NBS SPECIAL PUBLICATION 400-32

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Semiconductor Measurement Technology:

Microelectronic Test Pattern NBS-4

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards[1] was established by an act of Congress March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau consists of the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Institute for Computer Sciences and Technology, the Office for Information Programs, and the Office of Experimental Technology Incentives Program.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of the Office of Measurement Services, and the following center and divisions:

Applied Mathematics — Electricity — Mechanics — Heat — Optical Physics — Center for Radiation Research — Laboratory Astrophysics[2] — Cryogenics[2] — Electromagnetics[2] — Time and Frequency[2].

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to improved methods of measurement, standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; provides advisory and research services to other Government agencies; and develops, produces, and distributes standard reference materials. The Institute consists of the Office of Standard Reference Materials, the Office of Air and Water Measurement, and the following divisions:

Analytical Chemistry — Polymers — Metallurgy — Inorganic Materials — Reactor Radiation — Physical Chemistry.

THE INSTITUTE FOR APPLIED TECHNOLOGY provides technical services developing and promoting the use of available technology; cooperates with public and private organizations in developing technological standards, codes, and test methods; and provides technical advice services, and information to Government agencies and the public. The Institute consists of the following divisions and centers:

Standards Application and Analysis — Electronic Technology — Center for Consumer Product Technology: Product Systems Analysis; Product Engineering — Center for Building Technology: Structures, Materials, and Safety; Building Environment; Technical Evaluation and Application — Center for Fire Research: Fire Science; Fire Safety Engineering.

THE INSTITUTE FOR COMPUTER SCIENCES AND TECHNOLOGY conducts research and provides technical services designed to aid Government agencies in improving cost effectiveness in the conduct of their programs through the selection, acquisition, and effective utilization of automatic data processing equipment; and serves as the principal focus wthin the executive branch for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. The Institute consist of the following divisions:

Computer Services — Systems and Software — Computer Systems Engineering — Information Technology.

THE OFFICE OF EXPERIMENTAL TECHNOLOGY INCENTIVES PROGRAM seeks to affect public policy and process to facilitate technological change in the private sector by examining and experimenting with Government policies and practices in order to identify and remove Government-related barriers and to correct inherent market imperfections that impede the innovation process.

THE OFFICE FOR INFORMATION PROGRAMS promotes optimum dissemination and accessibility of scientific information generated within NBS; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System; provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world. The Office consists of the following organizational units:

Office of Standard Reference Data — Office of Information Activities — Office of Technical Publications — Library — Office of International Standards — Office of International Relations.

---

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.

[2] Located at Boulder, Colorado 80302.

Semiconductor Measurement Technology:

Microelectronic Test Pattern NBS-4

W. Robert Thurber and
Martin G. Buehler

Electronic Technology Division
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

This activity was supported by
The Defense Advanced Research Projects Agency
and
The National Bureau of Standards

U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, Secretary

Dr. Sidney Harman, Under Secretary

Jordan J. Baruch, Assistant Secretary for Science and Technology

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

Issued April 1978

Library of Congress Catalog Card Number: 78-606024

National Bureau of Standards Special Publication 400-32
Nat. Bur. Stand. (U.S.), Spec. Publ. 400-32, 66 pages (Apr. 1978)
CODEN: XNBSAV

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1978

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
Stock No. 003–003–01906–2, Price $2.75
(Add 25 percent additional for other than U.S. mailing).

CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

The work was conducted as part of the Semiconductor Technology Program at the National Bureau of Standards. Portions of this work were supported by the Defense Advanced Research Projects Agency (Order No. 2397) and the NBS.

In the semiconductor industry it is common practice to design photomasks in English units. The photomasks used in this study were laid out in English units. The equivalent metric unit is given in parentheses; in some cases the equivalent is rounded off to an appropriate number of significant figures.

The authors wish to thank several members of the Electronic Technology Division for their assistance. Y. M. Liu developed the wafer fabrication processes, W. A. Cullins prepared most of the drawings, Cindy Cannon photographed the wafers and masks, and Jane Walters typed the manuscript.

MICROELECTRONIC TEST PATTERN NBS-4

by

W. Robert Thurber and Martin G. Buehler

Abstract: Microelectronic test pattern NBS-4 is a revision of test pattern NBS-3 which was designed primarily for evaluation of the resistivity-dopant density relationship in silicon. Major changes include the addition of optional BASE-CONTACT and GATE masks and the incorporation of several new structures, some useful for the resistivity-dopant density work, and others, mostly sheet resistors, included for evaluation of new designs.

The NBS-4 pattern contains 38 test structures such as planar four-probe resistors, sheet resistors, MOS capacitors, *p-n* junctions, bipolar and MOS transistors, Hall effect device, and process control structures. The overall pattern is a square 200 mil (5.08 mm) on a side and is divided into four quadrants which are separated by scribe lines. A detailed layout of each structure is presented including both a top view and a cross sectional view. Photomicrographs of each quadrant and the quadrants of the six masks used in the fabrication of the pattern are shown in an appendix.

Key Words: Dopant density; microelectronics; MOS capacitors; *n-p-n* transistor fabrication; *p-n* junctions; resistivity; semiconductor electronics; sheet resistors; silicon; test pattern; test structures.

1. INTRODUCTION

The purpose of this report is to describe the microelectronic test structures found on test pattern NBS-4. This is accomplished primarily by drawings of the structures, supplemented by photomicrographs of the masks and fabricated wafers. Test pattern NBS-4 is a revision of test pattern NBS-3 [1] which was designed for study of the resistivity-dopant density relationship in silicon. Significant changes include the addition of optional BASE-CONTACT and GATE masks and the incorporation of new structures for the resistivity-dopant density work and for the measurement of sheet resistance. The pattern is composed of an array of 38 test structures, such as planar four-probe resistors, sheet resistors, MOS capacitors, *p-n* junctions, bipolar and MOS transistors, Hall effect device, and process control structures, which for the most part are adaptations of commonly used configurations. Table 1 gives a list of the test structures, their purpose, and one or more references with details on their use. A majority of the structures are the same, or very similar, to ones on test pattern NBS-3, and the publication [1] on that pattern includes discussion of each structure, equations for calculation of the quantities determined by each, and additional references.

The devices specifically designed for the resistivity-dopant density evaluation are indicated by an asterisk in table 1. The square array four-probe resistor [2] has proven to be the best structure for resistivity measurements, and four structures of the same basic design, differing only in the size of the collector pipes, were added as part of NBS-4. Two new MOS capacitor structures were added for dopant density measurements. These devices are designed for steady-state, deep-depletion, capacitance-voltage measurements. Bulk dopant density values can be obtained from the following structures: MOS capacitors (4.2, 4.3, and 4.8), base-collector diode (4.10), MOSFET

Table 1 — Planar Test Structures on Test Pattern NBS-4

Page	Structure Number	Test Structure[a]	Purpose	References
12	4.1	*Collector resistor (pipes 0.20 mil on a side)	Resistivity	1,2
15	4.2	*MOS capacitor over collector (base DGR)	Dopant density	4
16	4.3	*MOS capacitor over collector (emitter DGR)	Dopant density	4
23,24	4.4	Alignment markers	Mask alignment	
12	4.5	*Collector resistor (pipes 0.30 mil on a side)	Resistivity	1,2
24	4.6	Logo	Identification	
12	4.7	*Collector resistor (pipes 0.40 mil on a side)	Resistivity	1,2
17	4.8	*MOS capacitor over collector (FP, CS)	Dopant density, V_{fb}[b]	1,5
12	4.9	*Collector resistor (pipes 0.50 mil on a side)	Resistivity	1,2
19	4.10	*Base-collector diode (FP, CS)	Dopant density	1,6
7	4.11	Base sheet resistor (VDP, FP, CS)	Sheet resistance	1,3
18	4.12	MOS capacitor over base	Surface dopant density	1
20	4.13	Bipolar transistor	Proper fabrication	1,7
20	4.14	Base-collector diode (FP, CS)	Dopant density	1,8
21	4.15	*MOSFET (circular, W/L = 18.2)	Dopant density	1,9
22	4.16	MOSFET (rectangular, W/L = 4)	Proper fabrication	1
12	4.17	*Collector resistor (pipes 0.25 mil on a side)	Resistivity	1,2
14	4.18	Collector spreading resistor	Back-side resistance	1,10
11	4.19	Metal sheet resistor (Greek cross)	Sheet resistance	1
9	4.20	Base-under-emitter sheet resistor (Greek cross)	Sheet resistance	7,11
10	4.21	Base-contact sheet resistor (Greek cross)	Sheet resistance	12
6	4.22	Base sheet resistor (narrow Greek cross)	Sheet resistance	3,12
9	4.23	Base sheet resistor (B, W/L = 0.25)	Sheet resistance	7,13
6	4.24	Base sheet resistor (Greek cross)	Sheet resistance	2,12
6	4.25	Base sheet resistor (Greek cross, tab contacts)	Sheet resistance	2,12
6	4.26	Base sheet resistor (offset quadrate cross)	Sheet resistance	2,12
11	4.27	Metal-to-emitter contact resistor	Contact resistance	1
10	4.28	Emitter sheet resistor (offset quadrate cross)	Sheet resistance	1,12
11	4.29	Metal-to-base contact resistor	Contact resistance	1
17	4.30	MOS capacitor over collector (square)	Measurement limitations	1
13	4.31	*Hall effect device (VDP)	Carrier density	1,14
10	4.32	Emitter sheet resistor (B, W/L = 0.25)	Sheet resistance	1
9	4.33	Base sheet resistor (B, W/L = 0.25)	Sheet resistance	1,13
25	4.34	Surface profilometer structure	Process control	1
8	4.35	Incremental base sheet resistor (VDP)	Dopant profile	1,3
26	4.36	Etch-control structures[c]	Process control	1
26	4.37	Resolution structures[c]	Process control	1
13	4.38	Metal step-coverage resistor	Metal continuity	1

* = structures designed for resistivity-dopant density evaluation.

[a] B = bridge; CS = channel stop; DGR = diffused guard ring; FP = field plate; L = length along current path; VDP = van der Pauw; W = width of current path.

[b] V_{fb} = flat band voltage.

[c] B = BASE mask; BC = BASE-CONTACT mask; C = CONTACT mask; E = EMITTER mask; G = GATE mask; M = METAL mask.

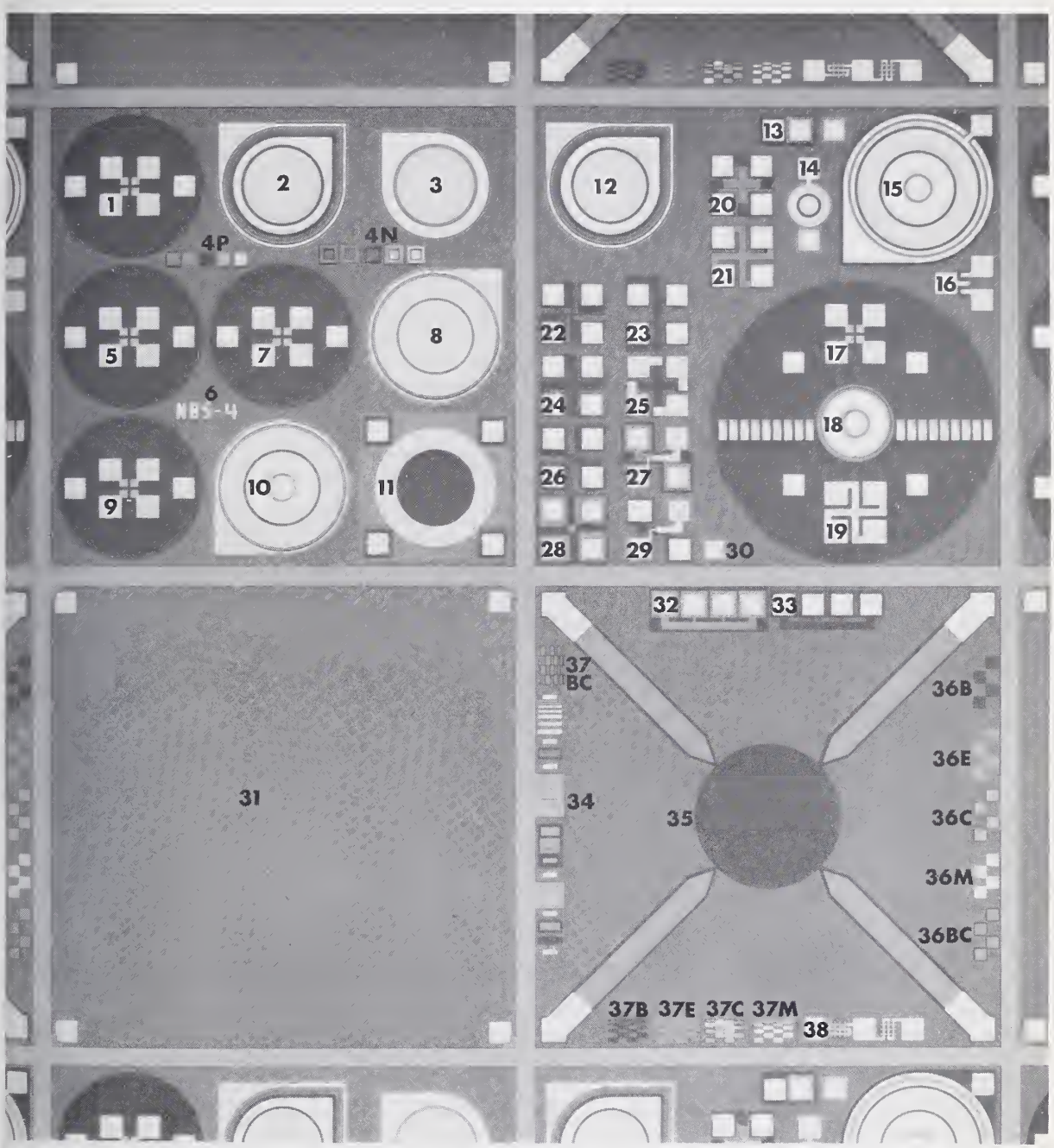


Figure 1. Test pattern NBS-4 fabricated with BASE (B), EMITTER (E), BASE-CONTACT (BC), CONTACT (C), and METAL (M) masks. The length of the pattern along one side is 200 mil (5.08 mm).

(4.15), and Hall effect device (4.31). Bulk resistivity values can be found from the square array four-probe collector resistors (4.1, 4.5, 4.7, 4.9, and 4.17) and the Hall effect device (4.31). It should be noted that the collector Hall effect device (4.31) is functional only after it has been scribed from the wafer and the back-side metal removed. To accommodate this structure, the scribe grid was omitted from the BASE and EMITTER masks and included on only the CONTACT and GATE masks.

The new pattern also contains eight base sheet resistors, four of which were not included on test pattern NBS-3. Comparative measurements have been made on the six van der Pauw base sheet resistors [3]. The base-under-emitter sheet resistor (4.20) is a new structure on the pattern. The metal sheet resistor (4.19) is of somewhat different design than that on test pattern NBS-3 to avoid the problem of burnout due to high current density in narrow connecting arms. The incremental base sheet resistor (4.35) was modified slightly from the one on test pattern NBS-3. The width of the arms near the body was increased to minimize arm resistance which is especially important as the structure is thinned by repeated layer removal. The addition of the base-contact diffusion in the arms further reduces the resistance. Also, the metal contact pads were enlarged to allow multiple wire bonds. Many of the remaining test structures are in support of the primary devices. They were included to provide tests which can assure that proper fabrication steps have been followed and aid in diagnosing problems.

A photomicrograph of test pattern NBS-4 is shown in figure 1. The overall pattern is 200 mils (5.08 mm) on a side and is divided into four quadrants. Enlarged views of each quadrant of the fabricated test pattern and the six masks are shown in the Appendix. The masks are: BASE, BASE-CONTACT, EMITTER GATE, CONTACT, and METAL. The BASE and BASE-CONTACT masks delineate regions to be diffused with a conductivity type opposite from the collector substrate and the EMITTER mask delineates regions to be diffused with a conductivity type the same as the collector substrate. Emitter-diffused regions are more heavily doped than the collector. The BASE-CONTACT mask is designed to delineate heavily doped diffused regions where electrical contacts are made to base-diffused regions. It is intended for use in the processing of p-type wafers where low resistance contacts to n-type base regions are a problem. With respect to the placement of the alignment markers, the base-contact diffusion was designed to follow the base diffusion. However, the diffusions do not have to be done in this order and in the processing sequence used for the resistivity-dopant density study the base-contact diffusion was made following the emitter diffusion so that the surface dopant density of the base-contact regions was not reduced by any subsequent high-temperature processing steps. The BASE-CONTACT mask is generally not used for n-type wafers as aluminum makes good electrical contact to the typical p-type base diffusion. The GATE mask is used whenever a thin, high quality oxide is needed for the MOS devices. During this step, which follows the diffusions, the previous oxide is removed in the areas delineated by the GATE mask and new oxide is grown.

2. TEST STRUCTURES

This section discusses the notation used on the drawings of the test structures which follow in sections 3 through 7. The structures are grouped in five major categories: resistors, MOS capacitors, diodes, transistors, and miscellaneous. The new structures on the pattern were designed using the same design rules as for test pattern NBS-3 [1].

In the following sections both a detailed top view layout and cross sectional view of each test structure are given. Figure 2 illustrates the scheme used. In the top views and in the horizontal direction for cross sectional views, the distance between grid lines represents 0.50 mil (12.7 μm). In the cross sectional views, metal regions are black and oxide regions are dotted. All oxide areas are shown with a thickness of one unit above the silicon surface with the exception of gate oxide regions which are only a half unit thick. In top views the gate oxide regions are denoted by dashed lines as there is frequently not a line in the cross sectional view to indicate the boundary of the gate oxide. Regions with a base diffusion are clear and indicated by a solid line two units below the silicon surface. Regions with an emitter diffusion are clear and indicated by a solid line one unit below the silicon surface. Regions with a base-contact diffusion are clear and indicated by a solid line one-half unit below the silicon surface. (In these views a *unit* is the distance between adjacent grid lines. Also the silicon surface is assumed to be flat for the sake of simplicity; the incorporation of silicon into the oxide during thermal oxidation has been ignored.)

The following notation is used to define metal contact pads on the top view of the drawings:

B = base contact	G = gate contact	I_1, I_2 = current contacts
C = collector contact	S = source contact	V_1, V_2 = voltage contacts
E = emitter contact	D = drain contact	

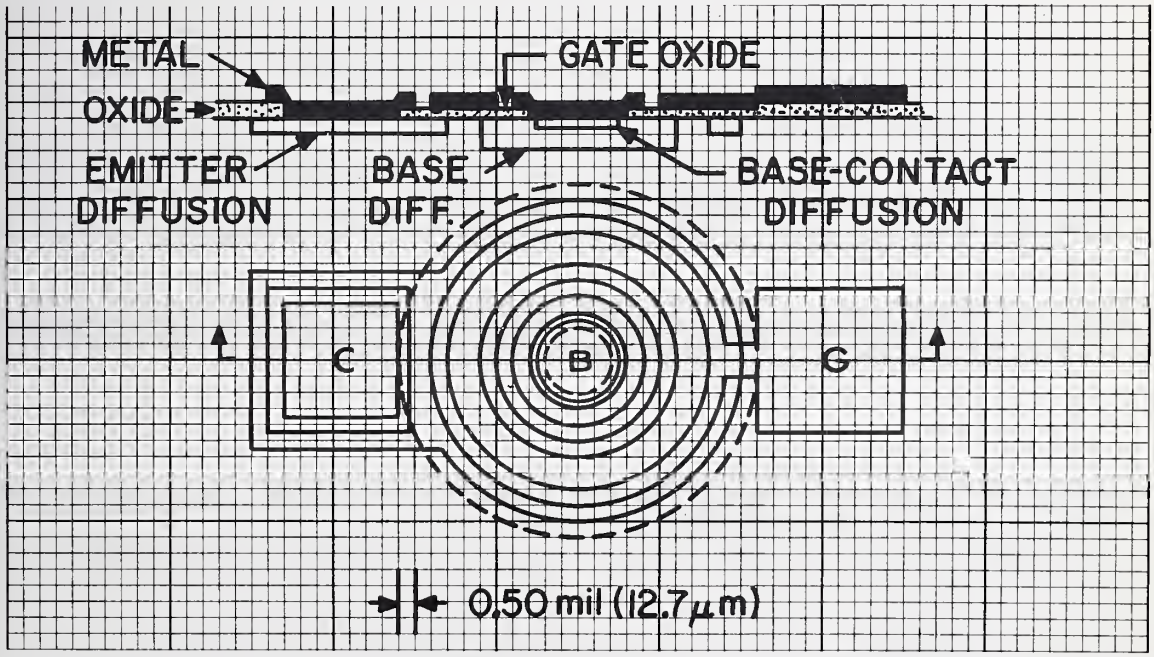
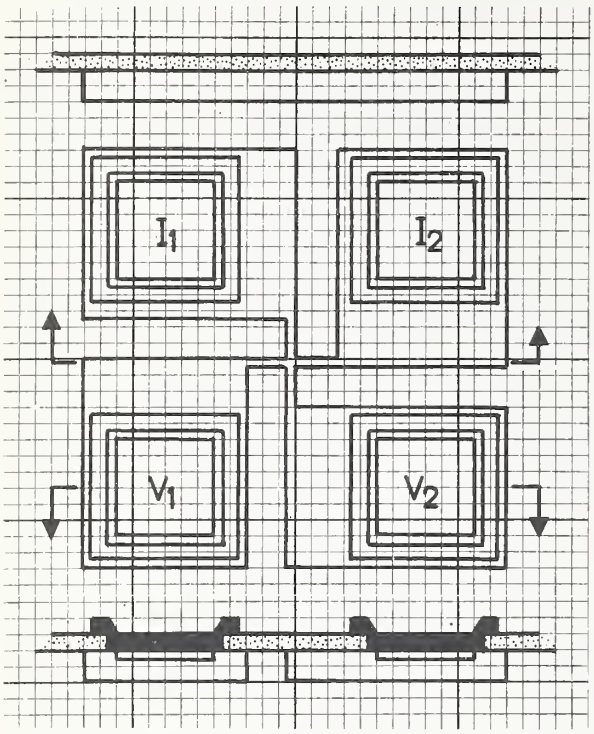
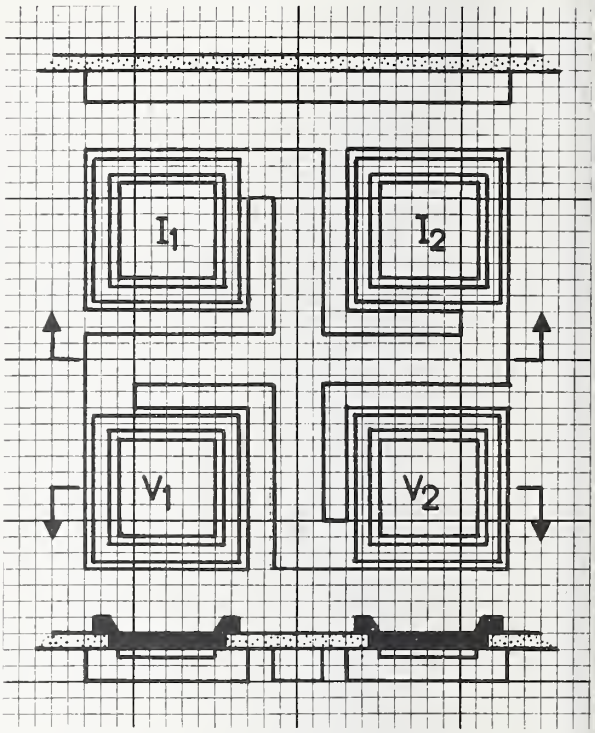


Figure 2. An illustration of the notation used in views of a test structure. The emitter diffusion is used for emitter regions of a bipolar transistor, channel stop (CS) regions, and low-resistance contacts to the collector. The base diffusion provides both bipolar transistor base regions and MOS transistor source-drain regions.

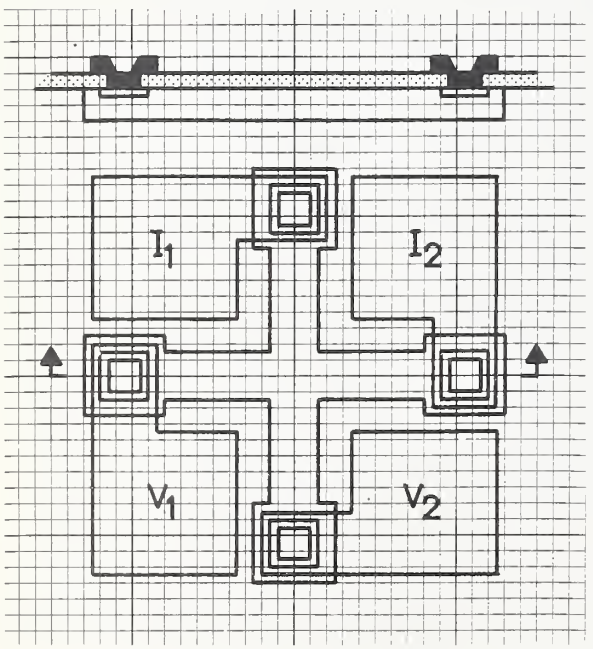
3.1 Base Sheet Resistor
(Greek Cross)
Structure 4.22



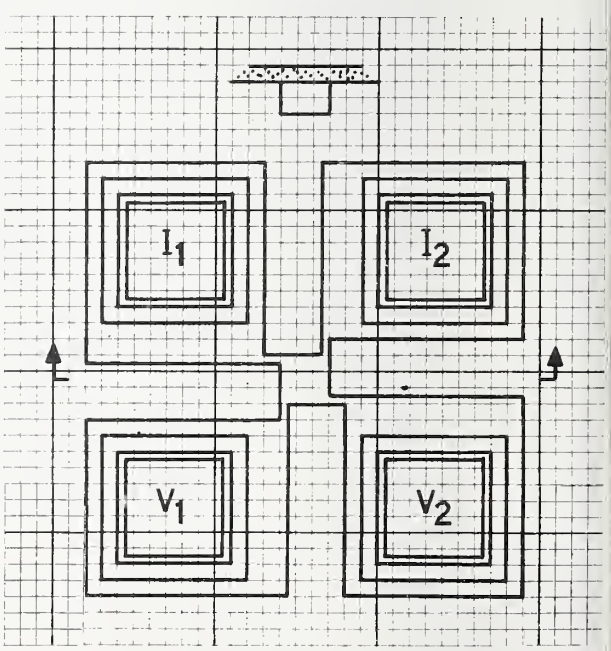
3.2 Base Sheet Resistor
(Greek Cross)
Structure 4.24



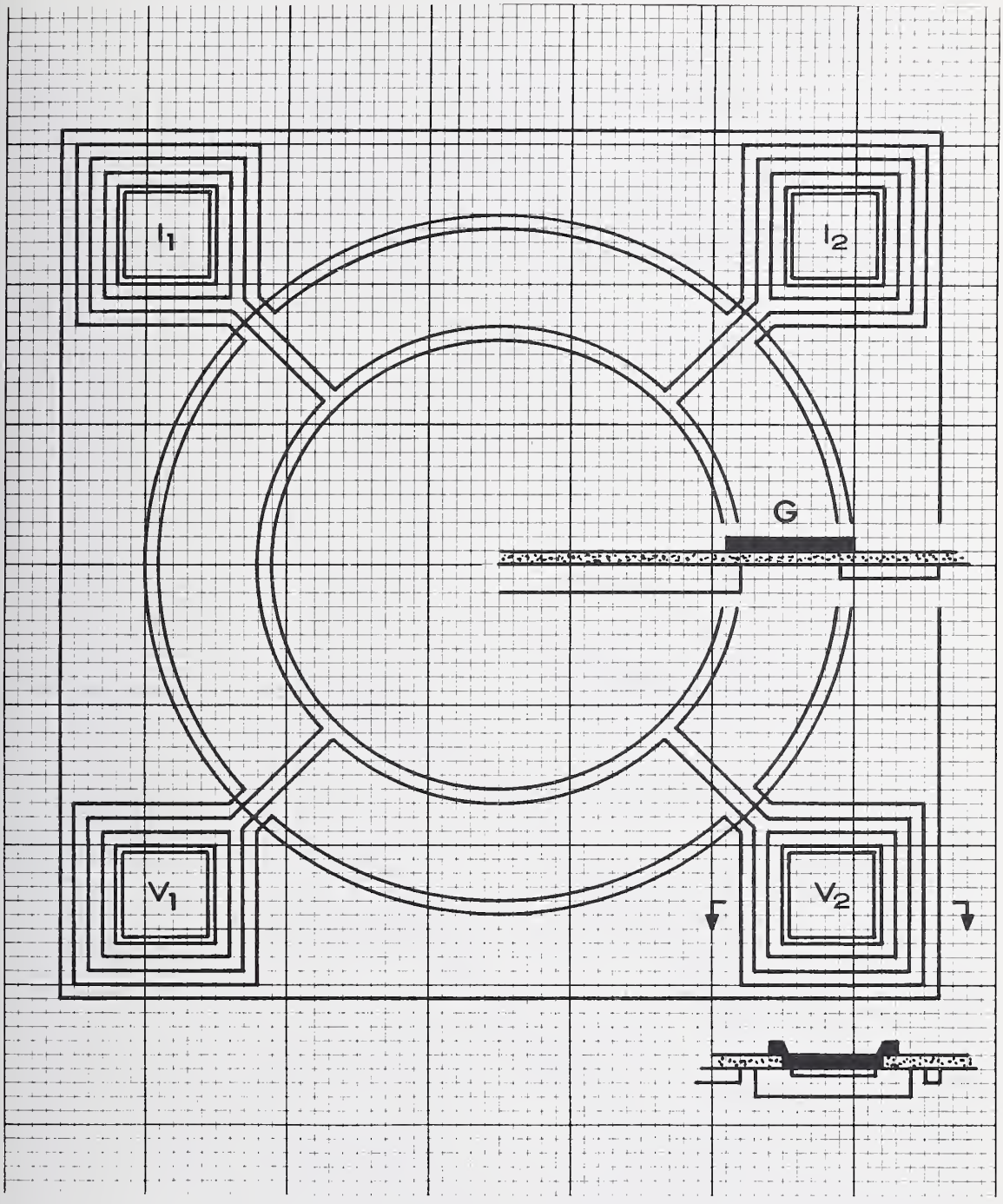
3.3 Base Sheet Resistor
(Greek Cross)
Structure 4.25



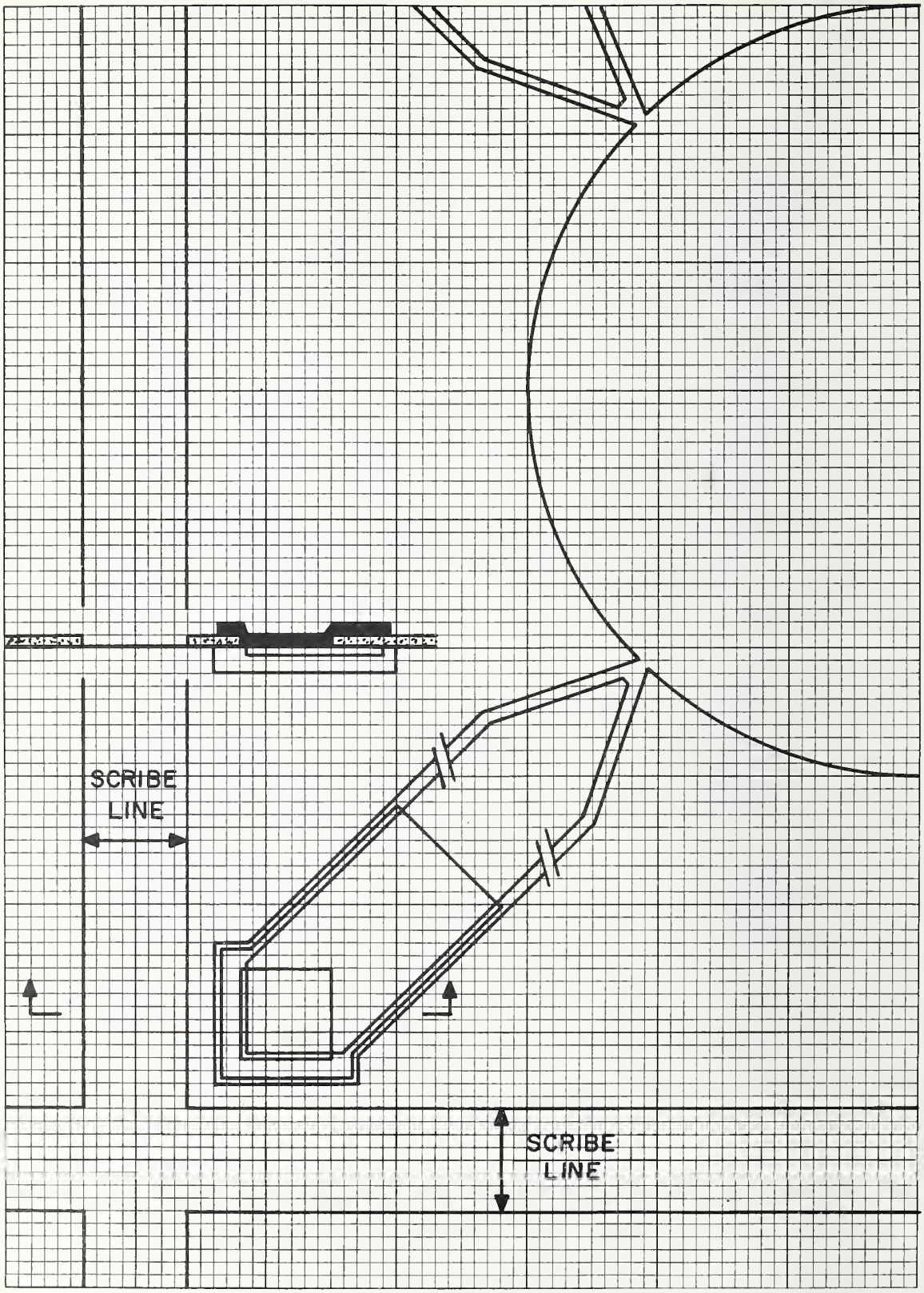
3.4 Base Sheet Resistor
(Offset Quadrate Cross)
Structure 4.26



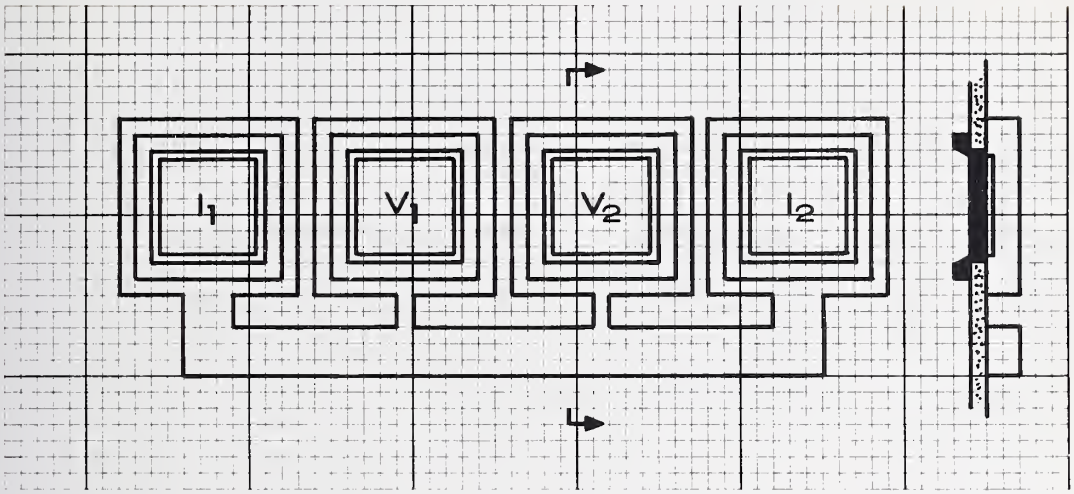
3.5 Base Sheet Resistor (van der Pauw, field plate, channel stop)
Structure 4.11



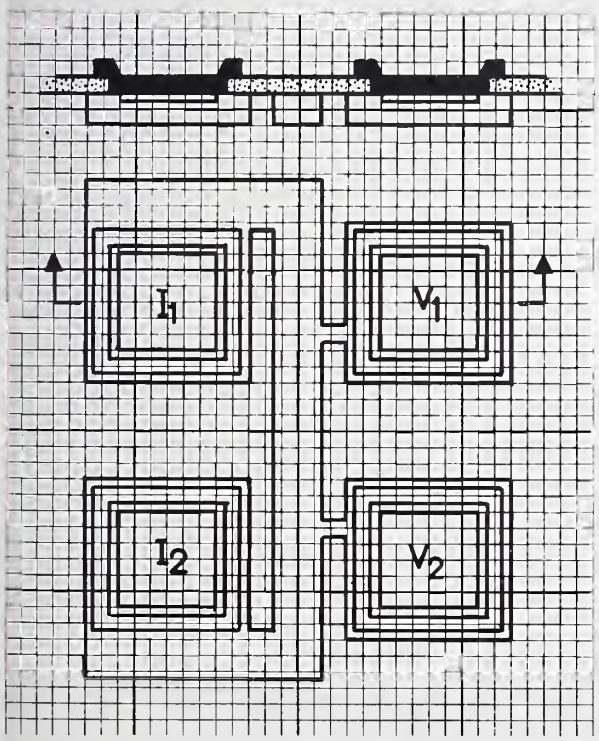
3.6 Incremental Base Sheet Resistor (van der Pauw)
Structure 4.35



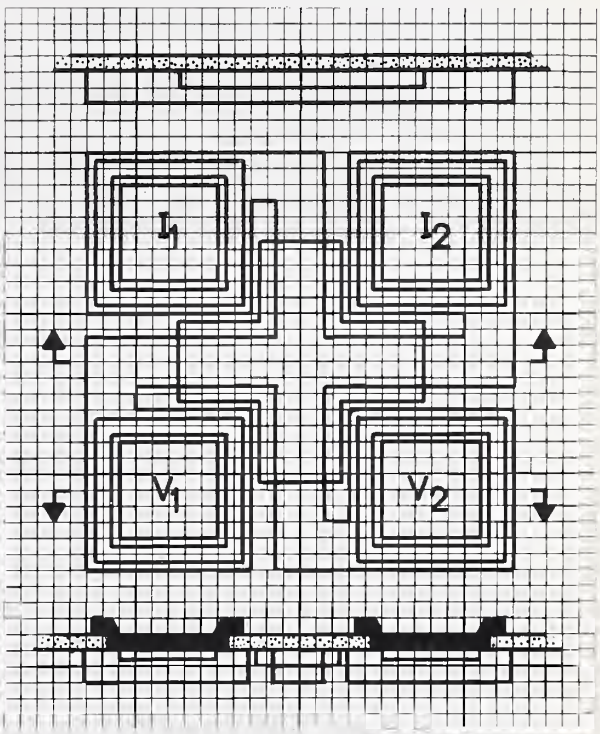
3.7 Base Sheet Resistor (Bridge)
Structure 4.33



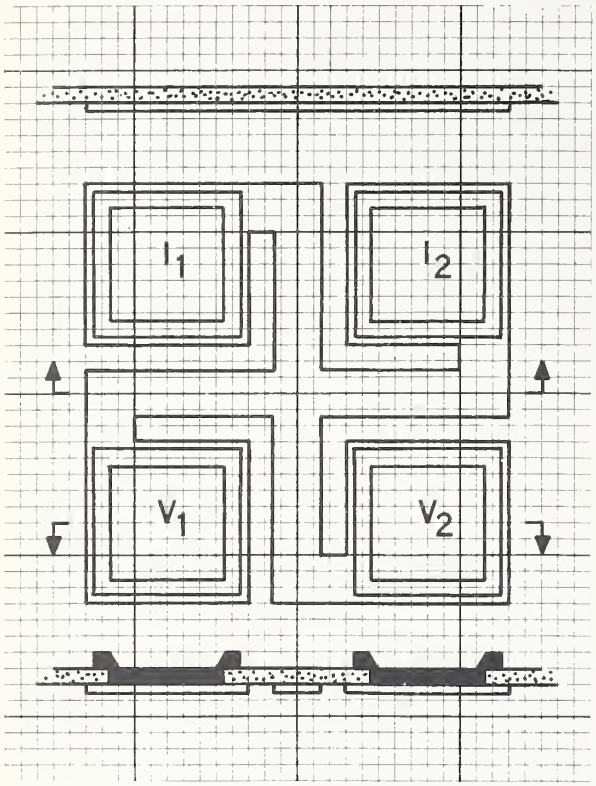
3.8 Base Sheet Resistor
(Bridge)
Structure 4.23



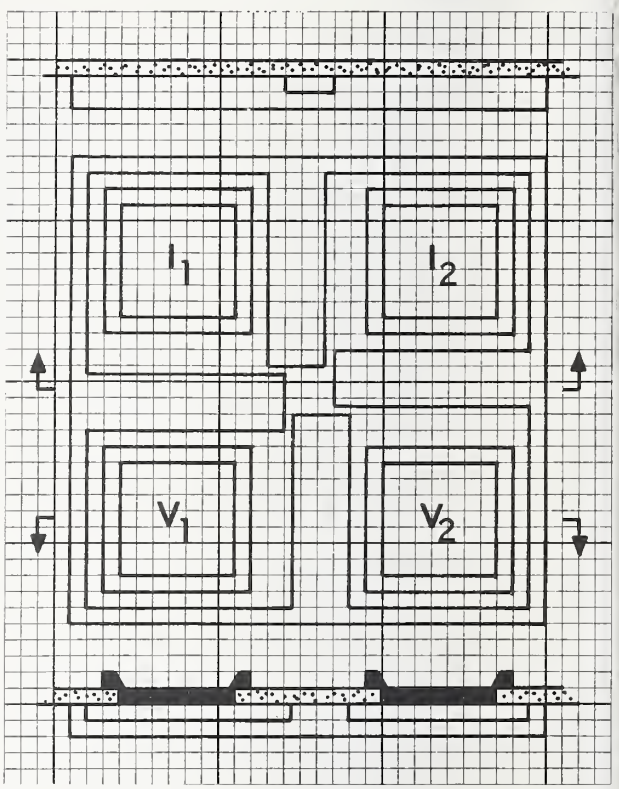
3.9 Base-under-Emitter Sheet Resistor
(Greek Cross)
Structure 4.20



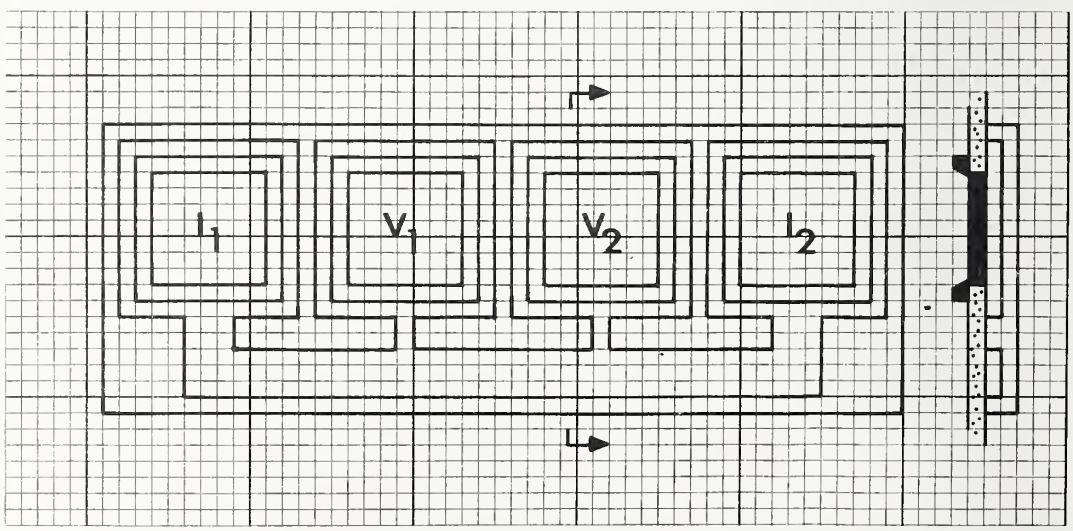
3.10 Base-Contact Sheet Resistor
(Greek Cross)
Structure 4.21



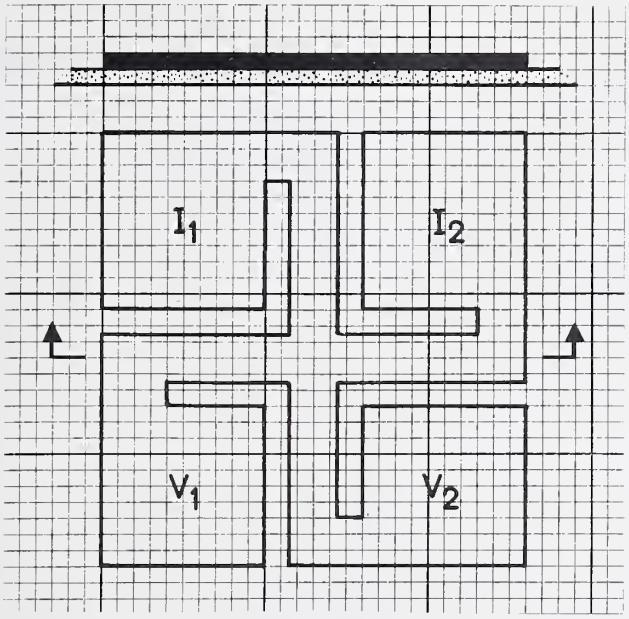
3.11 Emitter Sheet Resistor
(Offset Quadrate Cross)
Structure 4.28



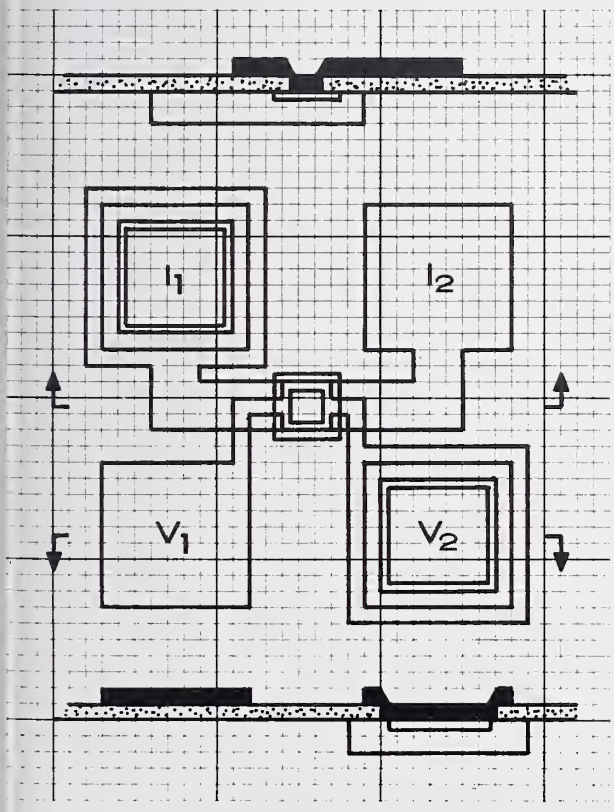
3.12 Emitter Sheet Resistor (Bridge)
Structure 4.32



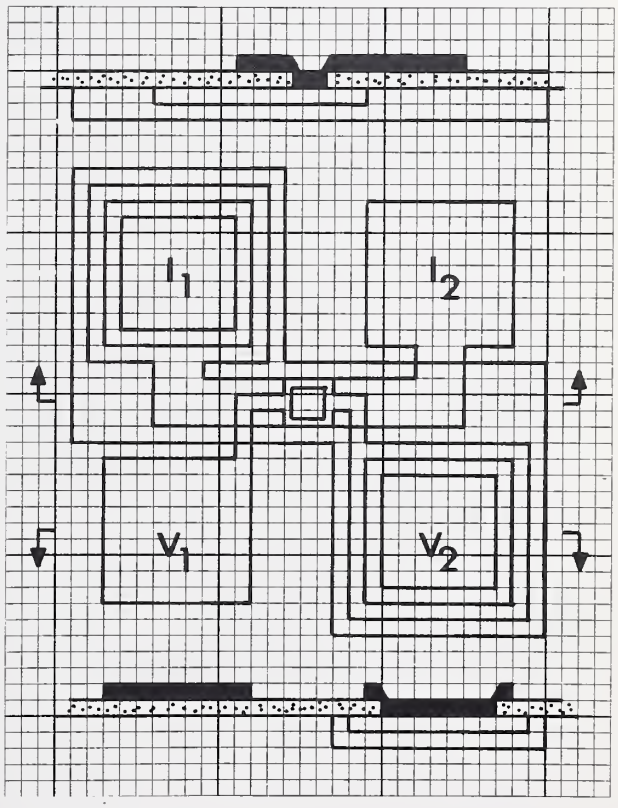
3.13 Metal Sheet Resistor
(Greek Cross)
Structure 4.19



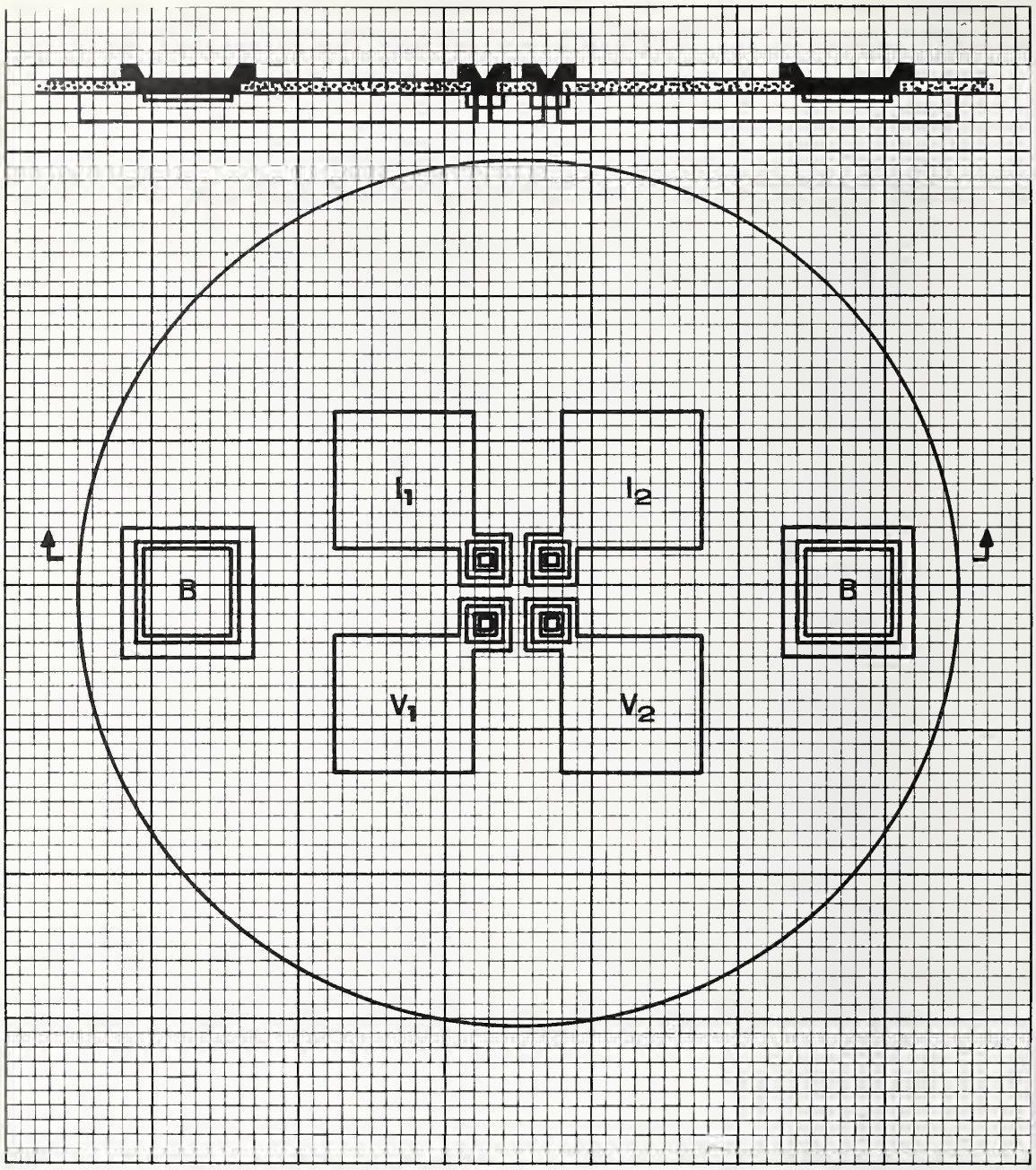
3.14 Metal-to-Base
Contact Resistor
Structure 4.29



3.15 Metal-to-Emitter
Contact Resistor
Structure 4.27



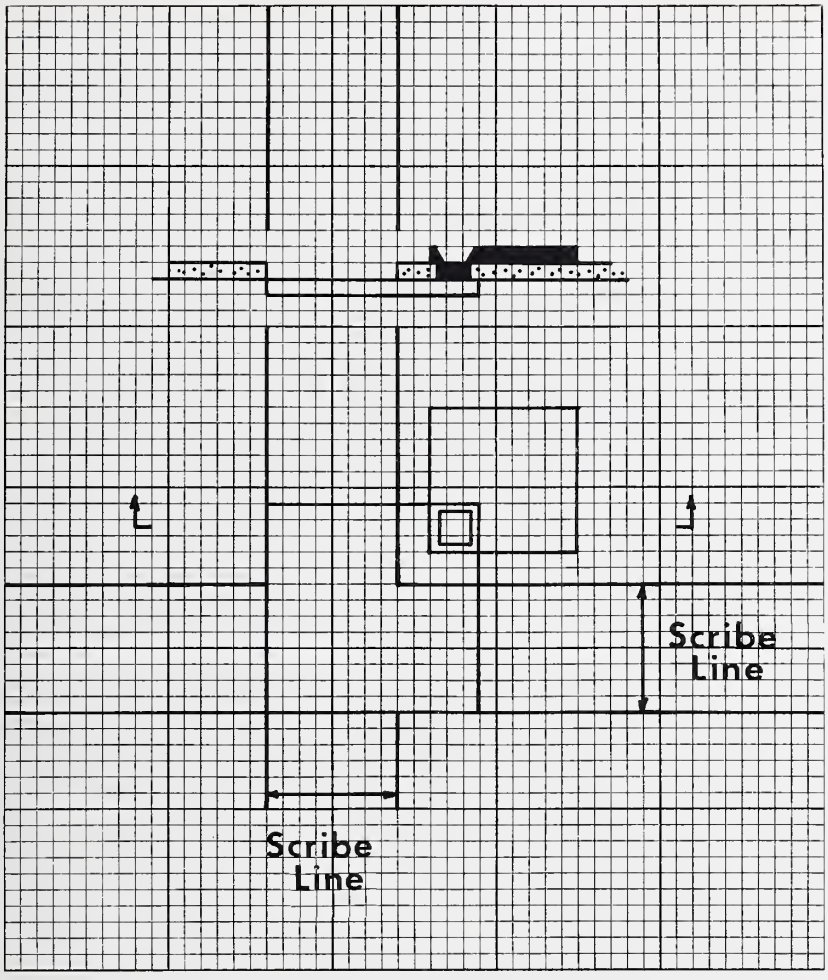
3.16 Collector Four-Probe Resistors
Structure 4.9, pipes 0.50 mil (12.7 μm) on a side



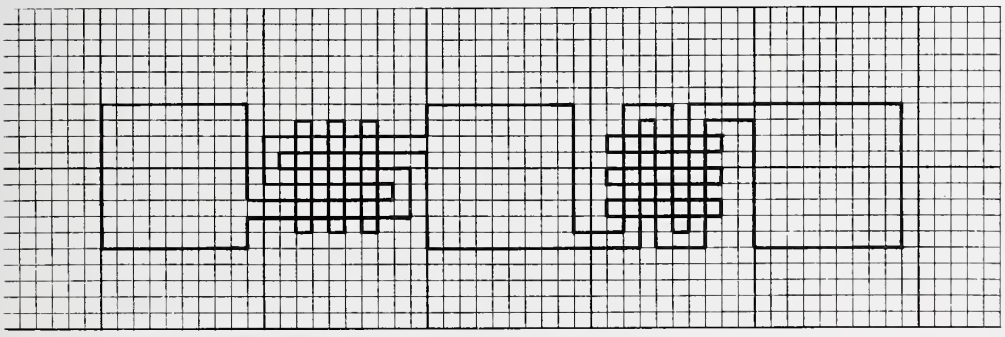
Other similar structures, which differ primarily in pipe size, are:

Structure 4.1, pipes 0.20 mil (5.1 μm) on a side
Structure 4.5, pipes 0.30 mil (7.5 μm) on a side
Structure 4.7, pipes 0.40 mil (10.2 μm) on a side
Structure 4.17, pipes 0.25 mil (6.4 μm) on a side

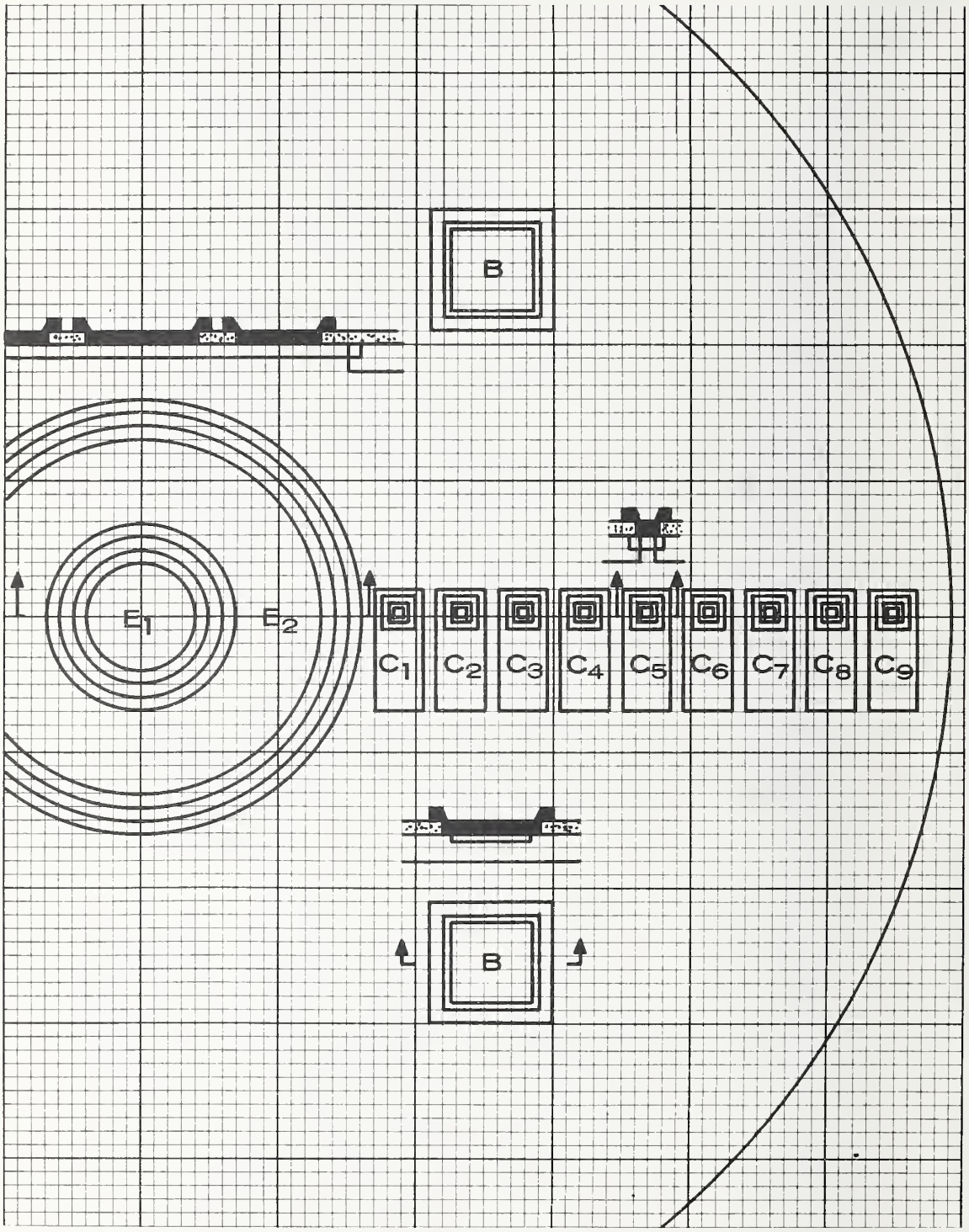
3.17 Collector Hall Effect Device (van der Pauw)
Structure 4.31



3.18 Metal Step-Coverage Resistor
Structure 4.38

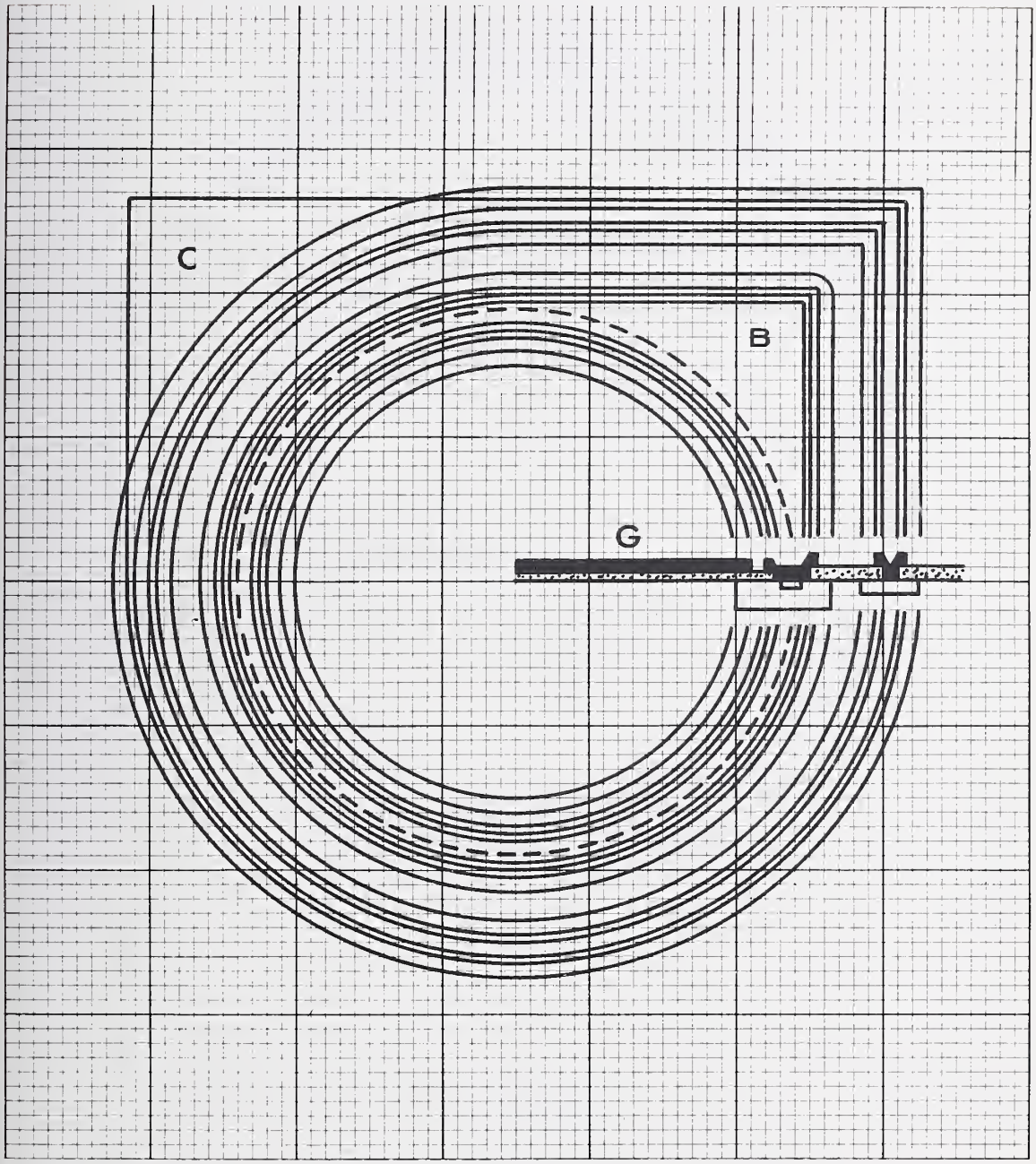


3.19 Collector Spreading Resistor
Structure 4.18

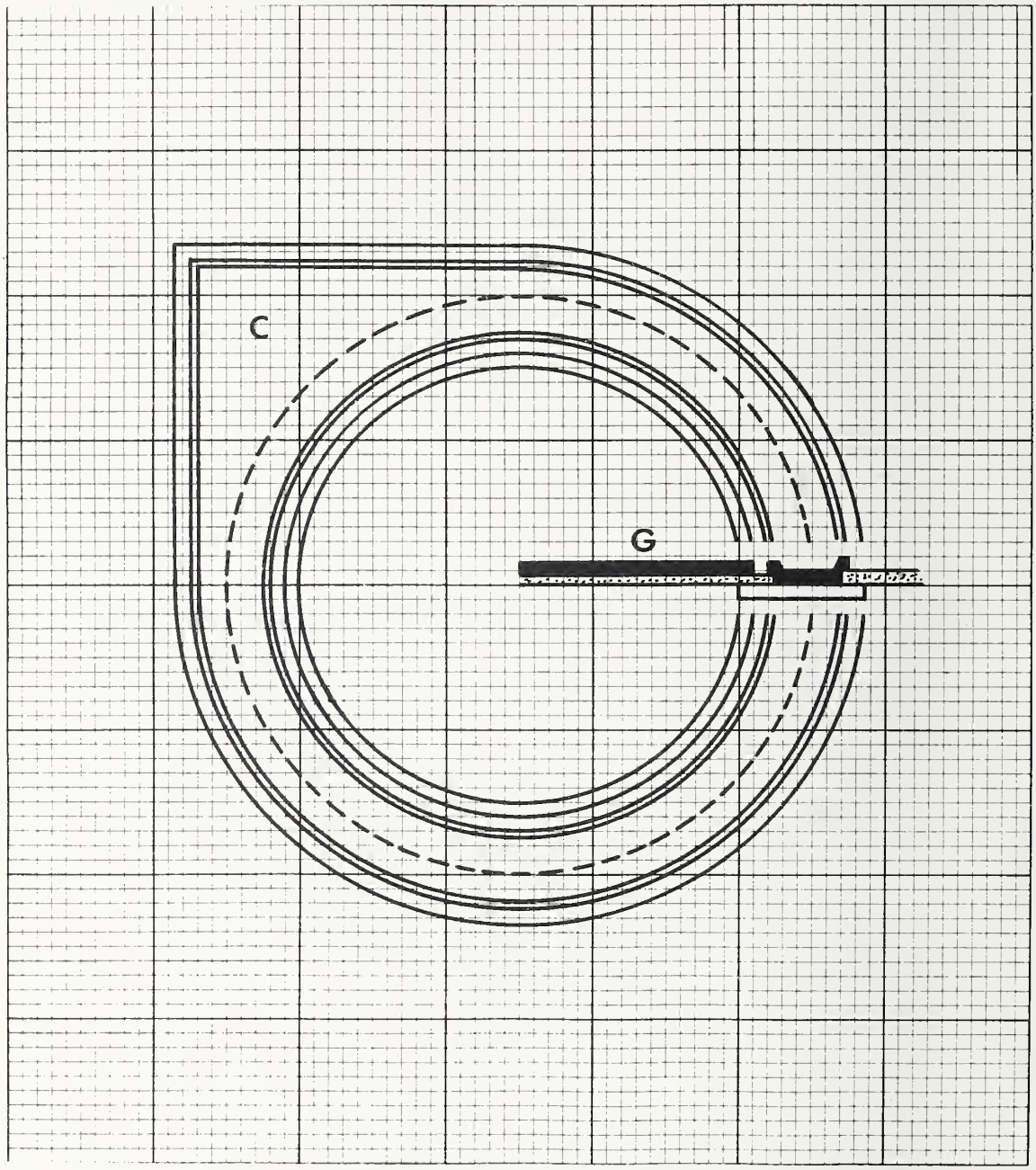


4. MOS CAPACITORS

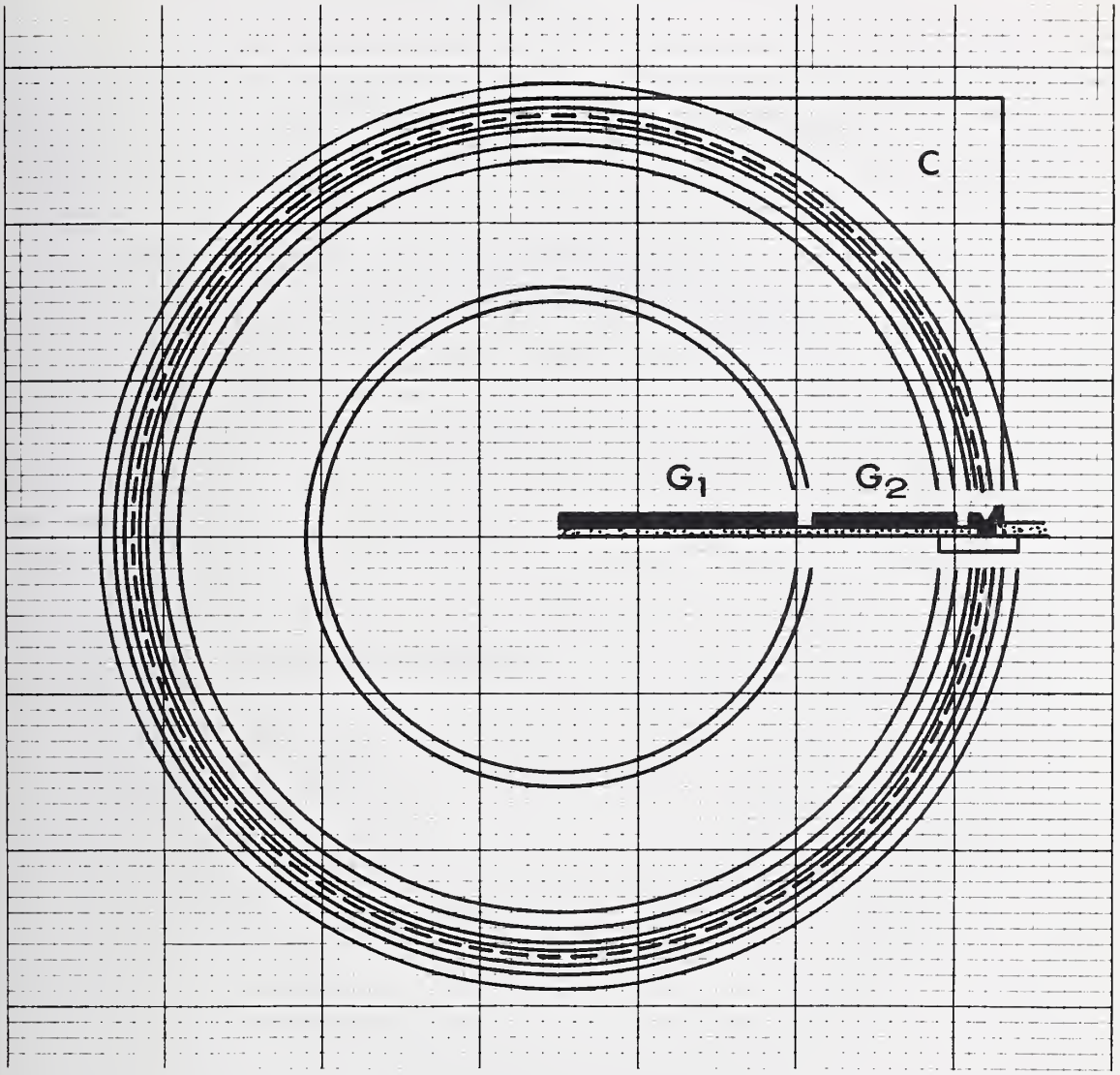
4.1 MOS Capacitor over Collector (Base DGR, Channel Stop)
Structure 4.2



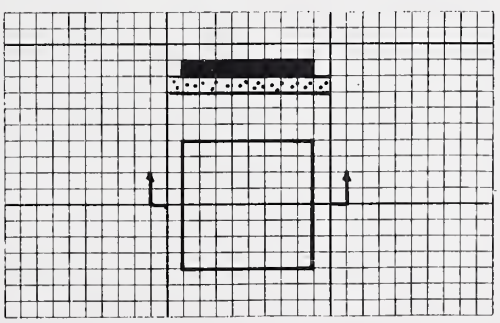
4.2 MOS Capacitor over Collector (Emitter DGR)
Structure 4.3



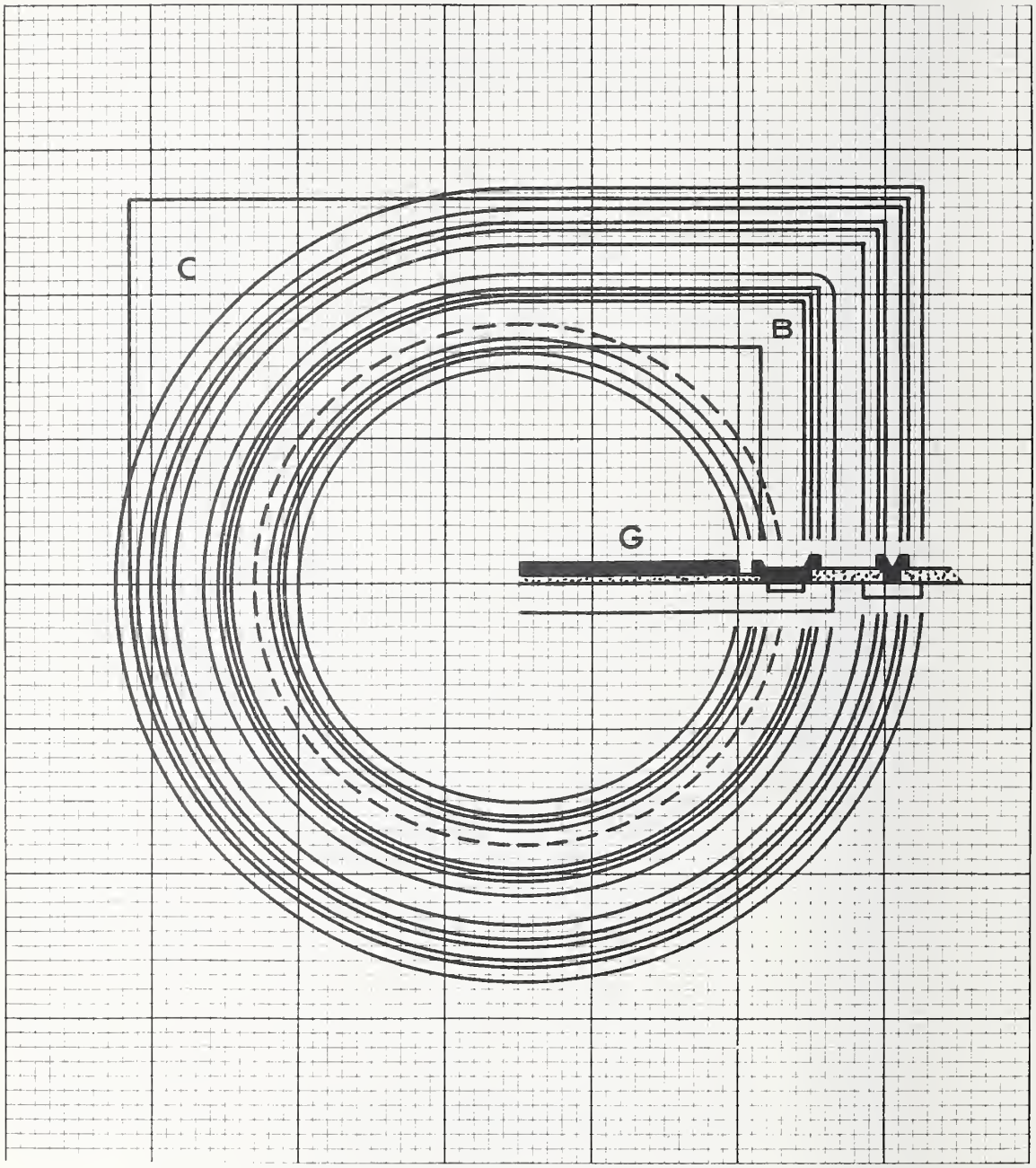
4.3 MOS Capacitor over Collector (Field Plate, Channel Stop)
Structure 4.8



4.4 MOS Capacitor over Collector
Structure 4.30

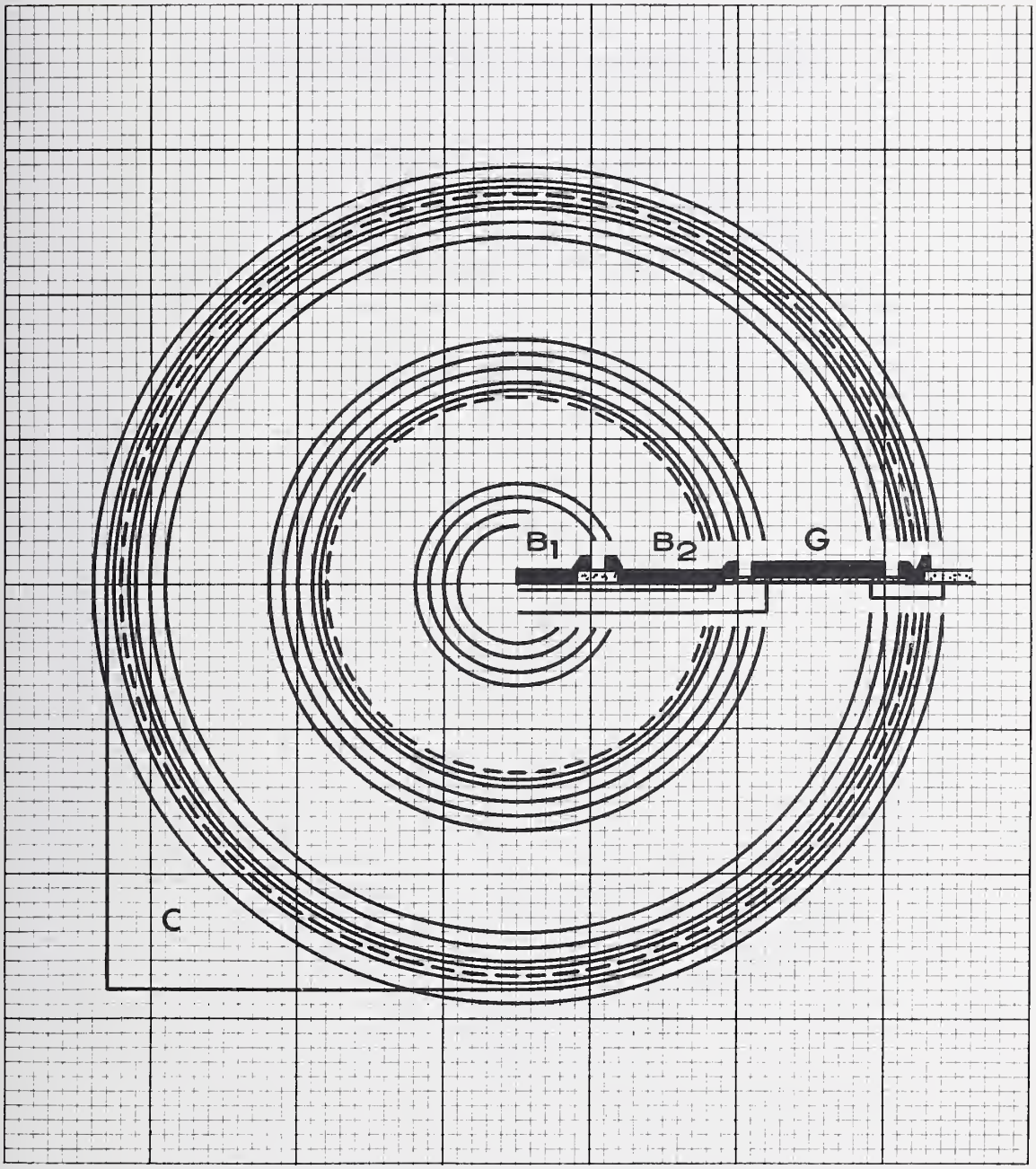


4.5 MOS Capacitor over Base
Structure 4.12

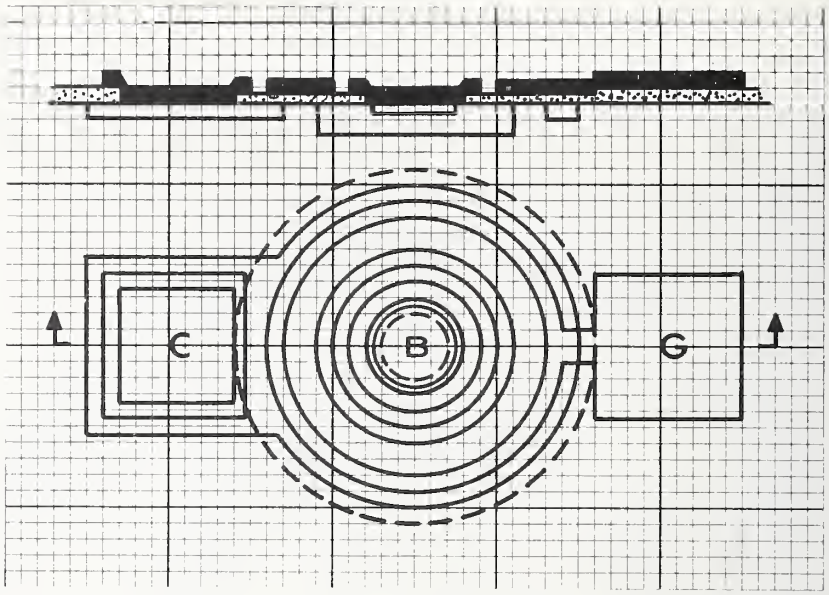


5. DIODES

5.1 Base-Collector Diode (Field Plate, Channel Stop) Structure 4.10

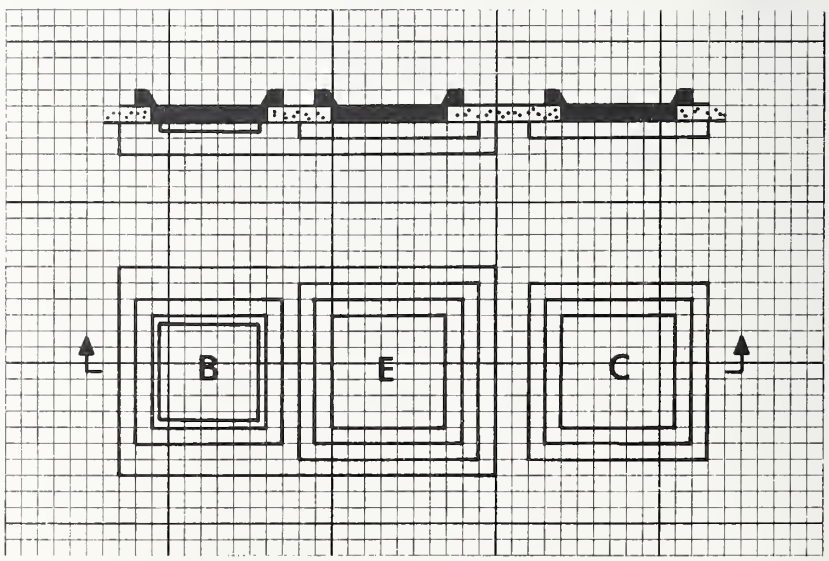


5.2 Base-Collector Diode (Field Plate, Channel Stop)
Structure 4.14

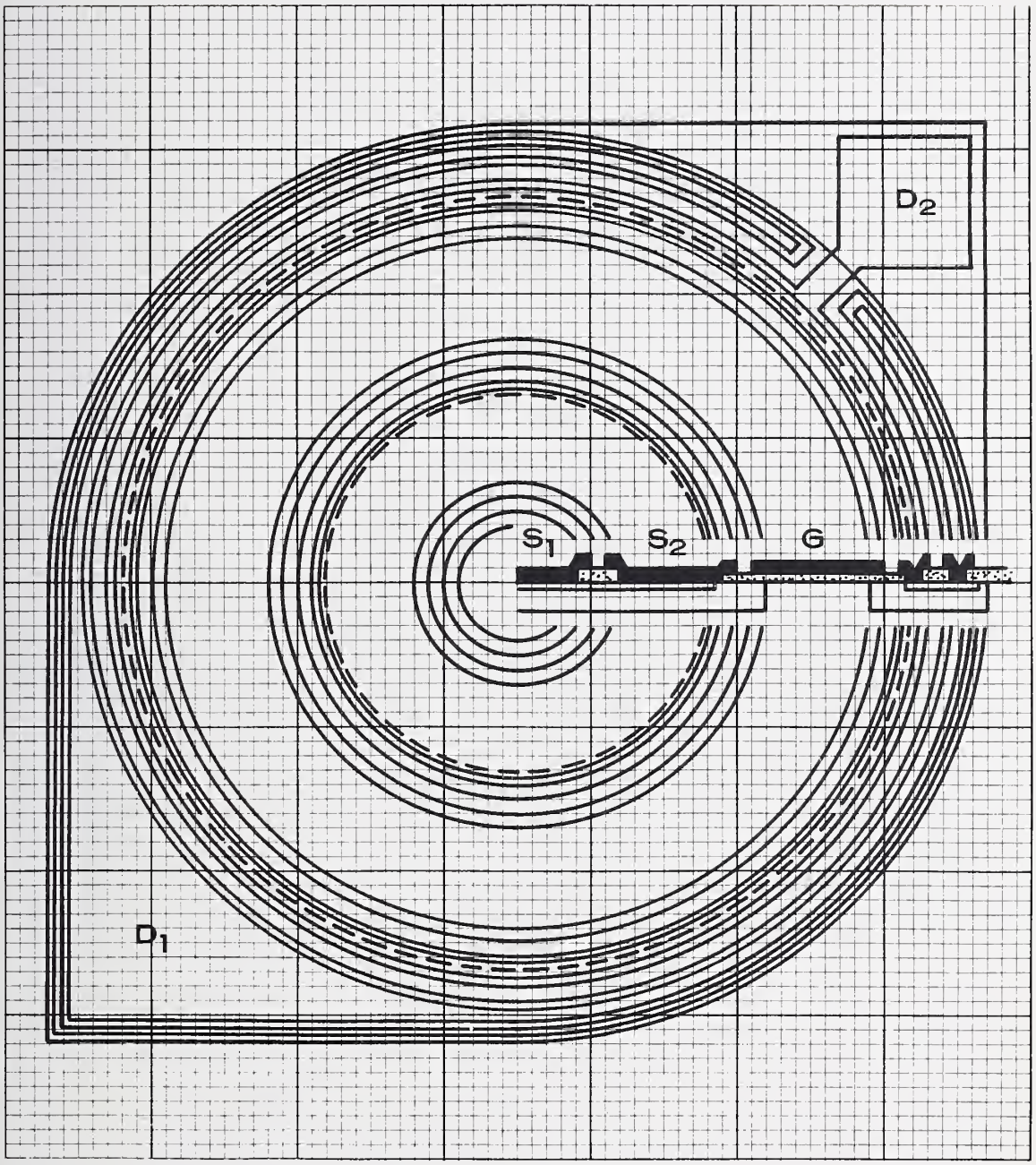


6. TRANSISTORS

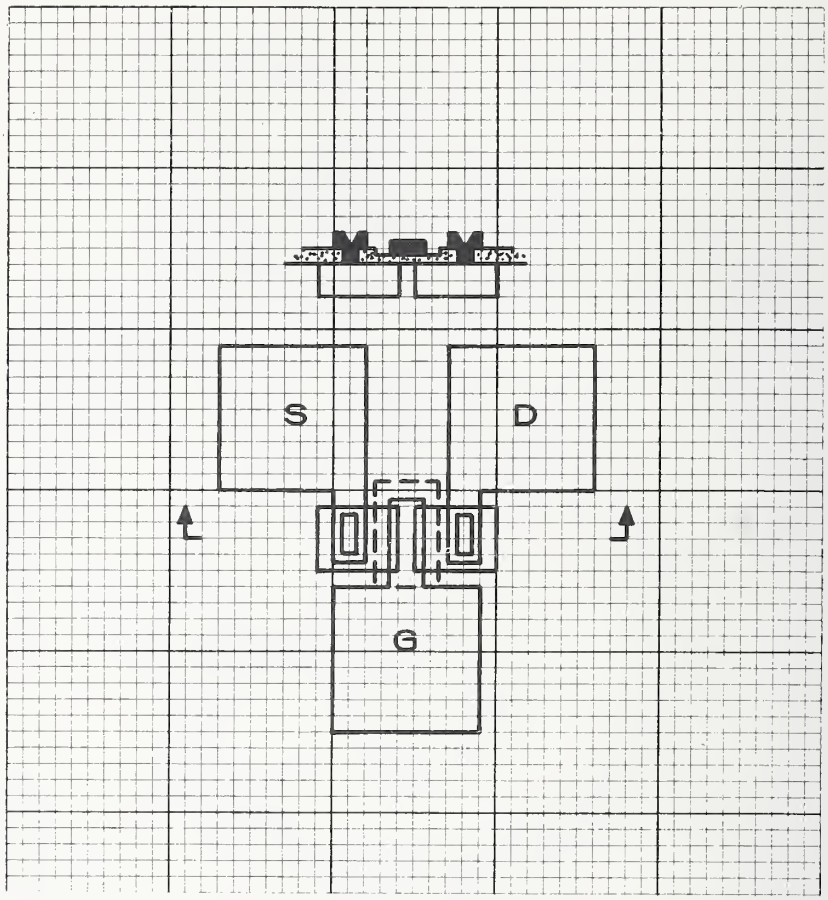
6.1 Bipolar Transistor
Structure 4.13



6.2 MOS Transistor (Circular)
Structure 4.15

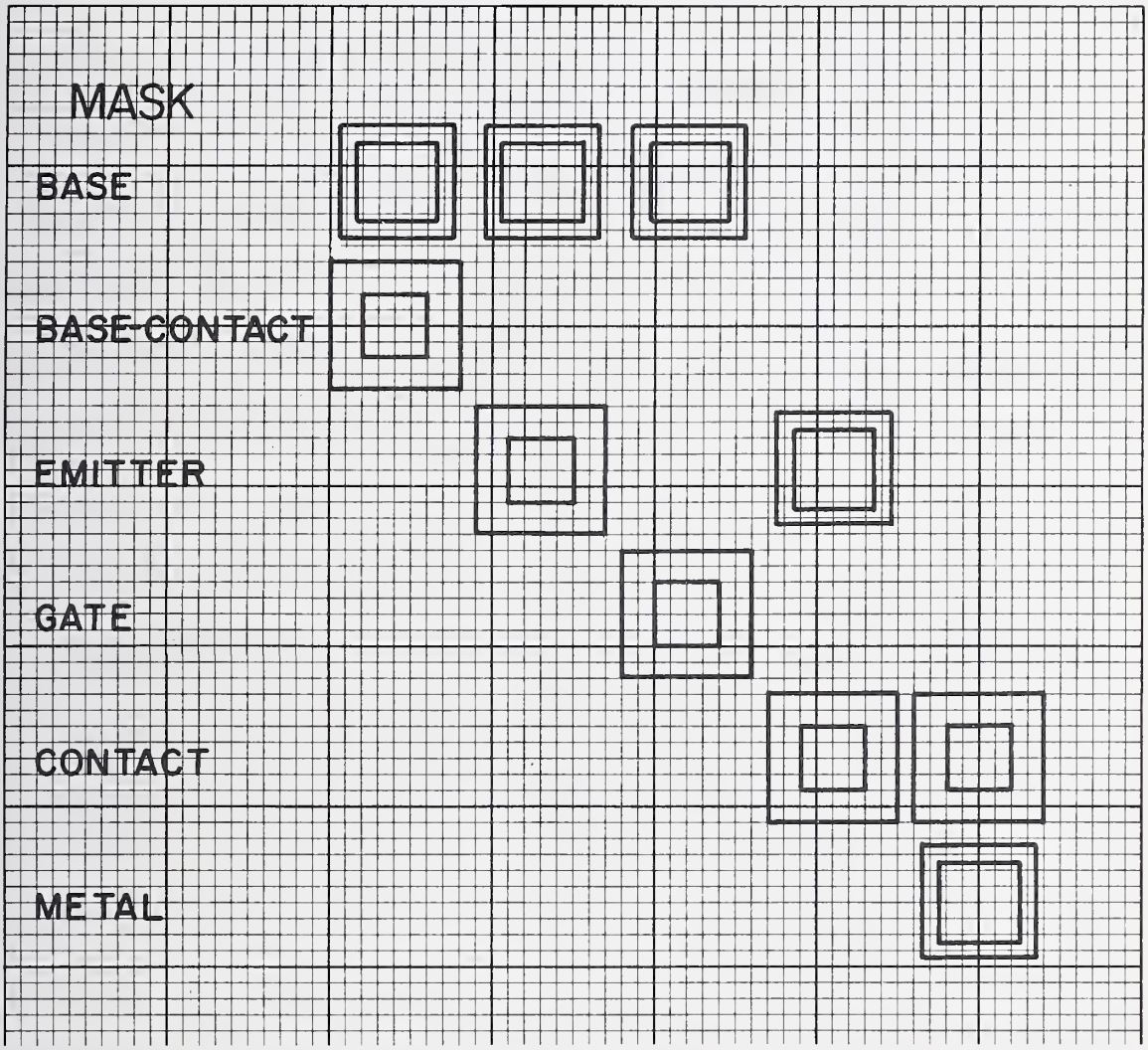


6.3 MOS Transistor
Structure 4.16



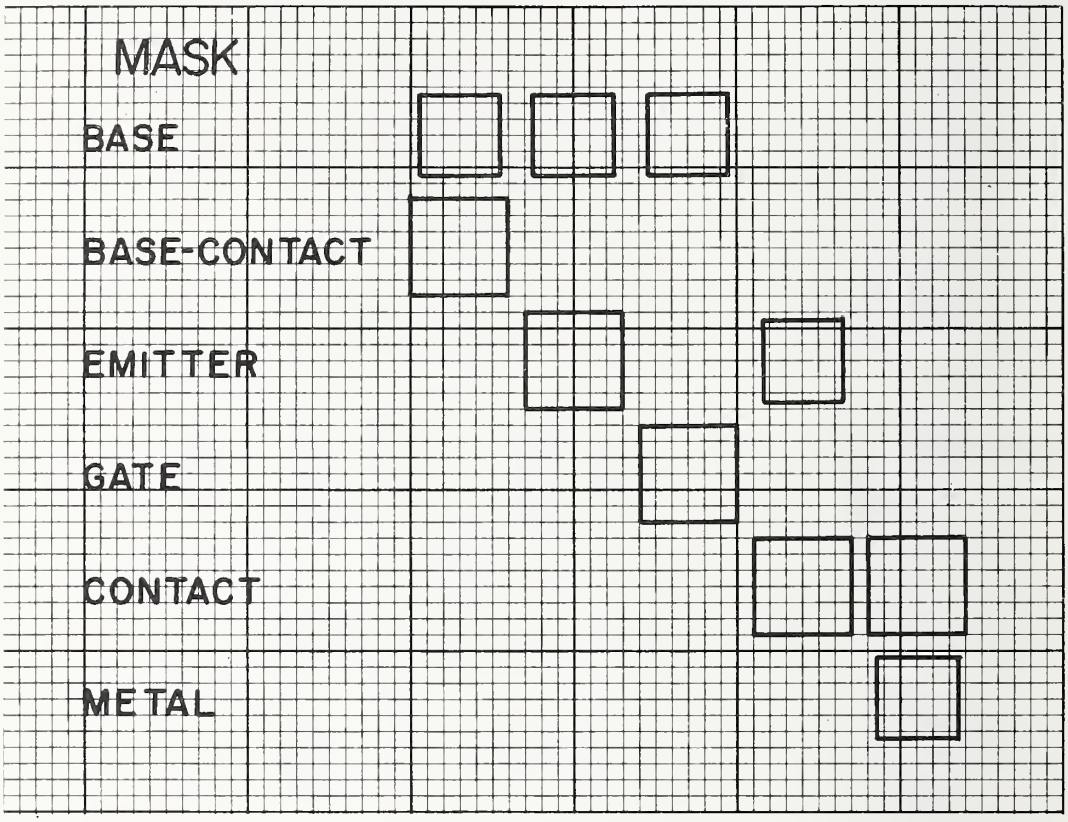
7. MISCELLANEOUS

7.1 Alignment Markers for Negative Photoresist *
Structure 4.4 N

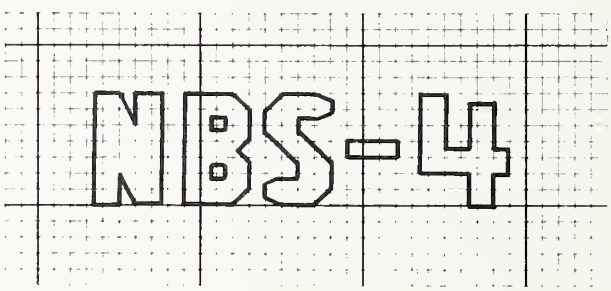


*This structure will also work with positive photoresist.

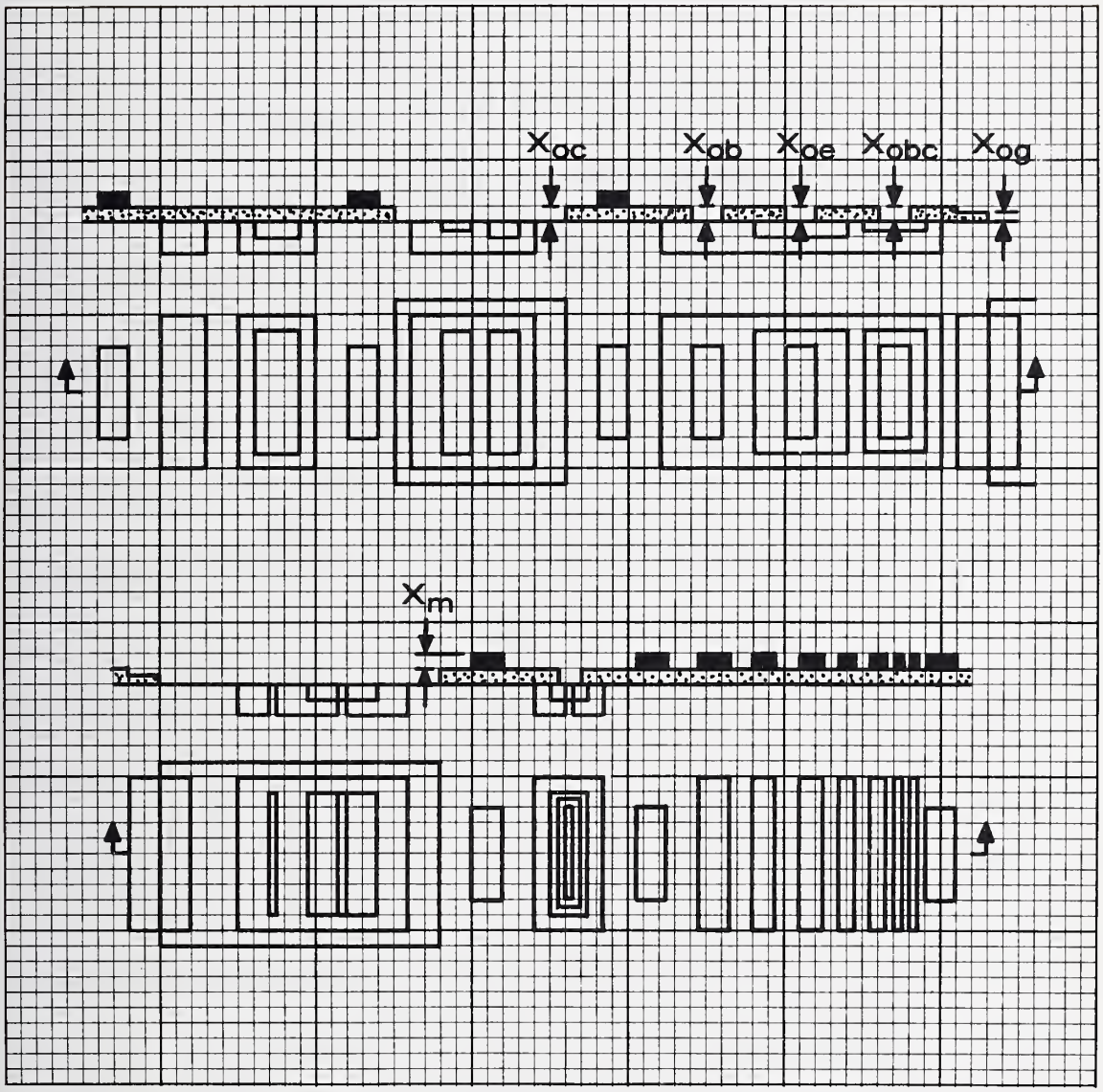
7.2 Alignment Markers for Positive Photoresist
Structure 4.4 P



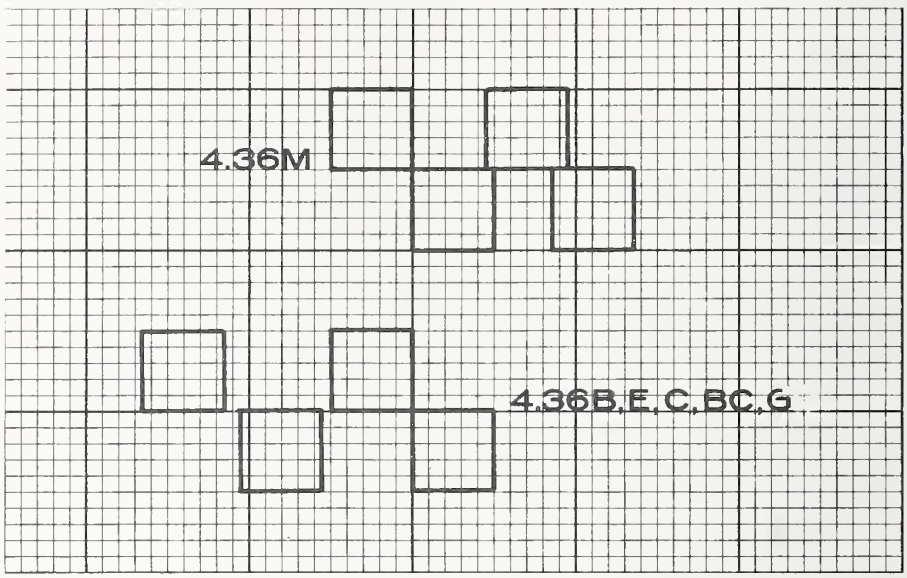
7.3 NBS Logo
Structure 4.6



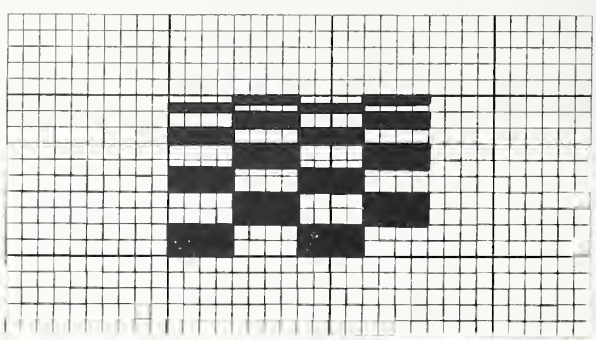
7.4 Surface Profilometer Structure
Structure 4.34



7.5 Etch Control Structures
Structures 4.36 B, E, C, M, BC, G



7.6 Resolution Structures
Structures 4.37 B, E, C, M, BC, G



REFERENCES

1. Buehler, M. G., *Semiconductor Measurement Technology*: Microelectronic Test Pattern NBS-3 for Evaluating the Resistivity-Dopant Density Relationship of Silicon, NBS Special Publication 400-22 (May 1976).

2. Buehler, M. G., and Thurber, W. R., A Planar Four-Probe Test Structure for Measuring Bulk Resistivity, *IEEE Trans. Electron Devices* ED-23, 968-974 (1976).

3. Buehler, M. G., and Thurber, W. R., An Experimental Study of Various Cross Sheet Resistor Test Structures, *J. Electrochem. Soc.* 125, 645-650 (1978).

4. Brown, D. M., Connery, R. J., and Gray, P. V., Doping Profiles by MOSFET Deep Depletion C(V), *J. Electrochem. Soc.* 122, 121-127 (1975).

5. Koyama, R. Y., and Buehler, M. G., Semiconductor Measurement Technology, W. M. Bullis, Ed., NBS Special Publication 400-17, pp. 8-11,26-27 (November 1975).

6. Mattis, R. L., and Buehler, M. G., A New Method for Calculating Background Dopant Density from *p-n* Junction Capacitance-Voltage Measurements, *J. Electrochem. Soc.* 124, 1918-1923 (1977).

7. Buehler, M. G., and Sawyer, D. E., Microelectronic Test Patterns Aid Production of Custom ICs, *Circuits Manufacturing* 17, No. 2, 46-56 (February 1977).

8. Buehler, M. G., David, J. M., Mattis, R. L., Phillips, W. E., and Thurber, W. R., *Semiconductor Measurement Technology*: Planar Test Structures for Characterizing Impurities in Silicon, NBS Special Publication 400-21 (December 1975).

9. Buehler, M. G., Dopant Profiles Determined from Enhancement Mode MOSFET d-c Measurements, *Appl. Phys. Letters* 31, 848-850 (1977).

10. Brooks, R. D., and Mattes, H. G., Spreading Resistance Between Constant Potential Surfaces, *Bell System Tech. J.* 50, 775-784 (1971).

11. Saltich, J. L., Volk, C. E., and Clark, L. E., Use of Specific Emitter Efficiency in Evaluation and Design of Bipolar Transistors, *Proc. IEEE* 61, 680-681 (1973).

12. David, J. M., and Buehler, M. G., A Numerical Analysis of Various Cross Sheet Resistor Test Structures, *Solid-State Electronics* 20, 539-543 (1977).

13. Buehler, M. G., Grant, S. D., and Thurber, W. R., Bridge and van der Pauw Sheet Resistors for Characterizing the Line Width of Conducting Layers, *J. Electrochem. Soc.* 125, 650-654 (1978).

14. Chwang, R., Smith, B. J., and Crowell, C. R., Contact Size Effects on the van der Pauw Method for Resistivity and Hall Coefficient Measurements, *Solid-State Electronics* 17, 1217-1227 (1974).

APPENDIX

In the following figures, the center-to-center distance between the scribe lines is 100 mil (2.54 mm). For all masks except the METAL mask the areas delineated for subsequent diffusion, oxidation, or oxide removal appear white in the photomicrographs of the masks. On the METAL mask the metallization pattern is black on a white background.

Table 2 – Test Structures Shown in Figures 3-9.

Number	Test Structure
4.1	Collector resistor (pipes 0.20 mil on a side)
4.2	MOS capacitor over collector (base DGR)
4.3	MOS capacitor over collector (emitter DGR)
4.4	Alignment markers
4.5	Collector resistor (pipes 0.30 mil on a side)
4.6	Logo
4.7	Collector resistor (pipes 0.40 mil on a side)
4.8	MOS capacitor over collector (FP, CS)
4.9	Collector resistor (pipes 0.50 mil on a side)
4.10	Base-collector diode (FP, CS)
4.11	Base sheet resistor (VDP, FP, CS)

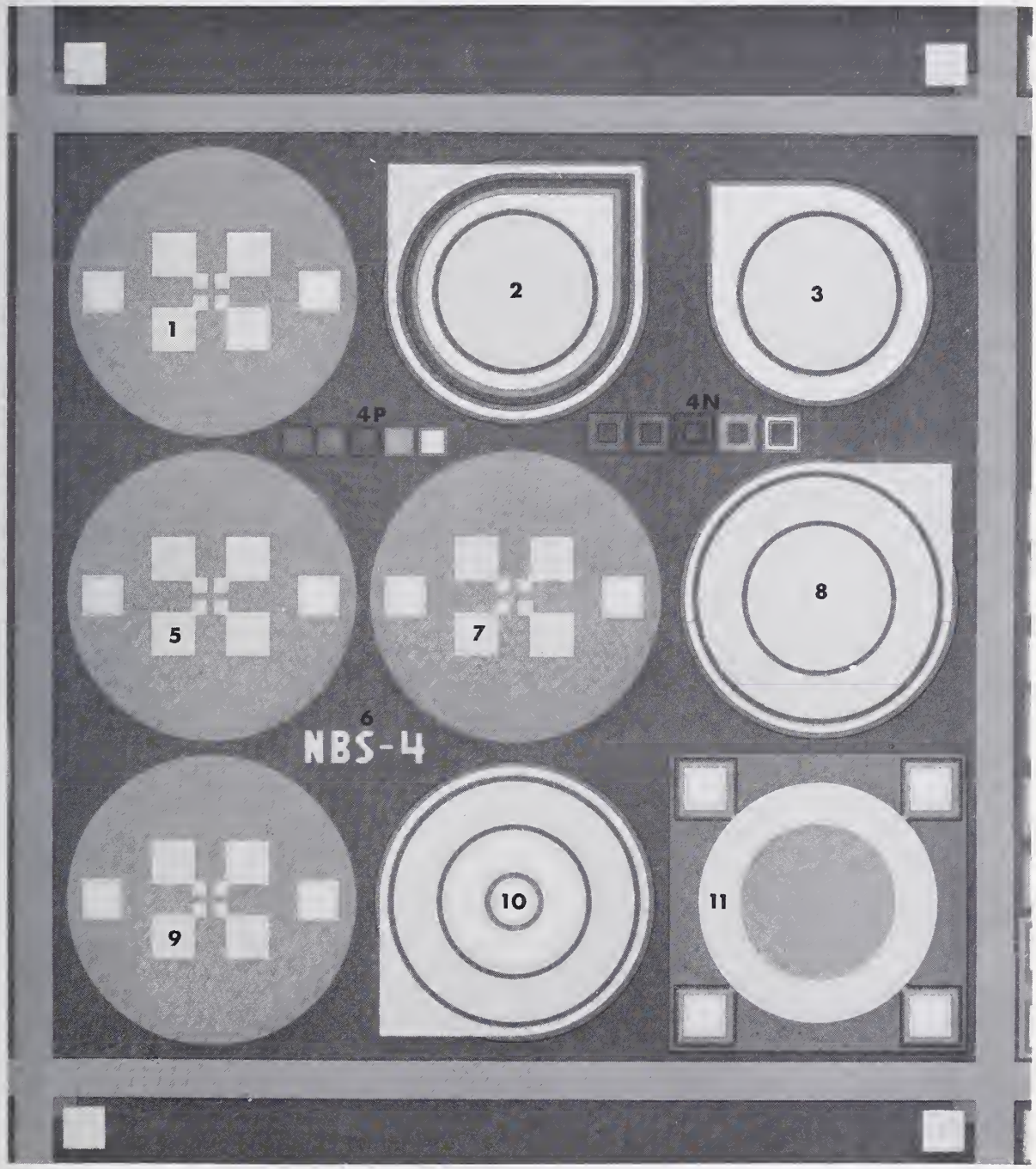


Figure 3. Quadrant 1 of test pattern NBS-4. Test structures are identified in table 2.

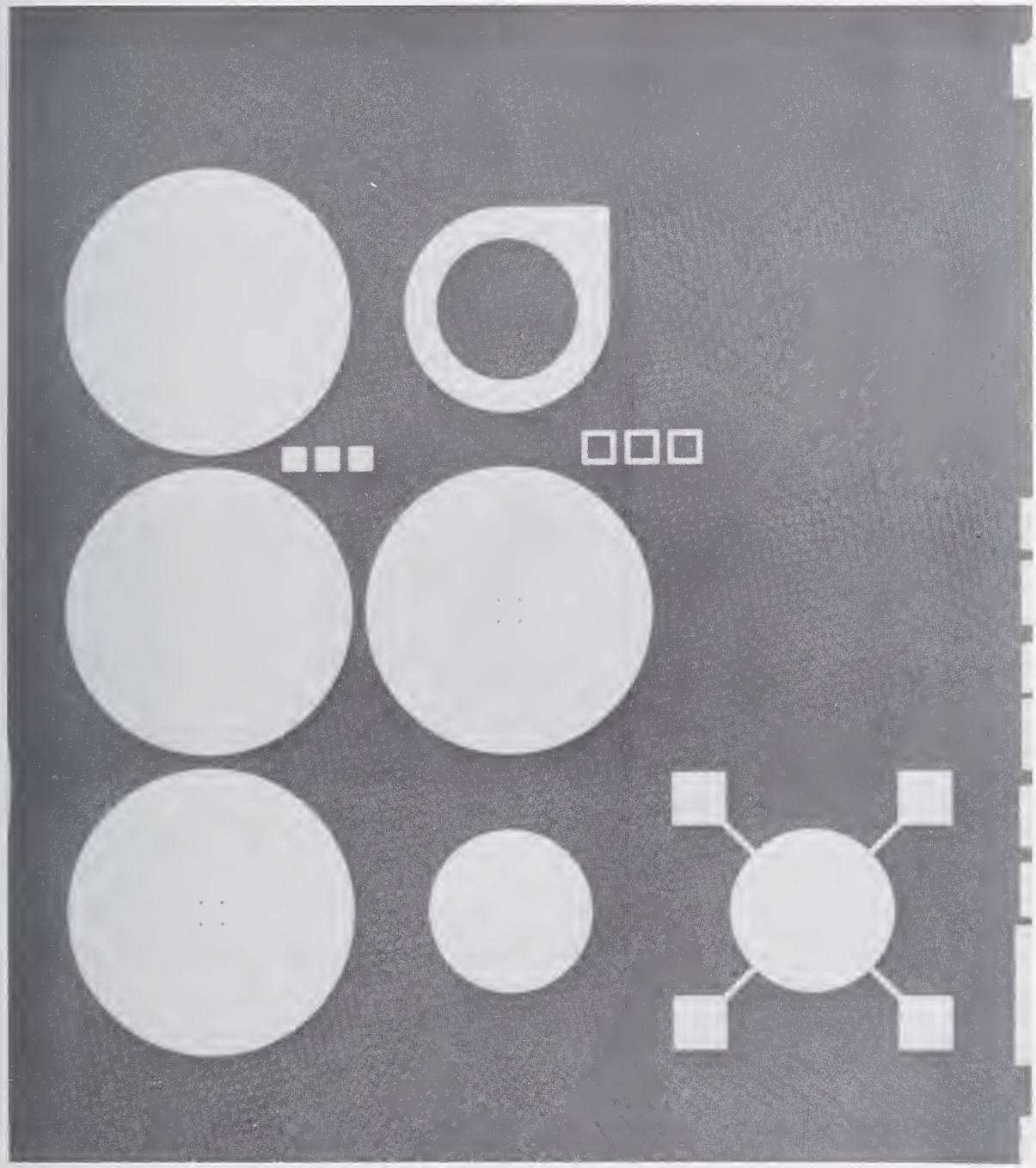


Figure 4. BASE mask for quadrant 1 of test pattern NBS-4. Test structures located in this quadrant are listed in table 2.

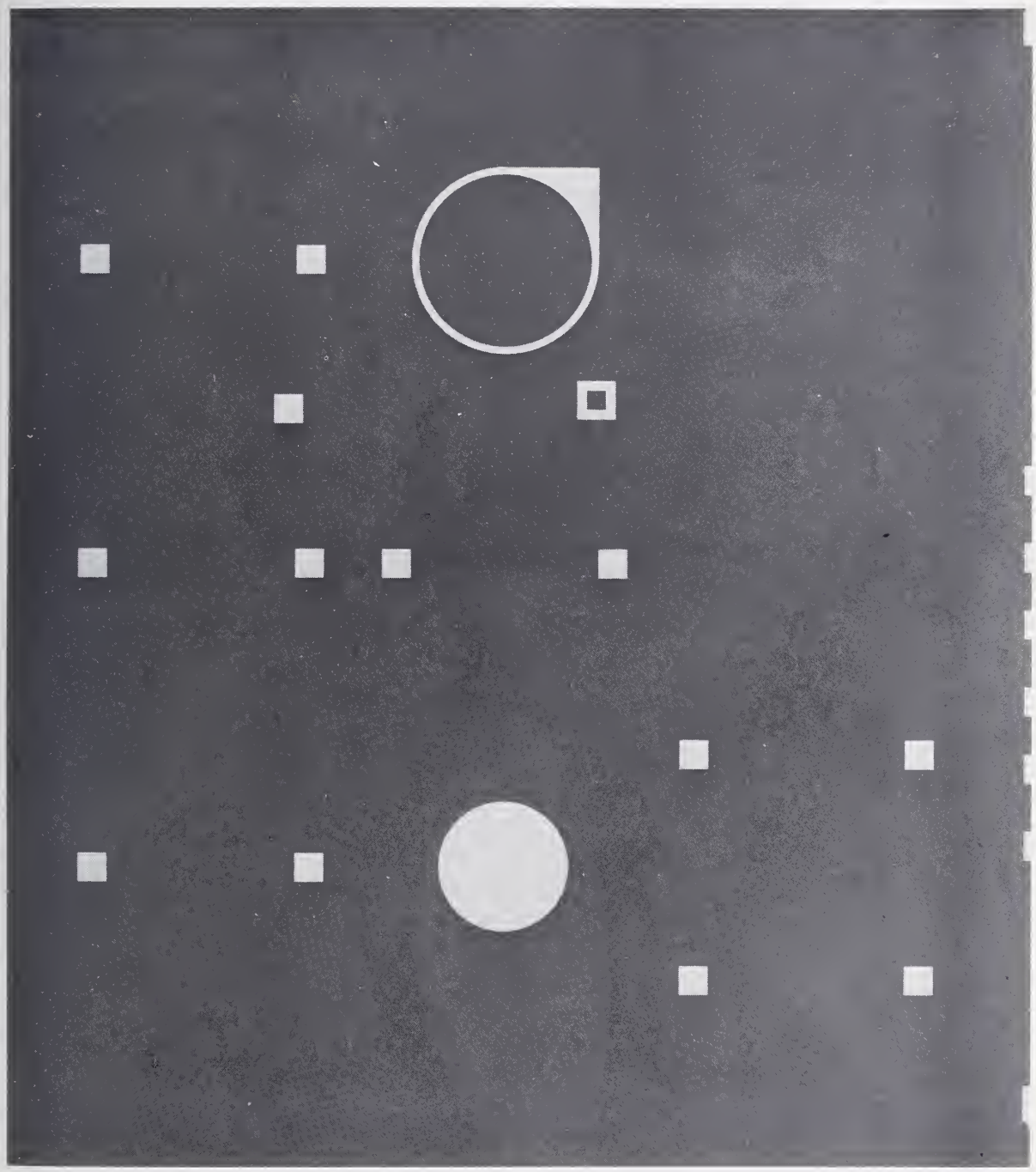


Figure 5. BASE-CONTACT mask for quadrant 1 of test pattern NBS-4. Test structures located in this quadrant are listed in table 2.

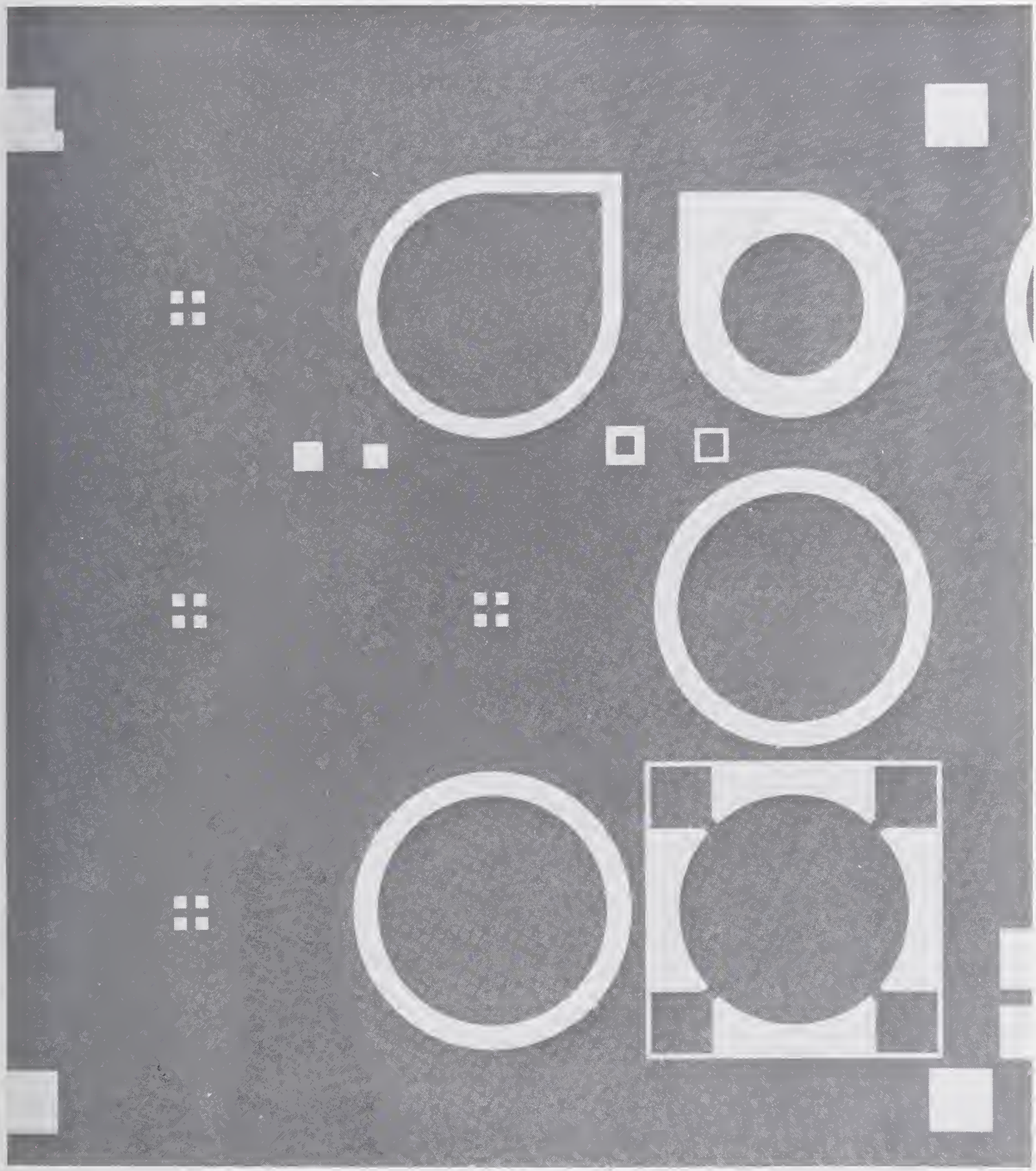


Figure 6. EMITTER mask for quadrant 1 of test pattern NBS-4. Test structures located in this quadrant are listed in table 2.

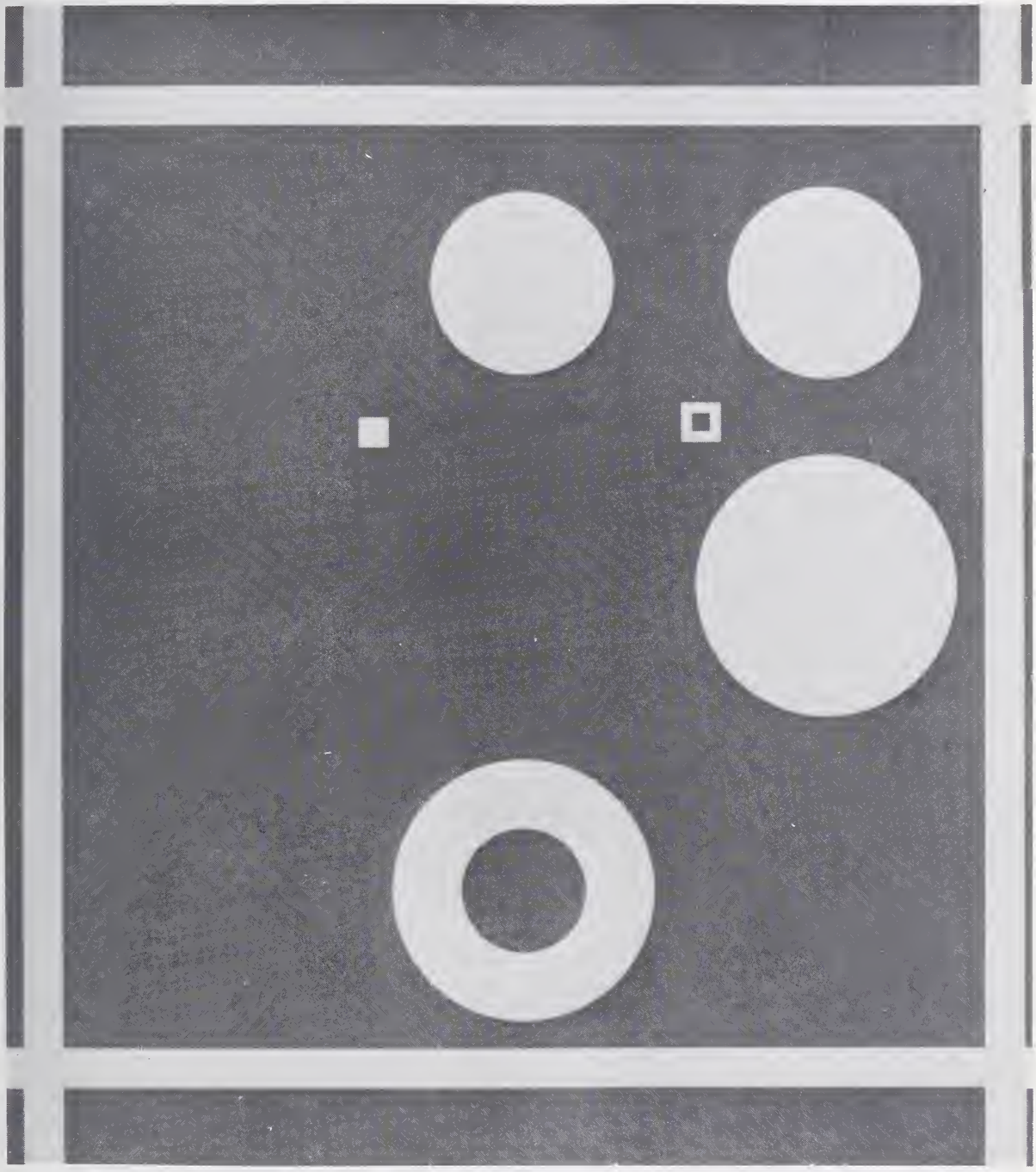


Figure 7. GATE mask for quadrant 1 of test pattern NBS-4. Test structures located in this quadrant are listed in table 2.

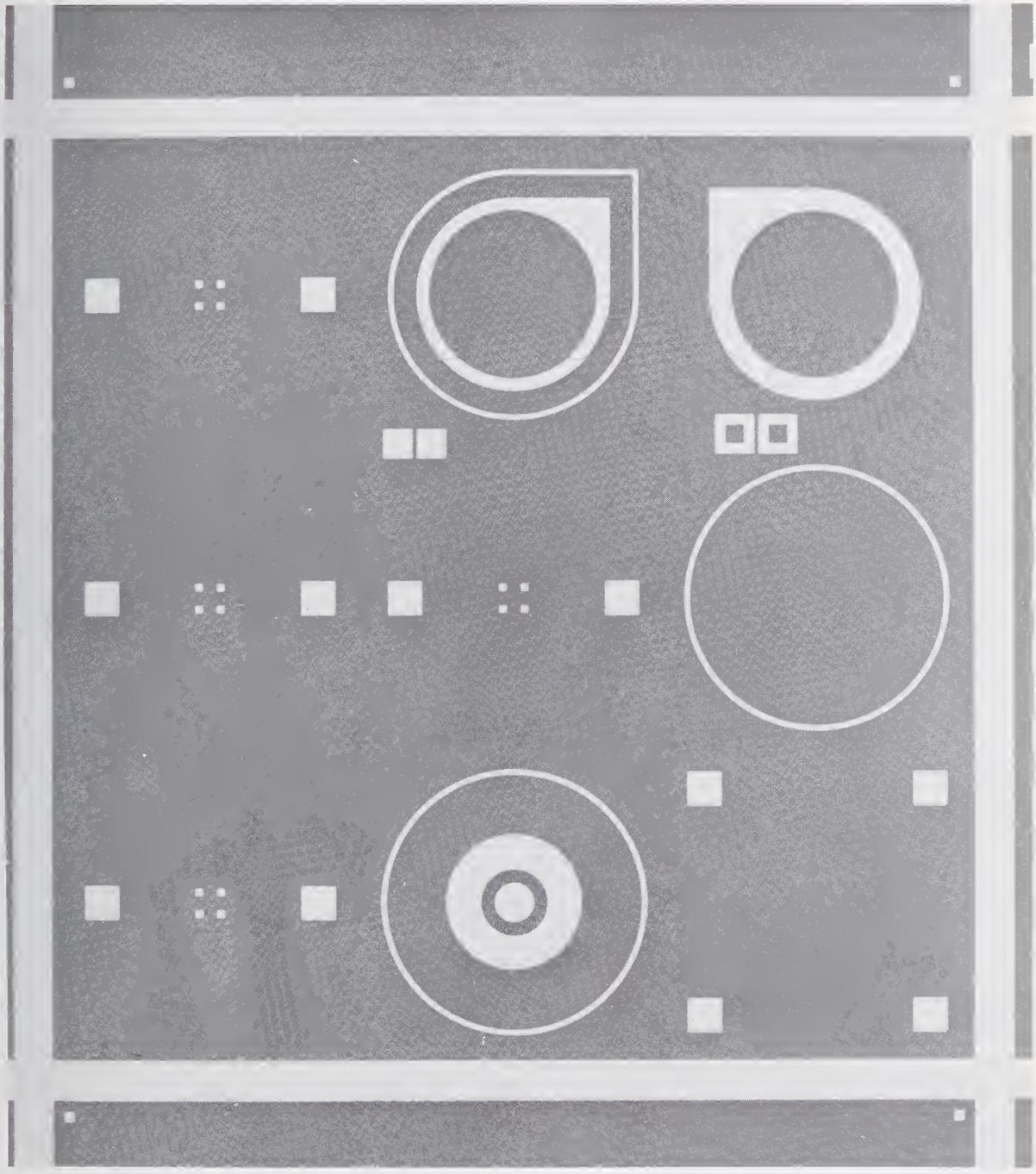


Figure 8. CONTACT mask for quadrant 1 of test pattern NBS-4. Test structures located in this quadrant are listed in table 2.

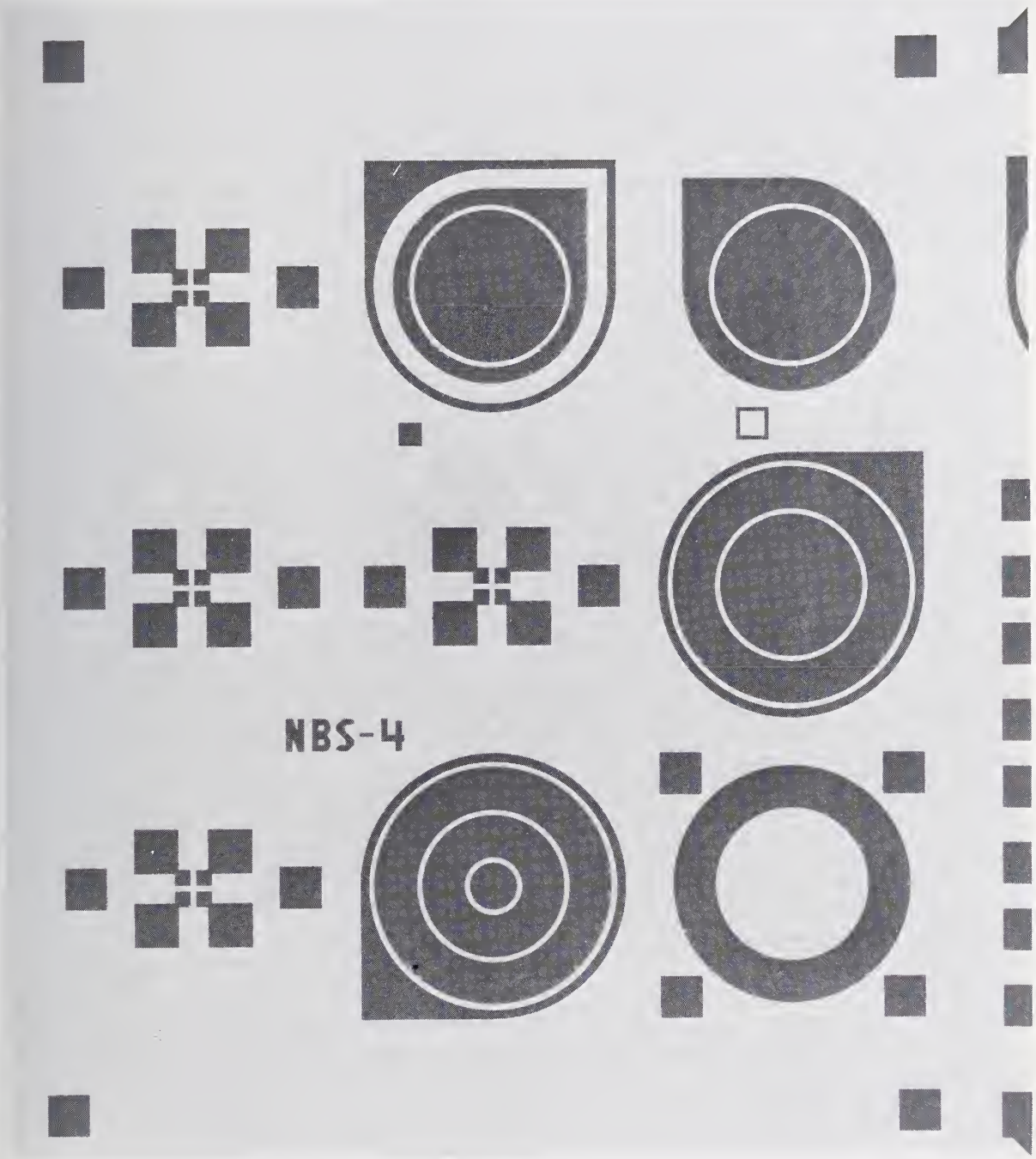


Figure 9. METAL mask for quadrant 1 of test pattern NBS-4. Test structures located in this quadrant are listed in table 2.

Table 3 — Test Structures Shown in Figures 10-16.

Number	Test Structure
4.12	MOS Capacitor over base
4.13	Bipolar transistor
4.14	Base-collector diode (FP, CS)
4.15	MOSFET (circular, W/L = 18.2)
4.16	MOSFET (rectangular, W/L = 4)
4.17	Collector resistor (pipes 0.25 mil on a side)
4.18	Collector spreading resistor
4.19	Metal sheet resistor (Greek cross)
4.20	Base-under-emitter sheet resistor (Greek cross)
4.21	Base-contact sheet resistor (Greek cross)
4.22	Base sheet resistor (narrow Greek cross)
4.23	Base sheet resistor (bridge, W/L = 0.25)
4.24	Base sheet resistor (Greek cross)
4.25	Base sheet resistor (Greek cross, tab contacts)
4.26	Base sheet resistor (offset quadrate cross)
4.27	Metal-to-emitter contact resistor
4.28	Emitter sheet resistor (offset quadrate cross)
4.29	Metal-to-base contact resistor
4.30	MOS capacitor over collector (square)

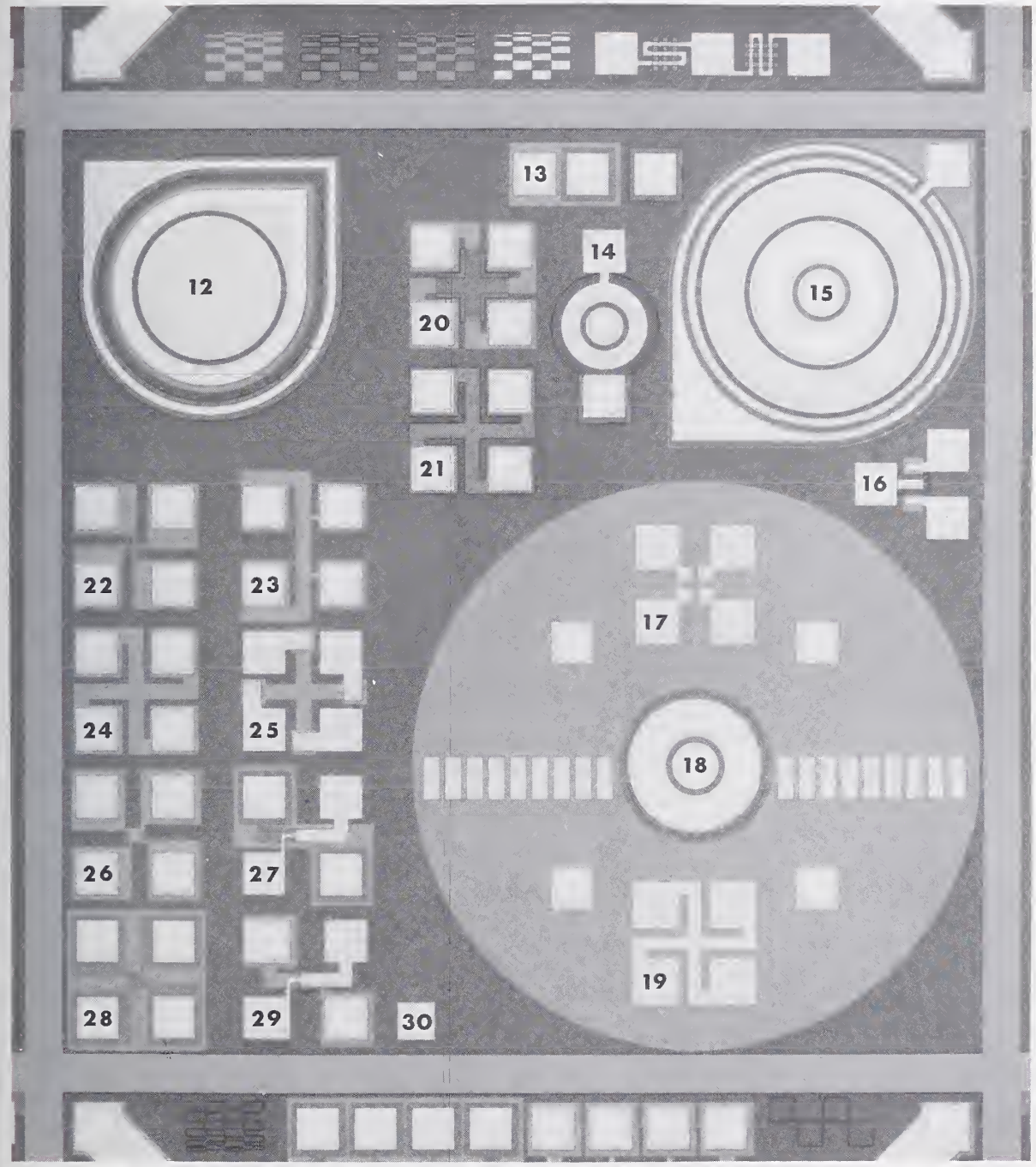


Figure 10. Quadrant 2 of test pattern NBS-4. Test structures are identified in table 3.

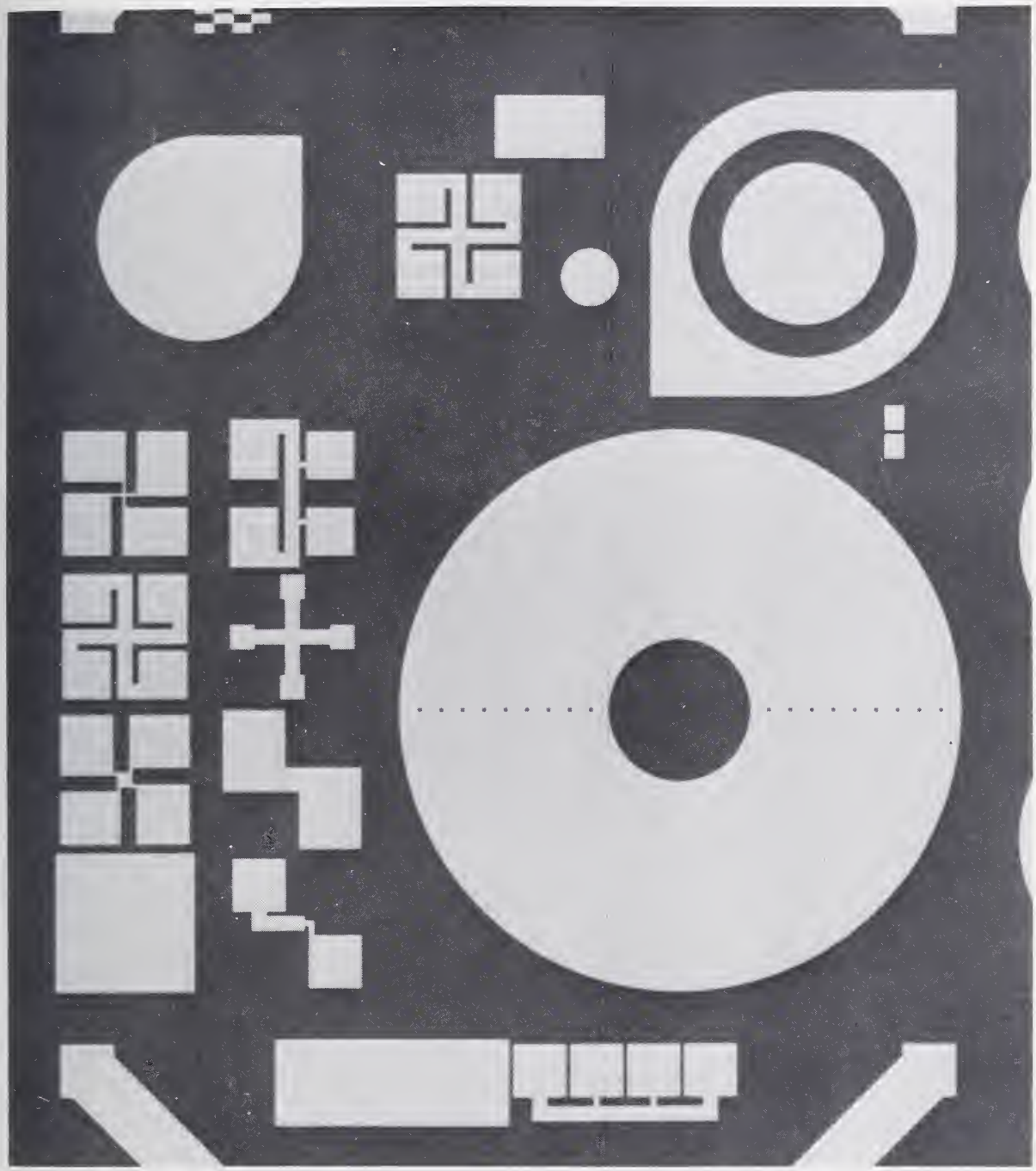


Figure 11. BASE mask for quadrant 2 of test pattern NBS-4. Test structures located in this quadrant are listed in table 3.

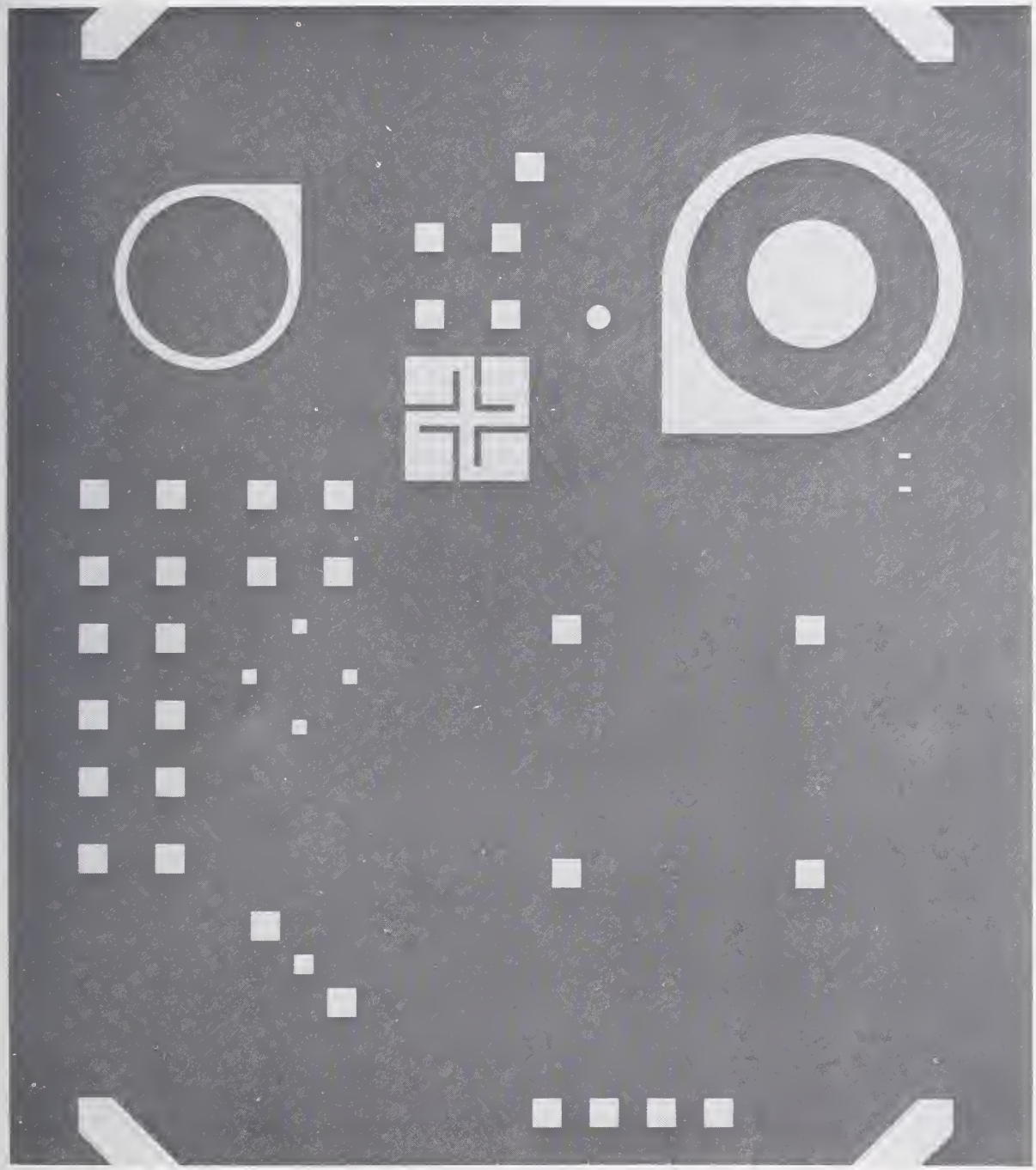


Figure 12. BASE-CONTACT mask for quadrant 2 of test pattern NBS-4. Test structures located in this quadrant are listed in table 3.

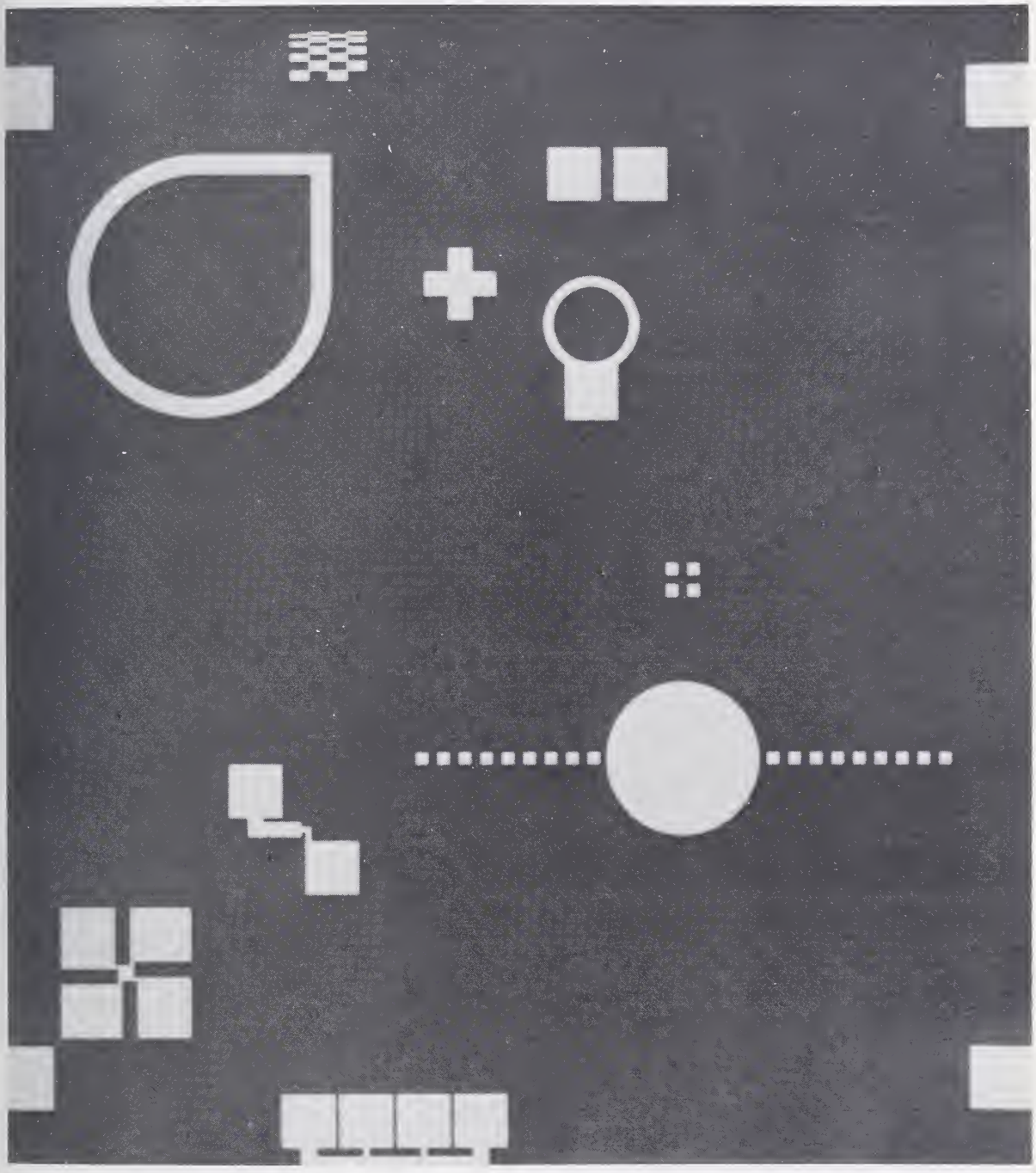


Figure 13. EMITTER mask for quadrant 2 of test pattern NBS-4. Test structures located in this quadrant are listed in table 3.

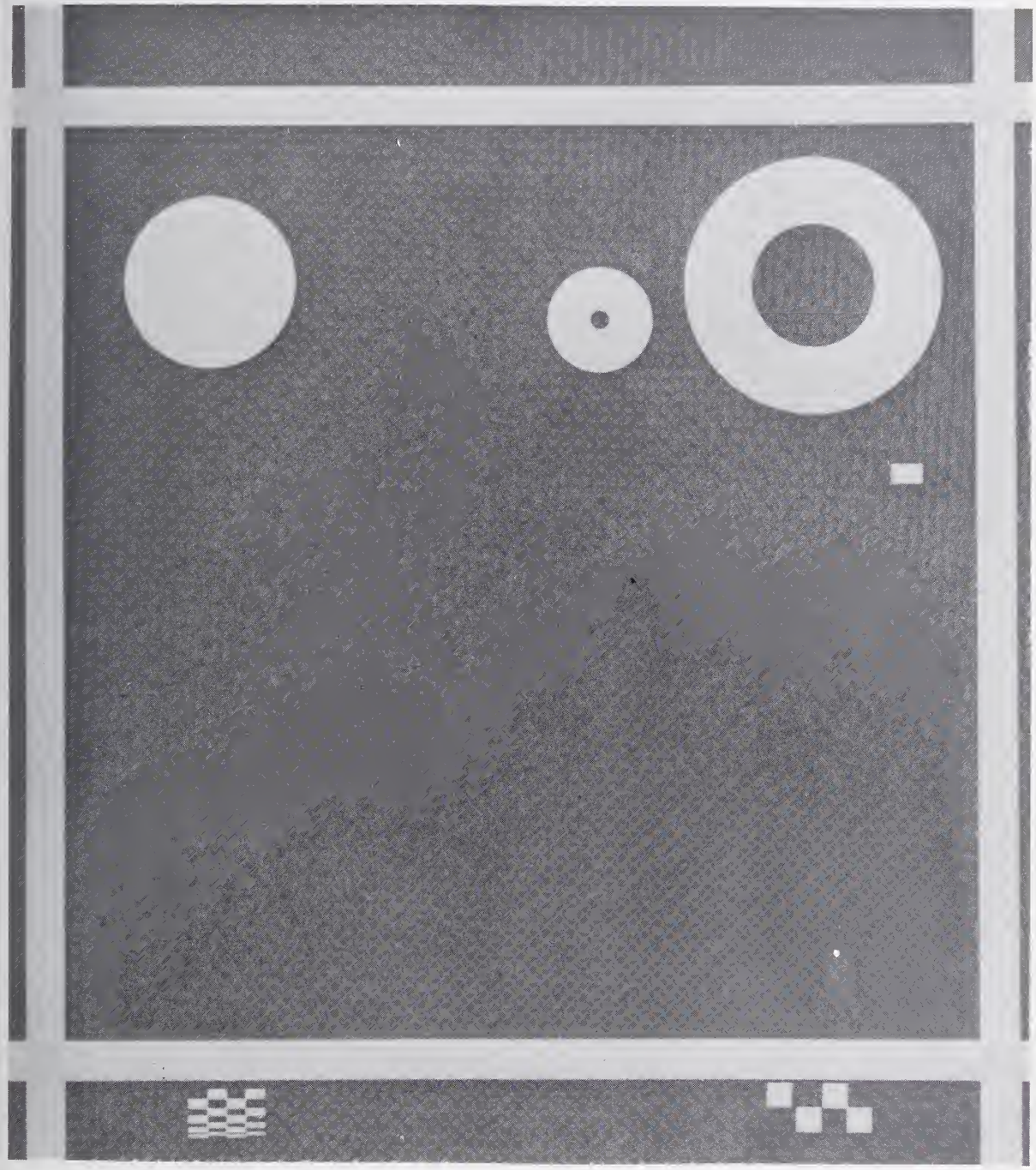


Figure 14. GATE mask for quadrant 2 of test pattern NBS-4. Test structures located in this quadrant are listed in table 3.

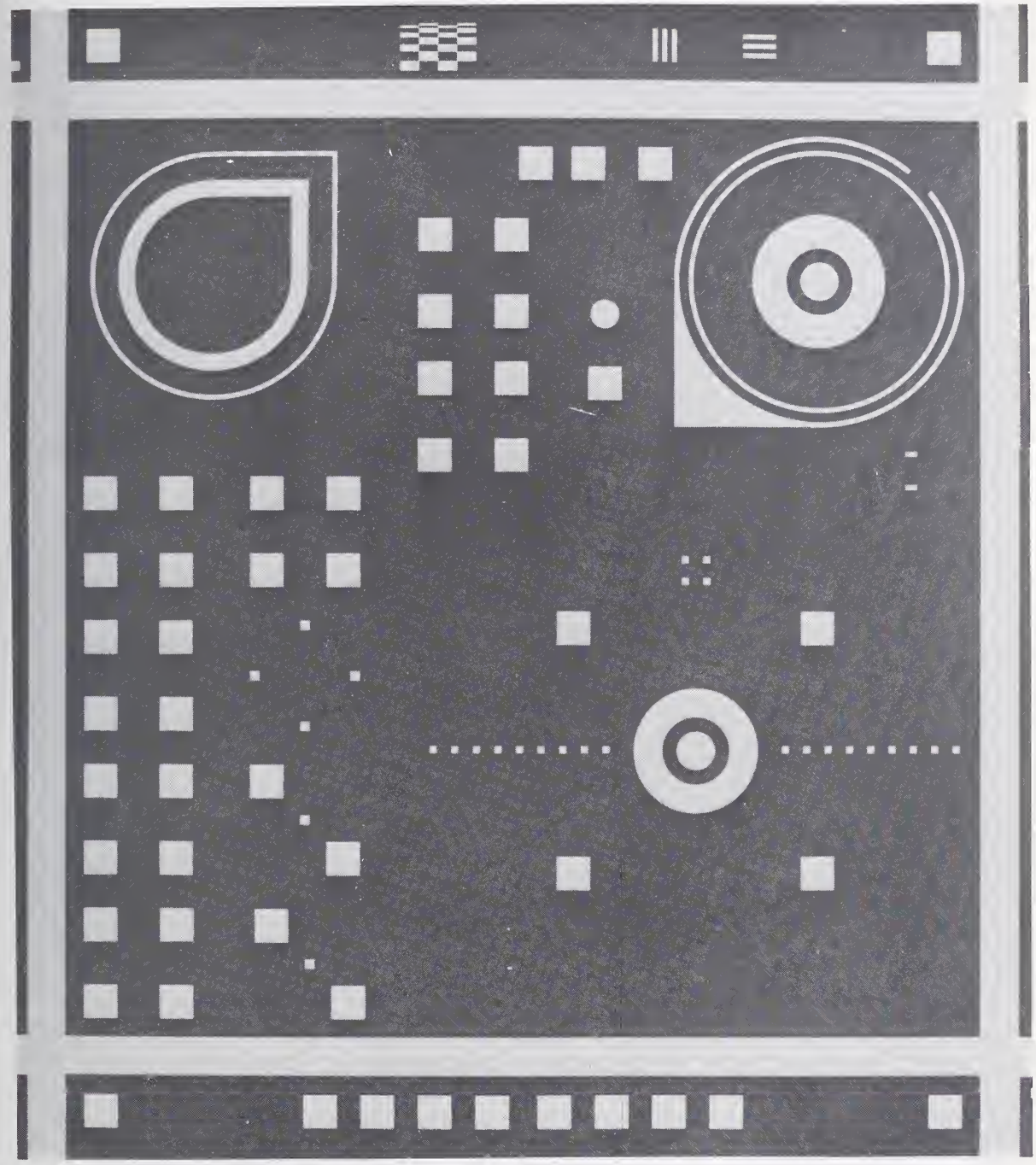


Figure 15. CONTACT mask for quadrant 2 of test pattern NBS-4. Test structures located in this quadrant are listed in table 3.

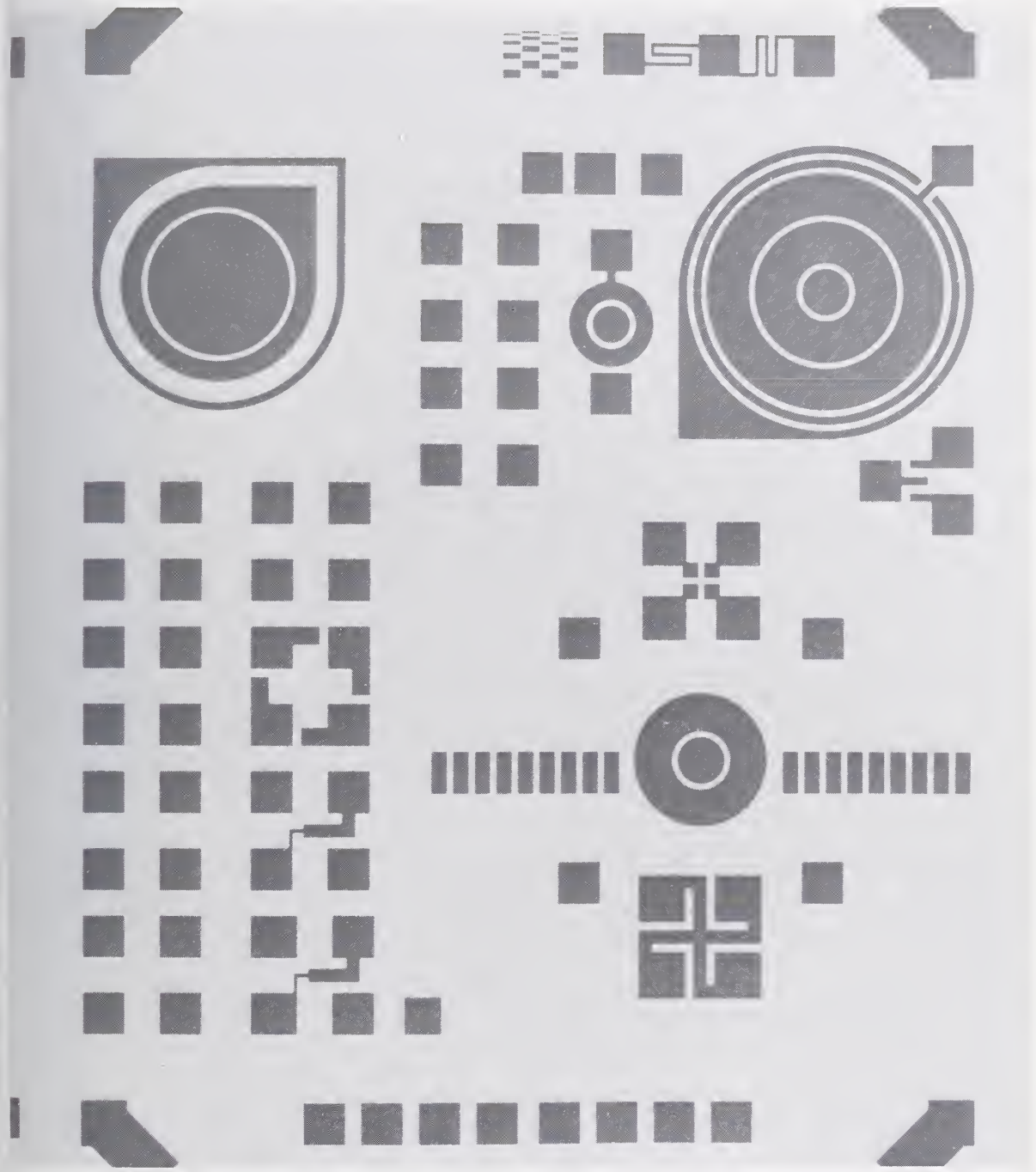


Figure 16. METAL mask for quadrant 2 of test pattern NBS-4. Test structures located in this quadrant are listed in table 3.

Table 4 — Test Structure Shown in Figures 17-23.

Number	Test Structure
4.31	Hall effect device (VDP)

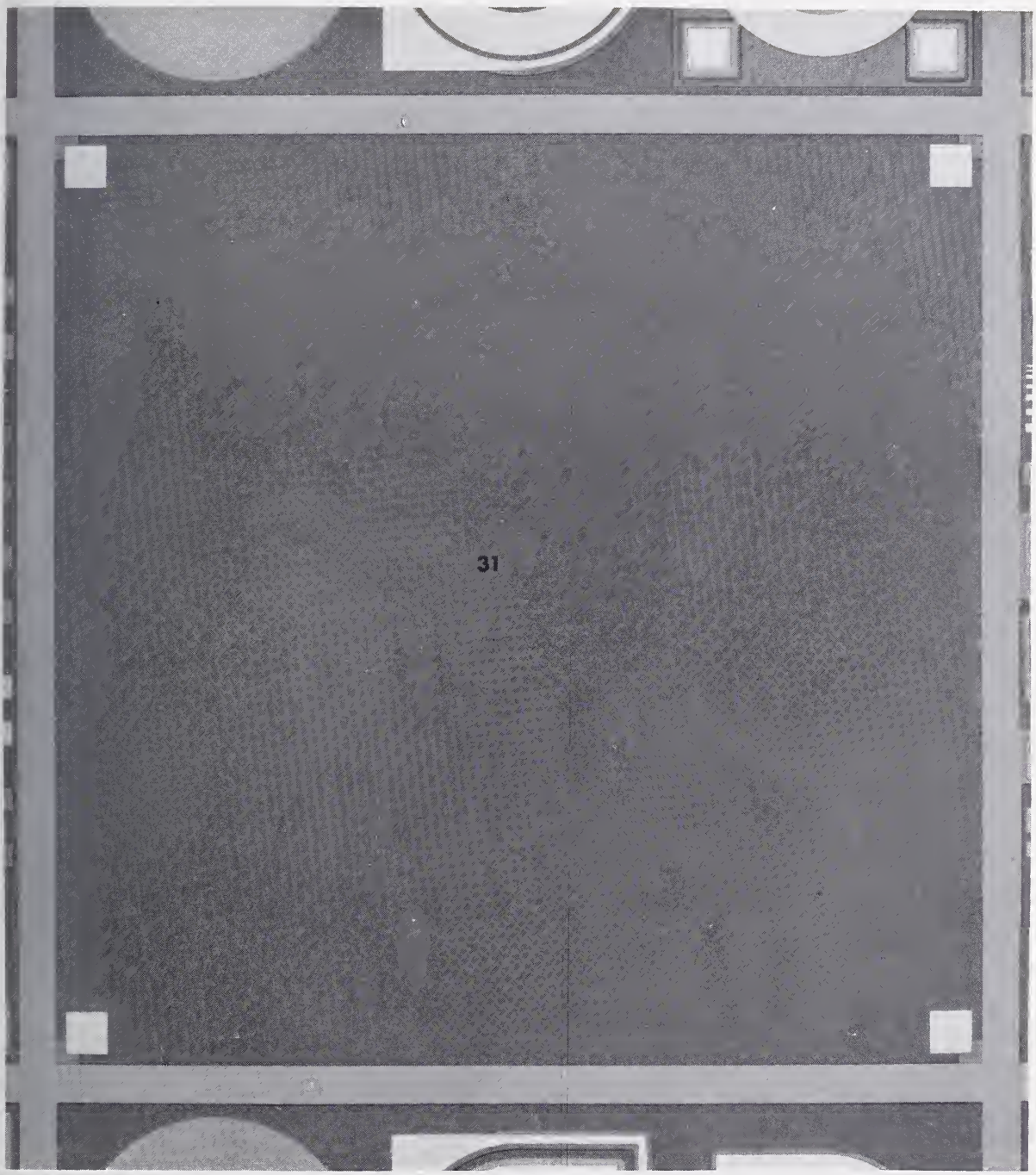


Figure 17. Quadrant 3 of test pattern NBS-4. The only test structure in this quadrant is the Hall effect device listed in table 4.

Figure 18. BASE mask for quadrant 3 of test pattern NBS-4. The Hall effect device is the only test structure located in this quadrant. This figure is included for completeness even though the structure has no base diffusion.

Figure 19. BASE-CONTACT mask for quadrant 3 of test pattern NBS-4. The Hall effect device is the only test structure located in this quadrant. This figure is included for completeness even though the structure has no base contact diffusion.

Figure 20. EMITTER mask for quadrant 3 of test pattern NBS-4. The Hall effect device is the only test structure located in this quadrant.

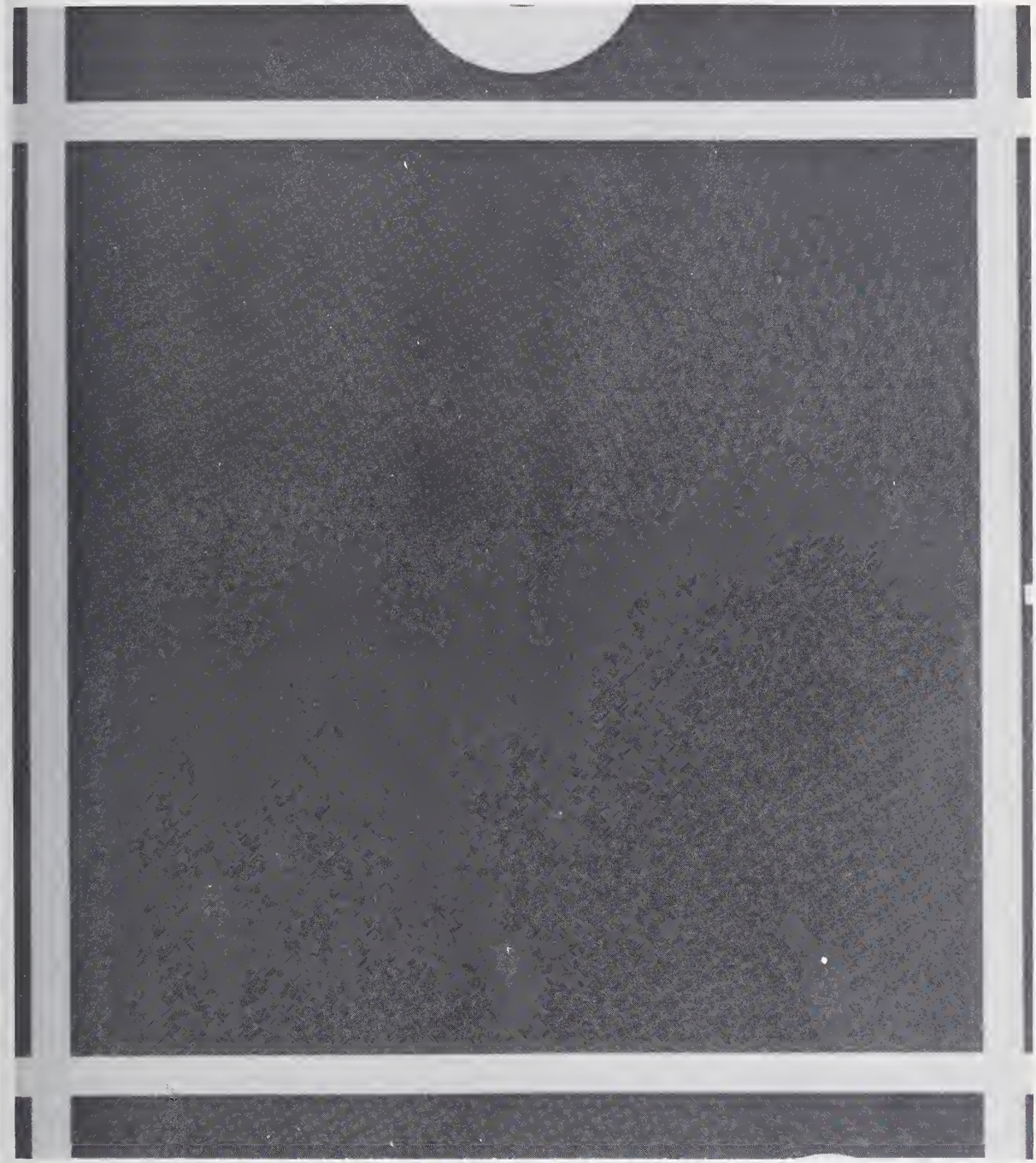


Figure 21. GATE mask for quadrant 3 of test pattern NBS-4. The Hall effect device is the only test structure located in this quadrant. The GATE mask is not involved in the fabrication of this structure, but it does remove oxide from the scribe lines surrounding the structure.

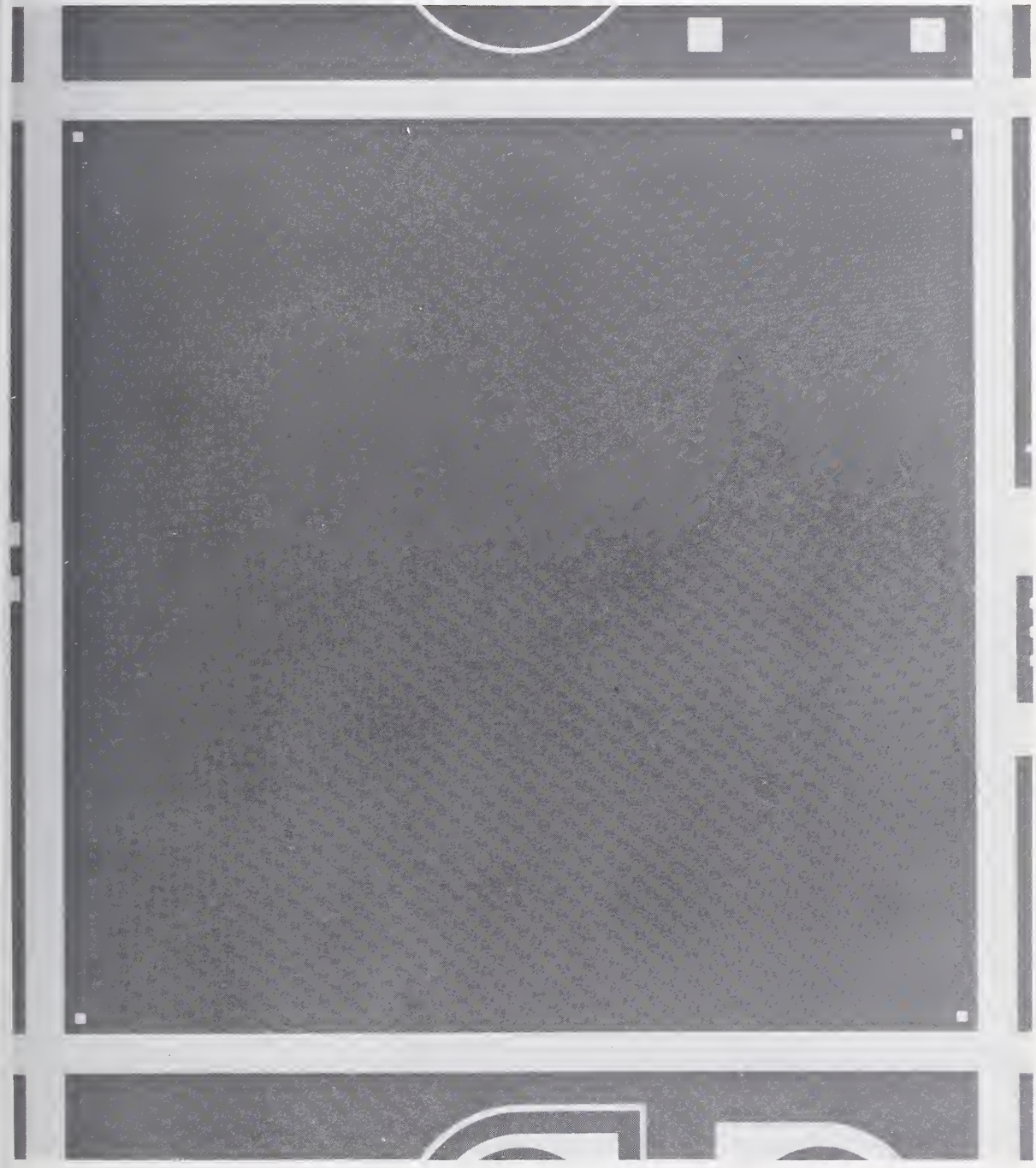


Figure 22. CONTACT mask for quadrant 3 of test pattern NBS-4. The Hall effect device is the only test structure located in this quadrant.

Figure 23. METAL mask for quadrant 3 of test pattern NBS-4. The Hall effect device is the only test structure located in this quadrant.

Table 5 — Test Structures Shown in Figures 24-30.

Number	Test Structure
4.32	Emitter sheet resistor (bridge, W/L = 0.25)
4.33	Base sheet resistor (bridge, W/L = 0.25)
4.34	Surface profilometer structure
4.35	Incremental base sheet resistor (VDP)
4.36	Etch-control structures
4.37	Resolution structures
4.38	Metal step-coverage resistor

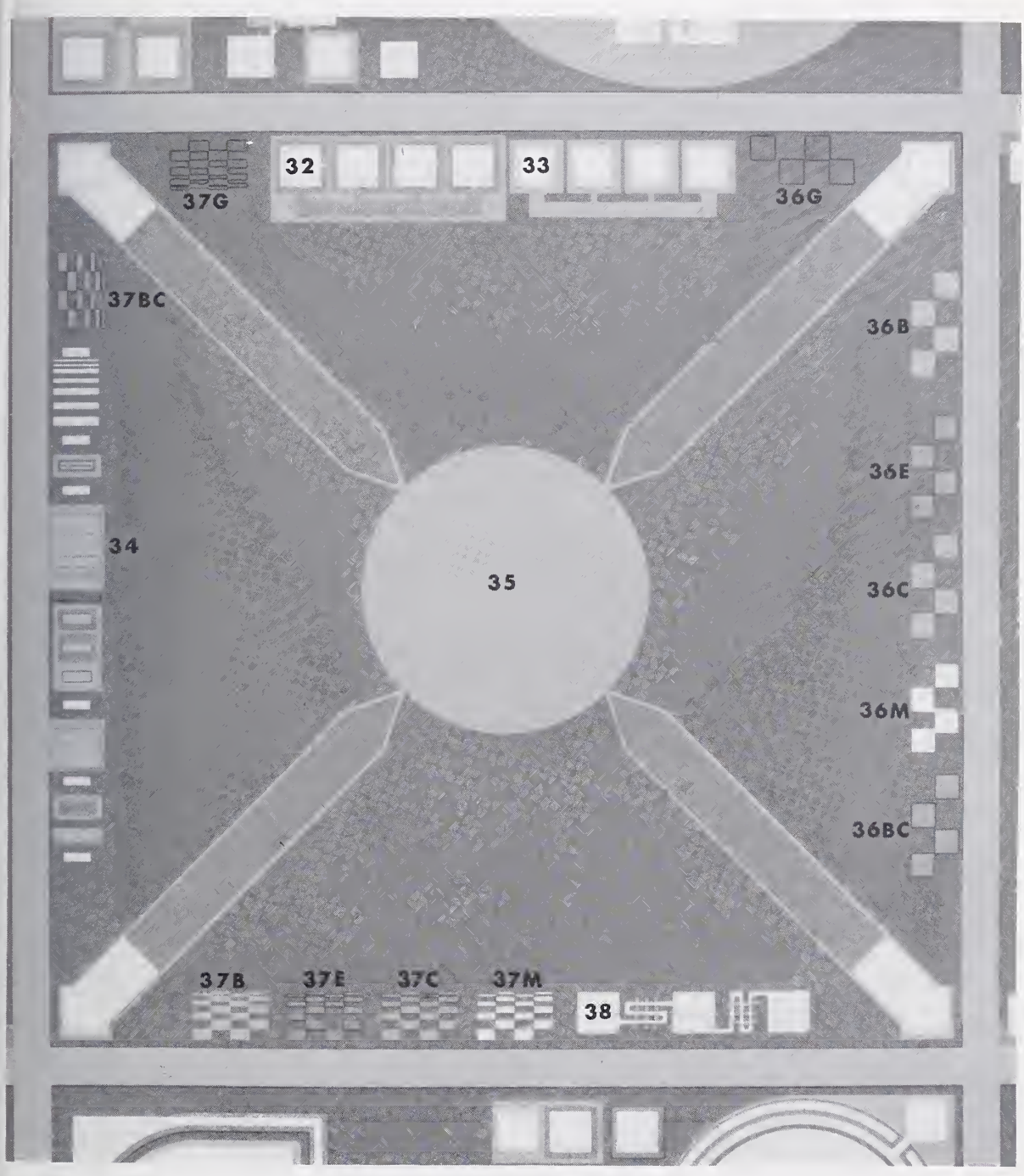


Figure 24. Quadrant 4 of test pattern NBS-4. Test structures are identified in table 5.

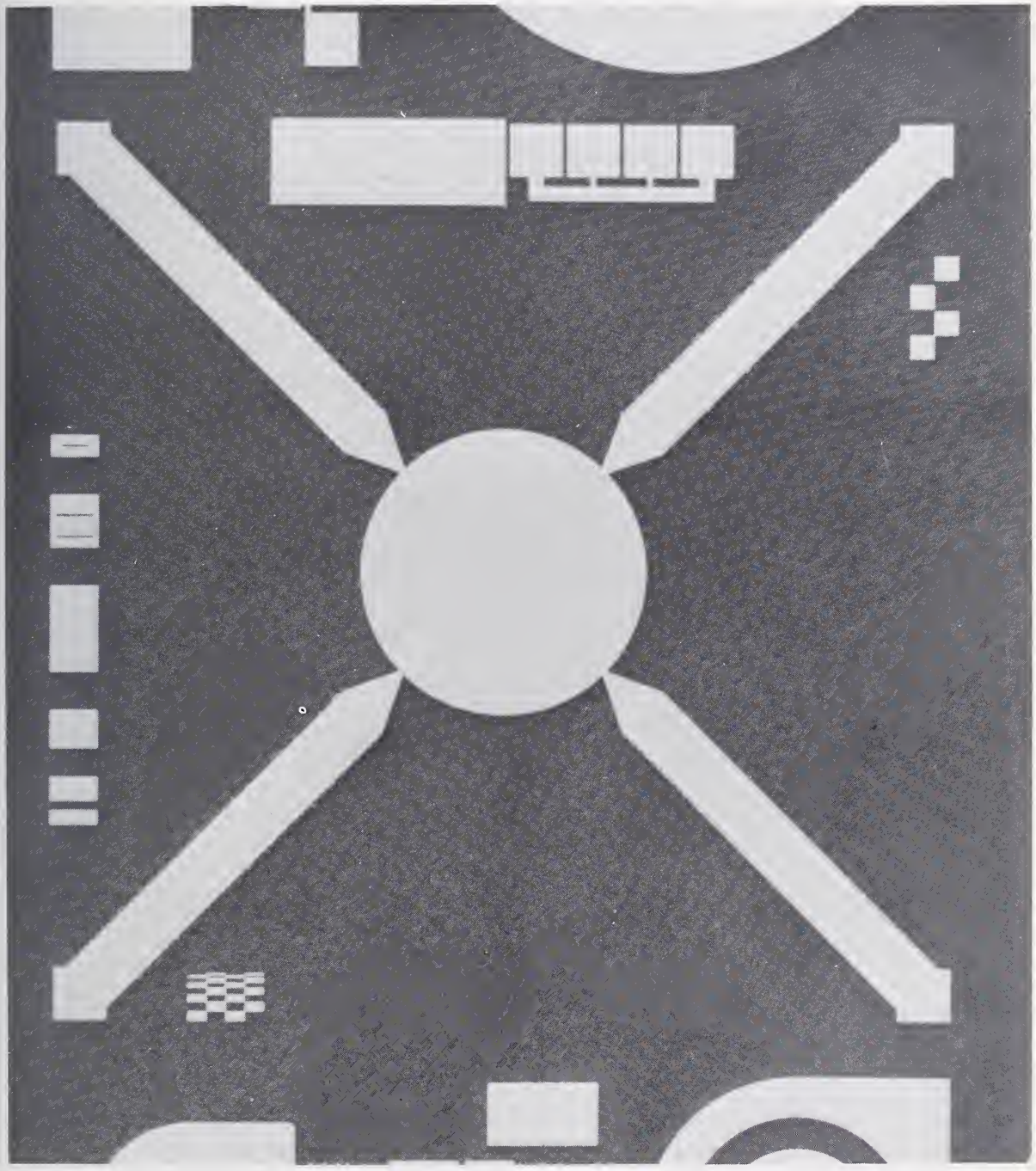


Figure 25. BASE mask for quadrant 4 of test pattern NBS-4. Test structures located in this quadrant are listed in table 5.

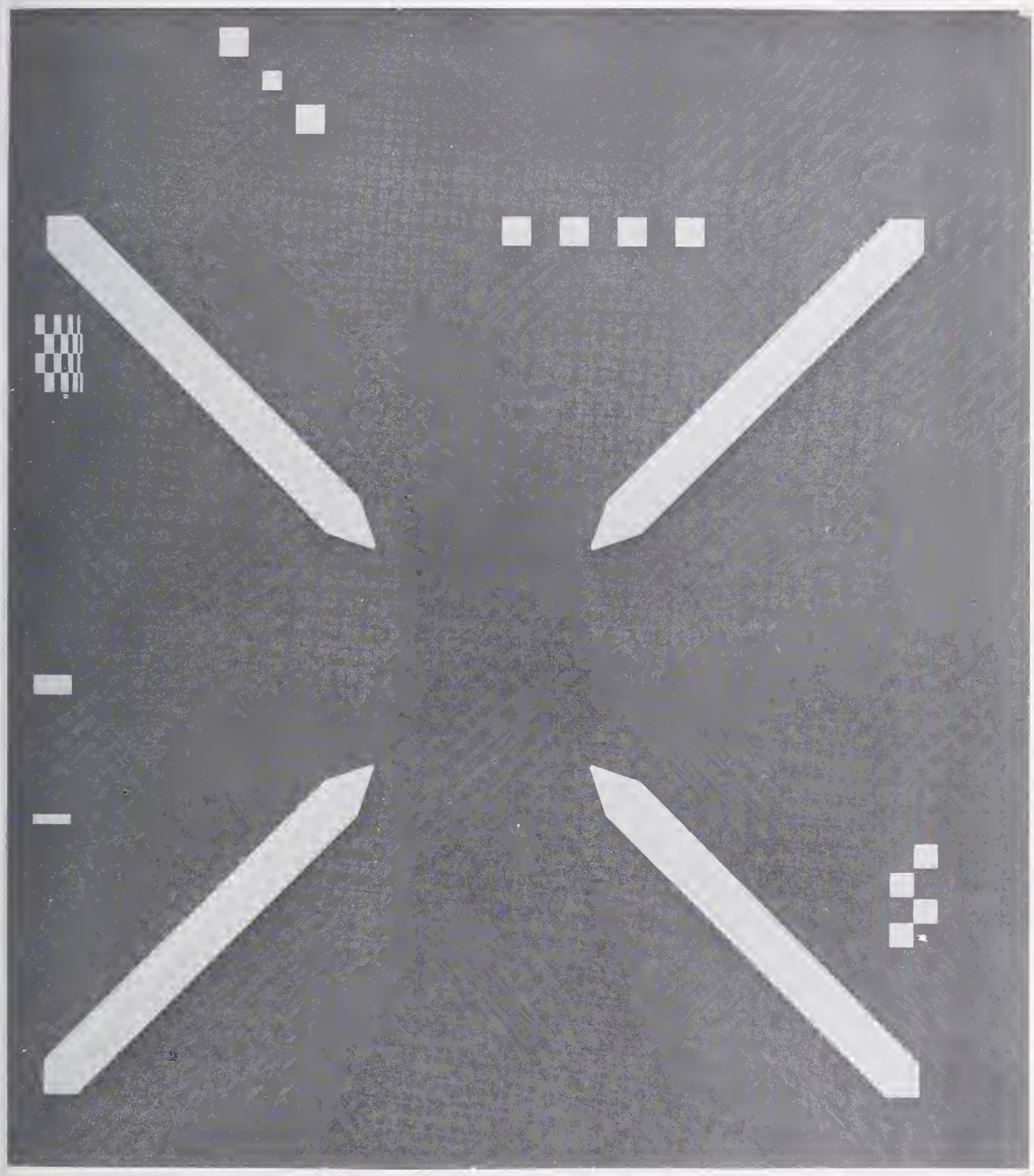


Figure 26. BASE-CONTACT mask for quadrant 4 of test pattern NBS-4. Test structures located in this quadrant are listed in table 5.

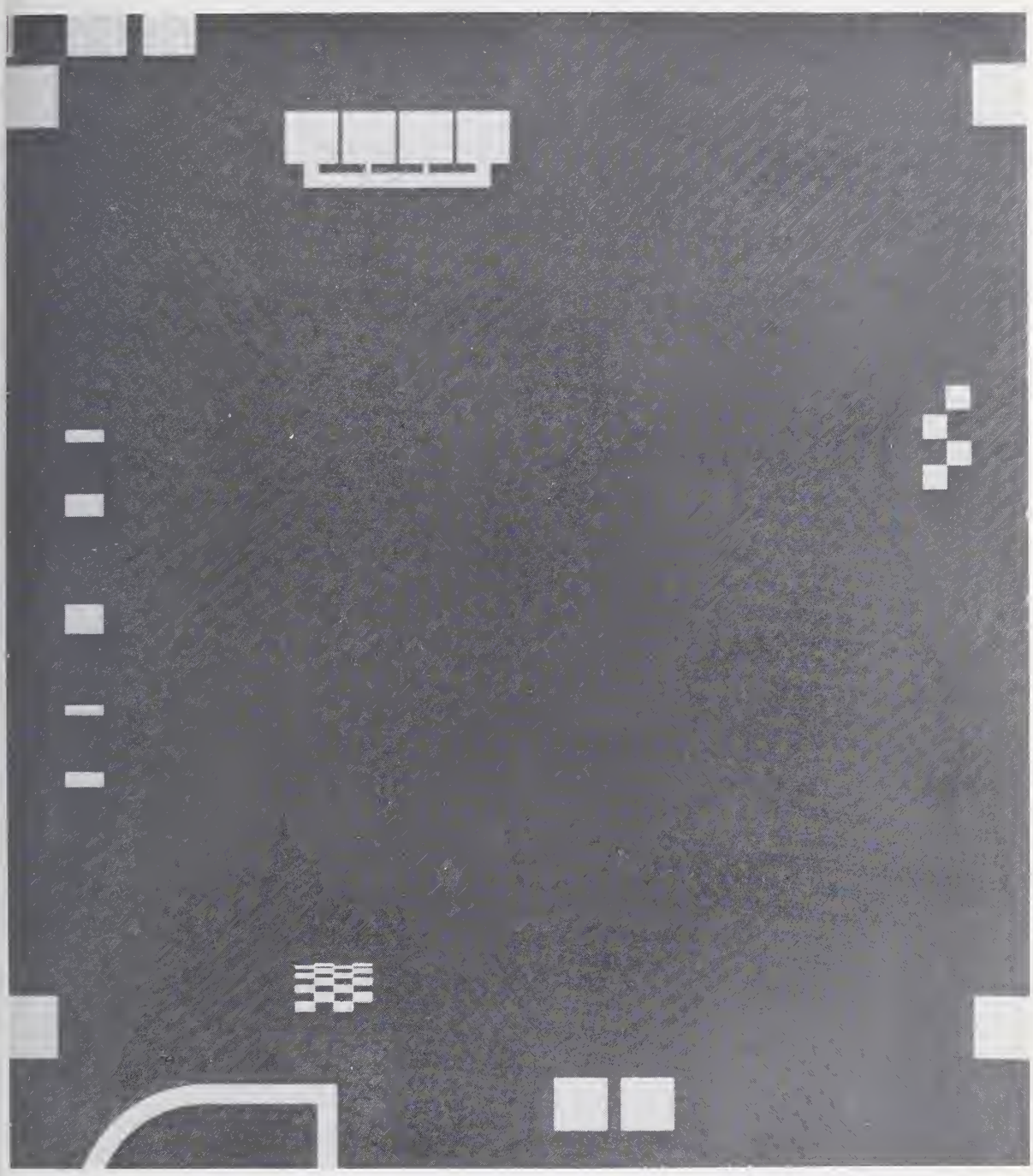


Figure 27. EMITTER mask for quadrant 4 of test pattern NBS-4. Test structures located in this quadrant are listed in table 5.

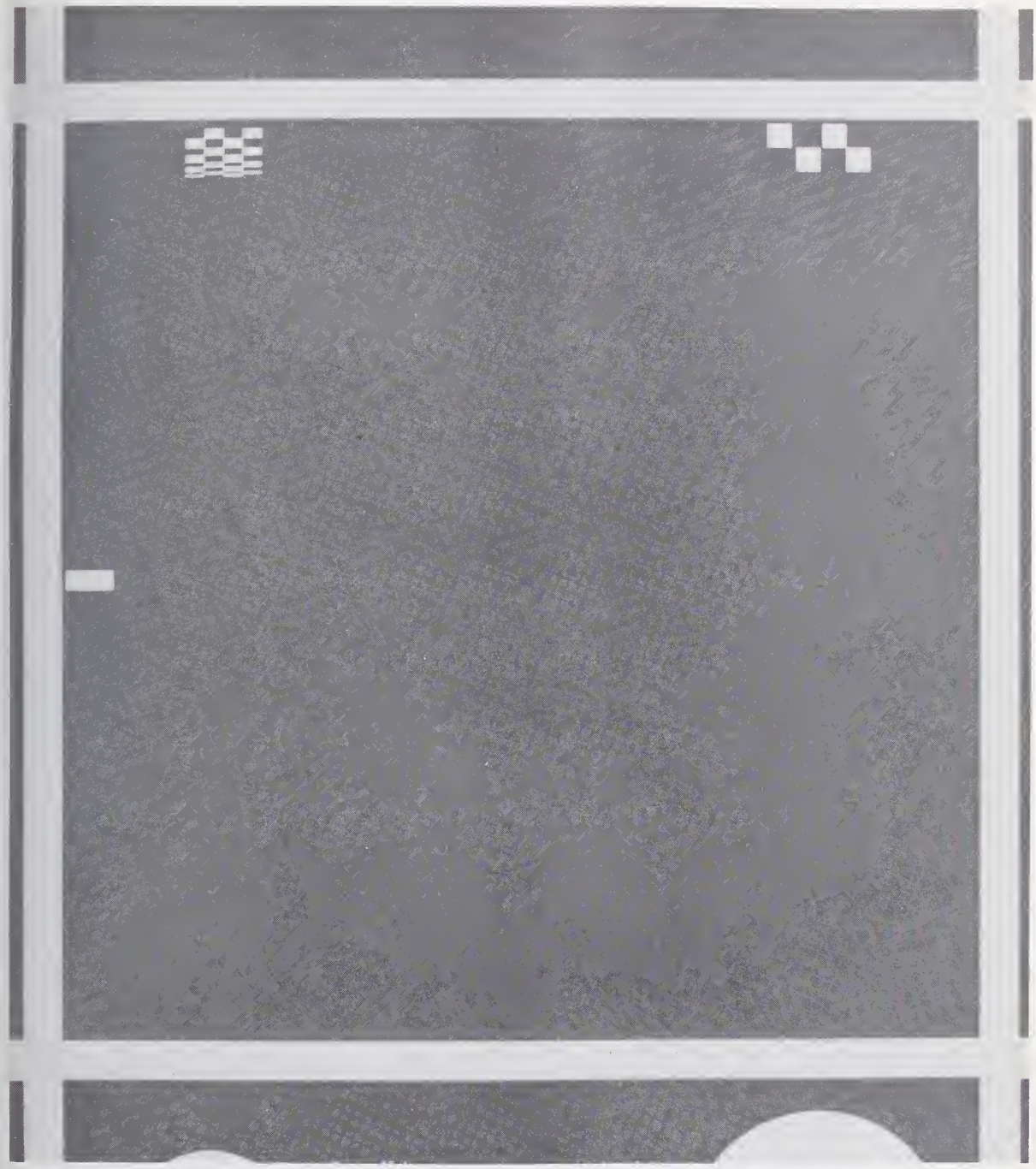


Figure 28. GATE mask for quadrant 4 of test pattern NBS-4. Test structures located in this quadrant are listed in table 5.

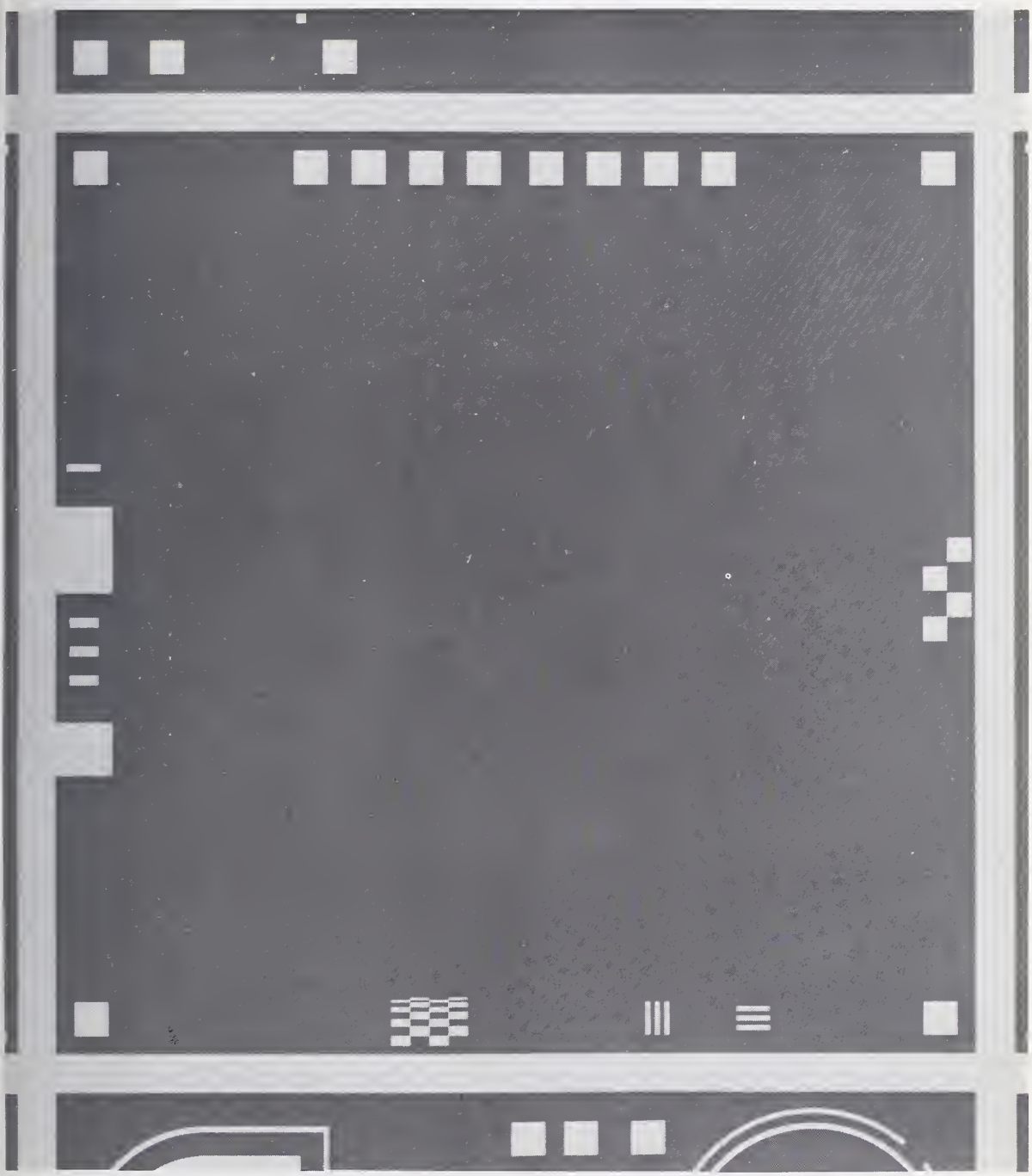


Figure 29. CONTACT mask for quadrant 4 of test pattern NBS-4. Test structures located in this quadrant are listed in table 5.

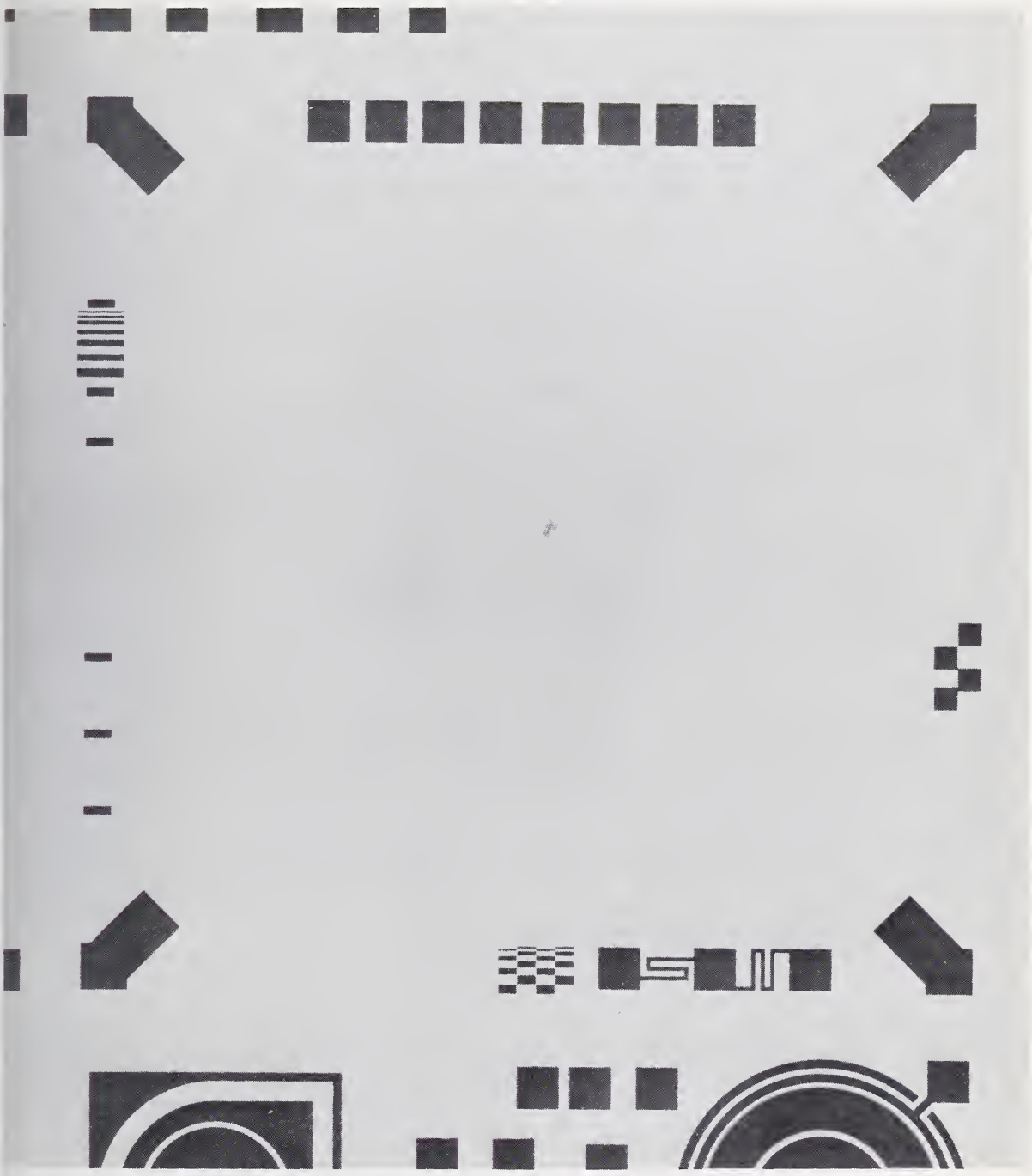


Figure 30. METAL mask for quadrant 4 of test pattern NBS-4. Test structures located in this quadrant are listed in table 5.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1978—261-238/56

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBS SP-400-32	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

Semiconductor Measurement Technology:
Microelectronic Test Pattern NBS-4

5. Publication Date: April 1978

6. Performing Organization Code

7. AUTHOR(S) W. Robert Thurber and Martin G. Buehler

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No. 4256372

11. Contract/Grant No. ARPA Order No. 2397

12. Sponsoring Organization Name and Complete Address (*Street, City, State, ZIP*)
ARPA - 1400 Wilson Blvd., Arlington, Virginia 22209
NBS - Washington, D. C. 20234

13. Type of Report & Period Covered: NBS Spec. Publ.

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

Library of Congress Catalog Card Number: 78-606024

16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

Microelectronic test pattern NBS-4 is a revision of test pattern NBS-3 which was designed primarily for evaluation of the resistivity-dopant density relationship in silicon. Major changes include the addition of optional BASE-CONTACT and GATE masks and the incorporation of several new structures, some useful for the resistivity-dopant density work, and others, mostly sheet resistors, included for evaluation of new designs.

The NBS-4 pattern contains 38 test structures such as planar four-probe resistors, sheet resistors, MOS capacitors, *p-n* junctions, bipolar and MOS transistors, Hall effect device, and process control structures. The overall pattern is a square 200 mil (5.08 mm) on a side and is divided into four quadrants which are separated by scribe lines. A detailed layout of each structure is presented including both a top view and a cross sectional view. Photomicrographs of each quadrant and the quadrants of the six masks used in the fabrication of the pattern are shown in an appendix.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)
Dopant density; microelectronics; MOS capacitors; *n-p-n* transistor fabrication; *p-n* junctions; resistivity; semiconductor electronics; sheet resistors; silicon; test pattern; test structures.

18. AVAILABILITY

[X] Unlimited

[ ] For Official Distribution. Do Not Release to NTIS

[X] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Stock No. SN003-003-

[ ] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
UNCLASSIFIED	66
20. SECURITY CLASS (THIS PAGE)	22. Price
UNCLASSIFIED	$2.75

USCOMM-DC 29042-P74

NBS TECHNICAL PUBLICATIONS

PERIODICALS

JOURNAL OF RESEARCH—The Journal of Research of the National Bureau of Standards reports NBS research and development in those disciplines of the physical and engineering sciences in which the Bureau is active. These include physics, chemistry, engineering, mathematics, and computer sciences. Papers cover a broad range of subjects, with major emphasis on measurement methodology, and the basic technology underlying standardization. Also included from time to time are survey articles on topics closely related to the Bureau's technical and scientific programs. As a special service to subscribers each issue contains complete citations to all recent NBS publications in NBS and non-NBS media. Issued six times a year. Annual subscription: domestic $17.00; foreign $21.25. Single copy, $3.00 domestic; $3.75 foreign.

Note: The Journal was formerly published in two sections: Section A "Physics and Chemistry" and Section B "Mathematical Sciences."

DIMENSIONS/NBS

This monthly magazine is published to inform scientists, engineers, businessmen, industry, teachers, students, and consumers of the latest advances in science and technology, with primary emphasis on the work at NBS. The magazine highlights and reviews such issues as energy research, fire protection, building technology, metric conversion, pollution abatement, health and safety, and consumer product performance. In addition, it reports the results of Bureau programs in measurement standards and techniques, properties of matter and materials, engineering standards and services, instrumentation, and automatic data processing.

Annual subscription: Domestic, $12.50; Foreign $15.65.

NONPERIODICALS

Monographs—Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

Handbooks—Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

Special Publications—Include proceedings of conferences sponsored by NBS, NBS annual reports, and other special publications appropriate to this grouping such as wall charts, pocket cards, and bibliographies.

Applied Mathematics Series—Mathematical tables, manuals, and studies of special interest to physicists, engineers, chemists, biologists, mathematicians, computer programmers, and others engaged in scientific and technical work.

National Standard Reference Data Series—Provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. Developed under a world-wide program coordinated by NBS. Program under authority of National Standard Data Act (Public Law 90-396).

NOTE: At present the principal publication outlet for these data is the Journal of Physical and Chemical Reference Data (JPCRD) published quarterly for NBS by the American Chemical Society (ACS) and the American Institute of Physics (AIP). Subscriptions, reprints, and supplements available from ACS, 1155 Sixteenth St. N.W., Wash., D.C. 20056.

Building Science Series—Disseminates technical information developed at the Bureau on building materials, components, systems, and whole structures. The series presents research results, test methods, and performance criteria related to the structural and environmental functions and the durability and safety characteristics of building elements and systems.

Technical Notes—Studies or reports which are complete in themselves but restrictive in their treatment of a subject. Analogous to monographs but not so comprehensive in scope or definitive in treatment of the subject area. Often serve as a vehicle for final reports of work performed at NBS under the sponsorship of other government agencies.

Voluntary Product Standards—Developed under procedures published by the Department of Commerce in Part 10, Title 15, of the Code of Federal Regulations. The purpose of the standards is to establish nationally recognized requirements for products, and to provide all concerned interests with a basis for common understanding of the characteristics of the products. NBS administers this program as a supplement to the activities of the private sector standardizing organizations.

Consumer Information Series—Practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace.

Order **above** *NBS publications from: Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.*

Order **following** *NBS publications—NBSIR's and FIPS from the National Technical Information Services, Springfield, Va. 22161.*

Federal Information Processing Standards Publications (FIPS PUB)—Publications in this series collectively constitute the Federal Information Processing Standards Register. Register serves as the official source of information in the Federal Government regarding standards issued by NBS pursuant to the Federal Property and Administrative Services Act of 1949 as amended, Public Law 89-306 (79 Stat. 1127), and as implemented by Executive Order 11717 (38 FR 12315, dated May 11, 1973) and Part 6 of Title 15 CFR (Code of Federal Regulations).

NBS Interagency Reports (NBSIR)—A special series of interim or final reports on work performed by NBS for outside sponsors (both government and non-government). In general, initial distribution is handled by the sponsor; public distribution is by the National Technical Information Services (Springfield, Va. 22161) in paper copy or microfiche form.

BIBLIOGRAPHIC SUBSCRIPTION SERVICES

The following current-awareness and literature-survey bibliographies are issued periodically by the Bureau:

Cryogenic Data Center Current Awareness Service. A literature survey issued biweekly. Annual subscription: Domestic, $25.00; Foreign, $30.00.

Liquified Natural Gas. A literature survey issued quarterly. Annual subscription: $20.00.

Superconducting Devices and Materials. A literature survey issued quarterly. Annual subscription: $30.00. Send subscription orders and remittances for the preceding bibliographic services to National Bureau of Standards, Cryogenic Data Center (275.02) Boulder, Colorado 80302.

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

OFFICIAL BUSINESS

Penalty for Private Use, $300

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE
COM-215

SPECIAL FOURTH-CLASS RATE
BOOK