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A BIBLIOGRAPHY OF THE NIST OPTOELECTRONICS DIVISION

Edited by
Annie J. Smith
Linda S. Derr

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Optoelectronics Division
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National Institute of Standards and Technology
Boulder, Colorado 80303-3328

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U.S. DEPARTMENT OF COMMERCE, Ronald H. Brown, Secretary
TECHNOLOGY ADMINISTRATION, Mary L. Good, Under Secretary for Technology
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Annie J. Smith and Linda S. Derr, Editors

INTRODUCTION

Gordon W. Day

The Optoelectronics Division was established in 1994 to provide the optoelectronics industry and its suppliers and customers with comprehensive and technically advanced measurement capabilities, standards, and traceability to those standards. The Division's roots extend to the first NIST (National Bureau of Standards) work on optoelectronics—research begun in the early 1960s to develop techniques for measuring the output power or energy of a laser.

The Division has strong ties to industry, academe, and other government laboratories. Through its predecessor organizations, it has been providing measurement services for the characterization of lasers and detectors since 1967 and each year conducts more that 150 calibrations for about 50 customers. Increasingly, these are related to the measurement of power in optical fiber systems. Division staff members represent NIST to the major domestic and international standards organizations active in optoelectronics—the Telecommunications Industry Association (TIA), the International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO), and the American National Standards Institute (ANSI)—and provide impartial technical expertise in their negotiations. The Division typically has 5 to 7 active Cooperative Research and Development Agreements (CRADAs) with companies and universities, and is involved in 20 to 30 additional informal collaborations each year. The Division offers the optoelectronics community an annual short course on laser measurements and biennially organizes a major international conference on optoelectronic measurements, the *Symposium on Optical Fiber Measurements*.

The Division is organized into four groups: the Sources and Detectors Group, the Fiber and Integrated Optics Group, the Optical Components Group, and the Optoelectronic Manufacturing Group, which work in six project areas, as follows:

Source and Detector Measurements
Accurate characterization of optoelectronic sources and detectors is crucial to the effective development and use of industrial technologies such as lightwave telecommunications, laser-based medical instrumentation, materials processing, photolithography, data storage, and laser safety equipment. NIST develops standards and provides measurement services for selected critical parameters intrinsic to optoelectronic sources and detectors, and for the calibration of optical fiber power meters and laser power/energy meters at commonly used wavelengths and powers. In addition, special test measurements are available for frequency response, impulse response, linearity, spectral responsivity, and spatial uniformity of optical power meters and

detectors. In support of source characterization, NIST develops measurement methods to evaluate and reduce laser intensity noise. Beam intensity profile and propagation measurement techniques are developed and evaluated. NIST participates in national and international standards committees that are developing standards for laser safety, laser radiation measurements (such as beam profile and pointing stability), and measurements related to optical power. NIST continues to extend and improve source and detector characterizations, including development of low noise, spectrally flat, highly uniform pyroelectric detectors, and tunable-wavelength optical-fiber power measurement systems.

Fiber and Integrated Optics

Optical fibers have largely replaced coaxial cable in long-distance telecommunications systems and are rapidly being installed in local-area applications. Optical waveguides in planar geometries, often called integrated optics, are increasingly used in communications and other optoelectronic systems. NIST staff interact with industry groups to develop measurement methods and reference standards for the characterization of these components. The joining of optical fibers requires the fiber to have accurately controlled dimensions. NIST-developed standard reference materials for cladding diameter allow manufacturers to calibrate instrumentation used in manufacturing and quality control; geometrical standards for fiber coatings and connector ferrules are being developed as well. Dispersion, the variation of propagation velocity with wavelength or polarization, sets the limit to the rate at which information can be transmitted; measurement methods and standards for both chromatic dispersion and polarization-mode dispersion are currently under development. The development of optical amplifiers has brought revolutionary changes to the design of communications; these new components require special methods of characterization now in development. Nonlinear properties of fiber, such as four-wave mixing and soliton effects, have been studied and applied to instrumentation. Novel implementations of reflectometry in fiber (OTDR) are also being studied.

Optical Fiber Sensors

Optical fiber sensors bring to metrology the same advantages that optical fibers provide to communications. The most important of these is that they are not electrical and, therefore, suffer less from electrical interference than many other sensors. NIST supports the industry broadly by providing measurements and standards for the characterization of optical materials and components used in sensors. It also develops and evaluates new sensor technology, primarily for other government laboratories. Much of its work is on sensors for electromagnetic quantities: electric current, voltage, and electric and magnetic fields.

Fiber and Discrete Components

Advanced optical communications systems use many different types of components to control and modify propagating signals. NIST develops the measurement technology to characterize these components and understand their limits. Fiber-coupled components such as optical isolators, wavelength division multiplexers, and fiber amplifiers have recently been installed in advanced optical communication systems. Future systems will likely incorporate recently developed components such as devices containing fiber gratings. Standards and characterization of these components are needed in order to evaluate the device's reliability and maintain the specifications required by new systems. Polarization-dependent loss (PDL) and polarization-dependent gain in components affect a system's performance, especially when there are many components in the system. Commercial instruments are available for measuring PDL and require NIST-developed calibration standards. Photo-induced Bragg gratings in optical fiber are likely to be incorporated in fiber lasers, dispersion compensators, and bandpass filters; NIST evaluates the long-term stability of these fiber gratings. Wavelength dependence of components will be important when wavelength division multiplexing is implemented. Wavelength standards are needed to calibrate instruments which will be used to characterize the wavelength dependence of these components.

Dielectric Materials and Devices

NIST is developing measurement methods and acquiring critical materials data to improve the manufacturing of dielectric optical devices. Of current concern are the ferroelectric materials lithium niobate and lithium tantalate, used in optical waveguide modulators, switches, and micro-lasers, and the glasses used in waveguide splitters, couplers, lasers, and optical amplifiers. NIST researchers are measuring the compositional uniformity of substrate material and deposited layers. Rapid, nondestructive testing of uniformity across a wafer, or from wafer to wafer, aids substrate and device manufacturers in processing decisions which increase device yield. In collaboration with industry, NIST is improving methods for the manufacture of compact, rare-earth-doped waveguide lasers and amplifiers. Measurements of dopant diffusion and solubility in substrate material, and the absorption and emission spectra of doped waveguides, are combined with computer models to characterize the influence of glass chemistry, ferroelectric domain-reversed regions, and other critical parameters. NIST's measurements of noise figure and cross-talk in waveguide amplifiers are valuable input to telecommunication system designers. Grating-based integrated optical components are gaining importance for wavelength division multiplexing, dispersion compensation, single-frequency lasers, and optical sensors. NIST scientists are studying the processing and metrology issues which lead to compact, robust devices having high efficiency.

Semiconductor Materials and Devices

The commercial success of semiconductor optoelectronic devices in an ever-widening array of applications (telecommunications, computer interconnection, data storage, display, printing, and sensor systems) requires low-cost manufacturing. NIST scientists develop measurement tools suitable for critical manufacturing stages of compound semiconductor light-emitting diodes, diode lasers, detectors, and modulators. To improve wafer yield, NIST is studying optical methods for the in-process monitoring and control of semiconductor layer deposition. The operation of optoelectronic devices depends critically on the thickness and compositional uniformity of epitaxial layers. NIST researchers use computer simulations and the correlation of data from several techniques–x-ray diffraction, transmission electron microscopy, reflectance spectroscopy, and photoluminescence spectroscopy–to improve the measurement accuracy. Test structures and novel measurement techniques have been developed to precisely measure optical constants, defect diffusion, and quantum micro-cavity effects. Researchers fabricate semiconductor quantum well devices for use in optical metrology and sensing. In support of next-generation optical interconnection, display, and data storage products, NIST scientists are measuring the properties of arrayed surface-emitting lasers.

Publications

This bibliography provides one means of access to the work of the division. It includes most of the papers published by the Division and its predecessor organization since 1970. A few important earlier papers and a few papers published by present NIST staff before they joined the Institute are included. The document is organized by subject, along the project lines defined above. It is updated annually. Before this year, publications listed here were included in a similar document, "Metrology for Electromagnetic Technology: A Bibliography of NIST Publications."

Purchase Procedures

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Reprints of papers published in non-NIST media may be available in limited quantities from the authors.

A Note on Abbreviations

NOTE: On August 23, 1988, the National Bureau of Standards (NBS) became the National Institute of Standards and Technology (NIST); therefore, documents with either prefix are considered NIST publications.

Most readers are familiar with the commonly used abbreviations for the names of the professional journals that appear in this bibliography. Some publication series are peculiar to NIST and may call for explanation. They are:

NISTIR - NIST Interagency/Internal Report
NIST TN - NIST Technical Note
NIST SP - NIST Special Publication
NIST HB - NIST Handbook
NIST JRES - NIST Journal of Research
NIST MN - NIST Monograph

NBSIR - NBS Interagency/Internal Report
NBS TN - NBS Technical Note
NBS SP - NBS Special Publication
NBS HB - NBS Handbook
NBS JRES - NBS Journal of Research
NBS MN - NBS Monograph

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