurn, int skippedTurns, double length,
    double THETA, int ENDCAP, int gdsLayer)


// grating
public static void createGrating(Struct currentStruct, String name,
    double x, double y, double width, double length, double pitch, int
    numberOfLines, int gdsLayer)


// gratingCoupler
public static void createGratingCoupler(Struct currentStruct, double x,
     double y, double r, double W, double pitch, double angleStart,
    double angleEnd, int numSides, int numElements, int gdsLayer)


// apodizedGrating
public static GArea  createApodizedGrating(Struct currentStruct, double
     x, double y, double gratingLength, double increment, double height
    , double dutyCycleCutoff, double p1, double p2, double p3, double
    p4, double d1, double d2, double d3, double d4, double d5, double
    THETA, int gdsLayer)


// gratingCWG
public static ArrayList<GArea> createGratingCWG(double x, double y,
    double wgWidth, double Length, double Height, double sleeve, double
     lambda0, double nEff, double nCladding, double thetaC, double R1,
    double gratingPeriod, double ratio, int numberOfElements, int
    numSides, int layerWaveGuide, int layerGrating, boolean ENDCAPS,
    double THETA, int gdsLayer, double shapeReso)
```

```java
// gratingCWG
public static void createGratingCWG(Struct currentStruct, double x,
    double y, double wgWidth, double Length, double Height, double
    sleeve, double lambda0, double nEff, double nCladding, double
    thetaC, double R1, double gratingPeriod, double ratio, int
    numberOfElements, int numSides, int layerWaveGuide, int
    layerGrating, boolean ENDCAPS, double THETA, int gdsLayer, double
    shapeReso)
```

```java
// gratingCWGinv
public static ArrayList<GArea> createGratingCWGinv(double x, double y,
    double wgWidth, double Length, double Height, double sleeve, double
     lambda0, double nEff, double nCladding, double thetaC, double R1,
    double gratingPeriod, double ratio, int numberOfElements, int
    numSides, int layerWaveGuide, int layerGrating, boolean ENDCAPS,
    double THETA, int gdsLayer, double shapeReso)
```

```java
// gratingCWGinv
public static void createGratingCWGinv(Struct currentStruct, double x,
    double y, double wgWidth, double Length, double Height, double
    sleeve, double lambda0, double nEff, double nCladding, double
    thetaC, double R1, double gratingPeriod, double ratio, int
    numberOfElements, int numSides, int layerWaveGuide, int
    layerGrating, boolean ENDCAPS, double THETA, int gdsLayer, double
    shapeReso)
```

```java
// phC
public static void createPhC(Struct currentStuct, String
    uniqueStructName, double x, double y, double radius, double pitchX,
     int elementsX, int elementsY, int numberOfSides, double
    arrayPitchDelta, int gdsLayer)
```

```java
// phCV
public static void createPhCV(Struct currentStuct, String
    uniqueStructName, double x, double y, double radius, double pitchX,
     int elementsX, int elementsY, int numberOfSides, double
    arrayPitchDelta, int gdsLayer, double shapeReso)
```

```java
// hex
public static void createHex(Struct currentStuct, String
    uniqueStructName, double x, double y, double radius, double pitchX,
     int elementsX, int elementsY, int numberOfSides, int gdsLayer)
```

```java
// hexV
public static void createHexV(Struct currentStuct, String
    uniqueStructName, double x, double y, double radius, double pitchX,
     int elementsX, int elementsY, int numberOfSides, int gdsLayer,
    double shapeReso)
```

```java
// discInfinite
public static void createDiscInfinite(Struct currentStuct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideLength, double waveguideWidth, boolean ENDCAP, int
    gdsLayer)

// ringInfinite
public static void createRingInfinite(Struct currentStuct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideLength, double
    waveguideWidth, boolean ENDCAP, int gdsLayer)


// discInfDS
public static void createDiscInfDS(Struct currentStuct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideLength, double waveguideWidth, double gap2, double
    length2, double width2, boolean ENDCAP, int gdsLayer)


// ringInfDS
public static void createRingInfDS(Struct currentStuct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideLength, double
    waveguideWidth, double gap2, double length2, double width2, boolean
     ENDCAP, int gdsLayer)


// discInfiniteInv
public static void createDiscInfiniteInv(Struct currentStuct, double x,
     double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideLength, double waveguideWidth, double sleeveWidth,
    boolean ENDCAP, int gdsLayer)


// ringInfiniteInv
public static void createRingInfiniteInv(Struct currentStuct, double x,
     double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideLength, double
    waveguideWidth, double sleeveWidth, boolean ENDCAP, int gdsLayer)


// discInfInvDS
public static void createDiscInfInvDS(Struct currentStuct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideLength, double waveguideWidth, double sleeveWidth,
    double gap2, double length2, double width2, double sleeve2, boolean
     ENDCAP, int gdsLayer)


// ringInfInvDS
public static void createRingInfInvDS(Struct currentStuct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideLength, double
    waveguideWidth, double sleeveWidth, double gap2, double length2,
    double width2, double sleeve2, boolean ENDCAP, int gdsLayer)
```

```
// discInfiniteInvPos
public static void createDiscInfiniteInvPos(Struct currentStuct, double
     x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double waveguideLength, double
    waveguideWidth, double sleeveWidth, boolean ENDCAP, int gdsLayer)


// ringInfiniteInvPos
public static void createRingInfiniteInvPos(Struct currentStuct, double
     x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideLength, double waveguideWidth, double sleeveWidth, boolean
     ENDCAP, int gdsLayer)


// discInfInvPosDS
public static void createDiscInfInvPosDS(Struct currentStuct, double x,
     double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double waveguideLength, double
    waveguideWidth, double sleeveWidth, double gap2, double length2,
    double width2, double sleeve2, boolean ENDCAP, int gdsLayer)


// ringInfInvPosDS
public static void createRingInfInvPosDS(Struct currentStuct, double x,
     double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideLength, double waveguideWidth, double sleeveWidth, double
    gap2, double length2, double width2, double sleeve2, boolean ENDCAP
    , int gdsLayer)


// discSymmetric
public static void createDiscSymmetric(Struct currentStuct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, double waveguideHeight,
    boolean ENDCAP, int gdsLayer, double shapeReso)


// ringSymmetric
public static void createRingSymmetric(Struct currentStuct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, boolean ENDCAP, int
    gdsLayer, double shapeReso)


// discSymDS
public static void createDiscSymDS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, double waveguideHeight,
    double gap2, double width2, double length2, boolean ENDCAP, int
```

```java
    gdsLayer, double shapeReso)


// ringSymDS
public static void createRingSymDS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, double gap2, double width2
    , double length2, boolean ENDCAP, int gdsLayer, double shapeReso)


// discSymPul
public static void createDiscSymPul(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, double waveguideHeight,
    double gap2, double angle2, double width2, double length2, double
    height2, boolean ENDCAP, int gdsLayer, double shapeReso)


// ringSymPul
public static void createRingSymPul(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, double gap2, double angle2
    , double width2, double length2, double height2, boolean ENDCAP,
    int gdsLayer, double shapeReso)


// discSymmetricLC
public static void createDiscSymmetricLC(Struct currentStruct, double x
    , double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double waveguideLength, double waveguideHeight, boolean ENDCAP, int
     gdsLayer, double shapeReso)


// ringSymmetricLC
public static void createRingSymmetricLC(Struct currentStruct, double x
    , double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, boolean ENDCAP, int
    gdsLayer, double shapeReso)


// discSymLCDS
public static void createDiscSymLCDS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion,double waveguideWidth,
    double waveguideLength, double waveguideHeight, double gap2, double
     width2, double length2, boolean ENDCAP, int gdsLayer, double
    shapeReso)
```

```
// ringSymLCDS
public static void createRingSymLCDS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, double gap2, double width2
    , double length2, boolean ENDCAP, int gdsLayer, double shapeReso)


//  discSymLCPul
public static void createDiscSymLCPul(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc1, int numberOfSidesCouplingRegion, double waveguideWidth,
     double waveguideLength, double waveguideHeight, double gap2,
    double Lc2, double width2, double length2, double height2, boolean
    ENDCAP, int gdsLayer, double shapeReso)


//  ringSymLCPul
public static void createRingSymLCPul(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc1, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, double gap2, double Lc2,
    double width2, double length2, double height2, boolean ENDCAP, int
    gdsLayer, double shapeReso)


// discSymmetricA
public static void createDiscSymmetricA(Struct currentStruct, double x,
     double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, boolean ENDCAP, int
    gdsLayer)


// ringSymmetricA
public static void createRingSymmetricA(Struct currentStruct, double x,
     double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, boolean ENDCAP, int gdsLayer)


//  discSymADS
public static void createDiscSymADS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, double gap2, double width2,
     double length2, boolean ENDCAP, int gdsLayer)


//  ringSymADS
public static void createRingSymADS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
```

```
    waveguideLength, double gap2, double width2, double length2,
    boolean ENDCAP, int gdsLayer)


//  discSymAPul
public static void createDiscSymAPul(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, double gap2, double angle2,
     double width2, double length2, boolean ENDCAP, int gdsLayer)


//  ringSymAPul
public static void createRingSymAPul(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double gap2, double angle2, double width2, double
    length2, boolean ENDCAP, int gdsLayer)


// discSymmetricLCA
public static void createDiscSymmetricLCA(Struct currentStruct, double
    x, double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double waveguideLength, boolean ENDCAP, int gdsLayer)


// ringSymmetricLCA
public static void createRingSymmetricLCA(Struct currentStruct, double
    x, double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, boolean ENDCAP, int gdsLayer)


// discSymLCADS
public static void createDiscSymLCADS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double waveguideLength, double gap2, double width2, double length2,
     boolean ENDCAP, int gdsLayer)


// ringSymLCADS
public static void createRingSymLCADS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double gap2, double width2, double length2,
    boolean ENDCAP, int gdsLayer)


// discSymLCAPul
public static void createDiscSymLCAPul(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc1, int numberOfSidesCouplingRegion, double waveguideWidth,
```

```
    double waveguideLength, double gap2, double Lc2, double width2,
    double length2, boolean ENDCAP, int gdsLayer)


// ringSymLCAPul
public static void createRingSymLCAPul(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc1, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double gap2, double Lc2, double width2, double
    length2, boolean ENDCAP, int gdsLayer)


// discSymmetricInv
public static void createDiscSymmetricInv(Struct currentStruct, double
    x, double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, boolean ENDCAP, int gdsLayer, double shapeReso)


// ringSymmetricInv
public static void createRingSymmetricInv(Struct currentStruct, double
    x, double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight,
    boolean ENDCAP, int gdsLayer, double shapeReso)


// discSymInvDS
public static void createDiscSymInvDS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, double gap2, double width2, double sleeve2, double
    length2, boolean ENDCAP, int gdsLayer, double shapeReso)


// ringSymInvDS
public static void createRingSymInvDS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
    gap2, double width2, double sleeve2, double length2, boolean
    ENDCAP, int gdsLayer, double shapeReso)


//  discSymInvPul
public static void createDiscSymInvPul(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, double gap2, double angle2, double width2, double
    sleeve2, double length2, double height2, boolean ENDCAP, int
    gdsLayer, double shapeReso)
```

```
//  ringSymInvPul
public static void createRingSymInvPul(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
     gap2, double angle2, double width2, double sleeve2, double length2
    , double height2, boolean ENDCAP, int gdsLayer, double shapeReso)


// discSymmetricInvLC
public static void createDiscSymmetricInvLC(Struct currentStruct,
    double x, double y, double radius, int numberOfSidesDiscRing,
    double gap, double Lc, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, boolean ENDCAP, int gdsLayer, double shapeReso)


// ringSymmetricInvLC
public static void createRingSymmetricInvLC(Struct currentStruct,
    double x, double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight,
    boolean ENDCAP, int gdsLayer, double shapeReso)


// discSymInvLCDS
public static void createDiscSymInvLCDS(Struct currentStruct, double x,
     double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double sleeveWidth, double waveguideLength, double waveguideHeight,
     double gap2, double width2, double sleeve2, double length2,
    boolean ENDCAP, int gdsLayer, double shapeReso)


// ringSymInvLCDS
public static void createRingSymInvLCDS(Struct currentStruct, double x,
     double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
     gap2, double width2, double sleeve2, double length2, boolean
    ENDCAP, int gdsLayer, double shapeReso)


// discSymInvLCPul
public static void createDiscSymInvLCPul(Struct currentStruct, double x
    , double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc1, int numberOfSidesCouplingRegion, double waveguideWidth,
     double sleeveWidth, double waveguideLength, double waveguideHeight
    , double gap2, double Lc2, double width2, double sleeve2, double
    length2, double height2, boolean ENDCAP, int gdsLayer, double
    shapeReso)
```

```
// ringSymInvLCPul
public static void createRingSymInvLCPul(Struct currentStruct, double x
    , double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc1, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
     gap2, double Lc2, double width2, double sleeve2, double length2,
    double height2, boolean ENDCAP, int gdsLayer, double shapeReso)



// discSymmetricInvA
public static void createDiscSymmetricInvA(Struct currentStruct, double
     x, double y, double radius, int numberOfSidesDiscRing, double gap,
     double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, boolean
     ENDCAP, int gdsLayer)


// ringSymmetricInvA
public static void createRingSymmetricInvA(Struct currentStruct, double
     x, double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, boolean ENDCAP, int gdsLayer)


//  discSymInvADS
public static void createDiscSymInvADS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    gap2, double width2, double sleeve2, double length2, boolean ENDCAP
    , int gdsLayer)


//  ringSymInvADS
public static void createRingSymInvADS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double width2,
    double sleeve2, double length2, boolean ENDCAP, int gdsLayer)


//  discSymInvAPul
public static void createDiscSymInvAPul(Struct currentStruct, double x,
     double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    gap2, double angle2, double width2, double sleeve2, double length2,
     boolean ENDCAP, int gdsLayer)

//  ringSymInvAPul
public static void createRingSymInvAPul(Struct currentStruct, double x,
     double y, double radius, double ringWidth, int
```

```
    numberOfSidesDiscRing, double gap, double waveguideAngle,int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double angle2,
    double width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)

// discSymmetricInvLCA
public static void createDiscSymmetricInvLCA(Struct currentStruct,
    double x, double y, double radius, int numberOfSidesDiscRing,
    double gap, double Lc, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, boolean
     ENDCAP, int gdsLayer)


// ringSymmetricInvLCA
public static void createRingSymmetricInvLCA(Struct currentStruct,
    double x, double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, boolean ENDCAP, int gdsLayer)


// discSymInvLCADS
public static void createDiscSymInvLCADS(Struct currentStruct, double x
    , double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double sleeveWidth, double waveguideLength, double gap2, double
    width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)


// ringSymInvLCADS
public static void createRingSymInvLCADS(Struct currentStruct, double x
    , double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double width2,
    double sleeve2, double length2, boolean ENDCAP, int gdsLayer)


// discSymInvLCAPul
public static void createDiscSymInvLCAPul(Struct currentStruct, double
    x, double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc1, int numberOfSidesCouplingRegion, double waveguideWidth,
     double sleeveWidth, double waveguideLength, double gap2, double
    Lc2, double width2, double sleeve2, double length2, boolean ENDCAP,
     int gdsLayer)


// ringSymInvLCAPul
public static void createRingSymInvLCAPul(Struct currentStruct, double
    x, double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc1, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double Lc2,
    double width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)
```

```
// discSymmetricInvPos
public static void createDiscSymmetricInvPos(Struct currentStruct,
    double x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight,
    boolean ENDCAP, int gdsLayer, double shapeReso)


// ringSymmetricInvPos
public static void createRingSymmetricInvPos(Struct currentStruct,
    double x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, boolean ENDCAP, int gdsLayer, double shapeReso)


// discSymInvPosDS
public static void createDiscSymInvPosDS(Struct currentStruct, double x
    , double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
     gap2, double width2, double sleeve2, double length2, boolean
    ENDCAP, int gdsLayer, double shapeReso)


// ringSymInvPosDS
public static void createRingSymInvPosDS(Struct currentStruct, double x
    , double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap,double
    waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, double gap2, double width2, double sleeve2, double
     length2, boolean ENDCAP, int gdsLayer, double shapeReso)


// discSymInvPosPul
public static void createDiscSymInvPosPul(Struct currentStruct, double
    x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
     gap2, double angle2, double width2, double sleeve2, double length2
    , double height2, boolean ENDCAP, int gdsLayer, double shapeReso)


// ringSymInvPosPul
public static void createRingSymInvPosPul(Struct currentStruct, double
    x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
```

```
    waveguideHeight, double gap2, double angle2, double width2, double
    sleeve2, double length2, double height2, boolean ENDCAP, int
    gdsLayer, double shapeReso)


// discSymmetricInvPosLC
public static void createDiscSymmetricInversePosLC(Struct currentStruct
    , double x, double y, double radius, double ringDiscSleeveWidth,
    int numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight,
    boolean ENDCAP, int gdsLayer, double shapeReso)


// ringSymmetricInvPosLC
public static void createRingSymmetricInversePosLC(Struct currentStruct
    , double x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    Lc, int numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight,
    boolean ENDCAP, int gdsLayer, double shapeReso)


// discSymInvPosLCDS
public static void createDiscSymInvPosLCDS(Struct currentStruct, double
     x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
     gap2, double width2, double sleeve2, double length2, boolean
    ENDCAP, int gdsLayer, double shapeReso)


// ringSymInvPosLCDS
public static void createRingSymInvPosLCDS(Struct currentStruct, double
     x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    Lc, int numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
     gap2, double width2, double sleeve2, double length2, boolean
    ENDCAP, int gdsLayer, double shapeReso)


// discSymInvPosLCPul
public static void createDiscSymInvPosLCPul(Struct currentStruct,
    double x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double Lc1, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
     gap2, double Lc2, double width2, double sleeve2, double length2,
    double height2, boolean ENDCAP, int gdsLayer, double shapeReso)


// ringSymInvPosLCPul
public static void createRingSymInvPosLCPul(Struct currentStruct,
    double x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
```

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    Lc1, int numberOfSidesCouplingRegion, double waveguideWidth, double
     sleeveWidth, double waveguideLength, double waveguideHeight,
    double gap2, double Lc2, double width2, double sleeve2, double
    length2, double height2, boolean ENDCAP, int gdsLayer, double
    shapeReso)

// discSymmetricInvPosA
public static void createDiscSymmetricInvPosA(Struct currentStruct,
    double x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, boolean ENDCAP, int gdsLayer)


// ringSymmetricInvPosA
public static void createRingSymmetricInvPosA(Struct currentStruct,
    double x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, boolean
     ENDCAP, int gdsLayer)


// discSymInvPosADS
public static void createDiscSymInvPosADS(Struct currentStruct, double
    x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double width2,
    double sleeve2, double length2, boolean ENDCAP, int gdsLayer)


// ringSymInvPosADS
public static void createRingSymInvPosADS(Struct currentStruct, double
    x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    gap2, double width2, double sleeve2, double length2, boolean ENDCAP
    , int gdsLayer)


//  discSymInvPosAPul
public static void createDiscSymInvPosAPul(Struct currentStruct, double
     x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double angle2,
    double width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)


//  ringSymInvPosAPul
public static void createRingSymInvPosAPul(Struct currentStruct, double
     x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideAngle, int numberOfSidesCouplingRegion, double
```

```
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    gap2, double angle2, double width2, double sleeve2, double length2,
     boolean ENDCAP, int gdsLayer)


//  discSymmetricInvPosLCA
public static void createDiscSymmetricInvPosLCA(Struct currentStruct,
    double x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, boolean ENDCAP, int gdsLayer)


//  ringSymmetricInvPosLCA
public static void createRingSymmetricInvPosLCA(Struct currentStruct,
    double x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    Lc, int numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, boolean ENDCAP, int gdsLayer)


// discSymInvPosLCADS
public static void createDiscSymInvPosLCADS(Struct currentStruct,
    double x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double width2,
    double sleeve2, double length2, boolean ENDCAP, int gdsLayer)


// ringSymInvPosLCADS
public static void createRingSymInvPosLCADS(Struct currentStruct,
    double x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    Lc, int numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double width2,
    double sleeve2, double length2, boolean ENDCAP, int gdsLayer)


// discSymInvPosLCAPul
public static void createDiscSymInvPosLCAPul(Struct currentStruct,
    double x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double Lc1, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double Lc2,
    double width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)


// ringSymInvPosLCAPul
public static void createRingSymInvPosLCAPul(Struct currentStruct,
    double x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    Lc1, int numberOfSidesCouplingRegion, double waveguideWidth, double
     sleeveWidth, double waveguideLength, double gap2, double Lc2,
    double width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)
```

```
//  discPulley
public static void createDiscPulley(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, double waveguideHeight,
    boolean ENDCAP, int gdsLayer, double shapeReso)



//  ringPulley
public static void createRingPulley(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, boolean ENDCAP, int
    gdsLayer, double shapeReso)


// discPulDS
public static void createDiscPulDS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, double waveguideHeight,
    double gap2, double width2, double length2, boolean ENDCAP, int
    gdsLayer, double shapeReso)


// ringPulDS
public static void createRingPulDS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, double gap2, double width2
    , double length2, boolean ENDCAP, int gdsLayer, double shapeReso)


// discPulPul
public static void createDiscPulPul(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, double waveguideHeight,
    double gap2, double angle2, double width2, double length2, double
    heigth2, boolean ENDCAP, int gdsLayer, double shapeReso)


// ringPulPul
public static void createRingPulPul(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, double gap2, double angle2
    , double width2, double length2, double heigth2, boolean ENDCAP,
    int gdsLayer, double shapeReso)
```

```
// discPulleyLC
public static void createDiscPulleyLC(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double waveguideLength, double waveguideHeight, boolean ENDCAP, int
     gdsLayer, double shapeReso)


// ringPulleyLC
public static void createRingPulleyLC(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, boolean ENDCAP, int
    gdsLayer, double shapeReso)


// discPulLCDS
public static void createDiscPulLCDS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double waveguideLength, double waveguideHeight, double gap2, double
     width2, double length2, boolean ENDCAP, int gdsLayer, double
    shapeReso)


// ringPulLCDS
public static void createRingPulLCDS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, double gap2, double width2
    , double length2, boolean ENDCAP, int gdsLayer, double shapeReso)


// discPulLCPul
public static void createDiscPulLCPul(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc1, int numberOfSidesCouplingRegion, double waveguideWidth,
     double waveguideLength, double waveguideHeight, double gap2,
    double Lc2, double width2, double length2, double heigth2, boolean
    ENDCAP, int gdsLayer, double shapeReso)


// ringPulLCPul
public static void createRingPulLCPul(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc1, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double waveguideHeight, double gap2, double Lc2,
    double width2, double length2, double heigth2, boolean ENDCAP, int
    gdsLayer, double shapeReso)


// discPulleyA
public static void createDiscPulleyA(Struct currentStruct, double x,
```

```
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, boolean ENDCAP, int
    gdsLayer)


// ringPulleyA
public static void createRingPulleyA(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, boolean ENDCAP, int gdsLayer)


// discPulADS
public static void createDiscPulADS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, double gap2, double width2,
     double length2, boolean ENDCAP, int gdsLayer)


// ringPulADS
public static void createRingPulADS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double gap2, double width2, double length2,
    boolean ENDCAP, int gdsLayer)


// discPulAPul
public static void createDiscPulAPul(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double waveguideLength, double gap2, double angle2,
     double width2, double length2, boolean ENDCAP, int gdsLayer)


// ringPulAPul
public static void createRingPulAPul(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double gap2, double angle2, double width2, double
    length2, boolean ENDCAP, int gdsLayer)


// discPulleyLCA
public static void createDiscPulleyLCA(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double waveguideLength, boolean ENDCAP, int gdsLayer)


// ringPulleyLCA
public static void createRingPulleyLCA(Struct currentStruct, double x,
```

```
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, boolean ENDCAP, int gdsLayer)


// discPulLCADS
public static void createDiscPulLCADS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double waveguideLength, double gap2, double width2, double length2,
     boolean ENDCAP, int gdsLayer)


// ringPulLCADS
public static void createRingPulLCADS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double gap2, double width2, double length2,
    boolean ENDCAP, int gdsLayer)


// discPulLCAPul
public static void createDiscPulLCAPul(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc1, int numberOfSidesCouplingRegion, double waveguideWidth,
     double waveguideLength, double gap2, double Lc2, double width2,
    double length2, boolean ENDCAP, int gdsLayer)


// ringPulLCAPul
public static void createRingPulLCAPul(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc1, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    waveguideLength, double gap2, double Lc2, double width2, double
    length2, boolean ENDCAP, int gdsLayer)


// discPulleyInv
public static void createDiscPulleyInverse(Struct currentStruct, double
     x, double y, double radius, int numberOfSidesDiscRing, double gap,
     double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, boolean ENDCAP, int gdsLayer, double shapeReso)


// ringPulleyInv
public static void createRingPulleyInverse(Struct currentStruct, double
     x, double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight,
    boolean ENDCAP, int gdsLayer, double shapeReso)
```

```
// discPulInvDS
public static void createDiscPulInvDS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, double gap2, double width2, double sleeve2, double
     length2, boolean ENDCAP, int gdsLayer, double shapeReso)


// ringPulInvDS
public static void createRingPulInvDS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
     gap2, double width2, double sleeve2, double length2, boolean
    ENDCAP, int gdsLayer, double shapeReso)


// discPulInvPul
public static void createDiscPulInvPul(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, double gap2, double angle2, double width2, double
    sleeve2, double length2, double height2, boolean ENDCAP, int
    gdsLayer, double shapeReso)


// ringPulInvPul
public static void createRingPulInvPul(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
     gap2, double angle2, double width2, double sleeve2, double length2
    , double height2, boolean ENDCAP, int gdsLayer, double shapeReso)


// discPulleyInvLC
public static void createDiscPulleyInvLC(Struct currentStruct, double x
    , double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double sleeveWidth, double waveguideLength, double waveguideHeight,
     boolean ENDCAP, int gdsLayer, double shapeReso)


// discPulleyInvLC
public static void createDiscPulleyInverseLC(Struct currentStruct,
    double x, double y, double radius, int numberOfSidesDiscRing,
    double gap, double Lc, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, boolean ENDCAP, int gdsLayer, double shapeReso)


// discPulInvLCDS
public static void createDiscPulInvLCDS(Struct currentStruct, double x,
```

```
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double sleeveWidth, double waveguideLength, double waveguideHeight,
    double gap2, double width2, double sleeve2, double length2,
    boolean ENDCAP, int gdsLayer, double shapeReso)


// ringPulInvLCDS
public static void createRingPulInvLCDS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
    gap2, double width2, double sleeve2, double length2, boolean
    ENDCAP, int gdsLayer, double shapeReso)


// discPulInvLCPul
public static void createDiscPulInvLCPul(Struct currentStruct, double x
    , double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc1, int numberOfSidesCouplingRegion, double waveguideWidth,
    double sleeveWidth, double waveguideLength, double waveguideHeight
    , double gap2, double Lc2, double width2, double sleeve2, double
    length2, double height2, boolean ENDCAP, int gdsLayer, double
    shapeReso)


// ringPulInvLCPul
public static void createRingPulInvLCPul(Struct currentStruct, double x
    , double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc1, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
    gap2, double Lc2, double width2, double sleeve2, double length2,
    double height2, boolean ENDCAP, int gdsLayer, double shapeReso)


// discPulleyInvA
public static void createDiscPulleyInvA(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, boolean
    ENDCAP, int gdsLayer)


// ringPulleyInvA
public static void createRingPulleyInvA(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, boolean ENDCAP, int gdsLayer)


// discPulInvADS
public static void createDiscPulInvADS(Struct currentStruct, double x,
    double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
```

```
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    gap2, double width2, double sleeve2, double length2, boolean ENDCAP
    , int gdsLayer)


// ringPulInvADS
public static void createRingPulInvADS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double width2,
    double sleeve2, double length2, boolean ENDCAP, int gdsLayer)


// discPulInvAPul
public static void createDiscPulInvAPul(Struct currentStruct, double x,
     double y, double radius, int numberOfSidesDiscRing, double gap,
    double waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    gap2, double angle2, double width2, double sleeve2, double length2,
     boolean ENDCAP, int gdsLayer)


// ringPulInvAPul
public static void createRingPulInvAPul(Struct currentStruct, double x,
     double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double angle2,
    double width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)


// discPulleyInvLCA
public static void createDiscPulleyInvLCA(Struct currentStruct, double
    x, double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double sleeveWidth, double waveguideLength, boolean ENDCAP, int
    gdsLayer)


// ringPulleyInvLCA
public static void createRingPulleyInvLCA(Struct currentStruct, double
    x, double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, boolean ENDCAP, int gdsLayer)


// discPulInvLCADS
public static void createDiscPulInvLCADS(Struct currentStruct, double x
    , double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc, int numberOfSidesCouplingRegion, double waveguideWidth,
    double sleeveWidth, double waveguideLength, double gap2, double
    width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)
```

```
// ringPulInvLCADS
public static void createRingPulInvLCADS(Struct currentStruct, double x
    , double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double width2,
    double sleeve2, double length2, boolean ENDCAP, int gdsLayer)



// discPulInvLCAPul
public static void createDiscPulInvLCAPul(Struct currentStruct, double
    x, double y, double radius, int numberOfSidesDiscRing, double gap,
    double Lc1, int numberOfSidesCouplingRegion, double waveguideWidth,
     double sleeveWidth, double waveguideLength, double gap2, double
    Lc2, double width2, double sleeve2, double length2, boolean ENDCAP,
     int gdsLayer)


// ringPulInvLCAPul
public static void createRingPulInvLCAPul(Struct currentStruct, double
    x, double y, double radius, double ringWidth, int
    numberOfSidesDiscRing, double gap, double Lc1, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double Lc2,
    double width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)


// discPulleyInvPos
public static void createDiscPulleyInvPos(Struct currentStruct, double
    x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight,
    boolean ENDCAP, int gdsLayer, double shapeReso)


// ringPulleyInvPos
public static void createRingPulleyInvPos(Struct currentStruct, double
    x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, boolean ENDCAP, int gdsLayer, double shapeReso)


// discPulInvPDS
public static void createDiscPulInvPDS(Struct currentStruct, double x,
    double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight, double
     gap2, double width2, double sleeve2, double length2, boolean
    ENDCAP, int gdsLayer, double shapeReso)
```

```
// ringPullnvPDS
public static void createRingPullnvPDS(Struct currentStruct, double x,
    double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, double gap2, double width2, double sleeve2, double
     length2, boolean ENDCAP, int gdsLayer, double shapeReso)


// discPullnvPPul
public static void createDiscPullnvPPul(Struct currentStruct, double x,
     double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, double gap2, double angle2, double width2, double
    sleeve2, double length2, double height2, boolean ENDCAP, int
    gdsLayer, double shapeReso)


// ringPullnvPPul
public static void createRingPullnvPPul(Struct currentStruct, double x,
     double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    waveguideHeight, double gap2, double angle2, double width2, double
    sleeve2, double length2, double height2, boolean ENDCAP, int
    gdsLayer, double shapeReso)


// discPulleyInvPosLC
public static void createDiscPulleyInvPosLC(Struct currentStruct,
    double x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight,
    boolean ENDCAP, int gdsLayer, double shapeReso)


// ringPulleyInvPosLC
public static void createRingPulleyInvPosLC(Struct currentStruct,
    double x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    Lc, int numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double waveguideHeight,
    boolean ENDCAP, int gdsLayer, double shapeReso)


// discPullnvPLCDS
public static void createDiscPullnvPLCDS(Struct currentStruct, double x
    , double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
```

```
    sleeveWidth , double waveguideLength , double waveguideHeight , double
     gap2, double width2 , double sleeve2 , double length2 , boolean
    ENDCAP, int gdsLayer , double shapeReso)

// ringPullnvPLCDS
public static void createRingPullnvPLCDS(Struct currentStruct , double x
    , double y, double radius , double ringWidth , double
    ringDiscSleeveWidth , int numberOfSidesDiscRing , double gap, double
    Lc, int numberOfSidesCouplingRegion , double waveguideWidth , double
    sleeveWidth , double waveguideLength , double waveguideHeight , double
     gap2, double width2 , double sleeve2 , double length2 , boolean
    ENDCAP, int gdsLayer , double shapeReso)


// discPullnvPLCPul
public static void createDiscPullnvPLCPul(Struct currentStruct , double
    x, double y, double radius , double ringDiscSleeveWidth , int
    numberOfSidesDiscRing , double gap, double Lc1, int
    numberOfSidesCouplingRegion , double waveguideWidth , double
    sleeveWidth , double waveguideLength , double waveguideHeight , double
     gap2, double Lc2, double width2 , double sleeve2 , double length2 ,
    double height2 , boolean ENDCAP, int gdsLayer , double shapeReso)


// ringPullnvPLCPul
public static void createRingPullnvPLCPul(Struct currentStruct , double
    x, double y, double radius , double ringWidth , double
    ringDiscSleeveWidth , int numberOfSidesDiscRing , double gap, double
    Lc1, int numberOfSidesCouplingRegion , double waveguideWidth , double
     sleeveWidth , double waveguideLength , double waveguideHeight ,
    double gap2, double Lc2, double width2 , double sleeve2 , double
    length2 , double height2 , boolean ENDCAP, int gdsLayer , double
    shapeReso)


// discPulleyInvPosA
public static void createDiscPulleyInvPosA(Struct currentStruct , double
     x, double y, double radius , double ringDiscSleeveWidth , int
    numberOfSidesDiscRing , double gap, double waveguideAngle , int
    numberOfSidesCouplingRegion , double waveguideWidth , double
    sleeveWidth , double waveguideLength , boolean ENDCAP, int gdsLayer)


// ringPulleyInvPosA
public static void createRingPulleyInvPosA(Struct currentStruct , double
     x, double y, double radius , double ringWidth , double
    ringDiscSleeveWidth , int numberOfSidesDiscRing , double gap, double
    waveguideAngle , int numberOfSidesCouplingRegion , double
    waveguideWidth , double sleeveWidth , double waveguideLength , boolean
     ENDCAP, int gdsLayer)


// discPullnvPADS
public static void createDiscPullnvPADS(Struct currentStruct , double x,
     double y, double radius , double ringDiscSleeveWidth , int
    numberOfSidesDiscRing , double gap, double waveguideAngle , int
    numberOfSidesCouplingRegion , double waveguideWidth , double
```

```
    sleeveWidth, double waveguideLength, double gap2, double width2,
    double sleeve2, double length2, boolean ENDCAP, int gdsLayer)


// ringPullnvPADS
public static void createRingPullnvPADS(Struct currentStruct, double x,
     double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    gap2, double width2, double sleeve2, double length2, boolean ENDCAP
    , int gdsLayer)


//  discPullnvPAPul
public static void createDiscPullnvPAPul(Struct currentStruct, double x
    , double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double waveguideAngle, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double angle2,
    double width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)


//  ringPullnvPAPul
public static void createRingPullnvPAPul(Struct currentStruct, double x
    , double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    waveguideAngle, int numberOfSidesCouplingRegion, double
    waveguideWidth, double sleeveWidth, double waveguideLength, double
    gap2, double angle2, double width2, double sleeve2, double length2,
     boolean ENDCAP, int gdsLayer)


// discPulleyInvPosLCA
public static void createDiscPulleyInvPosLCA(Struct currentStruct,
    double x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, boolean ENDCAP, int gdsLayer)


// ringPulleyInvPosLCA
public static void createRingPulleyInvPosLCA(Struct currentStruct,
    double x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    Lc, int numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, boolean ENDCAP, int gdsLayer)


// discPullnvPLCADS
public static void createDiscPullnvPLCADS(Struct currentStruct, double
    x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double Lc, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double width2,
    double sleeve2, double length2, boolean ENDCAP, int gdsLayer)
```

```
// ringPullnvPLCADS
public static void createRingPullnvPLCADS(Struct currentStruct, double
    x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    Lc, int numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double width2,
    double sleeve2, double length2, boolean ENDCAP, int gdsLayer)



// discPullnvPLCAPul
public static void createDiscPullnvPLCAPul(Struct currentStruct, double
     x, double y, double radius, double ringDiscSleeveWidth, int
    numberOfSidesDiscRing, double gap, double Lc1, int
    numberOfSidesCouplingRegion, double waveguideWidth, double
    sleeveWidth, double waveguideLength, double gap2, double Lc2,
    double width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)


// ringPullnvPLCAPul
public static void createRingPullnvPLCAPul(Struct currentStruct, double
     x, double y, double radius, double ringWidth, double
    ringDiscSleeveWidth, int numberOfSidesDiscRing, double gap, double
    Lc1, int numberOfSidesCouplingRegion, double waveguideWidth, double
     sleeveWidth, double waveguideLength, double gap2, double Lc2,
    double width2, double sleeve2, double length2, boolean ENDCAP, int
    gdsLayer)


// waveGuideInvPhC - al is a Double vector array containing rx1 ry1 N1
     .... rxn ryn Nn values
public static ArrayList<GArea> createWaveGuideInvPhC(ArrayList<Double>
    al, double x, double y, double a, double W, int gdsLayer)


// waveGuideInvPhC - al is a Double vector array containing rx1 ry1 N1
     .... rxn ryn Nn values
public static void createWaveGuideInvPhC(Struct currentStruct,
    ArrayList<Double> al, double x, double y, double a, double W, int
    gdsLayer)


// waveGuideInvPhCvary - al is a Double vector array containing rx1 ry1
     a1 N1 .... rxn ryn an Nn values
public static ArrayList<GArea> createWaveGuideInvPhCvary(ArrayList<
    Double> al, double x, double y, double W, int gdsLayer)


// waveGuideInvPhCvary - al is a Double vector array containing rx1 ry1
     a1 N1 .... rxn ryn an Nn values
public static void createWaveGuideInvPhCvary(Struct currentStruct,
    ArrayList<Double> al, double x, double y, double W, int gdsLayer)
```

```
// waveGuidePhC - al is a Double vector array containing rx1 ry1 N1
    .... rxn ryn Nn values
public static ArrayList<GArea> createWaveGuidePhC(ArrayList<Double> al,
     double x, double y, double a, double W, double So, double Sh, int
    gdsLayer)


// waveGuidePhC - al is a Double vector array containing rx1 ry1 N1
    .... rxn ryn Nn values
public static void createWaveGuidePhC(Struct currentStruct, ArrayList<
    Double> al, double x, double y, double a, double W, double So,
    double Sh, int gdsLayer)


// waveGuidePhCvary - al is a Double vector array containing rx1 ry1 a1
     N1 .... rxn ryn an Nn values
public static ArrayList<GArea> createWaveGuidePhCvary(ArrayList<Double>
     al, double x, double y, double W, double So, double Sh, int
    gdsLayer)


// waveGuidePhCvary - al is a Double vector array containing rx1 ry1 a1
     N1 .... rxn ryn an Nn values
public static void createWaveGuidePhCvary(Struct currentStruct,
    ArrayList<Double> al, double x, double y, double W, double So,
    double Sh, int gdsLayer)


// waveGuideInvRectPhC - al is a Double vector array containing Lx1 Ly1
     .... Lxn Lyn values
public static ArrayList<GArea> createWaveGuideInvRectPhC(ArrayList<
    Double> al, double x, double y, double a, double W, int gdsLayer)


// waveGuideInvRectPhC - al is a Double vector array containing Lx1 Ly1
     .... Lxn Lyn values
public static void createWaveGuideInvRectPhC(Struct currentStruct,
    ArrayList<Double> al, double x, double y, double a, double W, int
    gdsLayer)


// waveGuideInvRectPhCvary - al is a Double vector array containing Lx1
     Ly1 a1 .... Lxn Lyn an values
public static ArrayList<GArea> createWaveGuideInvRectPhCvary(ArrayList<
    Double> al, double x, double y, double W, int gdsLayer)


// waveGuideInvRectPhCvary - al is a Double vector array containing Lx1
     Ly1 a1 .... Lxn Lyn an values
public static void createWaveGuideInvRectPhCvary(Struct currentStruct,
    ArrayList<Double> al, double x, double y, double W, int gdsLayer)


// waveGuideRectPhC - al is a Double vector array containing Lx1 Ly1
    .... Lxn Lyn values
public static ArrayList<GArea> createWaveGuideRectPhC(ArrayList<Double>
     al, double x, double y, double a, double W, double So, double Sh,
```

```
    int gdsLayer)

// waveGuideRectPhC - al is a Double vector array containing Lx1 Ly1
    .... Lxn Lyn values
public static void createWaveGuideRectPhC(Struct currentStruct,
    ArrayList<Double> al, double x, double y, double a, double W,
    double So, double Sh, int gdsLayer)



// waveGuideRectPhCvary - al is a Double vector array containing Lx1
    Ly1 a1 ... Lxn Lyn an values
public static ArrayList<GArea> createWaveGuideRectPhCvary(ArrayList<
    Double> al, double x, double y, double W, double So, double Sh, int
     gdsLayer)


// waveGuideRectPhCvary - al is a Double vector array containing Lx1
    Ly1 a1 ... Lxn Lyn an values
public static void createWaveGuideRectPhCvary(Struct currentStruct,
    ArrayList<Double> al, double x, double y, double W, double So,
    double Sh, int gdsLayer)


// waveGuideInvRectFlushPhCvary - al is a Double vector array
    containing Lx1 Ly1 a1 ... Lxn Lyn an values
public static ArrayList<GArea> createWaveGuideInvRectFlushPhCvary(
    ArrayList<Double> al, double x, double y, double W, double d, int
    gdsLayer)


// waveGuideInvRectFlushPhCvary - al is a Double vector array
    containing Lx1 Ly1 a1 ... Lxn Lyn an values
public static void createWaveGuideInvRectFlushPhCvary(Struct
    currentStruct, ArrayList<Double> al, double x, double y, double W,
    double d, int gdsLayer)


// waveGuideRectFlushPhCvary - al is a Double vector array containing
    Lx1 Ly1 a1 ... Lxn Lyn an values
public static ArrayList<GArea> createWaveGuideRectFlushPhCvary(
    ArrayList<Double> al, double x, double y, double W, double d,
    double So, double Sh, int gdsLayer)


// waveGuideRectFlushPhCvary - al is a Double vector array containing
    Lx1 Ly1 a1 ... Lxn Lyn an values
public static void createWaveGuideRectFlushPhCvary(Struct currentStruct
    , ArrayList<Double> al, double x, double y, double W, double d,
    double So, double Sh, int gdsLayer)


// wgdcdV1
public static GArea createWgdcd1(double x, double y, double rad, int
    numSides, double dx, double dy, double wgWidth, double wgLength,
```

```
    double wgRad, double sleeve, double gap,double ry, double dEllipse,
     double cutWidth, double cutPosition, double THETA, int gdsLayer)


// wgdcdV2
public static GArea createWgdcd2(double x, double y, double rad, int
    numSides, double dx, double dy, double H2, double W2, double tipH,
    double tipW, double tipS, double tipY, double wgWidth, double
    wgLength, double wgRad, double sleeve, double gap, double cutWidth,
     double cutPosition, double THETA, int gdsLayer)


// wgdcdV3
public static GArea createWgdcd3(double x, double y, double rad, int
    numSides, double dx, double dy, double dBoxBelowGap, double H2,
    double W2, double wgWidth, double wgLength, double wgRad, double
    sleeve, double gap, double cutWidth, double cutPosition, double
    distance, double THETA, int gdsLayer)


// wgdcdV4
public static GArea createWgdcd4(double x, double y, double rad, int
    numSides, double dx, double dy, double dBoxBelowGap, double H2,
    double triH, double wgWidth, double wgLength, double wgRad, double
    sleeve, double gap, double cutWidth, double cutPosition, double
    distance, double THETA, int gdsLayer)


// wgdcdV5
public static GArea createWgdcd5(double x, double y, double rad, int
    numSides, double dx, double dy, double dBoxBelowGap, double triH,
    double wgWidth, double wgLength, double wgRad, double sleeve,
    double gap, double cutWidth, double cutPositionUpper, double
    cutPositionLower, double THETA, int gdsLayer)



// wgdcdV6
public static GArea createWgdcd6(double x, double y, double rad, int
    numSides, double dx, double dy, double dBoxBelowGap, double triCutH
    , double triH, double wgWidth, double wgLength, double wgRad,
    double sleeve, double gap, double cutWidth, double cutPositionUpper
    , double cutPositionLower, double THETA, int gdsLayer)


// wgdcdV7
public static GArea createWgdcd7(double x, double y, double rad, double
     rad2, int numSides, double dx, double dy, double wgWidth, double
    wgLength, double wgRad, double sleeve, double gap, double cutWidth,
     double cutPosition, double THETA, int gdsLayer)


// wgdcdV8
public static ArrayList<GArea> createWgdcd8(double x, double y, double
    bottomTaperWidth, double frameWidth, double bottomInteriorWidth,
    double sleeve, double wgWidthTop, double wgWidthBottom, double
    wgStraightLengthTop, double wgTaperedLength, double gap, double
```

```
cutWidth, double dCut, double largeBoxW, double largeBoxH, int L1,
int L2, int L3, double THETA, int gdsLayer)
```

4.2.9 MEMS NEMS Library Methods

```
// bentBeam
public static ArrayList<GArea> createBentBeam(double x, double y,
    double width, double length1, double length2, double length3,
    double baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)
```

```
// bentBeam
public static void createBentBeam(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    length3, double baseHeight, double baseWidth, double anchorDistance
    , int anchorLayer, double THETA, int gdsLayer)
```

```
// bentBeamArray
public static ArrayList<GArea> createBentBeamArray(double x, double y,
    double width, double length1, double length2, double length3,
    double length4, double hOffset, double pitch, int numElements,
    double centralBeamWidth, double dimpleHeight, double dimpleWidth,
    int dimpleLayer, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)
```

```
// bentBeamArray
public static void createBentBeamArray(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    length3, double length4, double hOffset, double pitch, int
    numElements, double centralBeamWidth, double dimpleHeight, double
    dimpleWidth, int dimpleLayer, double baseWidth, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)
```

```
// biMorph
public static ArrayList<GArea> createBiMorph(double x, double y, double
     width1, double width2, double width3, double width4, double
    length1, double length2, double length3, double pitch, double
    dimpleHeight, double dimpleWidth, int dimpleLayer, double
    baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)
```

```
// biMorph
public static void createBiMorph(Struct currentStruct, double x, double
     y, double width1, double width2, double width3, double width4,
    double length1, double length2, double length3, double pitch,
    double dimpleHeight, double dimpleWidth, int dimpleLayer, double
    baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)
```

```
// combDriveV1
public static ArrayList<GArea> createCombDriveV1(double x, double y,
    double width1, double width2, double length1, double length2, int
    numElectrodes, double pitch, double baseHeight, int baseLayer,
    double anchorDistance, int anchorLayer, double THETA, int gdsLayer)
```

```
// combDriveV1
public static void createCombDriveV1(Struct currentStruct, double x,
    double y, double width1, double width2, double length1, double
    length2, int numElectrodes, double pitch, double baseHeight, int
    baseLayer, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// linearDriveV1
public static ArrayList<GArea> createLinearDriveV1(double x, double y,
    double width1, double length1, double length2, double length3,
    double gap, int numElectrodes, double pitch, double baseHeight,
    double baseWidth, double rotorPitch, int rotorLayer, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// linearDriveV1
public static void createLinearDriveV1(Struct currentStruct, double x,
    double y, double width1, double length1, double length2, double
    length3, double gap, int numElectrodes, double pitch, double
    baseHeight, double baseWidth, double rotorPitch, int rotorLayer,
    double anchorDistance, int anchorLayer, double THETA, int gdsLayer)



// foldedSpring1A
public static ArrayList<GArea> createFoldedSpring1A(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, double baseHeight, double
    baseWidth, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// foldedSpring1A
public static void createFoldedSpring1A(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, double baseHeight,
    double baseWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// foldedSpring2A
public static ArrayList<GArea> createFoldedSpring2A(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, double baseHeight, double
    baseWidth, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// foldedSpring2A
public static void createFoldedSpring2A(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, double baseHeight,
    double baseWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)
```

```
// foldedSpring1B
public static ArrayList<GArea> createFoldedSpring1B(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, double baseHeight, double
    baseWidth, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// foldedSpring1B
public static void createFoldedSpring1B(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, double baseHeight,
    double baseWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// foldedSpring2B
public static ArrayList<GArea> createFoldedSpring2B(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, double baseHeight, double
    baseWidth, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// foldedSpring2B
public static void createFoldedSpring2B(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, double baseHeight,
    double baseWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// foldedSpring2C
public static ArrayList<GArea> createFoldedSpring2C(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, double baseHeight, double
    baseWidth, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// foldedSpring2C
public static void createFoldedSpring2C(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, double baseHeight,
    double baseWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// foldedSpring2D
public static ArrayList<GArea> createFoldedSpring2D(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, double baseHeight, double
    baseWidth, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)
```

```
// foldedSpring2D
public static void createFoldedSpring2D(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, double baseHeight,
    double baseWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// foldedSpring2E
public static ArrayList<GArea> createFoldedSpring2E(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, int numSides, double baseHeight,
    double baseWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// foldedSpring2E
public static void createFoldedSpring2E(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, int numSides, double
    baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// foldedSpring2F
public static ArrayList<GArea> createFoldedSpring2F(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, int numSides, double baseHeight,
    double baseWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// foldedSpring2F
public static void createFoldedSpring2F(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, int numSides, double
    baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// foldedSpring2G
public static ArrayList<GArea> createFoldedSpring2G(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, int numSides, double baseHeight,
    double baseWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// foldedSpring2G
public static void createFoldedSpring2G(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, int numSides, double
    baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)
```

```
// foldedSpring2H
public static ArrayList<GArea> createFoldedSpring2H(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, int numSides, double baseHeight,
    double baseWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// foldedSpring2H
public static void createFoldedSpring2H(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, int numSides, double
    baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)



// foldedSpring2I
public static ArrayList<GArea> createFoldedSpring2I(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, int numSides, double diameter,
    double anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// foldedSpring2I
public static void createFoldedSpring2I(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, int numSides, double
    diameter, double anchorDistance, int anchorLayer, double THETA, int
     gdsLayer)


// foldedSpring2J
public static ArrayList<GArea> createFoldedSpring2J(double x, double y,
     double width, double length1, double length2, double pitch, double
     amplitude, int numberOfPeriods, int numSides, double diameter,
    double anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// foldedSpring2J
public static void createFoldedSpring2J(Struct currentStruct, double x,
     double y, double width, double length1, double length2, double
    pitch, double amplitude, int numberOfPeriods, int numSides, double
    diameter, double anchorDistance, int anchorLayer, double THETA, int
     gdsLayer)


// bolometerL
public static ArrayList<GArea> createBolometerL(double x, double y,
    double w1, double w2, double w3, double g1, double g2, double g3,
    double L1, double L2, double r, double ri, int numSides, double a,
    double b, double c, double d, double e, double f, int La, int Lb,
    int Lc, int Ld, int Le, int Lf, double THETA, double shapeReso)
```

```
// bolometerL
public static void createBolometerL(Struct currentStruct, double x,
    double y, double w1, double w2, double w3, double g1, double g2,
    double g3, double L1, double L2, double r, double ri, int numSides,
     double a, double b, double c, double d, double e, double f, int La
    , int Lb, int Lc, int Ld, int Le, int Lf, double THETA, double
    shapeReso)


// bolometerU
public static ArrayList<GArea> createBolometerU(double x, double y,
    double w1, double w2, double w3, double g1, double g2, double g3,
    double L1, double L2, double r, double ri, int numSides, double a,
    double b, double c, double d, double e, double f, int La, int Lb,
    int Lc, int Ld, int Le, int Lf, double THETA, double shapeReso)


// bolometerU
public static void createBolometerU(Struct currentStruct, double x,
    double y, double w1, double w2, double w3, double g1, double g2,
    double g3, double L1, double L2, double r, double ri, int numSides,
     double a, double b, double c, double d, double e, double f, int La
    , int Lb, int Lc, int Ld, int Le, int Lf, double THETA, double
    shapeReso)


// gear
public static ArrayList<GArea> createGear(double x, double y, double
    rad, double width, double height, int numberOfGears, int numSides,
    double THETA, int gdsLayer)


// gear
public static void createGear(Struct currentStruct, double x, double y,
     double rad, double width, double height, int numberOfGears, int
    numSides, double THETA, int gdsLayer)


// gearT
public static ArrayList<GArea> createGearT(double x, double y, double
    rad, double width, double height, int numberOfGears, double
    triangleL, int numSides, double THETA, int gdsLayer)


// gearT
public static void createGearT(Struct currentStruct, double x, double y
    , double rad, double width, double height, int numberOfGears,
    double triangleL, int numSides, double THETA, int gdsLayer)


// straightSpring
public static ArrayList<GArea> createStraightSpring(double x, double y,
     double width, double radiusCenterHub, double widthRing, double
    radiusRing, int numSides, int numElements, double anchorDistance,
    int anchorLayer, double THETA, int gdsLayer)
```

```java
// straightSpring
public static void createStraightSpring(Struct currentStruct, double x,
     double y, double width, double radiusCenterHub, double widthRing,
    double radiusRing, int numSides, int numElements, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// circularSpring
public static ArrayList<GArea> createCircularSpring(double x, double y,
     double width, double radiusCenterHub, double widthRing, double
    radiusRing, int numSides, int numElements, double anchorDistance,
    int anchorLayer, double THETA, int gdsLayer)


// circularSpring
public static void createCircularSpring(Struct currentStruct, double x,
     double y, double width, double radiusCenterHub, double widthRing,
    double radiusRing, int numSides, int numElements, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// straightSpringE
public static ArrayList<GArea> createStraightSpringE(double x, double y
    , double width, double radiusCenterHub, double widthRing, double
    radiusRing, int numSides, int numElements, double gap, double
    electrodeWidth, int numElectrodes, double gapFraction, double
    anchorElectrodeDistance, double anchorDistance, int anchorLayer,
    double THETA, int gdsLayer)


// straightSpringE
public static void createStraightSpringE(Struct currentStruct, double x
    , double y, double width, double radiusCenterHub, double widthRing,
     double radiusRing, int numSides, int numElements, double gap,
    double electrodeWidth, int numElectrodes, double gapFraction,
    double anchorElectrodeDistance, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// circularSpringE
public static ArrayList<GArea> createCircularSpringE(double x, double y
    , double width, double radiusCenterHub, double widthRing, double
    radiusRing, int numSides, int numElements, double gap, double
    electrodeWidth, int numElectrodes, double gapFraction, double
    anchorElectrodeDistance, double anchorDistance, int anchorLayer,
    double THETA, int gdsLayer)


// circularSpringE
public static void createCircularSpringE(Struct currentStruct, double x
    , double y, double width, double radiusCenterHub, double widthRing,
     double radiusRing, int numSides, int numElements, double gap,
    double electrodeWidth, int numElectrodes, double gapFraction,
    double anchorElectrodeDistance, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)
```

```
// combRadialV1
public static ArrayList<GArea> createCombRadialV1(double x, double y,
    double w1, double r1, double w2, double r2, double wc, double gap,
    int numElements, int numSides, double thetaComb, double
    thetaOverlap, double anchorDistance, int anchorLayer, double THETA,
     int gdsLayer)


// combRadialV1
public static void createCombRadialV1(Struct currentStruct, double x,
    double y, double w1, double r1, double w2, double r2, double wc,
    double gap, int numElements, int numSides, double thetaComb, double
     thetaOverlap, double anchorDistance, int anchorLayer, double THETA
    , int gdsLayer)


// combRadialV2
public static ArrayList<GArea> createCombRadialV2(double x, double y,
    double w1, double r1, double w2, double r2, double wc, double gap,
    int numElements, int numSides, double thetaComb, double
    thetaOverlap, double anchorDistance, int anchorLayer, double THETA,
     int gdsLayer)


// combRadialV2
public static void createCombRadialV2(Struct currentStruct, double x,
    double y, double w1, double r1, double w2, double r2, double wc,
    double gap, int numElements, int numSides, double thetaComb, double
     thetaOverlap, double anchorDistance, int anchorLayer, double THETA
    , int gdsLayer)


// flexure2A
public static ArrayList<GArea> createFlexure2A(double x, double y,
    double width, double length1, double length2, double widthMass,
    double lengthMass, double baseHeight, double baseWidth, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// flexure2A
public static void createFlexure2A(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    widthMass, double lengthMass, double baseHeight, double baseWidth,
    double anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// flexure2B
public static ArrayList<GArea> createFlexure2B(double x, double y,
    double width, double length1, double length2, double widthMass,
    double lengthMass, double connectorHeight, double connectorWidth,
    double squareHeight, double squareWidth, double baseHeight, double
    baseWidth, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)
```

```
// flexure2B
public static void createFlexure2B(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    widthMass, double lengthMass, double connectorHeight, double
    connectorWidth, double squareHeight, double squareWidth, double
    baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// flexure2C
public static ArrayList<GArea> createFlexure2C(double x, double y,
    double width, double length1, double length2, double length3,
    double widthMass, double lengthMass, double amplitude, int periods,
     double baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// flexure2C
public static void createFlexure2C(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    length3, double widthMass, double lengthMass, double amplitude, int
     periods, double baseHeight, double baseWidth, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// flexure2D
public static ArrayList<GArea> createFlexure2D(double x, double y,
    double width1, double width2, double width3, double width4, double
    length1, double length2, double length3, double length4, double
    length5, double length6, double baseWidth, double anchorDistance,
    int anchorLayer, double THETA, int gdsLayer)


// flexure2D
public static void createFlexure2D(Struct currentStruct, double x,
    double y, double width1, double width2, double width3, double
    width4, double length1, double length2, double length3, double
    length4, double length5, double length6, double baseWidth, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// flexure2E
public static ArrayList<GArea> createFlexure2E(double x, double y,
    double width1, double width2, double width3, double width4, double
    width5, double length1, double length2, double length3, double
    length4, double gap, double baseExtent, double baseHeight, double
    baseWidth, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// flexure2E
public static void createFlexure2E(Struct currentStruct, double x,
    double y, double width1, double width2, double width3, double
    width4, double width5, double length1, double length2, double
    length3, double length4, double gap, double baseExtent, double
    baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)
```

```
// flexure4A
public static ArrayList<GArea> createFlexure4A(double x, double y,
    double width, double length1, double length2, double widthMass,
    double lengthMass, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// flexure4A
public static void createFlexure4A(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    widthMass, double lengthMass, double baseHeight, double baseExtent,
     double anchorDistance, int anchorLayer, double THETA, int gdsLayer
    )


// flexure4B
public static ArrayList<GArea> createFlexure4B(double x, double y,
    double width, double length1, double length2, double widthMass,
    double gap, double baseHeight, double baseWidth, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// flexure4B
public static void createFlexure4B(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    widthMass, double gap, double baseHeight, double baseWidth, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// flexure4C
public static ArrayList<GArea> createFlexure4C(double x, double y,
    double width, double length1, double length2, double length3,
    double length4, double widthMass, double gap, double baseHeight,
    double baseWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// flexure4C
public static void createFlexure4C(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    length3, double length4, double widthMass, double gap, double
    baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// flexure4D
public static ArrayList<GArea> createFlexure4D(double x, double y,
    double width1, double width2, double width3, double length1, double
     length2, double widthMass, double lengthMass, double gap, double
    baseHeight, double baseWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)
```

```
// flexure4D
public static void createFlexure4D(Struct currentStruct, double x,
    double y, double width1, double width2, double width3, double
    length1, double length2, double widthMass, double lengthMass,
    double gap, double baseHeight, double baseWidth, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// flexure4E
public static ArrayList<GArea> createFlexure4E(double x, double y,
    double width1, double width2, double width3, double width4, double
    length1, double length2, double length3, double length4, double
    length5, double baseHeight, double baseWidth, double anchorDistance
    , int anchorLayer, double THETA, int gdsLayer)


// flexure4E
public static void createFlexure4E(Struct currentStruct, double x,
    double y, double width1, double width2, double width3, double
    width4, double length1, double length2, double length3, double
    length4, double length5, double baseHeight, double baseWidth,
    double anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverL
public static ArrayList<GArea> createCantileverL(double x, double y,
    double width, double startL, double pitch, int numElements, double
    baseHeight, double baseExtent, double linearVar, double THETA, int
    gdsLayer)


// cantileverL
public static void createCantileverL(Struct currentStruct, double x,
    double y, double width, double startL, double pitch, int
    numElements, double baseHeight, double baseExtent, double linearVar
    , double THETA, int gdsLayer)


// cantileverP
public static ArrayList<GArea> createCantileverP(double x, double y,
    double width, double startL, double pitch, int numElements, double
    baseHeight, double baseExtent, double percentageVar, double THETA,
    int gdsLayer)


// cantileverP
public static void createCantileverP(Struct currentStruct, double x,
    double y, double width, double startL, double pitch, int
    numElements, double baseHeight, double baseExtent, double
    percentageVar, double THETA, int gdsLayer)


// cantileverSine
public static ArrayList<GArea> createCantileverSine(double x, double y,
     double width, double startL, double pitch, int numElements, double
     baseHeight, double baseExtent, double sineAmplitude, double THETA,
     int gdsLayer)
```

```
// cantileverSine
public static void createCantileverSine(Struct currentStruct, double x,
     double y, double width, double startL, double pitch, int
    numElements, double baseHeight, double baseExtent, double
    sineAmplitude, double THETA, int gdsLayer)


// cantileverLSE
public static ArrayList<GArea> createCantileverLSE(double x, double y,
    double width, double startL, double endL, double pitch, int
    numElements, double baseHeight, double baseExtent, double THETA,
    int gdsLayer)


// cantileverLSE
public static void createCantileverLSE(Struct currentStruct, double x,
    double y, double width, double startL, double endL, double pitch,
    int numElements, double baseHeight, double baseExtent, double THETA
    , int gdsLayer)


// cantileverNLSE
public static ArrayList<GArea> createCantileverNLSE(double x, double y,
     double width, double startL, double endL, double pitch, int
    numElements, double baseHeight, double baseExtent, double THETA,
    int gdsLayer)


// cantileverNLSE
public static void createCantileverNLSE(Struct currentStruct, double x,
     double y, double width, double startL, double endL, double pitch,
    int numElements, double baseHeight, double baseExtent, double THETA
    , int gdsLayer)


// cantileverCustom - al is an array list with values s1 w1 L1 .... sn
    wn Ln
public static ArrayList<GArea> createCantileverCustom(double x, double
    y, ArrayList<Double> al, double sEnd, double bH, double THETA, int
    gdsLayer)


// cantileverCustom - al is an array list with values s1 w1 L1 .... sn
    wn Ln
public static void createCantileverCustom(Struct currentStruct, double
    x, double y, ArrayList<Double> al, double sEnd, double bH, double
    THETA, int gdsLayer)


// cantileverSR
public static ArrayList<GArea> createCantileverSR(double x, double y,
    double width, double length, double baseHeight, double baseExtent,
    double anchorDistance, int anchorLayer, double THETA, int gdsLayer)
```

```
// cantileverSR
public static void createCantileverSR(Struct currentStruct, double x,
    double y, double width, double length, double baseHeight, double
    baseExtent, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// cantileverSTri
public static ArrayList<GArea> createCantileverSTri(double x, double y,
     double width, double length, double triangleHeight, double
    baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverSTri
public static void createCantileverSTri(Struct currentStruct, double x,
     double y, double width, double length, double triangleHeight,
    double baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverSTrap
public static ArrayList<GArea> createCantileverSTrap(double x, double y
    , double widthBottom, double widthTop, double length, double
    baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverSTrap
public static void createCantileverSTrap(Struct currentStruct, double x
    , double y, double widthBottom, double widthTop, double length,
    double baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverSPaddle
public static ArrayList<GArea> createCantileverSPaddle(double x, double
     y, double widthBot, double widthTop, double lengthBot, double
    lengthTop, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverSPaddle
public static void createCantileverSPaddle(Struct currentStruct, double
     x, double y, double widthBot, double widthTop, double lengthBot,
    double lengthTop, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverSCH
public static ArrayList<GArea> createCantileverSCH(double x, double y,
    double width, double radius, int numSides, double baseHeight,
    double baseExtent, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)
```

```
// cantileverSCH
public static void createCantileverSCH(Struct currentStruct, double x,
    double y, double width, double radius, int numSides, double
    baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverSCF
public static ArrayList<GArea> createCantileverSCF(double x, double y,
    double width, double radius, int numSides, double length, double
    baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverSCF
public static void createCantileverSCF(Struct currentStruct, double x,
    double y, double width, double radius, int numSides, double length,
     double baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverHR
public static ArrayList<GArea> createCantileverHR(double x, double y,
    double width, double length, double hollowW, double baseHeight,
    double baseExtent, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// cantileverHR
public static void createCantileverHR(Struct currentStruct, double x,
    double y, double width, double length, double hollowW, double
    baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverHTri
public static ArrayList<GArea> createCantileverHTri(double x, double y,
     double width, double length, double triangleHeight, double hollowW
    , double baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverHTri
public static void createCantileverHTri(Struct currentStruct, double x,
     double y, double width, double length, double triangleHeight,
    double hollowW, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverHTrap
public static ArrayList<GArea> createCantileverHTrap(double x, double y
    , double widthBottom, double widthTop, double length, double
    hollowW, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)
```

```
// cantileverHTrap
public static void createCantileverHTrap(Struct currentStruct, double x
    , double y, double widthBottom, double widthTop, double length,
    double hollowW, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverHPaddle
public static ArrayList<GArea> createCantileverHPaddle(double x, double
     y, double widthBot, double widthTop, double lengthBot, double
    lengthTop, double hollowW, double baseHeight, double baseExtent,
    double anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverHPaddle
public static void createCantileverHPaddle(Struct currentStruct, double
     x, double y, double widthBot, double widthTop, double lengthBot,
    double lengthTop, double hollowW, double baseHeight, double
    baseExtent, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// cantileverHCH
public static ArrayList<GArea> createCantileverHCH(double x, double y,
    double width, double radius, int numSides, double hollowW, double
    baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverHCH
public static void createCantileverHCH(Struct currentStruct, double x,
    double y, double width, double radius, int numSides, double hollowW
    , double baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverHCF
public static ArrayList<GArea> createCantileverHCF(double x, double y,
    double width, double radius, int numSides, double length, double
    hollowW, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverHCF
public static void createCantileverHCF(Struct currentStruct, double x,
    double y, double width, double radius, int numSides, double length,
     double hollowW, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverPB2
public static ArrayList<GArea> createCantileverPB2(double x, double y,
    double width, double length1, double length2, double lengthTop,
    double gap, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)
```

```
// cantileverPB2
public static void createCantileverPB2(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    lengthTop, double gap, double baseHeight, double baseExtent, double
     anchorDistance, int anchorLayer, double THETA, int gdsLayer) {


// cantileverPB3
public static ArrayList<GArea> createCantileverPB3(double x, double y,
    double width, double length1, double length2, double length3,
    double lengthTop, double gap, double baseHeight, double baseExtent,
     double anchorDistance, int anchorLayer, double THETA, int gdsLayer
    )


// cantileverPB3
public static void createCantileverPB3(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    length3, double lengthTop, double gap, double baseHeight, double
    baseExtent, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// cantileverUR
public static ArrayList<GArea> createCantileverUR(double x, double y,
    double width, double length1, double length2, double lengthTop,
    double baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverUR
public static void createCantileverUR(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    lengthTop, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverUCF
public static ArrayList<GArea> createCantileverUCF(double x, double y,
    double width, double length1, double length2, double lengthTop,
    double radius, int numSides, double baseHeight, double baseExtent,
    double anchorDistance, int anchorLayer, double THETA, int gdsLayer)

// cantileverUCF
public static void createCantileverUCF(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    lengthTop, double radius, int numSides, double baseHeight, double
    baseExtent, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// cantileverUC
public static ArrayList<GArea> createCantileverUC(double x, double y,
    double width, double length1, double length2, double diameter, int
    numSides, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)
```

```
// cantileverUC
public static void createCantileverUC(Struct currentStruct, double x,
    double y, double width, double length1, double length2, double
    diameter, int numSides, double baseHeight, double baseExtent,
    double anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverUCC
public static ArrayList<GArea> createCantileverUCC(double x, double y,
    double width1, double width2, double length1, double length2,
    double length3, double lengthTop, double baseHeight, double
    baseExtent, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// cantileverUCC
public static void createCantileverUCC(Struct currentStruct, double x,
    double y, double width1, double width2, double length1, double
    length2, double length3, double lengthTop, double baseHeight,
    double baseExtent, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)


// cantileverUCP
public static ArrayList<GArea> createCantileverUCP(double x, double y,
    double width1, double width2, double length1, double length2a,
    double length2b, double length3, double lengthTop, double
    baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverUCP
public static void createCantileverUCP(Struct currentStruct, double x,
    double y, double width1, double width2, double length1, double
    length2a, double length2b, double length3, double lengthTop, double
     baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverCE
public static ArrayList<GArea> createCantileverCE(double x, double y,
    double width, double length, double rX, double rY, int numSides,
    double baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// cantileverCE
public static void createCantileverCE(Struct currentStruct, double x,
    double y, double width, double length, double rX, double rY, int
    numSides, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverCEPaddle
public static ArrayList<GArea> createCnntileverCEPaddle(double x,
    double y, double width, double length, double rX1, double rY1,
```

```
    double rX2, double rY2, int numSides, double paddleW, double
    paddleL, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// cantileverCEPaddle
public static void createCnntileverCEPaddle(Struct currentStruct,
    double x, double y, double width, double length, double rX1, double
     rY1, double rX2, double rY2, int numSides, double paddleW, double
    paddleL, double baseHeight, double baseExtent, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// dcBeamL
public static ArrayList<GArea> createDcBeamL(double x, double y, double
     width, double startL, double pitch, int numElements, double
    baseHeight, double baseExtent, double linearVar, double THETA, int
    gdsLayer)


// dcBeamL
public static void createDcBeamL(Struct currentStruct, double x, double
     y, double width, double startL, double pitch, int numElements,
    double baseHeight, double baseExtent, double linearVar, double
    THETA, int gdsLayer)


// dcBeamP
public static ArrayList<GArea> createDcBeamP(double x, double y, double
     width, double startL, double pitch, int numElements, double
    baseHeight, double baseExtent, double percentageVar, double THETA,
    int gdsLayer)


// dcBeamP
public static void createDcBeamP(Struct currentStruct, double x, double
     y, double width, double startL, double pitch, int numElements,
    double baseHeight, double baseExtent, double percentageVar, double
    THETA, int gdsLayer)


// dcBeamLSE
public static ArrayList<GArea> createDcBeamLSE(double x, double y,
    double width, double startL, double endL, double pitch, int
    numElements, double baseHeight, double baseExtent, double THETA,
    int gdsLayer)


// dcBeamLSE
public static void createDcBeamLSE(Struct currentStruct, double x,
    double y, double width, double startL, double endL, double pitch,
    int numElements, double baseHeight, double baseExtent, double THETA
    , int gdsLayer)
```

```java
// dcBeamNLSE
public static ArrayList<GArea> createDcBeamNLSE(double x, double y,
    double width, double startL, double endL, double pitch, int
    numElements, double baseHeight, double baseExtent, double THETA,
    int gdsLayer)


// dcBeamNLSE
public static void createDcBeamNLSE(Struct currentStruct, double x,
    double y, double width, double startL, double endL, double pitch,
    int numElements, double baseHeight, double baseExtent, double THETA
    , int gdsLayer)


// dcBeamCustom - al is a vector array of s1 w1 L1 .... sn wn LN values
public static ArrayList<GArea> createDcBeamCustom(double x, double y,
    ArrayList<Double> al, double sEnd, double bH, double THETA, int
    gdsLayer)


// dcBeamCustom - al is a vector array of s1 w1 L1 .... sn wn LN values
public static void createDcBeamCustom(Struct currentStruct, double x,
    double y, ArrayList<Double> al, double sEnd, double bH, double
    THETA, int gdsLayer)


// dcBeamR
public static ArrayList<GArea> createDcBeamR(double x, double y, double
     width, double length, double baseHeight, double baseExtent, double
     anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// dcBeamR
public static void createDcBeamR(Struct currentStruct, double x, double
     y, double width, double length, double baseHeight, double
    baseExtent, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// dcBeamT
public static ArrayList<GArea> createDcBeamT(double x, double y, double
     width1, double length1, double width2, double length2, double
    baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// dcBeamT
public static void createDcBeamT(Struct currentStruct, double x, double
     y, double width1, double length1, double width2, double length2,
    double baseHeight, double baseExtent, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// dcBeamT2
public static ArrayList<GArea> createDcBeamT2(double x, double y,
    double width1, double width2, double width3, double width4, double
    length1, double length2, double length3, double gap, double
```

```
    baseHeight , double baseWidth , double anchorDistance , int
    anchorLayer , double THETA, int gdsLayer)


// dcBeamT2
public static void createDcBeamT2(Struct currentStruct , double x,
    double y, double width1 , double width2 , double width3 , double
    width4 , double length1 , double length2 , double length3 , double gap ,
     double baseHeight , double baseWidth , double anchorDistance , int
    anchorLayer , double THETA, int gdsLayer)


// dcBeamCB
public static ArrayList<GArea> createDcBeamCB(double x, double y,
    double width , double lengthStart , double lengthEnd , int numElements
    , double baseHeight , double baseWidth , double anchorDistance , int
    anchorLayer , double THETA, int gdsLayer)


// dcBeamCB
public static void createDcBeamCB(Struct currentStruct , double x,
    double y, double width , double lengthStart , double lengthEnd , int
    numElements , double baseHeight , double baseWidth , double
    anchorDistance , int anchorLayer , double THETA, int gdsLayer)


// dcBeamC
public static ArrayList<GArea> createDcBeamC(double x, double y, double
     width , double length , double rX1 , double rY1 , double rX2, double
    rY2 , int numSides , double baseHeight , double baseExtent , double
    anchorDistance , int anchorLayer , double THETA, int gdsLayer)


// dcBeamC
public static void createDcBeamC(Struct currentStruct , double x, double
     y, double width , double length , double rX1 , double rY1 , double rX2
    , double rY2 , int numSides , double baseHeight , double baseExtent ,
    double anchorDistance , int anchorLayer , double THETA, int gdsLayer)


// MARAs
public static void createMARAs(Struct currentStruct , String id , double
    x, double y, int numElements , double L1 , double W1, double L2 ,
    double W2, double space , double hOverlap , double lengthSide , double
     hElectrode , double LB , double HB, double diameter , int numSides ,
    int layerFront , int layerBack , int layerMetal , double THETA)


// MARA
public static ArrayList<GArea> createMARA(double x, double y, int
    numElements , double L1 , double W1, double L2 , double W2, double
    space , double hOverlap , double lengthSide , double hElectrode ,
    double LB , double HB, double diameter , int numSides , int layerFront
    , int layerBack , int layerMetal , double THETA)
```

```
// MARA
public static void createMARA(Struct currentStruct, double x, double y,
     int numElements, double L1, double W1, double L2, double W2,
    double space, double hOverlap, double lengthSide, double hElectrode
    , double LB, double HB, double diameter, int numSides, int
    layerFront, int layerBack, int layerMetal, double THETA)


// MATALWs
public static void createMATALWs(Struct currentStruct, String id,
    double x, double y, int numElements, double L, double Wa, double Wb
    , double space, double hOverlap, double lengthSide, double
    hElectrode, double LB, double HB, double diameter, int numSides,
    int layerFront, int layerBack, int layerMetal, double THETA)


// MATALW
public static ArrayList<GArea> createMATALW(double x, double y, int
    numElements, double L, double Wa, double Wb, double space, double
    hOverlap, double lengthSide, double hElectrode, double LB, double
    HB, double diameter, int numSides, int layerFront, int layerBack,
    int layerMetal, double THETA)


// MATALW
public static void createMATALW(Struct currentStruct, double x, double
    y, int numElements, double L, double Wa, double Wb, double space,
    double hOverlap, double lengthSide, double hElectrode, double LB,
    double HB, double diameter, int numSides, int layerFront, int
    layerBack, int layerMetal, double THETA)


// MATAs
public static void createMATAs(Struct currentStruct, String id, double
    x, double y, int numElements, double L1, double W1a, double W1b,
    double L2, double W2a, double W2b, double space, double hOverlap,
    double lengthSide, double hElectrode, double LB, double HB, double
    diameter, int numSides, int layerFront, int layerBack, int
    layerMetal, double THETA)


// MATA
public static ArrayList<GArea> createMATA(double x, double y, int
    numElements, double L1, double W1a, double W1b, double L2, double
    W2a, double W2b, double space, double hOverlap, double lengthSide,
    double hElectrode, double LB, double HB, double diameter, int
    numSides, int layerFront, int layerBack, int layerMetal, double
    THETA)


// MATA
public static void createMATA(Struct currentStruct, double x, double y,
     int numElements, double L1, double W1a, double W1b, double L2,
    double W2a, double W2b, double space, double hOverlap, double
    lengthSide, double hElectrode, double LB, double HB, double
    diameter, int numSides, int layerFront, int layerBack, int
    layerMetal, double THETA)
```

```
// MAR2s
public static void createMAR2s(Struct currentStruct, String id, double
    x, double y, int numElements, double L1, double W1a, double W1b,
    double L2, double W2a, double W2b, double space, double lowerSpace,
     double hOverlap, double hElectrode, double lengthSide, double LB,
    double HB, double diameter, int numSides, int layerFront, int
    layerBack, int layerMetal, double THETA)


// MAR2
public static ArrayList<GArea> createMAR2(double x, double y, int
    numElements, double L1, double W1a, double W1b, double L2, double
    W2a, double W2b, double space, double lowerSpace, double hOverlap,
    double hElectrode, double lengthSide, double LB, double HB, double
    diameter, int numSides, int layerFront, int layerBack, int
    layerMetal, double THETA)


// MAR2
public static void createMAR2(Struct currentStruct, double x, double y,
     int numElements, double L1, double W1a, double W1b, double L2,
    double W2a, double W2b, double space, double lowerSpace, double
    hOverlap, double hElectrode, double lengthSide, double LB, double
    HB, double diameter, int numSides, int layerFront, int layerBack,
    int layerMetal, double THETA)


// MAR3s
public static void createMAR3s(Struct currentStruct, String id, double
    x, double y, int numElements, double L1, double W1a, double W1b,
    double L2, double W2a, double W2b, double space, double lowerSpace,
     double hOverlap, double hElectrode, double LB, double HB, double
    diameter, int numSides, int layerFront, int layerBack, int
    layerMetal, double THETA)


// MAR3
public static ArrayList<GArea> createMAR3(double x, double y, int
    numElements, double L1, double W1a, double W1b, double L2, double
    W2a, double W2b, double space, double lowerSpace, double hOverlap,
    double hElectrode, double LB, double HB, double diameter, int
    numSides, int layerFront, int layerBack, int layerMetal, double
    THETA)


// MAR3
public static void createMAR3(Struct currentStruct, double x, double y,
     int numElements, double L1, double W1a, double W1b, double L2,
    double W2a, double W2b, double space, double lowerSpace, double
    hOverlap, double hElectrode, double LB, double HB, double diameter,
     int numSides, int layerFront, int layerBack, int layerMetal,
    double THETA)
```

```
// MARCs
public static void createMARCs(Struct currentStruct, String id, double
    x, double y, int numElements, double L1, double W1a, double W1b,
    double L2, double W2a, double W2b, double space, double lowerSpace,
     double hOverlap, double hElectrode, double LB, double HB, double
    diameter, int numSides, int layerFront, int layerBack, int
    layerMetal, double THETA)


// MARC
public static ArrayList<GArea> createMARC(double x, double y, int
    numElements, double L1, double W1a, double W1b, double L2, double
    W2a, double W2b, double space, double lowerSpace, double hOverlap,
    double hElectrode, double LB, double HB, double diameter, int
    numSides, int layerFront, int layerBack, int layerMetal, double
    THETA)


// MARC
public static void createMARC(Struct currentStruct, double x, double y,
     int numElements, double L1, double W1a, double W1b, double L2,
    double W2a, double W2b, double space, double lowerSpace, double
    hOverlap, double hElectrode, double LB, double HB, double diameter,
     int numSides, int layerFront, int layerBack, int layerMetal,
    double THETA)


// MAT2s
public static void createMAT2s(Struct currentStruct, String id, double
    x, double y, int numElements, double L1, double W1a, double W1b,
    double L2, double W2a, double W2b, double space, double lowerSpace,
     double hOverlap, double hElectrode, double lengthSide, double LB,
    double HB, double diameter, int numSides, int layerFront, int
    layerBack, int layerMetal, double THETA)


// MAT2
public static ArrayList<GArea> createMAT2(double x, double y, int
    numElements, double L1, double W1a, double W1b, double L2, double
    W2a, double W2b, double space, double lowerSpace, double hOverlap,
    double hElectrode, double lengthSide, double LB, double HB, double
    diameter, int numSides, int layerFront, int layerBack, int
    layerMetal, double THETA)


// MAT2
public static void createMAT2(Struct currentStruct, double x, double y,
     int numElements, double L1, double W1a, double W1b, double L2,
    double W2a, double W2b, double space, double lowerSpace, double
    hOverlap, double hElectrode, double lengthSide, double LB, double
    HB, double diameter, int numSides, int layerFront, int layerBack,
    int layerMetal, double THETA)


// MAT3s
public static void createMAT3s(Struct currentStruct, String id, double
    x, double y, int numElements, double L1, double W1a, double W1b,
```

```
    double L2, double W2a, double W2b, double space, double lowerSpace,
     double hOverlap, double hElectrode, double LB, double HB, double
    diameter, int numSides, int layerFront, int layerBack, int
    layerMetal, double THETA)


// MAT3
public static ArrayList<GArea> createMAT3(double x, double y, int
    numElements, double L1, double W1a, double W1b, double L2, double
    W2a, double W2b, double space, double lowerSpace, double hOverlap,
    double hElectrode, double LB, double HB, double diameter, int
    numSides, int layerFront, int layerBack, int layerMetal, double
    THETA)


// MAT3
public static void createMAT3(Struct currentStruct, double x, double y,
     int numElements, double L1, double W1a, double W1b, double L2,
    double W2a, double W2b, double space, double lowerSpace, double
    hOverlap, double hElectrode, double LB, double HB, double diameter,
     int numSides, int layerFront, int layerBack, int layerMetal,
    double THETA)


// MATCs
public static void createMATCs(Struct currentStruct, String id, double
    x, double y, int numElements, double L1, double W1a, double W1b,
    double L2, double W2a, double W2b, double space, double lowerSpace,
     double hOverlap, double hElectrode, double LB, double HB, double
    diameter, int numSides, int layerFront, int layerBack, int
    layerMetal, double THETA)


// MATC
public static ArrayList<GArea> createMATC(double x, double y, int
    numElements, double L1, double W1a, double W1b, double L2, double
    W2a, double W2b, double space, double lowerSpace, double hOverlap,
    double hElectrode, double LB, double HB, double diameter, int
    numSides, int layerFront, int layerBack, int layerMetal, double
    THETA)


// MATC
public static void createMATC(Struct currentStruct, double x, double y,
     int numElements, double L1, double W1a, double W1b, double L2,
    double W2a, double W2b, double space, double lowerSpace, double
    hOverlap, double hElectrode, double LB, double HB, double diameter,
     int numSides, int layerFront, int layerBack, int layerMetal,
    double THETA)


// MARALINEARs
public static void createMARALINEARs(Struct currentStruct, String id,
    double x, double y, int numElements, double L, double dL, double W,
     double space, double hOverlap, double lengthSide, double
    hElectrode, double LB, double HB, double diameter, int numSides,
    int layerFront, int layerBack, int layerMetal, double THETA)
```

```java
// MARALINEAR
public static ArrayList<GArea> createMARALINEAR(double x, double y, int
     numElements, double L, double dL, double W, double space, double
    hOverlap, double lengthSide, double hElectrode, double LB, double
    HB, double diameter, int numSides, int layerFront, int layerBack,
    int layerMetal, double THETA)

// MARALINEAR
public static void createMARALINEAR(Struct currentStruct, double x,
    double y, int numElements, double L, double dL, double W, double
    space, double hOverlap, double lengthSide, double hElectrode,
    double LB, double HB, double diameter, int numSides, int layerFront
    , int layerBack, int layerMetal)

// MARACURVEs
public static void createMARACURVEs(Struct currentStruct, String id,
    double x, double y, int numElements, double L, double dL, double W,
     double space, double hOverlap, double lengthSide, double
    hElectrode, double LB, double HB, double diameter, int numSides,
    int layerFront, int layerBack, int layerMetal, double THETA, double
     shapeReso)

// MARACURVE
public static ArrayList<GArea> createMARACURVE(double x, double y, int
    numElements, double L, double dL, double W, double space, double
    hOverlap, double lengthSide, double hElectrode, double LB, double
    HB, double diameter, int numSides, int layerFront, int layerBack,
    int layerMetal, double THETA, double shapeReso)

// MARACURVE
public static void createMARACURVE(Struct currentStruct, double x,
    double y, int numElements, double L, double dL, double W, double
    space, double hOverlap, double lengthSide, double hElectrode,
    double LB, double HB, double diameter, int numSides, int layerFront
    , int layerBack, int layerMetal, double THETA, double shapeReso)

// GuckelRing
public static ArrayList<GArea> createGuckelRing(double x, double y,
    double ringWidth, double radius, int numOfSides, double beamWidth,
    double base, double connectorLegth, double connectorWidth, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)

// GuckelRing
public static void createGuckelRing(Struct currentStruct, double x,
    double y, double ringWidth, double radius, int numOfSides, double
    beamWidth, double base, double connectorLegth, double
    connectorWidth, double anchorDistance, int anchorLayer, double
    THETA, int gdsLayer)
```

```
// GuckelRingArray
public static ArrayList<GArea> createGuckelRingArray(double x, double y
    , double ringWidth, double radiusStart, double radiusEnd, double
    deltaRadius, int numOfSides, double beamWidth, double base, double
    connectorLegth, double connectorWidth, double anchorDistance, int
    anchorLayer, double THETA, int gdsLayer)


// GuckelRingArray
public static void createGuckelRingArray(Struct currentStruct, double x
    , double y, double ringWidth, double radiusStart, double radiusEnd,
     double deltaRadius, int numOfSides, double beamWidth, double base,
     double connectorLegth, double connectorWidth, double
    anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// diamondRing
public static ArrayList<GArea> createDiamondRing(double x, double y,
    double width1, double width2, double width3, double length1, double
     length2, double length3, double baseHeight, double baseWidth,
    double anchorDistance, int anchorLayer, double THETA, int gdsLayer)


// diamondRing
public static void createDiamondRing(Struct currentStruct, double x,
    double y, double width1, double width2, double width3, double
    length1, double length2, double length3, double baseHeight, double
    baseWidth, double anchorDistance, int anchorLayer, double THETA,
    int gdsLayer)


// fluidCell
public static ArrayList<GArea> createFluidCell(double x, double y,
    double w1, double w2, double w2T, double w3, double w4, double L1,
    double L2, double r, double r1, double r2, double r3, int numSides,
     double a, double b, double c, double d, double e, double f, double
     g, double h, double i, int La, int Lb, int Lc, int Ld, int Le, int
     Lf, double THETA, double shapeReso)


// fluidCell
public static void createFluidCell(Struct currentStruct, double x,
    double y, double w1, double w2, double w2T, double w3, double w4,
    double L1, double L2, double r, double r1, double r2, double r3,
    int numSides, double a, double b, double c, double d, double e,
    double f, double g, double h, double i, int La, int Lb, int Lc, int
     Ld, int Le, int Lf, double THETA, double shapeReso)
```

Bibliography

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[1] A. J. Speth, A. D. Wilson, A. Kern, and T. H. P. Chang, "Electron beam lithography using vector scan techniques," *Journal of Vacuum Science & Technology*, vol. 12, pp. 1235–1239, Nov. 1975.

[2] W. D. Grobman and T. W. Studwell, "Data compaction and vector scan e-beam system performance improvement using a novel algorithm for recognition of pattern step and repeats," *Journal of Vacuum Science & Technology*, vol. 16, pp. 1803–1808, Nov. 1979.

[3] W. D. Grobman, "An overview of pattern data preparation for vector scan electron beam lithography," *Journal of Vacuum Science & Technology*, vol. 17, pp. 1156–1163, Sept. 1980.

[4] S. M. Arnold, "Electron beam fabrication of computer-generated holograms," *Optical engineering*, vol. 24, no. 5, pp. 245803–245803, 1985.

[5] T. Shiono, K. Setsune, O. Yamazaki, and K. Wasa, "Computer-controlled electron beam writing system for thin film micro-optics," *Journal of Vacuum Science & Technology B*, vol. 5, pp. 33–36, Jan. 1987.

[6] V. Bogli, P. Unger, H. Beneking, B. Niemann, P. Guttmann, and W. Meyer-Ilse, "Electron Beam Lithography And Nanometer Structures: Fabrication Of Microzone Plates," *Optical Engineering*, vol. 27, no. 2, pp. 272143–272143–, 1988.

[7] M. A. Gesley, F. J. Hohn, R. G. Viswanathan, and A. D. Wilson, "A vector scan thermal field emission nanolithography system," *Journal of Vacuum Science & Technology B*, vol. 6, pp. 2014–2018, Nov. 1988.

[8] U. Klein and F. Gotz, "Definition of geometries with complicated, curved boundaries for electron beam pattern generation," *Microelectronic Engineering*, vol. 9, no. 1, pp. 495–497, 1989.

[9] K. S. Urquhart, S. H. Lee, C. C. Guest, M. R. Feldman, and H. Farhoosh, "Computer aided design of computer generated holograms for electron beam fabrication," *Applied Optics*, vol. 28, pp. 3387–3396, Aug. 1989.

[10] R. W. Hawley and N. C. Gallagher Jr, "Efficient electron-beam pattern data format for the production of binary computer-generated holograms," in *OE/LASE'90, 14-19 Jan., Los Angeles, CA*, pp. 11–23, International Society for Optics and Photonics, 1990.

[11] T. Shiono and H. Ogawa, "Diffraction-limited blazed reflection diffractive microlenses for oblique incidence fabricated by electron-beam lithography," *Applied optics*, vol. 30, no. 25, pp. 3643–3649, 1991.

[12] T. Erdogan, O. King, G. W. Wicks, D. G. Hall, E. H. Anderson, and M. J. Rooks, "Circularly symmetric operation of a concentric-circle-grating, surface- emitting, AlGaAs/GaAs quantum-well semiconductor laser," *Applied Physics Letters*, vol. 60, no. 16, p. 1921, 1992.

[13] O. King, "Curved grating fabrication techniques for surface-emitting distributed feedback lasers," *Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures*, vol. 10, p. 2974, Nov. 1992.

[14] D. M. Newman, R. W. Hawley, D. L. Goeckel, R. D. Crawford, S. Abraham, and N. C. Gallagher, "Efficient storage, computation, and exposure of computer-generated holograms by electron-beam lithography," *Applied optics*, vol. 32, no. 14, pp. 2555–2565, 1993.

[15] T. Shiono and H. Ogawa, "Planar-optic-disk pickup with diffractive micro-optics," *Applied optics*, vol. 33, no. 31, pp. 7350–7355, 1994.

[16] F. Vasey, "Electron-beam lithography of curved structures with an enhanced vector-scan pattern generator supporting conic-based primitives," *Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures*, vol. 12, p. 3460, Nov. 1994.

[17] E. H. Anderson, V. Boegli, and L. P. Muray, "Electron beam lithography digital pattern generator and electronics for generalized curvilinear structures," *Journal of Vacuum Science & Technology B*, vol. 13, pp. 2529–2534, Nov. 1995.

[18] J. Fan, D. Zaleta, K. S. Urquhart, and S. H. Lee, "Efficient encoding algorithms for computer-aided design of diffractive optical elements by the use of electron-beam fabrication," *Applied optics*, vol. 34, no. 14, pp. 2522–2533, 1995.

[19] K. A. Goldberg, R. Beguiristain, J. Bokor, H. Medecki, D. T. Attwood, K. Jackson, E. Tejnil, and G. E. Sommargren, "Progress towards $\lambda/20$ extreme ultraviolet interferometry," *Journal of Vacuum Science & Technology B*, vol. 13, pp. 2923–2927, Nov. 1995.

[20] D. Prongue, H. Rothuizen, F. Vasey, and P. Vettiger, "Enhanced e-beam system for the fabrication of optical elements," *Microelectronic engineering*, vol. 27, no. 1, pp. 163–166, 1995.

[21] S. J. Spector, C. J. Jacobsen, and D. M. Tennant, "Process optimization for production of sub-20 nm soft x-ray zone plates," *Journal of Vacuum Science & Technology B*, vol. 15, pp. 2872–2876, Nov. 1997.

[22] H. Rothuizen, D. Prongue, F. Vasey, and P. Vettiger, "A conic primitive-based pattern generator for electron-beam lithography of diffractive optical elements," *Microelectronic Engineering*, vol. 34, pp. 243–260, Dec. 1997.

[23] E. Di Fabrizio, F. Romanato, M. Gentili, S. Cabrini, B. Kaulich, J. Susini, and R. Barrett, "High-efficiency multilevel zone plates for keV X-rays," *Nature*, vol. 401, pp. 895–898, Oct. 1999.

[24] E. H. Anderson, D. L. Olynick, B. Harteneck, E. Veklerov, G. Denbeaux, W. Chao, A. Lucero, L. Johnson, and D. Attwood, "Nanofabrication and diffractive optics for high-resolution x-ray applications," *Journal of Vacuum Science & Technology B*, vol. 18, pp. 2970–2975, Nov. 2000.

[25] K. K. Lee, D. R. Lim, H.-C. Luan, A. Agarwal, J. Foresi, and L. C. Kimerling, "Effect of size and roughness on light transmission in a Si/SiO_2 waveguide: Experiments and model," *Applied Physics Letters*, vol. 77, no. 11, p. 1617, 2000.

[26] W. Chao, B. D. Harteneck, J. A. Liddle, E. H. Anderson, and D. T. Attwood, "Soft X-ray microscopy at a spatial resolution better than 15 nm," *Nature*, vol. 435, pp. 1210–1213, June 2005.

[27] http://www.genisysgmbh.de/web/applications.html, "Mixed Exposure Options, HighResolution and Fast Writing, Multi-Pass Exposure, Fracture Optimization, Application Notes."

[28] E. Gogolides, V. Constantoudis, G. P. Patsis, and A. Tserepi, "A review of line edge roughness and surface nanotexture resulting from patterning processes," *Microelectronic Engineering*, vol. 83, pp. 1067–1072, Apr. 2006.

[29] M. Lu, D. M. Tennant, and C. J. Jacobsen, "Orientation dependence of linewidth variation in sub-50-nm Gaussian e-beam lithography and its correction," *Journal of Vacuum Science & Technology B*, vol. 24, pp. 2881–2885, Nov. 2006.

[30] K. Evans-Lutterodt, A. Stein, J. M. Ablett, N. Bozovic, A. Taylor, and D. M. Tennant, "Using Compound Kinoform Hard-X-Ray Lenses to Exceed the Critical Angle Limit," *Physical Review Letters*, vol. 99, p. 134801, Sept. 2007.

[31] M. Ubaldi, V. Stasi, D. Piccinin, and M. Martinelli, "Molecular roughness analysis of developed resist by LER method," *Microelectronic Engineering*, vol. 84, pp. 1088–1091, May 2007.

[32] M. Lu, L. E. Ocola, S. K. Gray, and G. P. Wiederrecht, "Fabrication of metallic nanoslit waveguides with sharp bends," *Journal of Vacuum Science & Technology B*, vol. 26, pp. 2151–2155, Nov. 2008.

[33] S. Sardo, F. Giacometti, S. Doneda, U. Colombo, M. D. Muri, A. Donghi, R. Morson, G. Mutinati, A. Nottola, M. Gentili, and M. C. Ubaldi, "Line edge roughness (LER) reduction strategy for SOI waveguides fabrication," *Microelectronic Engineering*, vol. 85, pp. 1210–1213, May 2008.

[34] A. Stein, K. Evans-Lutterodt, N. Bozovic, and A. Taylor, "Fabrication of silicon kinoform lenses for hard x-ray focusing by electron beam lithography and deep reactive ion etching," *Journal of Vacuum Science & Technology B*, vol. 26, pp. 122–127, Jan. 2008.

[35] L. E. Ocola, "Nanoscale geometry assisted proximity effect correction for electron beam direct write nanolithography," *Journal of Vacuum Science & Technology B*, vol. 27, pp. 2569–2571, Nov. 2009.

[36] R. J. Bojko, J. Li, L. He, T. Baehr-Jones, M. Hochberg, and Y. Aida, "Electron beam lithography writing strategies for low loss, high confinement silicon optical waveguides," *Journal of Vacuum Science & Technology B*, vol. 29, no. 6, p. 06F309, 2011.

[37] C. Browning, T. Quaglio, T. Figueiro, S. Pauliac, J. Belledent, A. Fay, J. Bustos, J.-C. Marusic, and P. Schiavone, "Photonic curvilinear data processing," p. 92350V, Oct. 2014.

[38] M. I. Davanco and K. Srinivasan, "Efficient spectroscopy of single embedded emitters using optical fiber taper waveguides," *Optics Express*, vol. 17, pp. 10542–10563, June 2009.

[39] M. Davanco and K. Srinivasan, "Fiber-coupled semiconductor waveguides as an efficient optical interface to a single quantum dipole," *Optics Letters*, vol. 34, pp. 2542–2544, Aug. 2009.

[40] M. T. Rakher, L. Ma, O. Slattery, X. Tang, and K. Srinivasan, "Quantum transduction of telecommunications-band single photons from a quantum dot by frequency upconversion," *Nature Photonics*, vol. 4, pp. 786–791, Nov. 2010.

[41] M. Davanco and K. Srinivasan, "Hybrid gap modes induced by fiber taper waveguides: Application in spectroscopy of single solid-state emitters deposited on thin films," *Optics Express*, vol. 18, pp. 10995–11007, May 2010.

[42] M. Davanco, M. T. Rakher, W. Wegscheider, D. Schuh, A. Badolato, and K. Srinivasan, "Efficient quantum dot single photon extraction into an optical fiber using a nanophotonic directional coupler," *Applied Physics Letters*, vol. 99, p. 121101, Sept. 2011.

[43] M. Davanco, M. T. Rakher, D. Schuh, A. Badolato, and K. Srinivasan, "A circular dielectric grating for vertical extraction of single quantum dot emission," *Applied Physics Letters*, vol. 99, p. 041102, July 2011.

[44] M. T. Rakher and K. Srinivasan, "Subnanosecond electro-optic modulation of triggered single photons from a quantum dot," *Applied Physics Letters*, vol. 98, p. 211103, May 2011.

[45] F. Ferdous, H. Miao, D. E. Leaird, K. Srinivasan, J. Wang, L. Chen, L. T. Varghese, and A. M. Weiner, "Spectral line-by-line pulse shaping of on-chip microresonator frequency combs," *Nature Photonics*, vol. 5, pp. 770–776, Dec. 2011.

[46] K. Srinivasan, H. Miao, M. T. Rakher, M. Davanco, and V. Aksyuk, "Optomechanical Transduction of an Integrated Silicon Cantilever Probe Using a Microdisk Resonator," *Nano Letters*, vol. 11, pp. 791–797, Feb. 2011.

[47] M. T. Rakher, L. Ma, M. Davanco, O. Slattery, X. Tang, and K. Srinivasan, "Simultaneous Wavelength Translation and Amplitude Modulation of Single Photons from a Quantum Dot," *Physical Review Letters*, vol. 107, p. 083602, Aug. 2011.

[48] S. Ates, I. Agha, A. Gulinatti, I. Rech, M. T. Rakher, A. Badolato, and K. Srinivasan, "Two-Photon Interference Using Background-Free Quantum Frequency Conversion of Single Photons Emitted by an InAs Quantum Dot," *Physical Review Letters*, vol. 109, p. 147405, Oct. 2012.

[49] M. Davanco, J. Chan, A. H. Safavi-Naeini, O. Painter, and K. Srinivasan, "Slot-mode-coupled optomechanical crystals," *Optics Express*, vol. 20, pp. 24394–24410, Oct. 2012.

[50] M. DavanÃğo, J. R. Ong, A. B. Shehata, A. Tosi, I. Agha, S. Assefa, F. Xia, W. M. J. Green, S. Mookherjea, and K. Srinivasan, "Telecommunications-band heralded single photons from a silicon nanophotonic chip," *Applied Physics Letters*, vol. 100, p. 261104, June 2012.

[51] F. Ferdous, H. Miao, P.-H. Wang, D. E. Leaird, K. Srinivasan, L. Chen, V. Aksyuk, and A. M. Weiner, "Probing coherence in microcavity frequency combs via optical pulse shaping," *Optics Express*, vol. 20, pp. 21033–21043, Sept. 2012.

[52] I. Agha, M. Davanco, B. Thurston, and K. Srinivasan, "Low-noise chip-based frequency conversion by four-wave-mixing Bragg scattering in SiN_x waveguides," *Optics Letters*, vol. 37, pp. 2997–2999, July 2012.

[53] H. Miao, K. Srinivasan, and V. Aksyuk, "A microelectromechanically controlled cavity optomechanical sensing system," *New Journal of Physics*, vol. 14, p. 075015, July 2012.

[54] Y. Liu, H. Miao, V. Aksyuk, and K. Srinivasan, "Wide cantilever stiffness range cavity optomechanical sensors for atomic force microscopy," *Optics Express*, vol. 20, pp. 18268–18280, July 2012.

[55] S. Ates, L. Sapienza, M. Davanco, A. Badolato, and K. Srinivasan, "Bright Single-Photon Emission From a Quantum Dot in a Circular Bragg Grating Microcavity," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 18, pp. 1711–1721, Nov. 2012.

[56] F. Intravaia, P. S. Davids, R. S. Decca, V. A. Aksyuk, D. Lopez, and D. A. R. Dalvit, "Quasianalytical modal approach for computing Casimir interactions in periodic nanostructures," *Physical Review A*, vol. 86, p. 042101, Oct. 2012.

[57] K. J. Chau and H. J. Lezec, "Revisiting the Balazs thought experiment in the case of a left-handed material: electromagnetic-pulse-induced displacement of a dispersive, dissipative negative-index slab," *Optics Express*, vol. 20, pp. 10138–10162, Apr. 2012.

[58] P.-H. Wang, F. Ferdous, H. Miao, J. Wang, D. E. Leaird, K. Srinivasan, L. Chen, V. Aksyuk, and A. M. Weiner, "Observation of correlation between route to formation, coherence, noise, and communication performance of Kerr combs," *Optics Express*, vol. 20, pp. 29284–29295, Dec. 2012.

[59] R. Kumar, J. R. Ong, J. Recchio, K. Srinivasan, and S. Mookherjea, "Spectrally multiplexed and tunable-wavelength photon pairs at 1.55 Îijm from a silicon coupled-resonator optical waveguide," *Optics Letters*, vol. 38, pp. 2969–2971, Aug. 2013.

[60] Y. Liu, M. Davanco, V. Aksyuk, and K. Srinivasan, "Electromagnetically Induced Transparency and Wideband Wavelength Conversion in Silicon Nitride Microdisk Optomechanical Resonators," *Physical Review Letters*, vol. 110, p. 223603, May 2013.

[61] I. Agha, S. Ates, M. Davanco, and K. Srinivasan, "A chip-scale, telecommunications-band frequency conversion interface for quantum emitters," *Optics Express*, vol. 21, pp. 21628–21638, Sept. 2013.

[62] K. C. Balram, M. Davanco, J. Y. Lim, J. D. Song, and K. Srinivasan, "Moving boundary and photoelastic coupling in GaAs optomechanical resonators," *Optica*, vol. 1, pp. 414–420, Dec. 2014.

[63] M. Davanco, S. Ates, Y. Liu, and K. Srinivasan, "Si_3N_4 optomechanical crystals in the resolved-sideband regime," *Applied Physics Letters*, vol. 104, p. 041101, Jan. 2014.

[64] M. Davanco, C. S. Hellberg, S. Ates, A. Badolato, and K. Srinivasan, "Multiple time scale blinking in InAs quantum dot single-photon sources," *Physical Review B*, vol. 89, p. 161303, Apr. 2014.

[65] I. Agha, S. Ates, L. Sapienza, and K. Srinivasan, "Spectral broadening and shaping of nanosecond pulses: toward shaping of single photons from quantum emitters," *Optics Letters*, vol. 39, pp. 5677–5680, Oct. 2014.

[66] R. Zhang, C. Ti, M. I. Davanco, Y. Ren, V. Aksyuk, Y. Liu, and K. Srinivasan, "Integrated tuning fork nanocavity optomechanical transducers with high fMQM product and stress-engineered frequency tuning," *Applied Physics Letters*, vol. 107, p. 131110, Sept. 2015.

[67] K. Grutter, M. Davanco, and K. Srinivasan, "SiN Nanobeam Optomechanical Crystals," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 21, pp. 1–11, July 2015.

[68] K. E. Grutter, M. I. Davanco, and K. Srinivasan, "Slot-mode optomechanical crystals: a versatile platform for multimode optomechanics," *Optica*, vol. 2, p. 994, Nov. 2015.

[69] K. A. Twedt, J. Zou, M. Davanco, K. Srinivasan, J. J. McClelland, and V. A. Aksyuk, "Imaging nanophotonic modes of microresonators using a focused ion beam," *Nature Photonics*, vol. 10, pp. 35–39, Jan. 2016.

[70] T. Tamir and S. T. Peng, "Analysis and design of grating couplers," *Applied physics*, vol. 14, pp. 235–254, Nov. 1977.

[71] K. A. Bates, L. Li, R. L. Roncone, and J. J. Burke, "Gaussian beams from variable groove depth grating couplers in planar waveguides," *Applied Optics*, vol. 32, p. 2112, Apr. 1993.

[72] R. Waldhausl, B. Schnabel, P. Dannberg, E.-B. Kley, A. Brauer, and K. Wolfgang, "Efficient Coupling into Polymer Waveguides by Gratings," *Applied Optics*, vol. 36, pp. 9383–9390, Dec. 1997.

[73] D. Taillaert, F. Van Laere, M. Ayre, W. Bogaerts, D. Van Thourhout, P. Bienstman, and R. Baets, "Grating Couplers for Coupling between Optical Fibers and Nanophotonic Waveguides," *Japanese Journal of Applied Physics*, vol. 45, pp. 6071–6077, Aug. 2006.

[74] F. Van Laere, G. Roelkens, M. Ayre, J. Schrauwen, D. Taillaert, D. Van Thourhout, T. Krauss, and R. Baets, "Compact and Highly Efficient Grating Couplers Between Optical Fiber and Nanophotonic Waveguides," *Journal of Lightwave Technology*, vol. 25, pp. 151–156, Jan. 2007.

[75] F. Van Laere, T. Claes, J. Schrauwen, S. Scheerlinck, W. Bogaerts, D. Taillaert, L. O'Faolain, D. Van Thourhout, and R. Baets, "Compact Focusing Grating Couplers for Silicon-on-Insulator Integrated Circuits," *IEEE Photonics Technology Letters*, vol. 19, pp. 1919–1921, Dec. 2007.

[76] http://www.skinni.com, "JGDS - Java GDS Library."

[77] http://www.genisysgmbh.de/web/applications.html, "GenISys - 3-D e-Beam Lithography Application Note,"

[78] A. Schleunitz and H. Schift, "Fabrication of 3d nanoimprint stamps with continuous reliefs using dose-modulated electron beam lithography and thermal reflow," *Journal of Micromechanics and Microengineering*, vol. 20, no. 9, p. 095002, 2010.

[79] A. Schleunitz, C. Spreu, M. Vogler, H. Atasoy, and H. Schift, "Combining nanoimprint lithography and a molecular weight selective thermal reflow for the generation of mixed 3d structures," *Journal of Vacuum Science & Technology B*, vol. 29, p. 06FC01, Nov. 2011.

[80] A. Schleunitz, V. A. Guzenko, A. Schander, M. Vogler, and H. Schift, "Selective profile transformation of electron-beam exposed multilevel resist structures based on a molecular weight dependent thermal reflow," *Journal of Vacuum Science & Technology B*, vol. 29, p. 06F302, Nov. 2011.

[81] H. Schift, M. Altana, and A. Schleunitz, "Sidewall-angle dependent mold filling of three-dimensional microcavities in thermal nanoimprint lithography," *Journal of Vacuum Science & Technology B*, vol. 30, p. 06FB09, Nov. 2012.

[82] N. D. Bassim, A. Giles, J. D. Caldwell, and L. E. Ocola, "Focused Ion Beam Direct Write Nanofabrication of Surface Phonon Polariton Metamaterial Nanostructures," *Microscopy and Microanalysis*, vol. 20, pp. 358–359, Aug. 2014.

[83] E. I. Bromley, J. N. Randall, D. C. Flanders, and R. W. Mountain, "A technique for the determination of stress in thin films," *Journal of Vacuum Science & Technology B*, vol. 1, pp. 1364–1366, Oct. 1983.

[84] H. Guckel, T. Randazzo, and D. W. Burns, "A simple technique for the determination of mechanical strain in thin films with applications to polysilicon," *Journal of Applied Physics*, vol. 57, pp. 1671–1675, Mar. 1985.

[85] M. G. Allen, M. Mehregany, R. T. Howe, and S. D. Senturia, "Microfabricated structures for the insitu measurement of residual stress, Young's modulus, and ultimate strain of thin films," *Applied Physics Letters*, vol. 51, pp. 241–243, July 1987.

[86] M. Mehregany, R. T. Howe, and S. D. Senturia, "Novel microstructures for the insitu measurement of mechanical properties of thin films," *Journal of Applied Physics*, vol. 62, pp. 3579–3584, Nov. 1987.

[87] H. Guckel, D. Burns, C. Visser, H. Tilmans, and D. Deroo, "Fine-grained polysilicon films with built-in tensile strain," *IEEE Transactions on Electron Devices*, vol. 35, pp. 800–801, June 1988.

[88] K. Najafi and K. Suzuki, "A novel technique and structure for the measurement of intrinsic stress and Young's modulus of thin films," in *IEEE*

Micro Electro Mechanical Systems, 1989, Proceedings, An Investigation of Micro Structures, Sensors, Actuators, Machines and Robots, pp. 96–97, Feb. 1989.

[89] L.-S. Fan, R. Muller, W. Yun, R. Howe, and J. Huang, "Spiral microstructures for the measurement of average strain gradients in thin films," in *IEEE Micro Electro Mechanical Systems, 1990. Proceedings, An Investigation of Micro Structures, Sensors, Actuators, Machines and Robots*, pp. 177–181, Feb. 1990.

[90] R. Pratt, G. Johnson, R. Howe, and J. Chang, "Micromechanical structures for thin film characterization," in *, 1991 International Conference on Solid-State Sensors and Actuators, 1991. Digest of Technical Papers, TRANSDUCERS '91*, pp. 205–208, June 1991.

[91] H. Guckel, D. Burns, C. Rutigliano, E. Lovell, and B. Choi, "Diagnostic microstructures for the measurement of intrinsic strain in thin films," *Journal of Micromechanics and Microengineering*, vol. 2, no. 2, p. 86, 1992.

[92] Y. Gianchandani, K. Najafi, and B. Orr, "Silicon micromachined thermal profilers," in *Electron Devices Meeting, 1993. IEDM '93. Technical Digest., International*, pp. 191–194, Dec. 1993.

[93] L. Lin, R. Howe, and A. Pisano, "A passive, in situ micro strain gauge," in *Micro Electro Mechanical Systems, 1993, MEMS '93, Proceedings An Investigation of Micro Structures, Sensors, Actuators, Machines and Systems. IEEE.*, pp. 201–206, Feb. 1993.

[94] F. Ericson, S. Greek, J. Soderkvist, and J. Schweitz, "High Sensitive Internal Film Stress Measurement By An Improved Micromachined Indicator Structure," in *The 8th International Conference on Solid-State Sensors and Actuators, 1995 and Eurosensors IX.. Transducers '95*, vol. 2, pp. 84–87, June 1995.

[95] Y. Gianchandani and K. Najafi, "Bent-beam strain sensors," *Journal of Microelectromechanical Systems*, vol. 5, pp. 52–58, Mar. 1996.

[96] L. Lin, A. Pisano, and R. Howe, "A micro strain gauge with mechanical amplifier," *Journal of Microelectromechanical Systems*, vol. 6, pp. 313–321, Dec. 1997.

[97] G. T. A. Kovacs, *Micromachined transducers sourcebook*. Boston, Ma: WCB, 1998.

[98] S. D. Senturia, *Microsystem design*. Boston: Kluwer Academic Publishers, 2001.

[99] M. Gad-el Hak, *The MEMS handbook*. Boca Raton, FL: CRC Press, 2002.

[100] N. Lobontiu and E. Garcia, *Mechanics of microelectromechanical systems*. New York: Kluwer Academic, 2005.

[101] N. Lobontiu, *Mechanical design of microresonators: modeling and applications*. McGraw-Hill nanoscience and technology series, New York: McGraw-Hill, 2006.

[102] J. A. Kubby, *A guide to hands-on MEMS design and prototyping*. Cambridge, UK ; New York: Cambridge University Press, 2011.

[103] V. Kempe, *Inertial MEMS: principles and practice*. Cambridge ; New York: Cambridge University Press, 2011.

[104] N. Unal, D. Mahalu, O. Raslin, D. Ritter, C. Sambale, and U. Hofmann, "Third dimension of proximity effect correction (PEC)," *Microelectronic Engineering*, vol. 87, pp. 940–942, May 2010.