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Electronics and Electrical Engineering Laboratory

J. M. Rohrbaugh
Compiler

Technical Progress Bulletin

97-4

Covering Laboratory Programs,
October to December 1997,
with 1998 EEEL Events Calendar

U.S. DEPARTMENT OF COMMERCE
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Electronics and Electrical Engineering Laboratory

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Electronics and Electrical
Engineering Laboratory
Semiconductor Electronics Division
Gaithersburg, MD 20899-0001

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U.S. DEPARTMENT OF COMMERCE
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ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY
TECHNICAL PROGRESS BULLETIN, May 1998 ISSUE

INTRODUCTION

This is the fifty-eighth issue of a publication providing information on the technical work of the National Institute of Standards and Technology Electronics and Electrical Engineering Laboratory (EEEL). This issue of the EEEL Technical Progress Bulletin covers the fourth quarter of calendar year 1997.

Organization of Bulletin: This issue contains abstracts for all relevant papers released for publication by NIST in the quarter and citations and abstracts for such papers published in the quarter. Entries are arranged by technical topic as identified in the Table of Contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication." This does not imply acceptance by any outside organization. Papers published in the quarter appear under the subheading "Recently Published." Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Laboratory conferences and workshops planned for calendar year 1998 and a list of sponsors of the work.

Electronics and Electrical Engineering Laboratory: EEEL programs provide national reference standards, measurement methods, supporting theory and data, and traceability to national standards. The metrological products of these programs aid economic growth by promoting equity and efficiency in the marketplace, by removing metrological barriers to improved productivity and innovation, by increasing U.S. competitiveness in international markets through facilitation of compliance with international agreements, and by providing technical bases for the development of voluntary standards for domestic and international trade. These metrological products also aid in the development of rational regulatory policy and promote efficient functioning of technical programs of the Government.

The work of the Laboratory is conducted by five technical research Divisions: the Semiconductor Electronics and the Electricity Divisions in Gaithersburg, Md., and the Electromagnetic Fields, Electromagnetic Technology, and the Optoelectronics Divisions in Boulder, Colo. The Office of Law Enforcement Standards conducts research and provides technical services to the U.S. Department of Justice and State and local governments, and other agencies in support of law enforcement activities. In addition, the Office of Microelectronics Programs (OMP) coordinates the growing number of semiconductor-related research activities at NIST. Reports of EEEL work funded through the OMP are included under the heading "Semiconductor Microelectronics."

Key contacts in the Laboratory are listed at the end of this publication; readers are encouraged to contact any of these individuals for further information. To request a subscription or for more information on the Bulletin, write to EEEL Technical Progress Bulletin, National Institute of Standards and Technology, Metrology Building, Room B-358, Gaithersburg, MD 20899 or call (301) 975-2220.

Laboratory Sponsors: The Laboratory Programs are sponsored by the National Institute of Standards and Technology and a number of other organizations, in both the Federal and private sectors; these are identified on page 24.

Note on Publication Lists: Publication lists covering the work of each division are guides to earlier as well as recent work. These lists are revised and reissued on an approximately annual basis and are available from the originating division. The current set is identified in the Additional Information section, page 22.

Certain commercial equipment, instruments, or materials are identified in this paper in order to specify adequately the experimental procedures. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Internet Access (World Wide Web): http://www.eeel.nist.gov

TO LEARN MORE ABOUT THE LABORATORY...

Two general documents are available that may be of interest. These are ***EEEL 1997 Technical Accomplishments, Advancing Metrology for Electrotechnology to Support the U.S. Economy*** and ***Measurements for Competitiveness in Electronics***. The first presents selected technical accomplishments of the Laboratory for the period October 1, 1996 through September 30, 1997. A brief indication of the nature of the technical achievement and the rationale for its undertaking are given for each example. The second identifies measurement needs for a number of technical areas and the general importance of measurements to competitiveness issues. The findings of each chapter dealing with an individual industry have been reviewed by members of that industry. A longer description of both documents follows:

EEEL 1997 Technical Accomplishments, Advancing Metrology for Electrotechnology to Support the U.S. Economy, NISTIR 6106 (December 1997).

The Electronics and Electrical Engineering Laboratory, working in concert with other NIST Laboratories, is providing measurement and other generic technology critical to the competitiveness of the U.S. electronics industry and the U.S. electricity-equipment industry. This report summarizes selected technical accomplishments and describes activities conducted by the Laboratory in FY 1997 in the field of semiconductors, magnetics, superconductors, low-frequency microwaves, lasers, optical fiber communications and sensors, video, power, electromagnetic compatibility, electronic data exchange, and national electrical standards. Also included is a profile of EEEL's organization, its customers, and the Laboratory's long-term goals.

EEEL is comprised of five technical divisions, Electricity and Semiconductor Electronics in Gaithersburg, Maryland, and Electromagnetic Fields, Electromagnetic Technology, and Optoelectronics in Boulder, Colorado. Through two offices, the Laboratory manages NIST-wide programs in microelectronics and law enforcement.
[Contact: JoAnne Surette, (301) 975-5267]

Measurements for Competitiveness in Electronics, NISTIR 4583 (April 1993).

Measurements for Competitiveness in Electronics identifies for selected technical areas the measurement needs that are most critical to U.S. competitiveness, that would have the highest economic impact if met, and that are the most difficult for the broad range of individual companies to address. The document has two primary purposes: (1) to show the close relationship between U.S. measurement infrastructure and U.S. competitiveness and show why improved measurement capability offers such high economic leverage, and (2) to provide a statement of the principal measurement needs affecting U.S. competitiveness for given technical areas, as the basis for a possible plan to meet those needs, should a decision be made to pursue this course.

The first three chapters, introductory in nature, cover the areas of: the role of measurements in competitiveness, NIST's role in measurements, and an overview of U.S. electronics and electrical-equipment industries. The remaining nine chapters address individual fields of electronic technology: semiconductors, magnetics, superconductors, microwaves, lasers, optical-fiber communications, optical-fiber sensors, video, and electromagnetic compatibility. Each of these nine chapters contains four basic types of information: technology review, world markets and U.S. competitiveness, goals of U.S. industry for competitiveness, and measurement needs. Three appendices provide definitions of the U.S. electronics and electrical-equipment industries.
[Contact: Ronald M. Powell, (301) 975-2220]

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FUNDAMENTAL ELECTRICAL MEASURMENTS

Released for Publication

Cage, M. E., Jeffery, A., and Elmquist, R.E., **Suggested Triple-Series Connection Measurement Tests of the AC Quantized Hall Resistance and the AC Longitudinal Resistance**, to be published in the Digest of the 1998 Conference on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998.

Based on equivalent circuit calculations, a single ac ratio bridge can be used to accurately determine the ac quantized Hall resistance to provide an independent value of the ac-longitudinal resistance by making quantized Hall resistance measurements for two different combinations of triple-series connections to a standards-quality quantum Hall device.
[Contact: Marvin E. Cage, (301) 975-4224]

Elmquist, R.E., **Cryogenic Current Comparator Measurements at 77 K Using Thallium-2223 Thin-Film Shields**, to be published in the Digest of the 1998 Conference on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998.

This paper describes resistance ratio measurements using cryogenic current comparator (CCC) devices that operate at 77 K. The magnetic shields are Thallium-based thick films on MgO substrates. The effectiveness of three shield geometries is determined using one-to-one and ten-to-one winding ratios.
[Contact: Randloph E. Elmquist, (301) 975-6591]

Jeffery, A.M., Lee, L.H., and Shields, J.Q., **Model Tests to Investigate the Effects of Geometrical Imperfections on the NIST Calculable Capacitor**, to be published in the Digest of the 1998 Conference on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998.

A calculable capacitor links the U.S. capacitance unit to the SI unit and has a relative standard uncertainty of 2×10^{-8}. Geometrical imperfections are one of the largest sources of this uncertainty. Tests with a model calculable capacitor have been done to better evaluate and reduce this uncertainty.
[Contact: Anne-Marie Jeffery, (301) 975-4246]

Lee, K.C., **Dependence of Contact Resistance on Current for Good and Bad Ohmic Contacts to Quantized Hall Resistors**, to be published in the Digest of the 1998 Conference on Precision Electromagnetic Measurements, Washington, DC , July 6-10, 1998.

Dependence of contact resistance on current has been measured for a large number of ohmic contacts to quantized Hall resistors under quantum Hall effect conditions. A definite trend is observed in the current dependences of resistances of good and bad contacts, regardless of the physical cause of the poor contact.
[Contact: Kevin C. Lee, (301) 975-4236]

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Recently Published

Benz, S.P., Hamilton, C.A., Burroughs, C.J., Harvey, T.E., and Christian, L.A., **Stable 1 Volt Programmable Voltage Standard**, Applied Physics Letters, Vol. 71, No. 13, pp. 1866-1868 (29 September 1997).

Several fully functional programmable voltage standard chips, each having a total of 32 768 Nb-PdAu-Nb Josephson junctions, have been fabricated and tested. The chips are based on a new design that provides fast programmability (1 μs) between voltages and stable voltage operation from -1 to +1 V. A comparison of the new standard with a conventional Josephson voltage standard is in agreement to 0.5 ± 1.1 parts in 10^9. We demonstrate the utility of this standard by measuring the linearity of a digital voltmeter.
[Contact: Samuel P. Benz, (303) 497-5258]

SEMICONDUCTOR MICROELECTRONICS

Compound Materials

Released for Publication

Bennett, H.S., **High Dopant and Carrier Concentration Effects in Gallium Aluminum Arsenide: Band Structure, Effective Carrier Concentrations, and Mobilities**, to be published in the Proceedings of the International Conference on Surfaces and Interfaces of Mesoscopic Devices, Maui, Hawaii, December 8-13, 1997.

A common critical need identified in the technology roadmaps from the Optoelectronics Industry

Development Association and the National Electronics Manufacturing Initiative is the need for predictive computer simulations of processes, devices, and circuits. The goal of this paper is to respond to this need by calculating self-consistently from one quantum mechanical theory band gap changes, distorted densities of states for the carriers, and effective carrier concentrations for $Ga_{1-y}Al_yAs$. These calculations and the recently reported majority and minority electron and hole mobilities now give together an internally self-consistent description of carrier transport in $GaAs/Ga_{1-y}Al_yAs$ heterostructures based on first-principles with no fitting parameters to experimental measurements. This new self-consistent description of carrier transport across heterostructure interfaces will reduce the number of unknown or variational parameters in simulators for heterostructures and should lead to improved predictive capabilities for III-V device simulators. Even though this paper reports on the GaAs/-$Ga_{1-y}Al_yAs$ system at 300 K, other ternary or elemental semiconductors may be treated by the same theory. Also, the theory and models summarized here are valid for temperatures other than 300 K.
[Contact: Herbert S. Bennett, (301) 975-2079]

DiCamillo, B.A., Nguyen, N.V., Monk, D.H., Tietjen, M.E., and Pellegrino, J.G., **Analysis of an AlGaAs Heterostructure: SE versus RHEED**.

[See Analysis and characterization Techniques.]

Compound Materials

Recently Published

Amirtharaj, P.M., and Burnett, J., **Optical Properties of Mercury Cadium Telluride**, Book Chapter in Narrow-Gap II-VI Compounds for Opto-Electronic and Electro-Magnetic Applications, P. Capper, Ed. (Chapman and Hall, London, 1997), pp. 133-179.

The optical properties of mercury cadmium telluride are reviewed. The goals of this review are: (1) to present an overview of the optical properties of the narrow-gap alloy MCT in the spectral region extending from 6 eV, in the ultraviolet, to 1 meV in the far infrared. The chosen spectral region spans in decreasing order with energy, interbandelectronic transitions including direct transitions across the forbidden gap, phonons (lattice excitations), and plasmons (collective charge oscillations); and (2) to provide a detailed review of the near band-edge optical behavior of HgTe-CdTe superlattices. Near band-edge optical response in the narrow-gap region extending from 0 eV to ~0.3 eV, the range of interest for infrared detector applications, are emphasized. The basic principles of interaction of light with the crystal are discussed, and illustrative examples are provided. References are made to earlier reviews, and important papers in the published literature.
[Contact: Paul M. Amirtharaj, (301) 975-5974]

Kim, J.S., Lowney, J.R., and Thurber, W.R., **Transport Properties of Narrow-Gap II-VI Compound Semiconductors**, Book Chapter in Narrow-Gap II-VI Compounds for Opto-Electronic and Electro-Magnetic Applications, P. Capper, Ed. (Chapman and Hall, London, 1997), pp. 180-210.

The present understanding of the transport properties and their specific measurement methodologies in narrow-gap semiconductors, mainly the HgCdTe ternary system, are overviewed. Because of the importance of the multicarrier approach to the electrical characterization of advanced semiconductor materials, structures, or devices, the reduced-conductivity-tensor (RCT) scheme of multicarrier analysis is discussed in detail. Selected RCT data and their implications are also presented. The two-terminal magnetoresistance and high-magnetic-field measurement methods are also discussed.
[Contact: Jin S. Kim, (301) 975-2238]

Woicik, J.C., Pellegrino, J.G., Steiner, B., Miyano, K.E., Bompadre, S.G., Sorensen, L.B., Lee, T.-L., and Khalid, S., **Bond-Length Distortions in Strained Semiconductor Alloys**, Physical Review Letters, Vol. 79, No. 25, pp. 5026-5029 (22 December 1997).

Extended X-ray absorption fine structure measurements performed at In-*K* edge have resolved the outstanding issue of bond-length strain in semiconductor-alloy heterostructures. We determine the In-As bond length to be 2.581 ± 0.004 Å in a buried, 213 Å thick $Ga_{0.78}In_{0.22}As$ layer grown coherently on GaAs (00l). This bond length corresponds to a strain-induced contraction of 0.015 ± 0.004 Å relative to the In-As bond length in bulk $Ga_{1-x}In_xAs$ of the same composition; it is consistent with a simple model which assumes a uniform bond-length distortion in the epilayer despite the inequivalent In-As and Ga-As bond lengths.
[Contact: Joseph G. Pellegrino, (301) 975-2123]

Analysis and Characterization Techniques

Released for Publication

DiCamillo, B.A., Nguyen, N.V., Monk, D.H., Tietjen, M.E., and Pellegrino, J.G., **Analysis of an AlGaAs Heterostructure: SE versus RHEED**.

The correlation between in-situ spectroscopic ellipsometry (SE) and reflection high-energy electron diffraction (RHEED) data in a molecular beam epitaxy (MBE) environment is presented. The comparison of an optical-based probe with an electron-based probe for in-situ growth monitoring is examined. An AlGaAs sample was examined in-situ with SE. The modeled Al composition and thickness were 31.5% ± 1.7% and 2016.4 Å ± 4.7 Å, respectively. The corresponding values from RHEED are 29.4% ± 0.9% and 2017.9 Å ± 7.2 Å. Our measurements indicate that RHEED and in-situ ellipsometric measurements differ from the nominal 30% Al composition by -0.6% and 1.5%, respectively, and from the nominal 2000 Å thickness by 17.9 Å and 16.4 Å, respectively. The most important consequence of this study on the comparison of RHEED and SE is that although both techniques are capable of measuring the composition and thickness equivalently, the SE technique is capable of real-time monitoring during rotation provided the angle of incidence can be measured accurately and limits on the thickness and composition are provided for the modeling.

The angle of incidence can be measured accurately, and limits on the thickness and composition are provided for the modeling. The angle of incidence and sample manipulator profoundly impact quantitative in-situ SE measurements, the latter by virtue of the fact that wobble on the manipulator affects the angle of incidence. Data from the AlGaAs sample were modeled over a range of incident angles between 76.20° and 76.45° to determine how the accuracy of the angle of incidence used in modeling affects the quantitative determination of Al composition and AlGaAs thickness. A variation of 0.01° in the above range of angles of incidence shifts the Al composition and AlGaAs thickness by 0.29% and 1.4 Å, respectively, for an AlGaAs heterostructure with a nominal composition and thickness of 30% and 2000 Å, respectively.
[Contact: Barbara DiCamillo, (301) 975-3241]

Kopanski, J.J., and Mayo, S., **Intermittent-Contact Scanning Capacitance Microscope for Lithographic Overlay Measurement**.

A new scanning capacitance microscope (SCM) mode was implemented by using an atomic force microscope (AFM) operated in intermittent contact and by measuring the tip-to-sample capacitance change at the tip vibration frequency. The intermittent-contact-mode SCM was able to image and determine the overlay separation of metal lines buried under an 1 µm thick, planarized dielectric layer. Modeling of the intermittent-contact SCM signal across buried metal lines was consistent with the experimental results. This hybrid intermittent-contact AFM and SCM has the potential to measure the lithographic overlay between metal lines located at consecutive levels beneath dielectric layers in an integrated circuit.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Analysis and Characterization Techniques

Recently Published

Kopanski, J.J., Marchiando, J.F., and Alvis, R., **Practical Metrology Aspects of Scanning Capacitance Microscopy for Silicon 2-D Dopant Profiling**, Proceedings of the Electrochemical Society Symposium on Diagnostic Techniques for Semiconductor Materials, and Devices, Electrochemical Society Spring Meeting, Montreal, Canada, May 4-9, 1997, pp. 102-113.

When operated under controlled conditions, the scanning capacitance microscope (SCM) can function as a practical and quantitative two-dimensional dopant profiling tool for silicon. An investigation of the SCM operating procedures and conditions necessary to produce SCM images that are readily amenable to quantitative interpretation is discussed. The data interpretation formalism and models used to rapidly convert SCM images to dopant profiles are described. SCM images of cross-sectioned p-n junctions are compared to model predictions.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Device Physics and Modeling

Released for Publication

Bennett, H.S., **High Dopant and Carrier Concentration Effects in Gallium Aluminum Arsenide: Band Structure, Effective Carrier Concentrations, and Mobilities**, to be published in

the Proceedings of the International Conference on Surfaces and Interfaces of Mesoscopic Devices, Maui, Hawaii, December 8-13, 1997.

[See Compound Materials.]

Cresswell, M.W., Allen, R.A., Guthrie, W.F., Ghoshtagore, R.N., Linholm, L.W., and Sniegowski, J.J., **Electrical Linewidth Test Structures Fabricated in Mono-Crystalline Films for Reference-Material Applications**.

[See Integrated-Circuit Test Structues.]

Device Physics and Modeling

Recently Published

Adams, V.H., Blackburn, D.L., Joshi, Y.K., and Berning, D.W., **Issues in Validating Package Compact Thermal Models for Natural Convection Cooled Electronic Systems**, IEEE Transactions on Components, Packaging, and Manufacturing Technology, Vol. 20., No. 4, pp. 420-431 (December 1997).

A methodology is proposed for the validation of compact thermal models of electronic packages which utilizes data and simulations obtained from a simple, but realistic system containing the package. The test system used to demonstrate the methodology is the enclosure specified by the Electronic Industries Association JEDEC Subcommittee JC15.1 for thermal measurements in a natural convection environment. Simulations for a detailed model and several different compact models for a 88-pin plastic quad flat-package in the enclosure are in good agreement with experimental measurements of junction temperature. The study shows that the system must be well characterized, including accurate knowledge of circuit board thermal conductivity and accurate simulation of radiation heat transfer, to serve for validation purposes. For the package used in this study, system level considerations can outweigh package level considerations for predicting junction temperature. Given that the system is accurately modeled, the JEDEC enclosure can serve as a viable experimental validation tool for compact models.
[Contact: David L. Blackburn, (301) 975-2068]

Adams, V.H., Joshi, Y., and Blackburn, D.L., **Application of Compact Model Methodologies to Natural Convection Cooling of an Array of Electric Packages in a Low Profile Enclosure**, Proceedings of the Pacific Rim/ADME International Intersociety electronic and Photonic Packaging Conference, Kohala Coast, Hawaii, June 15-19, 1997.

Accurate prediction of electronic component junction temperature is necessary to allow for adequate reliability and performance analysis in the design process. Compact modeling of the electronic components within a computational fluid dynamics (CFD) simulation of the system may be a viable method to meet this requirement. Two compact modeling methods, a simple block model and a thermal resistance model, and a physically accurate detailed model are applied to a narrow-aspect-ratio, horizontal enclosure containing a three-by-three array of plastic quad flat packages cooled by natural convection in air. Three-dimensional steady-state calculations are carried out to investigate the coupled conduction, natural convection, and thermal radiation resulting from variable power input to the nine packages. The study focuses on a comparison of the two compact modeling strategies and the detailed model in a CFD simulation with experimental results for the same system geometry. Results show that system level considerations, including thermal radiation, dominate the accurate prediction of device junction temperatures. Since internal component level effects are small, either of the models is adequate to predict junction temperatures. Board-level parameters such as effective board thermal conductivity, total thermal loading and spatial distribution of board power also have a significant effect on device junction temperature.
[Contact: David L. Blackburn, (301) 975-2068]

Williams, P.A., Rose, A.H., and Wang, C.M., **Rotating-Polarizer for Accurate Retardance Measurement**, Applied Optics, Vol. 36, No. 25, pp. 6466-6472 (1 September 1997).

We demonstrate an automated polarimeter based on a rotating polarizer for the measurement of linear retardance independent of laser power and detector gain. The retardance is found when a curve is fitted to a unique normalization of the intensity response of the polarimeter over a range of input polarizer orientations. The performance of this polarimeter is optimal for measurements of quarter-wave retardance and minimal for half-wave retardance. Uncertainties are demonstrated by measurements on six stable

double Fresnel rhombs of nominal quarter-wave retardance, yielding expanded uncertainties between 0.031° and 0.67°. The accuracy has also been verified by blind comparisons with interferometric and modified null retardance measurement techniques.
[Contact: Paul A. Williams, (303) 497-3805]

Insulators and Interfaces

Recently Published

Nguyen, N.V., and Richter, C.A., **Thickness Determination of Ultra-Thin SiO_2 Films on Si by Spectroscopic Ellipsometry**, Proceedings of the Electrochemical Society 191st Meeting, Fourth International Symposium on Silicon Nitride and Silicon Dioxide Thin Insulating Films, Montreal, Canada, May 4-9, 1997, pp. 183-193.

For ultra-thin SiO_2 films with thicknesses less than 100 Å on Si, the accurate determination of the thickness and the index of refraction is a technologically important issue because of the strict tolerances required for the fabrication of sub-micrometer integrated circuit (IC) devices. Ellipsometry is traditionally and commonly employed to determine these quantities. In this study, we use spectroscopic ellipsometry (SE), to measure a set of device quality SiO_2 films ranging from 45 Å to 2000 Å in thickness. We demonstrate that a variety of models for the oxide index of refraction together with different sets of the silicon substrate dielectric functions fit the measured SE data comparably well. We show, however, that the resulting variations (relative error) in derived thickness and refractive index of oxide films thinner that 100 Å can be as large as 23% and 13%, respectively.
[Contact: Nhan Van Nguyen, (301) 975-2044]

Integrated-Circuits Test Structures

Released for Publication

Cresswell, M.W., Allen, R.A., Guthrie, W.F., Ghoshtagore, R.N., Linholm, L.W., and Sniegowski, J.J., **Electrical Linewidth Test Structures Fabricated in Mono-Crystalline Films for Reference-Material Applications**.

The physical widths of reference features incorporated into electrical linewidth test structures patterned in films of mono-crystalline silicon have been determined from Kelvin voltage measurements. The films in which the test structures are patterned are electrically insulated from the bulk-silicon substrate by a layer of silicon dioxide provided by SIMOX (Separation by the IMplantation of OXygen) processing. The motivation is to facilitate the development of linewidth reference materials for Critical-Dimension (CD) metrology-instrument calibration. Appropriate selection of the orientation of the starting silicon, and the orientation of the structures' features relative to the crystal lattice, enables a lattice-plane-selective etch to generate reference-feature properties of rectangular cross section and atomically planar sidewalls. These properties are highly desirable for CD applications in which feature widths are certified with nanometer-level uncertainty for use by a diverse range of CD instruments. End applications include the development and calibration of new generations of CD instruments directed at controlling processes for manufacturing devices having sub-quarter-micrometer features.
[Contact: Michael W. Cresswell, (301) 975-2072]

Schafft, H.A., **Reliability Test Chips: NIST 33 & NIST 34 for JEDEC Inter-Laboratory Experiments and More**, to be published in the Proceedings of the 1997 IEEE International Integrated Reliability Workshop Final Report, Lake Tahoe, California, October 13-16, 1997.

[See Reliability.]

Microfabrication Technology

Released for Publication

Morillo, J., Su, Q., Panchapakesan, B., Wuttig, M., and Novotny, D.B., **Micromachined Silicon Torsional Resonator for Magnetic Anisotropy Measurement**.

[See Magnetic Materials and Measurements.]

Johnson, R.B., Chung, R., and Gaitan, M., **Real-Time Thermal Infrared Scene Generation Technology and Its Application in the Test and Calibration of Infrared Sensors and Seekers**, Proceedings of the 1996 Digest of Papers Government Microcircuit Applications Conference, Orlando, Florida, March 18-21, 1996, pp. 145-148 (1997).

For over two decades, researchers have investigated a wide variety of technologies for use as a real-time infrared scene generator. During the past several years, the most promising technology to meet the myriad of applications appears to be the silicon micromachined resistive-array approach. Each thermal pixel is created by a micro-scale resistor. The present investigation reports the recent results achieved by using the standard commercial CMOS foundry process, rather than a costly custom fabrication process, to produce the chip and the subsequent post-foundry etching. Both chip-level and pixel-specific electronics are readily included on the chip since IC technology is employed.

The principles used in device architecture formulation, chip design, and fabrication of large arrays of these thermal pixels are discussed along with experimental results of recent array designs. The application of this technology in the development of a low-cost, real-time infrared test set for field evaluation of infrared sensors and seekers is presented to illustrate that low-cost, high-performance flat-panel thermal infrared displays are now viable and practicable.
[Contact: Michael Gaitan, (301) 975-2070]

Milanović, V., Gaitan, M., Bowen, E.D., and Zaghloul, M.E., **Micromachined Microwave Transmission Lines by Commercial CMOS Fabrication**, Proceedings of the 39th Midwest Syposium on Circuits and Systems, Ames, Iowa, August 18-21, 1997, pp. 1189-1192.

Coplanar waveguides were designed and fabricated in standard CMOS with post-processing micromachining. Transmission line layouts were designed with commercial CAD tools; ICs were fabricated through a commercial CMOS foundry, and subsequently suspended by maskless top-side etching. Absence of the lossy silicon substrate after etching results in significantly improved insertion loss and dispersion characteristics, and phase velocity. Two types of layout are presented for different ranges of characteristic impedance. Measurements were performed at frequencies from 1 GHz to 40 GHz before and after micromachining. These show improvement of loss characteristics of orders of magnitude. For the entire range of frequencies, for the 50 Ω layout, losses are as high as 38 dB/cm. Phase velocity in the micromachined transmission lines is close to that in free space.
[Contact: Michael Gaitan, (301) 975-2070]

Milanović, V., Gaitan, M., and Zaghloul, M.E., **Micromachined Thermocouple Microwave Detector in CMOS Technology**, Proceedings of the 39th Midwest Symposium on Circuits and Systems, Ames, Iowa, August 18-21, 1997, pp. 273-276.

This paper presents the design and testing of thermocouple microwave power detector fabricated through a commercial *n*-well CMOS foundry with an additional maskless etching procedure. The detector measures true rms power of signals in the frequency range from 50 MHz to 20 GHz and input power ranging from -30 dBm to +10 dBm. The device has linearity better than ±0.4% for output vs. input power over the 40 dB dynamic range. Measurements of the return loss, obtained using an automatic network analyzer, show an acceptable input return loss of less than - 20 dB over the entire frequency range. The sensitivity of the detector was measured to be (1.328 ± 0.004) mV/mW.
[Contact: Michael Gaitan, (301) 975-2070]

Pauza, A.J., Booij, W.E., Herrmann, K., Moore, D.F., Blamire, M.G., **Electron-Beam High-Temperature Superconductor Josephson Junctions**, Journal of Applied Physics, Vol. 82, No. 11, pp. 5612-5632 (1 December 1997).

[See Cryoelectronic Metrology.]

Tea, N.H., Milanović, V., Zincke, C.A., Suehle, J.S., Gaitan, M., and Geist, J., **Hybrid Postprocessing Etching for CMOS-Compatible MEMS**, Journal of Microelectromechanical Systems, Vol. 6, No. 4, pp. 363-372 (4 December 1997).

A major limitation in the fabrication of microstructures as a post-CMOS (complementary metal oxide semiconductor) process has been overcome by the development of a hybrid processing technique, which combines both an isotropic and anisotropic etch step. Using this hybrid technique, microelectromechanical structures with sizes ranging from 0.05 to ~1 mm in width and up to 6 mm in length were fabricated in CMOS technology. The mechanical robustness of the microstructures determines the limit on their dimensions. Examples of an application of this hybrid technique to produce microwave coplanar

transmission lines are presented. The performance of the micromachined microwave coplanar waveguides meets the design specifications of low loss, high-phase velocity, and 50 Ω characteristic impedance. Various commonly used etchants were investigated for topside maskless post-micromachining of (100) silicon wafers to obtain the microstructures. The isotropic etchant used is gas-phase xenon difluoride (XeF_2), while the wet anisotropic etchants are either ethylenediamine-pyrocatechol or tetramethylammonium hydroxide. The advantages and disadvantages of these etchants with respect to selectivity, reproducibility, handling, and process compatibility are also described.
[Contact: John S. Suehle, (301) 975-2247]

Plasma Processing

Released for Publication

Christophorou, L.G., and Olthoff, J.K., **Electron Interactions with Plasma Processing Gases: CF_4, CHF_3, C_2F_6, and C_3F_8**, to be published in the Proceedings of the 1998 Symposium on Atomic and Surface Physics and Related Topics, Going, Austria, January 15-30, 1998.

A review of our efforts to evaluate and assess electron interaction data for the plasma processing community is presented. Specifically, we present in this paper our recommended electron-interaction cross sections for CF_4, CHF_3, C_2F_6, and C_3F_8.
[Contact: Loucas G. Christophorou, (301) 975-2432]

Christophorou, L.G., Olthoff, J.K., and Green, D.S., **Gases for Electrical Insulation and Arc Interruption: Possible Present and Future Alternatives to Pure SF_6.**

The electric power industry's preferred gaseous dielectric (besides air), sulfur hexafluoride (SF_6) has been shown to be a greenhouse gas. In this report, we provide information that is useful in identifying possible replacement gases, in the event that replacement gases are deemed a reasonable approach to reducing the use of SF_6 in high-voltage electrical equipment. The report focuses on the properties of SF_6 as a dielectric gas and on the data available for possible alternatives to pure SF_6 (i.e., SF_6 alone). On the basis of published studies and consultation with experts in the field, we attempted to identify alternative dielectric gases to pure SF_6 for possible immediate or future use in existing or modified electrical equipment. The possible alternative gases are discussed as three separate groups: (I) mixtures of SF_6 and nitrogen for which a large amount of research results are available; (ii) gases and mixtures (e.g., pure N_2 low concentrations of SF_6 in N_2, and SF_6-He mixtures) for which a smaller yet significant amount of data are available; and (iii) potential gases for which little experimental data are available.
[Contact: Loucas L. Christophorou, (301) 975-2432]

Stricklett, K.L., Kassoff, J.M., Firebaugh, S., Olthoff, J.K., and Van Brunt, R.J., **Appearance Potentials of Ions Produced by Electron-Impact Induced Dissociative Ionization of SF_6, SF_4, SO_2, SOF_2, SO_2F_2, SOF_4, SF_5Cl, S_2F_{10} and $S_2O_2F_{10}$.**

[See Power Systems Metrology.]

Plasma Processing

Recently Published

Christophorou, L.G., Olthoff, J.K., and Wang, Y., **Electron Interactions with CCl_2F_2**, Journal of Physical and Chemical Reference Data, Vol. 26, No. 5, pp. 1205-1237 (1997).

In this article, available information on the cross sections and rate coefficients for collisional interactions of dichlorodifluoromethane (CCl_2F_2) with electrons is critically evaluated and synthesized. This gas has many industrial uses and is of atomospheric and environmental interest. The CCl_2F_2 molecule fragments rather extensively under electron impact, principally via dissociative ionization and dissociative attachment; the latter process is temperature dependent. Information is presented and discussed on: (1) electron scattering process (cross sections for total electron scattering, momentum transfer, differential elastic electron scattering, integral elastic electron scattering, and inelastic electron scattering for rotational and vibrational (direct and indirect) excitation); (2) electron impact ionization (cross sections for total, partial, and double ionization and coefficients for electron impact ionization); (3) electron attachment (electron attachment cross sections and rate constants and their energy and temperature dependencies, electron attachment coefficients, dissociative attachment fragment anions, and negative ion states); (4) optical emission under

electron impact; and (5) electron transport coefficients (electron drift velocity and ratio of transverse electron diffusion coefficient to electron mobility). Based upon the assessment of published experimental data, recommended values of various cross sections and rate coefficients are generated in graphical and tabular form. Areas where additional data are needed are identified, such as the measurement of the cross sections for momentum transfer and electron impact dissociation of CCl_2F_2 into neutral species.
[Contact: Loucas G. Christophorou, (301) 975-2432]

Han, X., and Wang, Y., **Characterization of Pulsating Partial Discharges in SF_6-N_2 Mixture**, Proceedings of the Conference on Electrical Insulation and Dielectric Phenomena, Minneapolis, Minnesota, October 19-22, 1997, pp. 538-541.

[See Power Systems Metrology.]

Wang, Y., **New Method for Measuring Statistical Distributions of Partial Discharge Pulses**, Journal of Research of the National Institute of Standards and Technology, Vol. 102, No. 5, pp. 569-576 (September-October 1997).

[See Power Systems Metrology.]

Photodetectors

Recently Published

Johnson, R.B., Chung, R., and Gaitan, M., **Real-Time Thermal Infrared Scene Generation Technology and Its Application in the Test and Calibration of Infrared Sensors and Seekers**, Digest of Papers of the Government Microcircuit Applications Conference, Orlando, Florida, March 18-21, 1996, pp 145-148 (1997).

[See Microfabrication Technology.]

Reliability

Released for Publication

Schafft, H.A., **Reliability Test Chips: NIST 33 & NIST 34 for JEDEC Inter-Laboratory Experiments and More**, to be published in the Final Report of the 1997 IEEE International Integrated Reliability Workshop, Lake Tahoe, California, October 13-16, 1997.

Two reliability test patterns, NIST 33 and NIST 34, are being designed, and a third, NIST 36, is being planned to be used in a number of inter-laboratory experiments as part of the activities of the Metal Reliability Task Group of the EIA/JEDEC Committee JC 14.2 on Wafer Level Reliability. These chips will also be used for other tasks, many of which will provide additional characterization data in support of the JEDEC inter-laboratory experiments.

The immediate use of NIST 33 is to perform inter-laboratory experiments to determine the within-laboratory and the between-laboratory precision of two JEDEC standard test methods: the isothermal test (JESD63) and the SWEAT test (JEP119). These experiments are intended also to determine the impact of modifications of the designs of test structures used in this electromigration accelerated stress tests. Supplemental to these experiments will be one to determine the precision of the ASTM standard electromigration stress test (F1260).
[Contact: Harry A. Schafft, (303) 975-2234]

SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

DC and Low-Frequency Metrology

Released for Publication

Chang, Y.M., and Tillett, S.B., **NIST Calibration Service for Capacitance Standards at Low Frequencies**, to be published as a NIST Special Publication.

This document describes the capacitance calibration service provided by NIST, including measurement procedures and systems used to calibrate capacitance standards of nominal values in the range of 0.001 pF to 1 μF, at frequencies up to 10 kHz. Discussed are the process to transfer the unit of capacitance from the NIST capacitance primary laboratory, which maintains the U.S. representation of the farad, traceable to the calculable capacitor, and the quality controls of reference standards and check standards in the calibration laboratory. Also included, are summaries of calibration uncertainties of capacitors of various dielectric materials, such as fused-silica, nitrogen, air, and mica.
[Contact: Y. May Chang, (301) 975-4237]

Dziuba, R.F., Jarrett, L.L., and Secula, A.J.,

Fabrication of High-Value Standard Resistors, to be published in the Digest of the 1998 Conference on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998.

The National Institute of Standards and Technology has fabricated stable, transportable 10 MΩ and 1 GΩ standard resistors for use in an international comparison of high resistances. This fabrication process is being applied to the construction of standard resistors of values up to 100 TΩ, with initial results indicating significant improvements in stability and fewer adverse effects induced by mechanical shock and vibration.
[Contact: Ronald F. Dziuba, (301) 975-4239]

Jarrett, D.G., **A Guarded Transfer Standard for High Resistance Measurements**, to be published in the Digest of the 1998 Conference on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998.

An improved design for a guarded transfer standard in the resistance range 1 MΩ to 100 GΩ is described. Existing transfer standards and limitations are reviewed. Interchangeable guard networks are used in the improved transfer standards to ensure complete guarding during all phases of the measurement process, thus reducing errors caused by leakages to ground.
[Contact: Dean G. Jarrett, (301) 975-4240]

DC and Low-Frequency Metrology

Recently Published

Boynton, P.A., Sims, J.E., and Dziuba, R.F., **NIST Measurement Assurance Program for Resistance**, NIST Technical Note 1424 (November 1997).

The National Institute of Standards and Technology offers resistance Measurement Assurance Program (MAP) transfers at the 1 Ω and 10 kΩ levels, to provide a method of assessing and maintaining the quality of a customer's measurement process. This document describes the basic concepts of a resistance MAP, and the procedures for participating in the program. A discussion of the data analysis follows, with an explanation of the uncertainty of the estimate of the transfer. Also included is a sample MAP scenario, with data sheets, analysis results, and a final test report.
[Contact: Paul A. Boynton, (301) 975-3014]

Souders, T.M., Waltrip, B.C., Laug, O.B., and Deyst, J.P., **A Wideband Sampling Voltmeter**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 4, pp. 947-953 (August 1997).

A high-accuracy sampling voltmeter, designed to span the frequency range of 10 Hz to 200 MHz, is described. The instrument operates autonomously, at a measurement update rate of at least one per second. A novel quasi equivalent time-sampling process is used, with a custom strobed comparator as the sampling device and decision element. The architecture and control are presented, along with the time-base design principles. Major error sources associated with the time-base are also discussed.
[Contact: John P. Deyst, (303) 497-2437]

Waveform Metrology

Released for Publication

Paulter, N.G., **The Effect of Histogram Size on Histogram-Derived Pulse Parameters**.

The effects of the number of histogram bins on histogram-derived pulse parameters of step-like waveforms are examined. An empirical method for selecting the optimal number of bins is described.
[Contact: Nicholas G. Paulter, (301) 975-2405]

Cryoelectronic Metrology

Recently Published

Benz, S.P., Hamilton, C.A., Burroughs, C.J., Harvey, T.E., and Christian, L.A., **Stable 1 Volt Programmable Voltage Standard**, Applied Physics Letters, Vol. 71, No. 13, pp. 1866-1868 (29 September 1997).

[See FUNDAMENTAL ELECTRICAL MEASUREMENTS.]

Pauza, A.J., Booij, W.E., Herrmann, K., Moore, D.F., and Blamire, M.G., **Electron-Beam High-Temperature Superconductor Josephson Junctions**, Journal of Applied Physics, Vol. 82, No. 11, pp. 5612-5632 (1 December 1997).

Results are presented on the fabrication and characterization of high critical temperature Josephson junctions in thin films of $YBa_2Cu_3O_{\delta-7}$ produced by the process of focused electron-beam irradiation using 350 keV electrons. The junctions so produced have uniform spatial current densities, can be described in terms of the resistive shunted junction model, and their current densities can be tailored for a given operating temperature. The physical properties of the damaged barrier can be described as a superconducting material of either reduced or zero critical temperature (T_c), which has a length of ~15 nm. The T_c reduction is caused primarily by oxygen Frenkel defects in the Cu–O planes. The large beam currents used in the fabrication of the junctions mean that the extent of the barrier is limited by the incident electron-beam diameter, rather than by scattering within the film. The properties of the barrier can be calculated using a superconductor-/normal/-superconductor (SNS) junction model with no boundary resistance. From the SNS model, we can predict the scaling of the critical current-resistance (I_cR_n) product and gain insight into the factors controlling the junction properties, T_c, and reproducibility. From the measured I_cR_n scaling data, we can predict the I_cR_n product of a junction at a given operating temperature with a given current density. I_cR_n products of ~2 mV can be achieved at 4.2 K. The reproducibility of several junctions in a number of samples can be characterized by the ratio of the maximum-to-minimum critical currents on the same substrate of less than 1.4. Stability over several months has been demonstrated at room and refrigerator temperatures (297 K and 281 K) for junctions that have been initially over damaged and then annealed at temperatures ~380 K. Junctions manufactured using conventional lithography (0.5 μm wide) and which are suitable for digital electronics (I_c = 500 μA at 40 K) can achieve I_cR_n products of 650 μV at 40 K. The production of 100 of these stabilized junctions could be accomplished in ~4 h of irradiation time. The I_cR_n scaling also indicates that junctions suitable for high sensitivity superconducting quantum interference devices (I_c ~100 μA) can be made with I_cR_n products of ~120 μV at 77 K.
[Contact: David A. Rudman, (303) 497-5081]

Antenna Metrology

Released for Publication

Stubenrauch, C.F., MacReynolds, K., Will, J.E., Norgard, J.D., Seifert, M., and Cormack, R.H., **Microwave Antenna Far-Field Patterns Determined from Infrared Holograms**, Proceedings of the 19th Meeting and Symposium of the Antenna Measurement Techniques Association, Boston, Massachusetts, November 17-21, 1997, pp. 125-130.

We describe a technique which uses field intensity patterns formed by the interference of an unknown test antenna and a known reference antenna - holograms in the classical optical sense - for determining the far-field pattern of the unknown antenna. The field intensity is measured by acquiring an infrared picture of the temperature distribution on a resistive screen heated by incident microwave energy. The output of the camera is processed to yield the electric field intensity on the surface of the resistive screen. Required measurements are the field patterns of the unknown antenna and two holograms taken with relative phase differences between the reference and unknown antennas of 0° and 90°. In addition, the amplitude and phase of the reference field at the measurement plane are needed. These can be obtained from a separate measurement of the reference using standard near-field techniques. The algorithm gives the complex near field of the antenna under test which can then be processed to obtain the far-field pattern of the antenna under test. We present results showing far-field patterns which acceptably reproduce the main beam and near sidelobes. Such techniques will allow rapid testing of certain antenna types.
[Contact: Carl F. Stubenrauch, (303) 497-3927]

Antenna Metrology

Recently Published

Francis, M.H., **Aperture-Sampling Requirements**, IEEE Antennas and Propagation Magazine, Vol. 39, No. 5, pp. 76-77 (October 1997).

This paper comments on and relates to the angle of coverage to the near-field sample spacing. However, if the near-field samples does not contain at least two samples per period for the fastest varying near-field, aliasing will occur. As a result, the periodically continued patterns begin to overlap, and the measured pattern between the near-field sampling and the maximum angle of coverage when we also require that the effect of aliasing be negligible.

[Contact: Michael H. Francis, (303) 497-5873]

Kent, B.M., and Muth, L., **Establishing a Common RCS Range Documentation Standard Based on ANSI/NCSL Z-540-1994-1 and ISO Guide 25**, Proceedings of the 19th Meeting and Symposium of the Antenna Measurement Techniques Association, Boston, Massachusetts, November 17-21, 1997, pp. 303-307.

This paper presents a brief overview of ANSI/NCSL standard Z-540. Z-540 offers a straightforward way to organize range documentation. We discuss the major points and sections of Z-540, and how to organize a format-universal "range book." Since Z-540 is the U.S. equivalent of International Standard (ISO) 25, it is especially useful for two reasons: (1) it is applicable to Radar Cross Section (RCS) ranges and (2) its quality control requirements are consistent with the ISO 9002 series of quality standards. Properly applied, Z-540 may greatly improve the quality and consistency of RCS measurements produced, and reported to range customers.
[Contact: Lorant T. Muth, (303) 497-3603]

Muth, L.A., Wittmann, R.C., and Kent, B.M., **Measurement Assurance and Certification of Radar Cross Section Measurements**, Proceedings of the National Conference of Standards Laboratories, Success in the 21st Century Depends on Modern Metrology, Atlanta, Georgia, July 27-31, 1997 (unpaged).

A standard for radar cross section (RCS) measurement assurance is being developed at the National Institute of Standards and Technology, and we discuss several aspects of its creation. Uniform technical criteria are required to sustain and improve measurement quality. Determination of significant sources of error and the quantitative assessment of measurement uncertainty are fundamentally important. A fully developed measurement assurance program (MAP) goes beyond technical range characterization issues. Addtional MAP features include range operations, interlaboratory comparisons, traceability, and documentation, to name a few. To ensure the RCS ranges operate in conformance with standards established and accepted by the RCS community, periodic reviews of range MAPs will be conducted by a certifying board composed of peers. Well-defined technical and managerial requirements must be satisfied for certificaiton to be granted.
[Contact: Lorant A. Muth, (303) 497-3603]

Skinner, J.P., Kent, B.M., Wittman, R.C., Mensa, D.L., and Andersh, D., **Radar Image Normalization and Interpretation**, Proceedings of the 19th Meeting and Symposium of the Antenna Measurement Techniques Association, Boston, Massachusetts, November 17-21, 1997, pp. 303-307.

Calibrated radar images are often quantified as radar cross section. This interpretation, which is not strictly correct, can lead to misunderstanding of test target scattering properties. To avoid confusion, we recommend that a term such as "scattering brightness" be adopted as a standard label for image-domain data.
[Contact: Ronald C. Wittman, (303) 497-3326]

Noise Metrology

Released for Publication

Randa, J., Billinger, R., and Rice, J., **On-Wafer Measurements of Noise Temperature**.

The NIST Noise Project has developed the theoretical formalism and experimental methods for performing accurate noise-temperature measurements on wafer. This report summarizes the theoretical formulation and describes the design, methods, and results of tests performed to verify our ability to measure on-wafer noise temperature. With known off-wafer noise sources, several different configurations were used to obtain different, known, on-wafer noise temperatures. These were then measured, and the results were compared to predictions. Good agreement was found, with a worst-case disagreement of 2.6%. An uncertainty analysis of the measurements resulted in an estimated standard uncertainty (1σ) of 1.1% or less for most values of noise temperature. The tests also confirm our ability to produce known noise temperature on wafer, with an uncertainty of about 1%.
[Contact: James Randa, (303) 497-3150]

Noise Metrology

Recently Published

Randa, J., and Terrell, L.A., **Noise-Temperature**

Measurement System for the WR-28 Band, NIST Technical Note 1395 (August 1997).

The NIST Noise Project has constructed and tested a radiometer for the measurement of noise sources in the WR-28 waveguide band (26.5 GHz to 40 GHz). It is a total-power radiometer which incorporates a six-port reflectometer for the measurement of relevant reflection coefficients. The radiometer is similar in design to existing NIST systems covering the WR-62 (12.4 GHz to 18 GHz) and WR-42 (18 GHz to 26.5 GHz) bands. This paper reviews the theory and describes the design, testing, and operation of the system. Because of the similarities between the present system and the existing WR-62 and WR-42 systems, much of this document also applies to those systems.
[Contact: James Randa, (303) 497-3150]

Microwave and Millimeter-Wave Metrology

Released for Publication

DeGroot, D.C., and Jargon, J.A., **Long Term Stability in a Calibrated Time-Domain Network Analyzer**.

We report on a fully-calibrated digital sampling oscilloscope with time-domain reflection/transmission capabilities, and by comparing identical calibrations, determine the upper bounds on the uncertainty due to the repeatability limits. We show the overall accuracy of our time-domain network analyzer system to be limited by the oscilloscope's ability to repeat measurements in the short term.
[Contact: Don DeGroot, (303) 497-7212]

Jargon, J.A., **Revised Uncertainty of the NIST 30 MHz Phase Shifter Measurement Service**, to be published in the Proceedings of the 1998 Measurement Science Conference, Pasadena, California, February 5-6, 1998.

Although the measurement service for 30 MHz phase shifters has been in operation for many years at the National Institute of Standards and Technology, modifications have been made to the system, and changes in policy on statements of uncertainty have occurred since the last published analysis. The linear displacement of the standard phase shifter is now measured with an electronic counter instead of a mechanical one, and a new comparison receiver has been installed in the system. Uncertainties are now divided into two distinct categories: Type A and Type B. Type A uncertainties depend upon the repeatability of the system and device under test. Type B uncertainties are based upon scientific judgment using all of the available relevant information, and, in this case, include the standard phase shifter, resolution of the comparison receiver, mismatch within the system, and phase shift of the standard waveguide below-cutoff attenuator. The individual components are stated and combined to comply with the NIST policy on statements of uncertainty. The combined standard uncertainty is on the order of ±0.28° per 30° increment.
[Contact: Jeffrey A. Jargon, (303) 497-3596]

Randa, J., Billinger, R., and Rice, J., **On-Wafer Measurements of Noise Temperature**.

[See Noise Metrology.]

Williams, D.F., and Walker, D.K., **Series-Resistor Calibration**, Conference Digest of the 50th Automatic RF Techniques Group, Portland, Oregon, December 4-5, 1997, pp.131-137.

We develop a coplanar-waveguide probe-tip scattering parameter calibration based on a thru, a reflect, and an accurately modeled series resistor. Comparison to a multiline Thru-Reflect-Line Calibration verifies the accuracy of the method.
[Contact: Dylan F. Williams, (303) 497-3138]

Microwave and Millimeter-Wave Metrology

Recently Published

DeGroot, D.C., Marks, R.B., and Jargon, J.A., **A Method for Comparing Vector Network Analyzers**, Conference Digest of the 50th Automatic RF Techniques Group, Portland, Oregon, December 4-5, 1997, pp. 107-114.

We present a method of comparing two distinct vector network analyzer systems by taking the differences in calibrated *S*-parameters over a set of test devices. The maximum magnitude of all *S*-parameter differences in the ensemble of data provides an estimate of the upper bound on the system differences for the set of test devices measured. If the maximum ensemble difference is greater than the repeatability limits, either the residual errors in the two

systems are not negligible, or they do not agree. We demonstrate our method here by making comparisons between two commercial frequency-domain network analyzer (FDNA) systems and by comparing an experimental time-domain network analyzer to a commercial FDNA.
[Contact: Donald C. Degrade, (303) 497-7212]

Marks, R.B., **Formulations of the Basic Vector Network Analyzer Error Model Including Switch Terms,** Conference Digest of the 50th Automatic RF Techniques Group, Portland, Oregon, December 4-5, 1997, pp. 115-126.

This paper explores details of the relationship between two expressions of the basic error model describing a two-port vector network analyzer. One of these formulations is the conventional twelve-term formulation; the other is in terms of error boxes. The paper focuses on the role of the switch terms. By fully detailing the relationship between the two formulations, the paper arrives at several significant new results, including an explicit constraint on the parameters of the twelve-term model.
[Contact: Roger B. Marks, (303) 497-3037]

Marks, R.B., and Heutmaker, M.S., **Conference Report of the 1997 Wireless Communications Conference, Boulder, Colorado, August 11-1, 1997**, Journal of Research of the National Institute of Standards and Technology, Vol. 102, No. 6, pp. 697-702.

This conference report reviews the 1997 Wireless Communications Conference, which was held in Boulder, Colorado on August 11-13, 1997. The report emphasizes the contributions of the conference in technology areas including broadband telecommunications systems, radio frequency devices and components, nonlinear effects, and propagation.
[Contact: Roger B. Marks, (303) 497-3037]

Milanović, V., Gaitan, M., Bowen, E.D., and Zaghloul, M.E., **Micromachined Microwave Transmission Lines by Commercial CMOS Fabrication**, Proceedings of the 39th Midwest Syposium on Circuits and Systems, Ames, Iowa, August 18-21, 1997, pp. 1189-1192.

[See Microfabrication Technology.]

Milanović, V., Gaitan, M., and Zaghloul, M.E., **Micromachined Thermocouple Microwave Detector in CMOS Technology**, Proceedings of the 39th Midwest Symposium on Circuits and Systems, Ames, Iowa, August 18-21, 1997, pp. 273-276.

[See Microfabrication Technology.]

Electromagnetic Properties

Recently Published

Johnk, R.T., and Ondrejka, A., **Electrical Material Properties from a Free-Space Time-Domain RF Absorber Reflectivity Measurement System**, Proceedings of the 1997 IEEE Electromagnetic Capatability Conference, Austin, Texas, August 18-22, 1997, pp. 537-542.

The scattering information obtained from the measurements of selected test structures is used to extract the relative permittivities of the various dielectric layers. Tests have been successfully conducted on single- and multiple-layer dielectric panels, from which good estimates of material properties have been obtained. Results have been obtained in tests performed at both normal and oblique incidence. In addition, an edge-effect removal algorithm that significantly improves the estimated dielectric constant for small panels has recently been developed.
[Contact: Robert T. Johnk, (303) 497-3737]

Krupka, J., Derzakowski, K., Abramowicz, A., Tobar, M., and Geyer, R.G., **Complex Permittivity Measurements of Extremely Low Loss Dielectric Materials Using Whispering Gallery Modes**, Digest of the 1997 IEEE Microwave and Techniques Symposium, Denver, Colorado, June 8-13, 1997, pp. 1347-1350.

Whispering-gallery modes are used for very accurate complex permittivity measurements of both isotropic and uniaxially anisotropic dielectric materials. A mode-matching technique is used to find the relationship between the complex permittivity, resonant frequency, and the dimensions of a resonant structure. The total uncertainty in permittivity is smaller than 0,05% and is limited principally by uncertainty in sample dimensions.
[Contact: Richard G. Geyer, (303) 497-5852]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Christophorou, L.G., and Olthoff, J.K., **Electron Interactions with Plasma Processing Gases: CF_4, CHF_3, C_2F_6, and C_3F_8**, to be published in the Proceedings of the 1998 Symposium on Atomic and Surface Physics and Related Topics, Going, Austria, January 15-30, 1998.

[See Plasma Processing.]

Misakian, M., **Exposure Parameters During Studies with ELF Magnetic and Electric Fields**, to be published in the Proceedings of the Second Congress for Electricity and Magnetism in Biology and Medicine, Bologna, Italy, June 8-13, 1997.

Following a brief introduction to terminology that describes power frequency and other extremely low frequency (ELF) magnetic and electric fields, a short survey is given of methods for simulating and characterizing in a laboratory setting fields encountered in the environment. The remainder of the paper surveys candidate exposure parameters that may be considered during in vivo and in vitro laboratory studies with ELF magnetic and electric fields. The possible exposure parameters for animal studies exposed to electric fields include surface electric fields and induced (internal) electric fields and currents. The candidate exposure parameters during animal and cell culture studies with magnetic fields include induced electric fields and currents, field polarization, and the alternating as well as static magnetic field. The complexities in characterizing some of the above parameters because of differences in geometry are discussed.
[Contact: Martin Misakian, (301) 975-2426]

Stricklett, K.L., Kassoff, J.M., Firebaugh, S., Olthoff, J.K., and Van Brunt, R.J., **Appearance Potentials of Ions Produced by Electron-Impact Induced Dissociative Ionization of SF_6 and Related Compounds**.

Methods are described for determination of ionization and fragment ion appearance potentials by electron impact. These methods are based on the use of a commercial mass spectrometer and are applied to the principal sulfur-bearing compounds produced by decomposition of SF_6 by electrical discharges. The compounds investigated include: SF_4, SO_2, SOF_2, SO_2F_2, SOF_4, SF_5Cl, S_2F_{10}, S_2OF_{10}, and $S_2O_2F_{10}$, as well as SF_6. Experimental conditions are recommended for improved sensitivity to trace levels of these compounds in SF_6.
[Contact: Kenneth L. Stricklett, (301) 975-3955]

Stricklett, K.L., and Vangel, M., **Analysis of Proposals for Compliance and Enforcement Testing Under the New Part 431**, to be published as NISTIR 6092.

Two proposals are evaluated for establishing compliance with the average efficiency levels prescribed by section 342(b)(1) of the Energy Policy and Conservation Act of 1975, as amended (EPCA), Public Law 94-163: The Department of Energy's (DOE's) proposed rule for Electric Motors, at 10 *Code of Federal Regulations* Part 431, sections 431.24 and 431.127, published in the *Federal Register*, November 27, 1996; and the April 18, 1997, "Proposal for the Method of Determining Compliance and Enforcement for Electric Motors under the Efficiency Labeling Program of DOE, 10 CFR Part 431," submitted by the Motor and Generator Section of the National Electrical Manufacturers Association (NEMA).

The operating characteristics of the DOE proposal and the NEMA proposal are examined within the context of EPAC: Compliance with the energy efficiency levels of motors prescribed by section 342(b)(1) of EPCA is assumed to be satisfied when the true mean full load efficiency of the population of each basic model of electric motor equals the applicable nominal full load efficiency.
[Contact: Kenneth L. Stricklett, (301) 975-3955]

Power Systems

Recently Published

Christophorou, L.G., Olthoff, J.K., and Wang, Y., **Electron Interactions with CCl_2F_2**, Journal of Physical and Chemical Reference Data, Vol. 26, No. 5, pp. 1205-1237 (1997).

[See Plasma Processing.]

Han, X., and Wang, Y., **Characterization of**

Pulsating Partial Discharges in SF_6-N_2 Mixture, Proceedings of the Conference on Electrical Insulation and Dielectric Phenomena, Minneapolis, Minnesota, October 19-22, 1997, pp. 538-541.

We have measured the pulsating partial discharges in a point-to-plane gap in SF_6-N_2 mixtures. The unconditional distributions of amplitude and time separation, as well as the first-order conditional amplitude distributions of the measured partial pulses, have been determined.
[Contact: Xiaolian Han, (301) 975-4278]

Wang, Y., **New Method for Measuring Statistical Distributions of Partial Discharge Pulses**, Journal of Research of the National Institute of Standards and Technology, Vol. 102, No. 5, pp. 569-576 (September-October 1997).

A new digital detection system is described for measuring pulsating discharges (PDs). The PD detection can continuously record all PD pulses that occur over extended periods of time, with a minimum inter-pulse separation of 6 μs and vertical amplitude resolution of 12 bits. Earlier PD detection systems detected PD pulse amplitude and time using complex custom-designed hardware, while the present system continuously records the complete electrical waveform that carries the PD pulses using a commercial data acquisition board and extracts, in real time, the time and amplitude information of all PD pulses in software. The current approach considerably reduces the development and maintenance cost of the PD detection system, significantly increases the system portability, and may prove to be a crucial step for transferring the digital PD detection and analysis technology developed in laboratories to industry. The features of the new system are illustrated by the study of dc-excited PD pulses occurring in a point-to-plane gap in air. A new surface-mediated burst mode of PDs is discovered in which a PD pulse has a certain probability to induce another pulse. The probability is determined for several gap voltages and is found to vary strongly with the applied voltage.
[Contact: Yicheng Wang, (301) 975-4278]

Wang, Y., Han, X., Van Brunt, R.J., Horwath, J., and Schweichart, D., **Digital Recording and Analysis of Positive Partial Discharges in Air**, Proceedings of the 12th International Conference on Gas Discharges and Their Applications, Greifswald, Germany, October 8-12, 1997, pp. 1-256–1-259.

A new surface-mediated burst mode of partial discharges is discovered in which a partial discharge pulse has a fixed probability to induce a following pulse, forming a burst of evenly-separated pulses. The probability is determined for several gap voltages and is found to vary strongly with the applied voltage.
[Contact: Yieheng Wang, (301) 975-4278]

Pulse Power Metrology

Released for Publication

FitzPatrick, G.J., and Zhang, Y.X., **A Compact Precision High Voltage Impulse Divider**.

A reference resistive high voltage (hv) divider has been developed for measurement of micro-second-type high-voltage impulses having peak amplitudes of up to 300 kV. The divider measurement system is capable of measuring hv impulse voltage peaks with estimated relative expanded uncertainties of less than 0.5%, using a coverage factor of k = 2, i.e., corresponding to a two standard deviation estimate. The details of the design including the specialized components and techniques used for the construction of the hv and low voltage (lv) arms, and shielding approaches are described. The divider is intended for use as a reference system for comparative measurements with other dividers.
[Contact: Gerald J. FitzPatrick, (301) 975-2737]

Magnetic Materials and Measurements

Released for Publication

Morillo, J., Su, Q., Panchapakesan, B., Wuttig, M., and Novotny, D.B., **Micromachined Silicon Torsional Resonator for Magnetic Anisotropy Measurement**.

A novel method for measuring the out-of-plane magnetic anisotropy of thin films has been developed using the existing techniques of silicon micromachining. The torsion pendulum which is commonly used to measure the perpendicular magnetic anisotropy energy constant, K_u, is modified into a single crystal silicon high Q torsional resonator. This article describes the principle of a silicon torsional resonator, the experimental procedure for

measuring magnetic anisotropy, and results. The theoretical values of K_u for Terfenol-D and Metglas© thin films were compared to the experimentally determined values and found to be within the error limits which for Metglas© is better than 1%. The agreement is worse, 5% to 15% for amorphous stressed Terfenol-D, as its magnetoelastic energy is less accurately known. The results indicate that there is no conceptual limits of accuracy for measuring the magnetic anisotropy using the new method.
[Contact: Donald B. Novotny, (301) 975-2966]

Magnetic Materials and Measurements

Recently Published

Oti, J.O., Kim, Y,K., and Suvarna, S., **A Personal Computer Based Semi-Analytical Micromagnetics Design Tool**, IEEE Transactions on Magnetics, Vol. 33, No. 5, pp. 4119-4121 (September 1997).

A personal computer-based semi-analytical micromagnetics design tool is described. The program enables the flexible modeling of systems of interacting single-domain rectangular prisms. The program utilizes a convenient graphical windowing interface that facilitates the design and analysis of the system. Magnetization and magnetoresistive curve properties of the system are calculated by the program. A design example of the magnetoresistive responses of spin valves with partially overlapping magnetic layers is presented.
[Contact: John O Oti, (303) 497-5557]

Oti, J.O., and Russek, S.E., **Micromagnetic Simulations of Magnetoresistive Behavior of Sub-Micrometer Spin-Valve MRAM Devices**, IEEE Transactions on Magnetics, Vol. 33, No. 5, pp. 3298-3300 (5 September 1997).

The effects of device shape and size on the giant magnetoresistive (MR) response of $NiFe_{7.5nm}/Co_{0.6nm}/Cu_{3nm}/Co_{0.6nm}/NiFe_{7.5nm}/FeMn$ spin-valve magnetoresistive random access memory stripes are studied by micromagnetic simulation. Samples having aspect ratios of 10:1, 3:1 and 1.5:1, and linewidths varying from 0.5 μm to 1.5 μm are simulated. The effects of the magnetic layers and their self-demagnetization are studied.
[Contact: John O. Oti, (303) 497-5557]

Superconductors

Released for Publication

Wada, H., Goodrich, L.F., and ten Kate, H.J.J., **VAMAS Activities for Standardization of Measurement Methods for Superconducting Materials**, to be published as a Book Chapter in Advances in Superconductivity X (ISS '97) (Springer-Verlag Tokyo, Inc.).

This document describes the capacitance calibration service provided by NIST, including measurement procedures and systems used to calibrate capacitance standards of nominal values in the range of 0.001 pF to 1 μF, at frequencies up to 10 kHz. Discussed are the process to transfer the unit of capacitance from the NIST capacitance primary laboratory, which maintains the U.S. representation of the farad, traceable to the calculable capacitor, and the quality controls of reference standards and check standards in the calibration laboratory. Also included are summaries of calibration uncertainties of capacitors of various dielectric materials, such as fused-silica, nitrogen, air, and mica.
[Contact: Loren F. Goodrich, (303) 497-3143]

ELECTROMAGNETIC INTERFERENCE

Radiated EMI

Released for Publication

Butler, C.M., Hill, D.A., Novotny, D.R., and Motohisa, K., **EMI/EMC Metrology Challenges for Industry: A Workshop on Measurements, Standards, Calibrations and Accreditation**, to be published as NISTIR 5068.

The National Institute of Standards and Technology (NIST) held a two-day workshop,"EMI/EMC Metrology Challenges for Industry," at NIST, Boulder, CO, in January 1995. The workshop included six technical sessions that concentrated on the following six industries: (1) aerospace and aircraft, (2) computers and peripherals, (3) motor vehicles, (4) medical equipment, (5) consumer electronics, and (6) telecommunications. The attendees ranked 42 topics in electromagnetic compatibility and interference (EMI/EMC) in order of priority, and the results of the rankings are included in this report.
[Contact: David A. Hill, (303) 497-3274]

Kanda, M., **Electromagnetic Field Measurements**.

Although electromagnetic analysis tools can provide good numerical data about the effects of electromagnetic interference, measurements are the method of choice for obtaining quantitative, accurate data on electromagnetic noise problems. Furthermore, since electromagnetic interference measurements often provide the only data accepted by most regulatory agencies, the measurements and their accuracies have recently become a very important issue in order to regulate and harmonize various electromagnetic compatibility emission and immunity standards. The measurement techniques and instrumentations of most use for making accurate electromagnetic interference measurements are presented in this paper.
[Contact: Motohisa Kanda, (303) 497-5320]

Kawalko, S.F., and Motohisa, K., **The Near-Zone Gain of Open-Filled Rectangular Waveguides.**

The electromagnetic field measurements in an anechoic chamber are usually performed in the near-field region of the transmitting standards antennas. For the frequencies below 750 MHz, the approach used at the National Institute of Standards and Technology to establish the standard field strength is to calculate the radiated field strength in the near-field region of open-ended waveguides. The purpose of the communication is, therefore, to give accurate calculations for the near-zone gains of open-ended, unflanged rectangular waveguides using the method of moments. The estimation of numerical uncertainties in these calculations is also given.
[Contact: Stephen F. Kawalko, (303) 497-5854]

Radiated EMI

Recently Published

Hill, D.A., **Spherical-Wave Characterization of Interior and Exterior Electromagnetic Sources**, NIST Technical Note, NISTIR 5072 (December 1997).

This report presents spherical scanning formulations for the general case where electromagnetic sources are present both inside and outside the measurement region. The fields are expanded in terms of outgoing waves (due to interior sources) and standing waves (due to exterior sources). Additional information is required to solve for the increased number of unknowns, and results are derived for the spherical wave coefficients in terms of the tangential electric and magnetic fields on a sphere. The special case of an electrically small emitter is examined in detail, and several formulations are presented for the components of electric and magnetic dipoles. The dipole formulations are intended for use in detection of a weak emitter (such as a timing device) in a noisy environment.
[Contact: David A. Hill, (303) 497-3472]

Kawalko, S.F., and Motohisa, K., **The Effective Length and Input Impedance of the NIST Standard Dipoles**.

The National Institute of Standards and Technology uses the standard antenna method for the calibration of dipole-like electromagnetic interference antennas in the horizontal polarization in an open-area test site. The purpose of this short paper is to give accurate values and associated uncertainties of the effective lengths and the antenna impedance of the NIST standard dipoles.
[Contact: Motohisa Kanda, (303) 497-5320]

Ladbury, J.M., Koepke, G.H., and Camell, D.G., **Improvements in the CW Evaluation of Mode-Stirred Chambers**, Proceedings of the 1997 IEEE Electromagnetic Capatability Conference, Austin, Texas, August 18-22, 1997, pp. 33-37.

We present methods for improving the reliability of measurements made in a mode-stirred chamber. The combination of improved instrumentation and a larger paddle resulted in measurements that were significantly more reproducible (±1 dB) than previous measurements. We also give a simple model that is capable of describing the characteristics of a mode-stirred chamber at any frequency using only two parameters.
[Contact: John M. Ladbury, (303) 497-5372]

LAW ENFORCEMENT STANDARDS

Released for Publication

Ondrejka, A.R., and Johnk, R.T., **A Portable Calibrator for Across-the-Road Radar Systems**, to be published as NIST Technical Note 1398.

The operation of an across-the-road radar system is

affected by a number of variables such as the angle of the radar beam with respect to the direction of the traffic, the distance to the target, its size, shape, and direction of motion (toward or away from the radar unit). Radar systems are designed with some computing power to help compensate for these potential sources of error. A precision calibrator is necessary to determine that the radar instrumentation is operating properly and that the computer algorithm is displaying the correct speed.

This paper describes an inexpensive, easy-to-use electronic calibrator that can be used to improve the credibility of across-the-road type radars. The use of such a device can detect actual failures that generate erroneous speed readings. Regular documented use of the calibrator can greatly facilitate the maintenance of across-the-road systems by indicating faulty readings and trends in the radar operation, indicative of imminent failure.
[Contact: Robert T. Johnk, (303) 497-3737]

OPTOELECTRONICS

Released for Publication

Bertness, K.A., Hickernell, R.K., Hays, S.P., and Christensen, D.H., **Noise Reduction in Optical *In Situ* Measurements for Molecular Beam Epitaxy by Wobble Normalization**, to be published in the Proceedings of the 16th North American Conference on Molecular Beam Epitaxy, Ann Arbor, Michigan, October 5-8, 1997.

We demonstrate a normalization method for removing noise introduced into optical *in situ* measurements by sample rotation wobble during molecular beam epitaxy. The technique consists of measuring the phase angle of rotation of the sample through optical triggers attached to the sample manipulator rotation drive, acquiring a normalization curve at the various trigger points, then applying the normalization value appropriate to each trigger to subsequent data. This cyclic normalization is demonstrated on normal-incidence optical reflection data and atomic absorption measurements in which the flux-monitor light beam is reflected from the sample to allow determination of layer thickness in addition to atomic flux. Noise reductions by factors of 3 to 20 were observed in both systems, with greater improvements seen for samples with larger wobble angles. We achieve normalized optical reflectance data with a noise standard deviation of 1% over a period of 1 to 2 h and similar results for atomic absorption data on shorter time scales. The technique is limited by the long-term mechanical stability of the manipulator and collection optics; possible improvements are discussed.
[Contact: Kristine A. Bertness, (303) 497-3319]

Dyer, S.D., and Rochford, K.B., **Spectral Tailoring of an Erbium Superfluorescent Fiber Source**.

The output spectrum of an erbium superfluorescent fiber source (SFS) is tailored by replacing the broadband mirror in the conventional double-pass design with a combination of reflective Bragg gratings. We show an increase in bandwidth and a factor of two reduction in the coherence length compared to a conventional SFS.
[Contact: Shellee D. Dyer, (303) 497-7643]

Munroe, M.J., Christensen, D.H., and Trebiono, R., **Error Bars in Intensity and Phase Measurements of Ultrashort Laser Pules**, to be published in the Proceedings of the 1998 Conference on Lasers and Electro-Optics, San Francisco, California, May 3-5, 1998.

We present a simple method for determining the error in the retrieved intensity and phase vs. time (or frequency) due to noise in the measurement of a frequency-resolved optical-gating trace, independent of noise source.
[Contact: David H. Christensen, (303) 497-3354]

Vander Rhodes, G.H., Pomeroy, J.M., Ulu, G., Ünlü, M.S., Goldberg, B.B., Knopp, K.J., and Christensen, D.H., **Pump Intensity Profiling of Vertical-Cavity Surface-Emitting Lasers Using Near-Field Scanning Optical Microscopy**.

We have mapped the internal pump intensity distribution by monitoring the spontaneous emission intensity along the cleaved edge of an optically pumped vertical-cavity surface-emitting laser using the high spatial resolution and shallow depth of field provided by near-field scanning optical microscopy. The spontaneous emission from quantum wells placed throughout the distributed Bragg reflectors is correlated to the pump intensity. Our results show a distinct buildup of optical intensity between the mirror stacks. Simulations performed using the transfer

matrix method match well with experimental data.
[Contact: David H. Christensen, (303) 497-3354]

OPTOELECTRONICS

Recently Published

Dyer, S.D., and Rochford, K.B., **Spectral Tailoring of an Erbium Superfluorescent Fiber Source**, Proceedings of the 12th International Conference on Optical Fiber Sensors, Williamsburg, Virginia, October 27-31, 1997, pp. PD6-1–PD6-4.

We demonstrate a novel method for tailoring the output spectrum of an erbium superfluorescent fiber source (SFS). We show that the variation in the output spectrum can be reduced to $\pm$3 dB over a 27 nm bandwidth, and that the coherence length can be reduced by a factor of two compared to a conventional SFS. This is achieved by replacing the broadband mirror in the conventional double-pass source design with a combination of reflective Bragg gratings. Bragg grating feedback can be used to smooth the output spectrum, shorten the coherence length of the source, or otherwise customize the output spectrum. This spectrally tailored source has applications in low-coherence interferometric sensors, low-coherence optical reflectometry, and wavelength-selective optical component testing.
[Contact: Kent B. Rochford, (303) 497-5170]

Franzen, D.L., Mechels, S.E., and Schlager, J.B., **Differential Mode Delay Measurements in Multimode Fibers Using a Frequency Domain Technique with Variable Launch**, Digest of the Conference on Optical Fiber Measurements, Teddington, United Kingdom, September 29–October 1, 1997, pp. 109-112.

Differential mode delay (DMD) profiles are determined for multimode fibers using a frequency domain phase shift technique. The time resolution of 0.2 ps makes measurements on short lengths of fiber possible; comparisons with traditional time domain methods on longer lengths show agreement. DMD profiles obtained on several 62 μm diameter core fibers exhibit a diverse range of behavior.
[Contact: Douglas L. Franzen, (303) 497-3346]

Lehman, J.H., **Pyroelectric Trap Detector for Spectral Responsivity Measurements**, Optics and Photonics News, Vol. 8, No. 11, pp. 35-36 (November 1997).

We have designed and built a pyroelectric optical detector for use as a transfer standard for the calibration of optical power meters. The pyroelectric element is made from lithium tantalate ($LiTaO_3$). Gold black is used as the optical absorber in a multiple reflection wedge-shaped trap structure, with a 5 mm diameter input aperture and an f/4 field-of-view. The detector's spatial responsivity varies less than 1%. The responsivity as a function of wavelength varies less than 1% over a range from 0.45 μm to 1.55 μm and less than 4% from 1.55 μm to 10.6 μm. The measured noise equivalent power (NEP) is 5×10^{-8} $W/Hz^{1/2}$. For this wavelength range and detector area, the measured NEP and spatial uniformity represents a significant improvement over comparable predecessors.
[Contact: John H. Lehman, (303) 497-3654]

Mirin, R.P., Gossard, A., and Bowers, J., **Characterization and Modeling of InGaAs Quantum Dot Lasers**, Proceedings of the 8th International Conference on Modulated Semiconductor Structures, Santa Barbara, California, July 14-18, 1997 (unpaged).

Highly strained InGaAs grown by molecular beam epitaxy on GaAs has been shown to grow in a two-dimensional, layer-by-layer fashion for only a few monolayers before the transition to three-dimensional growth (Stranski-Krastanow). The islands that form in this manner are quantum-sized and coherently strained. They exhibit bright room temperature photoluminescence (PL) and can be used as the active region for an electrically-injected laser. In this presentation, we discuss the growth and characterization of InGaAs quantum dot (QD) lasers grown on (100) GaAs substrates, as well as modeling of the unusual laser length dependence on the lasing wavelength.
[Contact: Richard P. Mirin, (303) 497-7955]

Rochford, K.B., Rose, A.H., Williams, P.A., Wang, C.M., Clarke, I.G., Hale, P.D., and Day, G.W., **Design and Performance of a Stable Linear Retarder**, Applied Optics, Vol. 36, No. 25, pp. 6458-6465 (1 September 1997).

The National Institute of Standards and Technology has developed a nominally quarter-wave linear retarder for wavelengths near 1.3 μm that is stable

within ±0.1° retardance over a range of wavelength, input angle, temperature, and environmental variations. The device consists of two concentrated Fresnel rhombs made from a low stress-optic-coefficient glass that minimizes the residual birefringence from machining and packaging. Device machining, assembly, and antireflection coating tolerances are discussed, and the theoretical performance is compared with measurements. Humidity can modify retardance of the total-internal-reflection surfaces; we discuss packaging that mitigates this effect and provides an estimated 10 year lifetime for the device. Several measurement methods were intercompared to ensure that the device retardance can be measured with an uncertainty less than 0.1°. Similar retarders will be certified by NIST and made available as Standard Reference Materials.
[Contact: Kenneth B. Rochford, (303) 497-5170]

Rochford, K.B., and Wang, C.M., **Accurate Interferometric Retardance Measurements**, Applied Optics, Vol. 36, No. 25, pp. 6473-6479 (1 September 1997).

A two-polarization Michelson interferometer with a low-retardance beam splitter and digital signal processing is used to measure the retardance of optical devices. Error analysis of the improved optical system and data processing shows that the measurement has an uncertainty of 0.039° for measurements of nominally 90° retarders. Retardance variations arising from coherent reelections in the retarder used for intercomparison add an uncertainty of from 0.005° to 0.03°, increasing the combined measurement uncertainty to as much as 0.049°.
[Contact: Kenneth B. Rochford, (303) 497-5170]

Schlager, J.B., Mechels, S.E., and Franzen, D.L., **High Resolution Differential Mode Delay Measurements and Bandwidth of Multimode Fibers**, Proceedings of the 1997 IEEE Lasers and Electro-Optics Society Annual Meeting, San Francisco, California, November 10-13, 1997, pp. 46-47.

There is growing interest in the use of multimode fibers for high-speed data networks. According to present industry test procedures, multimode fiber bandwidth is characterized using overfilled launching conditions. Such a launch is achieved by uniformly exciting the core and launching with a numerical aperture (NA) which exceeds the fiber NA. The anticipated system sources, such as vertical cavity surface emitting lasers, launch mode distributions which significantly underfill the available fiber mode volume. For many multimode fibers, the bandwidth increases when the launching conditions are restricted; the specific behavior, however, depends on the differential mode delay (DMD) characteristics of the refractive index profile. We have developed a frequency domain phase shift technique capable of acquiring DMD profiles with a temporal resolution less than 0.2 ps. DMD measurements are now possible on fiber lengths as short as 15 m.
[Contact: John B. Schlager, (303) 497-3542]

Williams, P.A., Rose, A.H., and Wang, C.M., **Rotating-Polarizer for Accurate Retardance Measurement**, Applied Optics, Vol. 36, No. 25, pp. 6466-6472 (1 September 1997).

We demonstrate an automated polarimeter based on a rotating polarizer for the measurement of linear retardance independent of laser power and detector gain. The retardance is found when a curve is fitted to a unique normalization of the intensity response of the polarimeter over a range of input polarizer orientations. The performance of this polarimeter is optimal for measurements of quarter-wave retardance and minimal for half-wave retardance. Uncertainties are demonstrated by measurements on six stable double Fresnel rhombs of nominal quarter-wave retardance, yielding expanded uncertainties between 0.031° and 0.67°. The accuracy has also been verified by blind comparisons with interferometric and modified null retardance measurement techniques.
[Contact: Paul A. Williams, (303) 497-3805]

Veasey, D.L., Gary, J.M., Amin, J., and Aust, J. A., **Time-Dependent Modeling of Erbium-Doped Waveguide Lasers in Lithium Niobate Pumped at 980 and 480 nm**, IEEE Journal of Quantum Electronics, Vol. 33, No. 10, pp. 1647-1662 (October 1997).

We have developed a rigorous phenomenological model for analyzing rare-earth-doped waveguide lasers. The model is based on time-dependent laser rate equations for an arbitrary rare-earth-doped laser host with multiple energy levels. The rate equations are coupled with the laser signal and pump photon flux equations that have time-dependent boundary

conditions. The formulation results in a large and stiff set of transcendental and coupled differential equations that are solved using finite difference discretization and the method of lines. Solutions for the laser signal power, pump power, and populations of ion energy levels as functions of space and time are obtained for waveguide lasers. We have used the model to predict the CW characteristics and Q-switched performance of waveguide lasers in lithium niobate pumped by a 980 nm source. Our analysis shows that hole burning can occur in erbium-doped lithium niobate lasers because of the intensity variation across guided transverse modes. We have predicted that Q-switch pulse peak powers can exceed 1 kW with pulse widths less than 1 ns. Moreover, we have compared the CW and Q-switched performance of 980 nm pumped waveguide lasers and 1480 nm pumped waveguide lasers. An analysis of the effects of host- and fabrication-dependent parameters on CW 980 nm pumped lasers is included. These parameters include cooperative upconversion, excited state absorption, doping concentration, excess waveguide loss, cavity length, and mirror reflectance values. We demonstrate good quantitative agreement with waveguide laser experimental data obtained in our laboratory and with results from the literature.
[Contact: David L. Veasey, (303) 497-5192]

VIDEO TECHNOLOGY

Released for Publication

Boynton, P.A., and Kelley, E.F., **Assessment of Color Measurement Systems Using Interference Filters**, to be published in the Proceedings of the Commission Internationale de L'Eclairage (CIE) Expert 1997 Symposium, Scottsdale, Arizona, November 21-22, 1997.

Spectroradiometers and tristimulus colorimeters are used in display measurements to measure color in one of several color space coordinate systems. How well these instruments can measure the color coordinates can be relatively simply checked by using interference filters. If a narrow-band interference filter is measured, the chromaticity coordinates obtained from the instrument should fall very near the spectrum locus of a standard color space. Assuming the instrument is linear and the white point calibrated, if the colors on the spectrum locus are measured correctly, then all other colors within the color gamut should be measured accurately. The filter bandwidth and background noise in the instrument are modeled and shown to contribute to the distance of the color coordinates from the spectrum loss. Error sources within the measuring system are identified, which could explain these observed anomalies.
[Contact: Paul A. Boynton, (303) 975-3014]

Jones, G.R., and Kelley, E.F., **Bidirectional Reflectance Distribution Function Measurements on Flat Panel Displays**, to be published in the Proceedings of the Commission Internationale de L'Eclairage (CIE) Expert 1997 Symposium, Scottsdale, Arizona, November 21-22, 1997.

Commonly used methods for measuring reflections from the surface of an electronic display are often subject to large errors and ignore critical aspects of reflection from modern-day displays. Largely this is due to an oversimplification of the reflection process, namely, considering reflection to be a simple combination of diffuse (Lambertian) and regular specular reflections. The Flat Panel Laboratory at NIST is developing an alternative method that accurately predicts the reflected luminance from a flat panel display from known lighting conditions using the bidirectional reflection distribution function (BRDF) of the display. The BRDF reflection model employed separates the reflection into three components: diffuse (or Lambertian), specular, and haze. The simplifications made and methods to obtain the required coefficients are discussed. Calculated values for the reflected luminances are compared to measured values for several lighting conditions.
[Contact: George R. Jones, (301) 975-4225]

ADDITIONAL INFORMATION

Announcements

Knight, S., and Settle-Raskin, A., **Project Portfolio FY 1998 - The National Semiconductor Metrology Program**, NISTIR 5851 (March 1998).

The National Semiconductor Metrology Program (NSMP) is a NIST-wide effort designed to meet the highest priority measurement needs of the semiconductor industry as expressed by the *National Technology Roadmap for Semiconductors* and other authoritative industry sources. The NSMP was established in 1994 with a strong focus on

mainstream silicon CMOS technology and an ultimate funding goal of $25 million annually. Current annual funding of approximately $11 million supports the 29 internal projects which are summarized in the Project Portfolio booklet.

The NSMP is operated by NIST's Office of Microelectronics Programs, which also manages NIST's relationships with the Semiconductor Industry Association (SIA), SEMATECH, and the Semiconductor Research Corporation (SRC). These include NIST's memberships on the SIA committees that develop the *Roadmap* and numerous SRC technical management committees. In addition, NIST is active in the semiconductor standards development activities of American Society for Testing and Materials (ASTM), Deutsches Institut für Normung (DIN), Electronic Industries Association (EIA), International Organization for Standardization (ISO), and Semiconductor Equipment and Materials International (SEMI).
[Contact: Steven Knight, (301) 975-2871]

Lists of Publications

Bradford, A.G., **Metrology for Electromagnetic Technology: A Bibliography of NIST Publications**, NISTIR 5064 (August 1997).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NIST during the period from January 1970 through publication of this report. A few earlier references that are directly related to the present work of the Division are also included. This edition of the bibliography is the first since the Electromagnetic Technology Division split into two Divisions, and it includes publications from the areas of cryoelectronic metrology and superconductor and magnetic measurements. The optical electronic metrology section found in earlier editions is now being produced separately by the new Optoelectronics Division of NIST. That companion bibliography to this publication is NISTIR 5052.
[Contact: Ann G. Bradford, (303) 497-3678]

Lyons, R.M., **A Bibliography of the NIST Electromagnetic Fields Division Publications**, NISTIR 5063 (August 1997).

This bibliography lists the publications by the staff of the National Institute of Standards and Technology's Electromagnetic Fields Division for the period January 1970 through July 1997. It supersedes NISTIR 5050 which listed the publications of the Electromagnetic Fields Division from January 1970 through July 1996. Selected earlier publications from the Division's predecessor organizations are included.
[Contact: Ruth Marie Lyons, (303) 497-3132]

Schmeit, R.A., **Electrical and Electronic Metrology: A Bibliography of NIST Electricity Division's Publications, NIST List of Publication 94** (March 1998).

This bibliography covers publications of the Electricity Division (and predecessor organizational units), Electronics and Electrical Engineering Laboratory, National Institute of Standards and Technology, for the period of January 1968 through December 1997. A brief description of the Division's technical program is given in the introduction.
[Contact: Ruth A. Schmeit, (301) 975-2401]

Smith, A.J., **A Bibliography of Publications of the NIST Optoelectronics Division**, NISTIR 5065 (September 1997).

This bibliography lists publications of the staff of the Optoelectronics Division and its predecessor organizational units from 1970 through the date of this report.
[Contact: Annie J. Smith, (303) 497-5342]

Walters, E.J., **NIST List of Publications 103, National Semiconductor Metrology Program and the Semiconductor Electronics Division, 1990-1997** (March 1998).

This List of Publications includes all papers relevant to semiconductor technology published by NIST staff, including work of the National Semiconductor Metrology Program and the Semiconductor Electronics Division, and other parts of NIST having independent interests in semiconductor metrology. Bibliographic information is provided for publications from 1990 through 1997. Indices by topic area and by author are provided. Earlier reports of work performed by the Semiconductor Electronics Division (and its predecessor divisions) during the period from 1962 through December 1989 are provided in NIST List of Publications 72.
[Contact: E. Jane Walters, (301) 975-2050]

1998 Calendar of Events

July 20-21, 1998 (Breckenridge, Colorado) **International Workshop on Ferroelectric Integrated Optics**. This workshop targets the science and technology of optical ferroelectric materials, emphasizing areas such as optical telecommunications and remote sensing. Also, optical ferroelectric materials and advances will be discussed.
[Contact: Norman A. Sanford, (303) 497-5239]

August 9-12, 1998 (Colorado, Springs, Colorado)

1998 IEEE Radio and Wireless Conference (RAWCON'98). The 1998 IEEE Radio and Wireless Conference (RAWCON'98) is featuring a new name, and featuring 50 outstanding presentations and 254 attendees from 14 nations. RAWCON'98 will focus on the technology driving the advancement of commercial wireless communications, from systems to components to propagation, with special attention to radio and radio-frequency issues.
[Contact: Roger B. Marks, (303) 497-3037]

August 11-14, 1998 (Boulder, Colorado)

Laser Measurements Short Course. This course provides training on laser measurement theory and techniques. The course will emphasize the concepts, technqiues, and apparatus used in measuirng laser parameters and will include a visit to the NIST laser measurement laboratories.
[Contact: Thomas R. Scott, (303) 497-3651]

September 15-17, 1998 (Boulder, Colorado)

Symposium on Optical Fiber Measurements. This Symposium provides a forum for reporting the results of recent measurement research in the area of lightwave communications including optical fibers.
[Contact: Paul Williams, (303) 497-3805]

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NIST SILICON RESISTIVITY SRMs

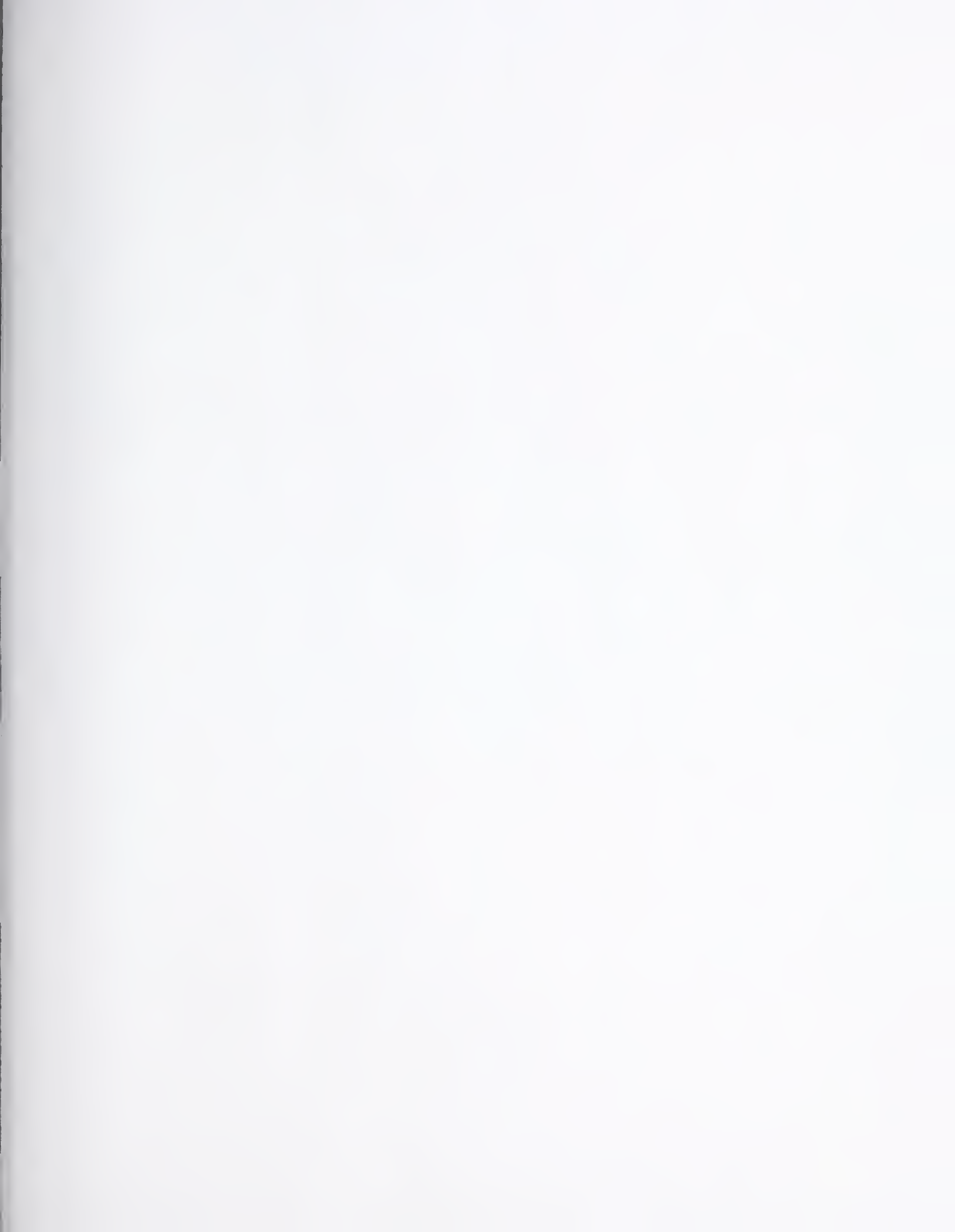
The Semiconductor Electronics Division of NIST provides Standard Reference Materials (SRMs) for bulk silicon resistivity through the NIST Standard Reference Materials Program. An improved set of resistivity SRMs, on 100 mm wafers, will be available according to the schedule in the table below. These wafer SRMs improve upon the earlier 50 mm diameter SRM sets 1521, 1522, and 1523.

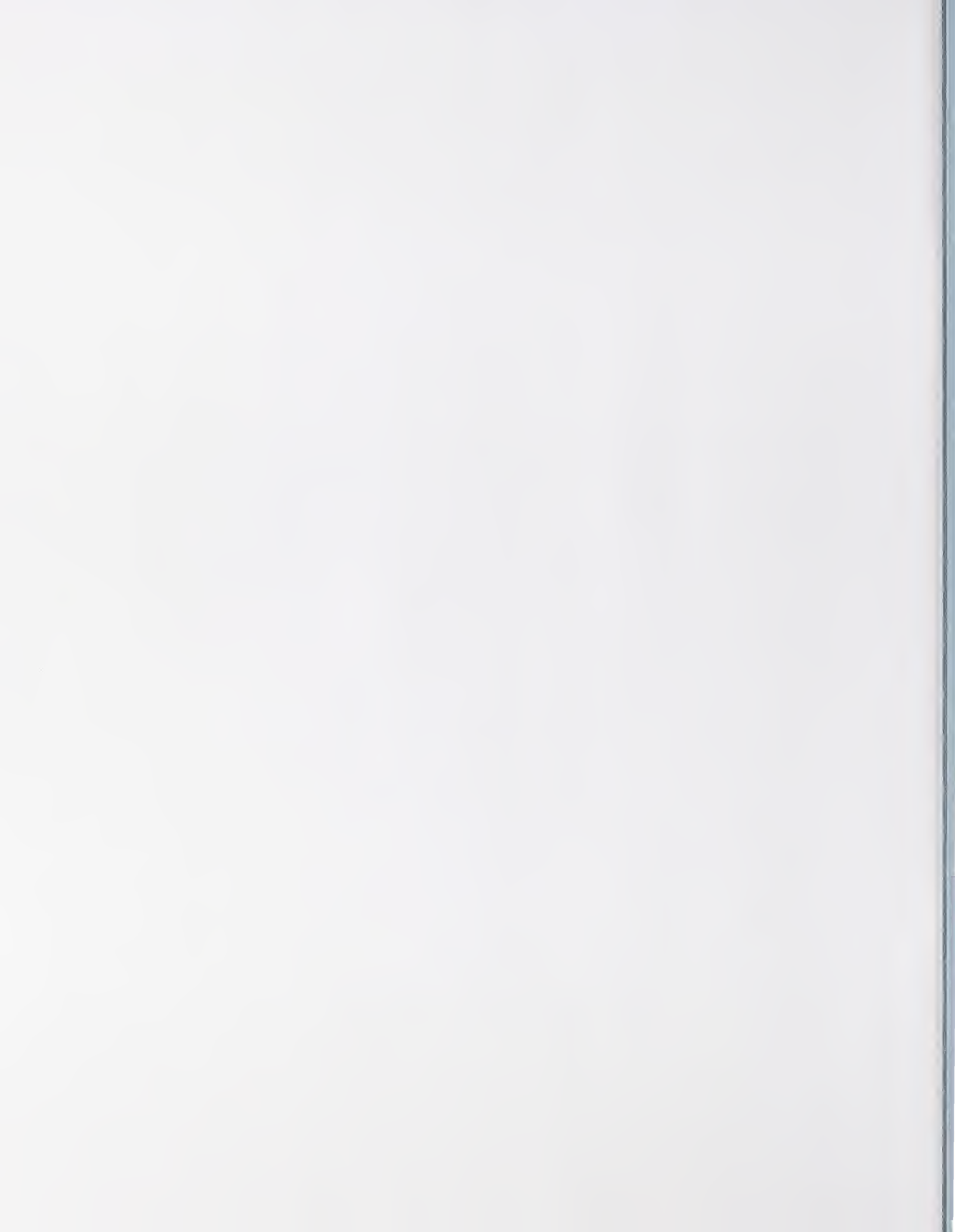
The new SRMs have similar values of nominal resistivity as the earlier set, but offer improved uniformity and substantially reduced uncertainty of certified values due both to material and procedural improvements. The most significant feature of the new SRMs is in their certification, which is performed using a dual-configuration four-probe measurement procedure rather than the single-configuration measurements specified in ASTM F84. Extensive testing has shown that the dual-configuration procedure reduces random variations of measurement and probe-to-probe differences.

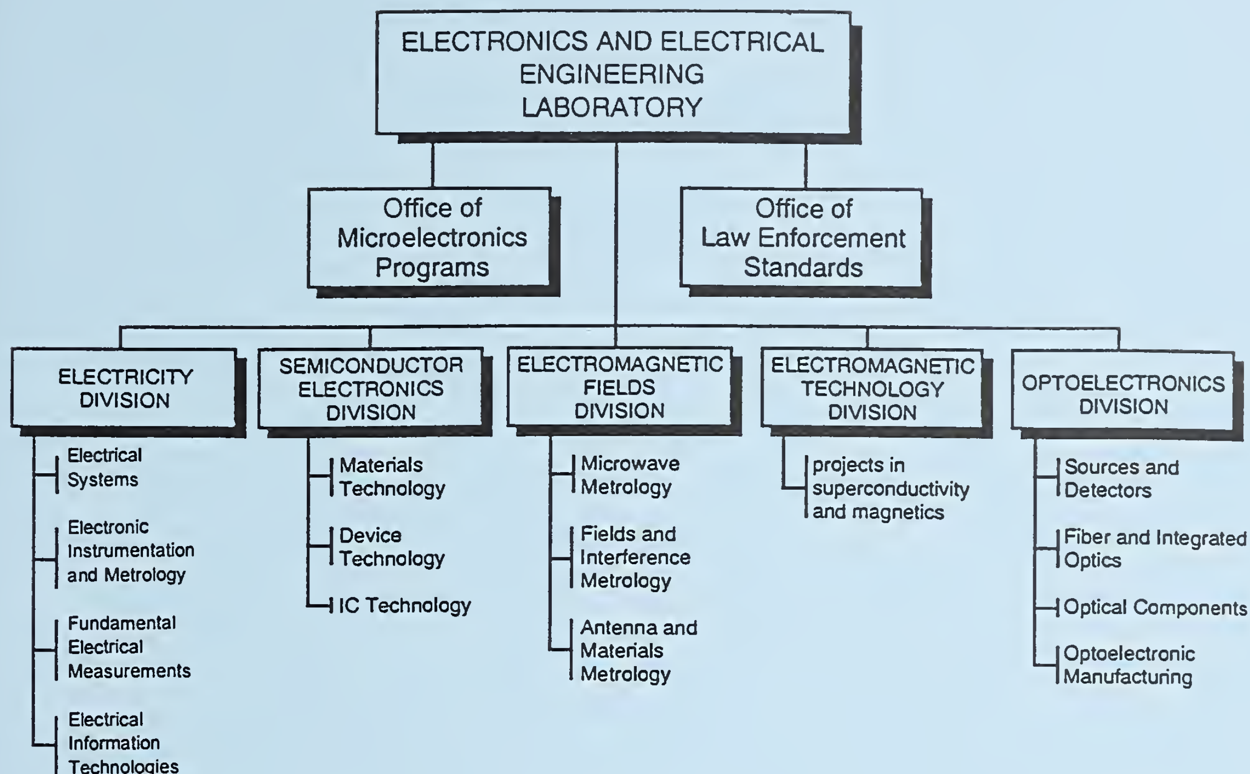
Technical insights presented by the rigorous certification process are available in NIST Special Publication 260-131, *Standard Reference Materials:* The Certification of 100 mm Diameter Silicon Resistivity SRMs 2541 through 2547 Using Dual-Configuration Four-Point Probe Measurements. Individual data for each wafer are supplied along with the SRM certificate.

NIST SILICON BULK RESISTIVITY STANDARD REFERENCE MATERIALS		
DATE UPDATED: 1 May 1998		
NOMINAL RESISTIVITY (ohm·cm)	**NEW SRMs**	**AVAILABILITY**
0.01	2541	NOW!
0.1	2542	NOW!
1	2543	beginning of CY 98
10	2544	NOW!
25	2545	NOW!
100	2546	NOW!
200	2547	NOW!

NIST sells SRMs on an as-available basis. For technical information, contact James R. Ehrstein, (301) 975-2060; for ordering information, call the Standard Reference Materials Program Domestic Sales Office: (301) 975-6776.







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