NISTIR 6255

Electronics and Electrical Engineering Laboratory

J. M. Rohrbaugh
Compiler

Technical Progress Bulletin

98-1

Covering Laboratory Programs,
January to March 1998,
with 1997-1998 EEEL Events Calendar

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards
and Technology

NIST

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Electronics and Electrical
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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, NOVEMBER 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 third 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 Unpublished papers appear under the subheading "Released for Publication."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 years 1997 through 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, CO. 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 20.

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 18.

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.

TO LEARN MORE ABOUT THE LABORATORY...

Two general documents are available that may be of interest. These are ***EEEL 1996 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, 1995 through September 30, 1996. 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 1996 Technical Accomplishments, Advancing Metrology for Electrotechnology to Support the U.S. Economy, NISTIR 5941 (December 1996).

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 1996 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]

TABLE OF CONTENTS

FUNDAMENTAL ELECTRICAL MEASURMENTS

Released for Publication

Burroughs, C.J., Benz, S.P., Hamilton, C.A., and Harvey, T.E., **Programmable 1 Volt DC Voltage Standard**, to be published in the Proceedings of the Conference on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998.

We have developed a Josephson voltage standard that produces intrinsically stable voltages that are programmable from -1.1 V to + 1.1 V. The standard uses a binary array sequence of 32 768 (SNS) Josephson junctions. The output can source or sink up to 2 mA, and thus has high-noise immunity.
[Contact: Charles J. Burroughs, (303) 497-3906]

Keller, M.W., Martinis, J.M., and Zimmerman, N.M., **Progress Toward a Capacitance Standard Based on Counting Electrons**, to be published in the Digest of the Conference on Precision Electromagnetic Measurements, Washington, DC, July 6-11, 1998.

We have combined an electron pump and a vacuum capacitor to create a prototype capacitance standard based on electron counting. We are testing various components individually to determine whether a standard with an overall inaccuracy of 1 part on 10^8 is feasible.
[Contact: Mark W. Keller, (303) 497-5430]

Newell, D.B., Steiner, R.L., Williams, E.R., and Picard, A., **The Next Generation of the NIST Watt Balance**, to be published in the Proceedings of the 1998 Conference on Precision Electromagnetic Measurements Digest, Washington, DC July 6-10, 1998.

Reduction in the total uncertainty of the NIST watt balance is limited by the present configuration of the experiment. Most of the major relative uncertainty components arise from the fact that the experiment is performed in air. To reduce the contribution of these components, a vacuum system for the NIST Watt Balance has been constructed. The vacuum system and other future modifications to the NIST Watt Balance are discussed.
[Contact: David L. Newell, (301) 975-4228]

Steiner, R.L., Newell, D.B., and Williams, E.R., **Experimental Noise Sources in the NIST Watt Balance**, to be published in the Proceedings of the 1998 Conference on Precision Electromagnetic Measurements Digest, Washington, DC, July 6-10, 1998.

The present NIST watt balance has a relative combined standard uncertainty of about 145 nW/W at the k = 1 level. The final results of this phase of the experiment are presented. Improvements in the Type B (nonstatistical) uncertainty contributions, along with several correction factors and noise sources are also discussed.
[Contact: Richard L. Steiner, (301) 975-4226]

Zimmerman, N.M., and Cobb, J.L., **Charge Offset and Noise in SET Transistors**, to be published in the Proceedings of the 1998 Conference on Precision Electromagnetic Measurements Digest, Washington, DC, July 6-10, 1998.

We report on several previous and ongoing investigations into the source of, and the amelioration of, the charge offset noise in SET (single-electron tunneling) transistors, made of Al/AlOx/Al tunnel junctions. Previous work has shown that significant time-dependent noise will arise from locations outside the tunnel junctions, as well as within the junctions. Our ongoing work includes attempts to reduce or eliminate the charge offset and noise in fabricated devices.
[Contact: Neil M. Zimmerman, (301) 975-5887]

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Recently Published

Jeffery, A., Shields, J.Q., and Lee, L.H., **An Easy-To-Use Combination Four-Terminal-Pair/Two-Terminal-Pair AC Transformer Bridge**, Journal of Research of the National Institute of Standards and Technology, Vol. 103, No. 2, pp. 163-166 (March-April 1998).

A new four-terminal-pair bridge, capable of achieving a relative standard uncertainty of 1×10^{-9}, was constructed at the National Institute of Standards and Technology (NIST) by converting a two-terminal-pair bridge. The conversion requires only the addition of components which are easily removed if two-terminal-pair measurements are to be made. The design and

testing of this bridge are described. The new four-terminal-pair bridge requires fewer auxiliary balances than the present four-terminal-pair bridge employed at NIST, which makes it much easier to use. This new design can be used to compare capacitance, resistance, and inductance standards.
[Contact: Anne-Marie Jeffery, (301) 975-4246]

Lee, K.C, **Degradation of GaAs/AlGaAs Quantized Hall Resistors with Alloyed AuGe/Ni Contacts**, Journal of Research of the National Institute of Standards and Technology, Vol. 103, No. 2, pp. 177-200 (March-April 1998).

Careful testing over a period of 6 years of a number of GaAs/AlGaAs quantized Hall resistors (QHR) made with alloyed AuGe/Ni contacts, both with and without passivating silicon nitride coating, has resulted in the identification of important mechanisms responsible for degradation in the performance of the devices as resistance standards. Covering the contacts with a film, such as low-temperature silicon nitride, that is impervious to humidity and other contaminants in the atmosphere prevents the contacts from degrading. The devices coated with silicon nitride used in this study, however, showed the effects of a conducting path in parallel with the 2-dimensional electron gas (2-DEG) at temperatures above 1.1 K which interferes with their use as resistance standards. Several possible causes of this parallel conduction are evaluated. On the basis of this work, two methods are proposed for protecting QHR devices with alloyed AuGe/Ni contacts from degradation: the heterostructure can be left unpassivated, but the alloyed contacts can be completely covered with a very thick (>3 μm) coating of gold; or the GaAs cap layer can be carefully etched away after alloying the contacts and prior to depositing a passivating silicon nitride coating over the entire sample. Of the two, the latter is more challenging to effect, but preferable because both the contact and the heterostructure are protected from corrosion and oxidation.
[Contact: Kevin C. Lee, (301) 975-4236]

SEMICONDUCTOR MICROELECTRONICS

Compound Materials

Recently Published

Bennett, H.S., **High Dopant and Carrier Effects In Gallium Aluminum Arsenide: Band Structure, Effective Carrier Concentrations and Mobilities**, Journal of Applied Physics, Vol. 83, No. 6, pp. 3102-3110 (15 March 1998).

[See Device Physics and Modeling.]

Analysis and Characterization Techniques

Recently Published

Kopanski, J.J., Marchiando, J.F., Berning, D.W., Alvis, R., and Smith, H.E., **Scanning Capacitance Microscopy Measurement of Two-Dimensional Dopant Profiles Across Junctions**, Journal of Vacuum Science and Technology B, pp. 339-343 (Jan/Feb 1998).

Cross-sectioned p^+/p and p-n junction test structures were imaged with a scanning capacitance microscope (SCM). To maintain a constant difference capacitance, our SCM utilizes an electronic attenuator circuit with a dynamic range of 20 V to less than 1 mV. Dopant profiles are extracted from SCM images using a formalism, which rapidly determines the theoretical SCM response from a database of calculated C-V curves. A dopant profile from a p^+/p junction determined via constant difference capacitance SCM is compared to a secondary ion mass spectroscopy profile from similar structures.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Marchiando, J.F., **Model Database for Determining Dopant Profiles from Scanning Capacitance Microscope Measurements**, Journal of Vacuum Science and Technology B, Vol. 16, No. 1, pp. 463-470 (Jan/Feb 1998).

To help correlate scanning capacitance microscope measurements of silicon with uniformly doped concentrations, model capacitance curves are calculated and stored in a database that depends on the probe-tip radius of curvature, the oxide thickness, and the dopant dent. The oxide thicknesses range from 5 nm to 20 nm, the dopant concentrations range from 10^{17} to 10^{20} cm^{-3}, and the probe-tip curvature is set to 10 nm. The cone-shaped probe is oriented

normal to the sample surface, so that the finite-element method in two dimensions may be used to solve Poisson's equation in the semiconductor region and Laplace's equation in the oxide and abient regions. The equations are solved within the semi-classical quasi static approximation, where capacitance measurement depends only on the charge due to majority carriers, with inversion and charge trapping effects being ignored. Comparison with one-dimensional-related models differs as much as 200% over the given doping range. For shallow gradient profiles satisfying quasiuniformity conditions, the database is used directly to find the doping profile. Converting a 512 × 512 point image takes less than 2 min.
[Contact: Jay F. Marchiando, (301) 975-2088]

Device Physics and Modeling

Released for Publication

Booth, J.C., and Holloway, C.L., **Expressions for the Conductor Loss of Superconductor Planar Structures of Arbitrary Thickness**.

[See Microwave and Millimeter-Wave Metrology.]

Hill, D.A., **A Plane-Wave, Integral Representation for Fields in Reverberation Chambers**.

[See Radiated EMI.]

Williams, D.F., **Metal-Insulator-Semiconductor Transmission Lines**.

[See Microwave and Millimeter-Wave Metrology.]

Device Physics and Modeling

Recently Published

Bennett, H.S., **High Dopant and Carrier Concentration Effects In Gallium Aluminium Arsenide: Band Structure, Effective Carrier Concentrations and Mobilities**, Journal of Applied Physics, Vol. 83, No. 6, pp. 3102-3110 (15 March 1998).

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 $Ga_{1-x}Al_yAs$. These calculations and the recently reported majority and minority electron and hole mobilities now give together an internally self-consistent description of carrier transport across the heterostructure interfaces will reduce the number of unknown or variational parameters in simulators for heterolstructuers and should lead to improved predictive capabilities for III-V device simulators. Even though this paper reports on the $GaAs/Ga_{1-x}Al_yAs$ system at 300 K, other ternary or elemental semiconductors may be treated by the same theory. Also, the theory and models summarized there are valid for temperatures other than 300 K.
[Contact: Herbert S. Bennett, (301) 975-2079]

Kim, J.S., **A Matrix Formulation of Magnetoresistance for an Arbitrary *J*-Fold Multicarrier Semiconductor System Via The Reduced-Conductivity-Tensor Scheme in the Nonquantizing Regime**, Journal of Applied Physics, Vol. 84, No. 1, pp. 292-300 (1 July 1998).

In this article, a matrix formulation of magnetoresistance in semiconductors is presented for an arbitrary *J*-fold multicarrier system which is based on the reduced-conductivity-tensor scheme and applicable in the nonquantizing regime where Landau orbital quantization is negligible. In the formalism, a unique expression of the magnetoresistance is deduced in terms of two vectors which depend on the carrier densities and mobilities, and three matrices which represent various inter-carrier couplings under the applied magnetic field. In particular the mobility-difference matrix plays a key role, and its simple form strongly suggests a two-carrier model of magnetoresistance for a narrow continuum distribution. Explicit closed-form formulas of magnetoresistance are derived for the two-carrier ($J = 2$) and three-carrier ($J = 3$) systems as special cases of the general formalism. The field dependence and asymptotic behavior of the magnetoresistance are also discussed, and a two-

carrier model of magnetoresistance is formally proposed.
[Contact: Jin S. Kim, (301) 975-2238]

Integrated-Circuit Test Structures

Released for Publication

Cresswell, M.W., Guillaume, N.M.P., Allen R.A., Guthrie, W.F., Ghoshtagore, R.N., Owen III, J.C., Osborne, Z., Sullivan, N., and Linholm, L.W., **Extraction of Sheet-Resistance from Four-Terminal Sheet Resistors in Monocrystalline Films Having Non-Planar Geometries**, to be published in the Proceedings of the 1998 International Conference on Microelectronic Test Structures, Kanazawa, Japan, March 23-26, 1998.

This paper describes methods for the extraction of sheet resistance from V/I measurements made on four-terminal sheet resistors incorporated into electrical linewidth test structures patterned with non-planar geometries in monocrystalline silicon-on-insulator films. The end application is using the uniquely high repeatability and low cost of electrical CD (Critical Dimension) metrology to serve as a secondary reference in establishing a traceability path for CD-reference artifacts.
[Contact: Michael W. Cresswell, (301) 975-2072]

Microfabrication Technology

Released for Publication

Milanović, V., Ozgur, M., DeGroot, D., Jargon, J., Gaitan, M., and Zaghloul, M.E., **Characterization of Broadband Transmission for Coplanar Waveguides In CMOS Silicon Substrates**.

[See Microwave and Millimeter-Wave Metrology.]

Plasma Processing

Released for Publication

Christophorou, L.G., and Olthoff, J.K., **Electron Interactions with C_3F_8**.

To aid the many and diverse applications for which perfluoropropane (C_3F_8) is suited, we critically evaluate and synthesize existing knowledge on electron scattering and electron energy-loss processes for the C_3F_8 molecule, and provide recommendations for the most reliable data. We also draw attention to electron-interaction data that are not presently available, but are needed for modeling the behavior of C_3F_8 in practical uses, especially plasma processing.
[Contact: Loucas G. Christophorou, (301) 975-2432]

Plasma Processing

Recently Published

Christophorou, L.G., and Olthoff, J.K., **Electron Interactions with C_2F_6**, Journal of Physical and Chemical Reference Data, Vol. 27, No. 1, pp. 1-29 (1998).

Perfluoroethane (C_2F_6, hexafluoroethane) is a man-made gas with many important applications (e.g., in the aluminum industry, the semiconductor industry, plasma chemistry and etching technologies, and pulsed power switching). In these and other uses, knowledge of the interactions of slow electrons (kinetic energies less than about 100 eV) is fundamental in optimizing performance parameter involved in the particular application. We, therefore, have critically evaluated and synthesized existing knowledge on electron interactions with C_2F_6. The following cross sections and their intercomparison are presented and discussed: total electron scattering, momentum transfer, integral elastic, differential elastic, differential vibrational, vibrational inelastic, total ionization, partial ionization, total dissociation, and electron attachment. Information is presented also on the coefficients for electron impact ionization, effective ionization, electron attachment, and electron transport (lateral diffusion coefficient and drift velocity), as well as on the rate constant for electron attachment as a function of the mean electron energy and gas temperature. While some information is available for these cross sections, additional measurements are needed for each of them, especially for inelastic scattering and momentum transfer. No published data are available for dissociation of C_2F_6 into neutral fragments. The coefficients are generally better known than the cross sections, although further measurements on electron diffusion coefficients and electron attachment at high

EIN values are indicated.
[Contact: Loucas G. Christophorou, (301) 975-2432]

Wang, Y., Van Brunt, R.J., and Olthoff, JK., **Mass Spectrometric Measurement of Molecular Dissociation in Inductively Coupled Plasmas**, Journal of Applied Physics, Vol. 83, No. 2, pp. 703-708.

The dissociation fraction of molecules in radio-frequency, planar, inductively-coupled plasmas are measured for mixtures of oxygen, nitrogen, sulfur hexafluoride, and chlorine in argon. A modified Gaseous Electronics Conference RF Reference Cell with an inductively-coupled source is used to produce the discharges, with pressures ranging from 1.3 Pa to 5.3 Pa and applied powers from 100 W to 300 W. Neutrals are sampled from the side of the discharge, and the degree of dissociation is determined mass spectrometrically by comparison of the intensities of the parent peaks with the plasma power on and off. Measured dissociation levels of O_2 in Ar:O_2 mixtures ranged from 0.02 (2%) to 0.08 (8%), while dissociation levels for Ar:SF_6 mixtures ranged from 0.92 to 0.98, depending on the plasma conditions. The degree of dissociation of mixtures was less than 2% for all plasma conditions studied.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Reliability

Recently Published

Chen, Y., Suehle, J.S., Shen, B., Bernstein, J., Messick, C., and Chaparala, P., **A New Technique to Extract TDDB Acceleration Parameters From Fast Q_{bd} Tests**, to be published in the Proceedings of the 1997 Integrated Reliability Workshop, Lake Tahoe, California, October 13-16, 1997, pp. 67-69 (1998).

A new technique is proposed to extract long-term constant voltage stress time-dependent dielectric breakdown (TDDB) acceleration parameters from highly accelerated constant current injection breakdown tests. This is the first time that an accurate correlation of the highly accelerated breakdown tests to long-term TDDB tests has been presented.
[Contact: John S. Suehle, (301) 975-2247]

Schafft, H.A., **Reliability Test Chips: NIST 33 & NIST 34 for JEDEC Inter-Laboratory Experiments and More**, Proceedings of the 1997 International Integrated Reliability Workshop Final Report, Lake Tahoe, California, October 13-16, 1997, pp. 144-145 (1998).

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.
[Contact: Harry A. Schafft, (301) 975-2234]

Suehle, J.S., **Electrical and Reliability Characterization of Ultra-Thin Film Dielectrics: Trends and Challenges**, Future Fab International, Vol. 1, No. 4, pp. 321-324 (1998).

The reliability of gate oxides is becoming a critical concern as oxide thickness is scaled below 5 nm in advanced CMOS technologies. Unlike devices fabricated with earlier generation technologies, advanced CMOS devices will operate with higher gate electric fields and direct tunneling currents passing through the gate dielectric.

Characterizing the reliability of ultra-thin gate oxides presents a new challenge to quality and reliability engineers. Traditional testing techniques will not be applicable for monitoring and characterizing the integrity and reliability of ultra-thin films. Charge-to-breakdown (Q_{bd}) tests may no longer provide meaningful information since direct tunneling currents can inject a significant amount of charge at low electric fields. Quasi or soft breakdown events in ultra-thin films make catastrophic breakdown difficult to observe. This requires the modification of the failure criteria in standardized reliability tests. In addition, quantum mechanical effects and polysilicon gate electrode depletion must now be considered when determining the oxide electric field.

This article reviews the issues presented above and discusses the challenges of characterizing the integrity and reliability of ultra-thin gate oxides.

[Contact: John S. Suehle, (301) 975-2247]

SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

DC and Low-Frequency Metrology

Released for Publication

Burroughs, C.J., Benz, S.P., Hamilton, C.A., Kinard, J.R., Lipe, T.E., and Sasaki, H., **Thermoelectric Transfer Difference Measurement of Thermal Converters Using a Josephson Source**, to be published in the Proceedings of the Conference on Precision Electromagnetic Measurement, Washington, DC, July 6-10, 1998.

We have measured the thermoelectric transfer difference of a single junction and a multijunction thermal voltage converter (TVC) using a Josephson source and compared the results to similar measurements using a conventional semiconductor source. Both sources use the fast reversed DC method. The Josephson source is an array of 16 384 SNS Josephson junctions that is rapidly switched between voltage states of +0.5 V, 0 V, and -0.5 V. A marginally significant difference is detected between measurements with the different sources.
[Contact: Samuel P. Benz, (303) 497-5258]

Kinard, J.R., Lipe, T.E., Childers, C.B., and Avramov-Zamurovic, S.A., **Comparison of High Voltage Thermal Converter Scaling to a Binary Inductive Voltage Divider**, to be published in the Proceedings of the 1998 Conference on Precision Electromagnetic Measurements Digest, Washington, DC, July 6-10, 1998.

High-voltage thermal converters (HVTCs) are used as standards of ac-dc difference and for the measurement and calibration of ac voltage up to 1000 V and 100 kHz. Their multiplying resistors can be compensated to yield small ac-dc differences by using adjustable internal shields; however, the ac-dc differences of HVTCs may vary as functions of warm-up time, applied frequency, and applied voltage. Voltage coefficients between 100 V and 1000 V can be quite significant compared to calibration uncertainties, and can be major sources of error in the buildup process used to characterize the HVTCs. Formal and informal international intercomparisons of HVTCs have revealed variations among the participating laboratories. The present work was undertaken to compare the scaling accuracy of HVTCs to the completely independent principle of a binary inductive voltage divider.
[Contact: Joseph R. Kinard, (301) 975-4250]

Reintsema, C.A., Grossman, E.N., Koch, J.A., Kinard, J.R., and Lipe, T.E., **Thermal Transfer Measurements at Microwatt Power Levels**, to be published in the Proceedings of the Conference on Precision Electromagnetic Measurements Digest, Washington, DC, July 6-10, 1998.

This paper presents the design, fabrication, and preliminary results for a thermal transfer standard operating at a power level of 10 μW, or less, and at temperatures below 10 K. The new converter employs a superconducting-resistive-transition edge thermometer.
[Contact: Carl D. Reintsema, (303) 497-5052]

Souders, M.T., **Code Probability of A/D Converters with Random Input Noise**, to be published in the Proceedings of the 1998 IEEE Instrumentation and Measurement Technology Center Conference, St. Paul, Minnesota, May 18-20, 1998.

The specific architecture of an A/D converter influences the code probability distributions that result from random input noise. In particular, the output codes of successive approximation A/D converters have a spiked distribution, and its variance is half that of the corresponding input noise. In addition, the distribution has a small bias. These and other related results are derived, and are qualitatively supported by measurement data on a real 16-bit A/D converter.
[Contact: Michael T. Souders, (301) 975-2406]

DC and Low-Frequency Metrology

Recently Published

Oldham, N., and Parker, M., **NIST Multifunction Calibration System**, NIST Special Publication, 250-46 (February 1998).

The NIST automated Multifunction Calibration

System (MCS) for voltage, current, and resistance is described. Developed primarily to calibrate digital multimeters and calibrators, the system can also be used to test thermal converters, and micropotentiometers. Methods for characterizing the MCS over a wide range of amplitudes at frequencies from dc to 30 MHz are described.
[Contact: Nile Oldham, (301) 975-2408]

Waveform Metrology

Released for Publication

Deyst, J.P., Paulter, N.G., Daboczi, T., Stenbakken, G.N., and Souders, T.M., **A Fast Pulse Oscilloscope Calibration System**, to be published in the Proceedings of the IEEE Instrumentation and Measurement Technology Center, St. Paul, Minnesota, May 18-20, 1998.

A system is described for calibrating high-bandwidth oscilloscopes using pulse signals. The fast pulse oscilloscope calibration system (FPOCS) is to be used to determine the step response parameters for digitizing oscilloscopes having bandwidths of ~20 GHz. The system can provide traceability to the U.S. National Institute of Standards and Technology (NIST). It is comprised of fast electrical step generation hardware, a personal computer and software, and a reference waveform, i.e., a data file containing an estimate of the step generator output signal. The reference waveform is produced by prior measurement of the step generator output signal (calibration step signal) by NIST. When the FPOCS is in use, the calibration step signal is applied to the device under test, which is an oscilloscope sampling channel. The measured step waveform is corrected for time base errors, then the reference waveform is deconvolved from it. The results are impulse, step, and frequency response estimates, and their associated parameters (e.g., transition duration, transition amplitude, -3 dB bandwidth) and uncertainties. The system and its components are described, and preliminary test results are presented.
[Contact: John P. Deyst, (301) 975-2437]

Stenbakken, G.N., and Deyst, J.P., **Time-Base Nonlinearity Determination Using Iterated Sine Fit Analysis**, to be published in the Proceedings of the 1998 IEEE Instrumentation and Measurement Technology Center, St. Paul, Minnesota, May 18-20, 1998.

A new method is presented to determine the time-base errors of sampling instruments. The method does not require a model for the time-base error and, thus, provides accurate estimates where model-based methods fail. Measurements of sinewaves at multiple phases and frequencies are used as test signals. A harmonic model is used to account for nonlinearity of the sampling channel and use of an independent method for estimating the channel noise and jitter allows an accurate estimate of the harmonic order. Methods are presented for separating the harmonics generated by the sampling channel from those generated by the time-base distortion. The use of an iterative sine fit procedure gives accurate results in a short time. A new weighting procedure is described which minimizes the error in the estimates. Guidelines are given for selecting good sets of test frequencies. Results are shown for both simulated and real data.
[Contact: Gerald N. Stenbakken, (301) 975-2440]

Cryoelectronic Metrology

Released for Publication

Burroughs, C.J., Benz, S.P., Hamilton, C.A., and Harvey, T.E., **Programmable 1 Volt DC Voltage Standard**, to be published in the Proceedings of the Conference on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998.

[See **FUNDAMENTAL ELECTRICAL MEASUREMENTS**.]

Zimmerman, N.M., and Cobb, J.L., **Charge Offset and Noise in SET Transistors**, to be published in the Proceedings of the 1998 Conference on Precision Electromagnetic Measurements Digest, Washington, DC, July 6-10, 1998.

[See **FUNDAMENTAL ELECTRICAL MEASUREMENTS**.]

Antenna Metrology

Released for Publication

Grossman, E.N., Koch, J.A., Reintsema, C.D., and Green, A., **Comparison of Method-of-Moments Predictions and Experiment for Lithographic Dipole Antenna Properties at 10 μm Wavelength**.

Dipole antennas designed for operation at 10 μm wavelength have been fabricated by optical lithography and their properties measured by detection of CO_2 laser radiation in integrated thin-film bolometers. We find a remarkably strong increase in cross-polarized signal as the antenna linewidth is increased. The measured beam pattern is a saddle point at broadside (local minimum in the H-plane, local maximum in the E-plane) as predicted by standard method-of-moments theory.
[Contact: Erich N. Grossman, (303) 497-5102]

Kawalki, S.F., and Motohisa, K., **Comparison of Numerical and Analytical Monopole Nonplanarity Correction Factors**.

[See Radiated EMI.]

Sorgnit, J., Mora, P., Muth, L.A., and Wittmann, R.C., **Uncertainty Analysis Procedures for Atlantic Test Range Dynamic Radar cross Section Measurements**, to be published as NISTIR 5073.

The Atlantic Test Range, Naval Air Warfare Center Aircraft Division at Patuxent River, Maryland, conducts dynamic radar cross section measurements on aircraft. This document, which follows general guidelines proposed by the National Institute of Standards and Technology, discusses the assessment of uncertainty in radar cross section measurements at the Atlantic Test Range.
[Contact: Lorant A. Muth, (303) 497-3603]

Antenna Metrology

Recently Published

Johnk, R.T., and Ondrejka A.R., **Time-Domain Calibrations of Sensors**, NIST Technical Note 1392 (February 1998).

This technical note covers in detail the procedures that are necessary to measure the receiving transfer function of broadband electric-field sensors using direct-pulse, time-domain methods. The calibration techniques presented here are applied to a cone and ground plane system in the 50 MHz to 14 GHz frequency range, as well as to a TEM cell in the 10 MHz to 100 MHz range. Measurement results using both types of facilities are presented for selected D-Dot sensors. In addition to a comparison of results from the two measurement facilities in the overlapping frequency range, a thorough combined uncertainty analysis is presented.
[Contact: Robert J. Johnk, (303) 497-3737]

Noise Metrology

Recently Published

Randa, J., Rice, J., Achkar, J., Colard, T., Sinclair, M, Wiliams, G., Buchholz, F.-I., and Schubert, D., **International Comparison of Noise-Temperature Measurements at 2, 4, and 12 GHz**, to be published in the Proceedings of the Conference on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998.

We report results of a recent international comparison of thermal noise-power measurements, performed under the auspieces of CIPM/CCE. The noise temperatures of two solid-state sources with GPC-7 connectors were measured at 2, 4, and 12 GHz. All results agreed within the expanded uncertainties. The comparison was performed in accordance with the guidelines recently adopted by the CCE.
[Contact: James Randa, (303) 497-3150]

Microwave and Millimeter-Wave Metrology

Released for Publication

Booth, J.C., and Holloway, C.L., **Expressions for the Conductor Loss of Superconductor Planar Structures of Arbitrary Thickness**.

We present closed form expressions of the attenuation constant due to conductor loss for superconducting coplanar waveguide (CPW) and microstrip lines, which are valid for any arbitrary conductor thickness. The closed form expression makes use of a numerically determined quantity (the stopping distance Δ) which depends on the materials

properties and edgeshape of the superconducting transmission line. Once this is determined, the attenuation constant for any planar geometry can be obtained without any further numerical calculation, making this technique attractive for use in the design of circuits utilizing superconducting planar elements. The results of this calculation are compared with full numerical calculations, and also with experimental data on high Tc coplanar transmission lines, illustrating both the accuracy and applicability of the calculation for determining the conductor loss of superconducting circuit elements.
[Contact: James C. Booth, (303) 497-7900]

Milanović, V., Ozgur, M., DeGroot, D., Jargon, J., Gaitan, M., and Zaghloul, M.E., **Characterization of Broadband Transmission for Coplanar Waveguides In CMOS Silicon Substrates**.

This paper presents characteristics of microwave transmission in coplanar waveguides (CPWs) on silicon substrates fabricated through commercial CMOS foundries. Due to the CMOS fabrication, the metal strips of the CPW are encapsulated in thin films of silicon dioxide. Many test sets were fabricated with different line dimensions, all on *p*-type substrates with resistivities in the range from 1.0 Ω•cm to 20.0 Ω•cm. Propagation constant and characteristic impedance measurements were performed at frequencies from 0.1 GHz to 40 GHz, using a vector analyzer and through-reflect-line (TRL) multiline deembeding technique. A quasi-TEM eqivalent circuit model was developed from the available process parameters, which accounts for the effects of the electromagnetic fields in the CPW multilayer dielectric cross-section to obtain accurate circuit representation for the effects of the transverse fields.
[Contact: Michael Gaitan, (301) 975-2070]

Williams, D.F., **Metal-Insulator-Semiconductor Transmission Lines**.

This paper investigates the one-dimensional metal-insulator-semiconductor transmission line. It develops closed-form expressions for equivalent-circuit parameters, compares them to exact calculations, and explores their limitations. It also investigates the usual assumption of single mode propagation and shows that, in certain fairly common circumstances, the fundamental mode of propagation becomes so lossy that it can no longer be considered to be the dominant propagating mode.
[Contact: Dylan F. Willliams, (303) 497-3138]

Williams, D.F., Arz, U., and Grabinski, H., **Accurate Characteristic Impedance Measurement on Silicon**, to be published in the Proceedings of the 1998 IEEE MTT International Microwave Symposium Digest, Baltimore, Maryland, June 7-12, 1998.

This paper presents a new method that accurately determines the characteristic impedance of planar transmission lines printed on lossy dielectrics even when a contact-pad capacitance and conductance are large. We demonstrate the method on a transmission line fabricated on a highly conductive silicon substrate.
[Contact: Dylan F. Williams, (303) 497-3805]

Microwave and Millimeter-Wave Metrology

Recently Published

DeGroot, D.C., and Jargon, J.A., **Long Term Stability in a Calibrated Time-Domain Network Analyzer**, Proceedings of the 1998 Measurement Science Conference, Pasadena, California, February 5-6, 1998 (unpaged).

We report on a fully calibrated digital sampling oscilloscope with time-domain reflection/transmission (TDR/T) capabilities. This system, known as a time-domain network analyzer (TDNA), calibrates Fourier-transformed TDR/T waveforms using a conventional network analyzer error model, and is used to measure the rf and microwave responses of devices and interconnects. While our TDNA measurements closely match data obtained with a commercial frequency-domain network analyzer, we observe a difference in the TDNA results that increases with frequency. By comparing identical TDNA calibrations, we determine the upper TDNA system to be limited by the oscilloscope's ability to repeat measurements in the short term. Remarkably, this measurement uncertainty did not increase when making measurements as long as one week after the initial calibration.
[Contact: Donald C. DeGroot, (303) 497-7212]

Jargon, J.A., **Revised Uncertainty of the NIST 30 MHz Phase Shifter Measurement Service** Proceedings of the 1998 Measurement Science Conference, Pasadena, California, February 5-6, 1998 (unpaged).

Although the measurement service for 30 MHZ phase shifters has been in operation for many years at the National Institute of Standards and Technology (NIST), 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 of the system are due to the standard phase shifter, resolution of the comparison receiver, mismatch within the system, phase shift of the standard waveguide below-cutoff attenuator, and repeatability. 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 $\pm 0.28°$ per 30° increment.
[Contact: Jeffrey A. Jargon, (303) 497-3596]

Williams, D.F., Janezic, M.D., Ralston, A.R.K., and List, R.S., **Quasi-TEM Model for Coplanar Waveguide on Silicon**, Digest of the 1997 Electrical Performance of Electronics Packaging Conference, San Jose, California, October 27-29, 1997, pp. 225-228.

This paper compares a simple quasi-TEM model for coplanar waveguide fabricated on moderately doped silicon substrates to measurement. While the coplanar waveguide currents and magnetic fields are unaffected by the substrate, a simple capacitive model can accurately account for the effects of the substrate.
[Contact: Dylan F. Williams, (303) 497-3138]

Electromagnetic Properties

Released for Publication

Krupka, J., Derzakowski, K., Riddle, B., and Baker-Jarvis, J., **$TE_{01\delta}$ Dielectric Resonator Technique for Measurements of Complex Permittivity of Low Loss Dielectric Materials as a Function of Temperature**.

An application of a $TE_{01\delta}$ mode dielectric resonator is described for precise measurements of complex permittivity and the thermal effects of permittivity for isotropic materials. The Rayleigh-Ritz technique was employed to find a rigorous relationship between permittivity, resonant frequency and the dimensions of the resonant structure, with relative accuracy better than 10^{-3}. The influence of conductor loss and its temperature dependence was taken into account in the dielectric loss tangent evaluation. Complex permittivities of several materials, including cross-linked polystyrene, polytetraflouroethylene, and alimina, were measured in the temperature range of 300 K to 400 K. Absolute errors of permittivity measurements were assessed to be smaller than 0.2%, limited mainly by uncertainty in the sample dimensions. It is shown that for properly chosen sample dimensions, materials with dielectric loss tangents in the range of 5×10^{-7} to 5×10^{3} can be measured using the $TE_{01\delta}$ mode dielectric resonator technique.
[Contact: Bill F. Riddle, (303) 497-5752]

Krupka, J., Geyer, R.G., Barker-Jarvis, J.R., and Mazierska, J., **Measurements on the Complex permittivity of Microwave Circuit-Board Substrates Using the Split-Dielectric and Reentrant Cavity Methods**.

A system for measuring printed circuit boards and substrates using a combination of dielectric resonators and a reentrant cavity is developed. Dielectric loss tangents of substrates were measured with low to medium loss. The dielectric properties of both the inplane and out-of-plane permittivity of the substrate under test are determined. Measurement results for the permittivity of common substrate materials and printed wiring board materials are presented.
[Contact: Richard G. Geyer, (303) 497-5852]

Krupka, J., and Weil, C.M., **Recent Advances in Metrology for the Electromagnetic Characterization of Bulk Materials at Microwave Frequencies**, to be published in the Proceedings of the 12th International Microwave Conference, Krakow, Poland, May 20-22, 1998.

We present an overview of recent advances realized in methods of characterizing bulk electronic materials, as well as the rf surface impedance or superconductor films, at microwave frequencies. We discuss a variety of different measurement techniques, including their relevant advantages and disadvantages, with emphasis on nondestructive methods where applicable. Accurate measurements of low-loss materials require high-Q resonator techniques. Many examples of these are presented, including the TE_{01p} mode cylindrical cavity, the split post dielectric resonator for characterizing flat sheets, the dielectric rod resonator for measuring the rf surface resistance of superconductors, and the whispering gallery mode technique which provides the highest known sensitivity for dielectric loss measurements. Measurements of medium- to high-loss materials are best performed using broadband free-space methods, as well as transmission line techniques, such as waveguide, coaxial air line, or the open-ended coax probe.
[Contact: Claude M. Weil, (303) 497-5305]

Krupka, J., Rogowski, J., Baker-Jarvis, J., and Geyer, R.G., **Scalar Permeability Measurements of Microwave Ferrites Using Lumped Circuit, Coaxial Line, and Resonance Techniques**, to be published in the Proceedings of the 12th International Microwave Conference, Krakow, Poland, May 20-22, 1998.

Complex scalar permeability measurement results of microwave ferrites at frequencies, from 1 Hz to 20 GHz are presented. Three different techniques were used to perform the measurements. The method chosen depended on frequency and magnetic loss. At low frequencies, 1-10^5 Hz, we applied lumped parameter circuit techniques. With this technique, nonlinear permeability effects were measured. At higher frequencies, from 1 MHz up to gyromagnetic resonance, coaxial transmission line techniques were used. At frequencies above gyromagnetic resonance, a dielectric ring resonator technique was used. By combining all three methods, the real and imaginary parts of sample permeability, with magnetic loss factors that vary from 10^{-5} to 10^2, may be measured. In addition, nonlinear effects in ferrite materials and saturation magnetization may be evaluated.
[Contact: James Baker-Jarvis, (303) 497-5621]

Other Signal Topics

Released for Publication

Christophorou, L.G., Olthoff, J.K., and Green, D.S., **A Search for Possible "Universal-Application" Gas Mixtures**, to be published in the Proceedings of the Eighth International Symposium of Gaseous Dielectrics, Virginia Beach, Virginia, June 2-5, 1998.

[See Power Systems Metrology.]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Christophorou, L.G., Olthoff, J.K., and Green, D.S., **A Search for Possible "Universal-Application" Gas Mixtures**, to be published in the Proceedings of the Eighth International Symposium of Gaseous Dielectrics, Virginia Beach, Virginia, June 2-5, 1998.

In an effort to respond to the recent concerns over the possible impact of SF_6 on global warming, we have searched for an SF_6 substitute gas that could be used in high voltage equipment instead of pure SF_6-insulated apparatus. Of the many unitary, binary, and tertiary gases/mixtures that have been tested to date, SF_6-N_2 mixtures seem to be the most promising and most thoroughly characterized gaseous dielectric media besides pure SF_6. Based upon research conducted world-wide over the last few decades, it appears that the optimum composition of an SF_6 for both high voltage insulation (such as in gas-insulated transmission lines and gas-insulated transformers) and possibly also for arc and current interruption purposes may be in the range 40% to 50% SF_6 in N_2. Most of the existing data support the use of such mixtures for gas-insulated transmission lines and gas-insulated transformers, but their use for circuit breakers is still in question, requiring further exploration.
[Contact: Loucas G. Christophorou, (301) 975-2432]

Wang, Y., Han, X., Van Brunt, R.J., Las, T., Slowikowska, H., Horwath, J.C., and Schweickart, D.L., **Digital Recording and Analysis of Partial**

Discharges in Point-Dielectric Gaps, to be published in the Proceedings of the 1998 International Symposium on Electrical Insulation, Washington, DC, June 7-11, 1998.

Pulsating partial discharges (Pds) occurring in point-dielectric gaps under an alternating voltage have been measured with a newly developed digital recording system. The dielectric is a cast epoxy resin with Al_2O_3 filler. In this paper, we analyze and report statistical characteristics of the Pds including amplitude distribution, phase-of-occurrence distribution, as well as the phase distributions of the individually selected PD pulses, e.g., the first-occurring or second-occurring pulse in each cycle.
[Contact: Yicheng Wang, (301) 975-4278]

Pulse Power Metrology

Recently Published

Christophorou, L.G., and Olthoff, J.K., **Electron Interactions With C_2F_6**, Journal of Physical and Chemical Reference Data, Vol. 27, No. 1, pp. 1-29 (1998).

[See Plasma Processing.]

Magnetic Materials and Measurements

Released for Publication

Weil, C.M., Janezic, M.D., Jones, C.A., and Vanzura, E.J., **Measurement Intercomparisons of Dielectric and Magnetic Material Characterization**, to be published in the Proceedings of the Conference on Precision Electromagnetic Measurements Digest, Washington, DC, July 6-10, 1998.

We discuss the results of three NIST-organized intercomparisons of dielectric and magentic material characterization of rf-microwave frequencies. Two studies used the broadband coaxial air-line technique and the third used an air-filled stripline resonator. We present general conclusions learned from these studies.
[Contact: Claude M. Weil, (303) 497-5305]

Magnetic Materials and Measurements

Recently Published

Crawford, T.M., Rogers, C.T., Silva, T.J., and Kim, Y.K., **Second-Harmonic Magneto-Optic Kerr Effect from Spin-Valve Test Structures: Correlation with Magnetoresistance Response**, IEEE Transactions on Magnetics, Vol. 33, No. 5, pp. 3598-3600 (September 1997).

We have simultaneously measured the second-harmonic magneto-optic Kerr effect and the magnetoresistance of patterned $Ta/Ni_{81}Fe_{19}/Cu/Ni_{81}Fe_{19}/Ta$ spin-valve test structures. For fields applied parallel to the bias-current direction, we observed a one-to-one correlation between the magnetoresistance and the magnetization-dependent second-harmonic intensity. The dependence of the second-harmonic intensity on magnetic field indicates that the detected second-harmonic response arises largely from the top $Ni_{81}Fe_{19}/Ta$ interface. The existence of this one-to-one correlation implies that the second harmonic depends linearly on magnetization, thus offering a method for interface-specific magnetometry.
[Contact: Thomas J. Silva, (303) 497-5619]

Kos, A.B., Russek, S.E., Kim, Y.K., and Cross, R.W., **High Current Density Measurements of Giant Magnetoresistive Spin-Valves for Magnetic Recording and Sensor Applications**, IEEE Transactions on Magnetics, Vol. 33, No. 5, pp. 3541-3543 (September 1997).

High current density measurements on giant magnetoresistive NiFe-Cu-NiFe-FeMn spin-valve devices are presented. The spin-valve magnetoresistive response, $\Delta R/R$, is highly temperature dependent; at temperatures near the blocking temperature there is a considerable reduction of pinning field and decrease in device response. It is desirable to measure certain high-current density effects such as electromigration and self-field effects separately from the effects of ohmic heating. For this purpose, we introduce pulsed current techniques necessary to reduce ohmic heating in wafer-level device measurements and we deduce a required pulse width of 15 ns to minimize device heating.
[Contact: Steven E. Russek, (303) 497-5097]

Silva, T.J., and Kos, A.B., **Nonreciprocal Differential Detection Method for Scanning Kerr-Effect Microscopy**, Journal of Applied Physics, Vol. 81, No. 8, pp. 5015-5017 (15 April 1997).

We describe an optical detection scheme for scanning Kerr-effect microscopy (SKEM) which does not require modification of the magnetic state of a sample for domain observation. The scheme exploits the nonreciprocal nature of the magneto-optic Kerr effect (MOKE) to distinguish polarization rotation due to sample magnetization from other spurious sources, such as sample roughness and birefringence of the microscope optics. We present SKEM images of domain structures in lithographically patterned $Ni_{81}Fe_{19}$ elements which demonstrate the imaging capabilities of the new detection scheme for materials with typical MOKE magnitudes.
[Contact: Thomas J. Silva, (303) 497-7826]

Superconductors

Released for Publication

Booth, J.C., and Holloway, C.L., **Expressions for the Conductor Loss of Superconductor Planar Structure of Arbitrary Thickness**.

[See Microwave and Millimeter-Wave Metrology.]

Ekin, J.W., Xu, Y., Mao, S., Venkatesan, T., Wilder, C., Eddy, M., and Wolf, S., **Correlation Between d-Wave Pairing Behavior and Magnetic-Field Dependent Zero-Bias Conductance Peak**.

A conductance peak at zero-bias voltage is consistently observed in the tunneling characteristics of a series of oxide-superconductor/noble-metal systems in which the oxide superconductors ($YBa_2Cu_3O_{7-\delta}$ and $Tl_2Ba_2CaCu_2O$) show d-wave pairing behavior, but no zero-bias conductance peak (ZBCP) is observed in systems in which the superconductor ($Nd_{1.85}Ce_{0.15}CuO_4$) shows BCS-like s-wave pairing behavior. The amplitude of the ZBCP in both the Y- and Tl-oxide systems is monotonically suppressed by magnetic fields up to 12 Tesla. The ZBCP characteristics are nearly independent of film manufacturer, junction resistivity (from 10^{-8} Ω-cm^2 to 10^{-3} Ω-cm^2), oxygen-annealing treatment, and the noble-metal material used as a counter-electrode (including Au, Ag, and Pt). Explanations of the correlation between the ZBCP and d-wave behavior are considered in terms of the Anderson-Applebaum model for magnetic interface scattering and the midgap-state model for d-wave interface states.
[Contact: John W. Ekin, (303) 497-5448]

Goodrich, L.F., **III-2: Intercomparison Program in USA, Part 1: I_c Comparison**.

An extensive interlaboratory comparison was conducted on high-temperature superconductor (HTS) critical-current measurements. This study was part of an international cooperative effort through the Versailles Project on Advanced Materials and Standards (VAMAS). The study involved six U.S. laboratories that are recognized leaders in the field of HTS. This paper includes the complete results from this comparison of critical-current measurements on Ag-sheated $Bi_2Sr_2Ca_2Cu_3O_{10-x}$ (2223) tapes. The effects of sample characteristics, specimen mounting, measurement technique, and specimen damage were studied. The future development of a standard HTS measurement method is also discussed. Most of the evolution of this emerging technology has occurred in improvement of the performance of the conductors. The successful completion of this interlaboratory comparison is an important milestone in the evolution of HTS technology and marks a level of maturity that the technology has reached.
[Contact: Loren F. Goodrich, (303) 497-3143]

Goodrich, L.F., **III-2: Intercomparison Program in USA, Part 2: Simulator Round Robin Test**.

An interlaboratory comparison of critical current (I_c) measurements was conducted on the superconductor simulator, which is an electric circuit that emulates the extremely nonlinear voltage-current characteristic of a superconductor. These simulators are high precision instruments, and are useful for establishing the integrity of part of a superconductor measurement system. This study includes measurements from participating U.S. laboratories, with NIST as the central, organizing laboratory. This effort was designed to determine the level of uncertainty in I_c measurements due to uncertainties in the measurement apparatus, technique, or the analysis system. The participating laboratories

measured the superconductor simulator with a variety of methods including dc and pulse. This comparison indicated the presence of systematic biases and higher variability at low voltages in the I_c determinations of the measurement systems. All critical current measurements at a criterion of 10 μV on the I_c simulator were within 2% of the NIST value for nominal critical currents of 2 and 50 A. These results could significantly benefit superconductor measurement applications that require high-precision quality assurance.
[Contact: Loren F. Goodrich, (303) 497-3143]

ELECTROMAGNETIC INTERFERENCE

Radiated

Released for Publication

Hill, D.A., **A Plane-Wave, Integral Representation for Fields in Reverberation Chambers**.

A plane-wave, integral representation is presented for well-stirred fields in a reverberation chamber. The representation automatically satisfies Maxwell's equations in a source-free region, and the statistical properties of the fields are introduced through the angular spectrum which is taken to be a random variable. Starting with fairly simple and physically appropriate assumptions for the angular spectrum, a number of properties of the electric and magnetic fields and the power received by an antenna or a test object are derived. Many of these properties and test object responses are in agreement with other theories or with measured results. An important result for radiated immunity testing is that the ensemble (stirring) average of received power is equal to the average over plane-wave incidence and polarization.
[Contact: David A. Hill, (303) 497-3472]

Johnk, R.T., and Ondrejka A.R., **Time-Domain Calibrations of Sensors**, NIST Technical Note 1392 (February 1998).

[See Antenna Metrology.]

Kawalki, S.F., and Motohisa, K., **Comparison of Numerical and Analytical Monopole Nonplanarity Correction Factors**.

In the calibration of a monopole antenna using another monopole, the separation distance can be comparable to the length of one or both of the antennas. In this case, the magnitude and phase of the incident field may vary along the length of the antenna under test. This variation in incident field can lead to an error in the measured characteristics of the antenna under test. This paper presents a numerical procedure for evaluating a correction factor to account for the effect of the nonuniform field and also to account for effects due to mutual coupling between the two antennas. Results for this numerically compound correction factor are compared with results obtained from an analytical expression for some representative cases.
[Contact: Kanda Motohisa, (303) 497-5320]

Masterson, K.D., and Novotny, D.R., **Transmission Cross Sections of Optical-Fiber Feedthroughs for Suppression of Electromagnetic Interference**, to be pubished in the Proceedings of the 1998 IEEE International Symposium on Electromagnetic Compatability, Denver, Colorado, August 24-28, 1998.

Various optical-fiber, bulkhead adapter feedthroughs were tested over a range from 1 GHz to 16 GHz to determine how much they degraded the shielding effectiveness of electronic enclosures. The shielding effectiveness varied widely, from a low of about 20 dB for polymer adapters to a high of nearly 90 dB for an all-metal FC connector system. The theory and test methodology are outlined.
[Contact: Keith D. Masterson, (303) 497-3756]

OPTOELECTRONICS

Released for Publication

[Lehman, J., Sauvageau, J., Vayshenker, I., Cromer, C., and Foley, K., **Silicon Wedge Trap Detector for Optical Fiber Power Measurements**.

We have designed and built an optical fiber power detector based on a large area, silicon PIN photodiode and a concave mirror in a wedge-trap configuration. Four such detectors were evaluated at our NIST calibration facility and one additionally was tested in a production-measurement environment at Motorola. The detector responsivity as a function of

input beam position was highly uniform and varied less than 1% for angles of incidence ranging from 0° to ± 15°. Absolute spectral responsivity measurements, for both collimated as well as diverging light input wavelengths ranging from 672 nm to 852 nm, showed that 99% of the light is absorbed by the photodiode. Measurements of electrical current output as a function of optical power input ranging from a few nanowatts to a few milliwatts indicated a detector nonlinear responsivity of only 0.05%. This device can be a valuable measurement tool when calibration conditions require a transfer standard that will accommodate different optical fiber connector types, collimated laser light, or diverging light from optical fiber or lamp sources.
[Contact: John Lehman, (303) 497-3654]

Leonhardt, R.W., **Calibration Service for Laser Power and Energy at 248 nm**, NIST Technical Note 1394 (January 1998).

This document describes the calibration service provided by the National Institute of Standards and Technology (NIST) for laser power and energy at the excimer laser wavelength of 248 nm. The service supports the calibration of laser-power meters from 400 μW to 7.5 W, and energy meters from 80 μJ to 150 mJ per pulse. Typical expanded measurement uncertainties range from 1.6% to 2%. The measurement system, which includes a source laser, beam optics, and NIST reference standard calorimeters, is reviewed. Theory and design considerations for the reference calorimeters that correlate optical energy to NIST electrical standards are discussed. Critical components of the calorimeters and beam delivery system are specified. Measurement-system parameters and calibration procedures are examined. Types of laser meters suitable for calibration are delineated. A detailed analysis of sources of error, estimates of uncertainty, and expanded uncertainty are presented.
[Contact: Rodney W. Leonhardt, (303) 497-5162]

Masterson, K.D., and Novotny, D.R., **Transmission Cross Sections of Optical-Fiber Feedthroughs for Suppression of Electromagnetic Interference**, to be published in the Proceedings of the 1998 IEEE International Symposium on Electromagnetic Compatability, Denver, Colorado, August 24-28, 1998.

[See Radiated EMI.]

Rose, A.H., and Bruno, T.J., **The Observation of Metastable OH in Annealed Optical Fiber**.

We discuss the observation of metastable OH in annealed optical fibers. The source of the OH is attributed to the silica glass reactions with hydrogen and water. Fibers were heated from room temperature to 1200 °C with the polymer jacket. The spectral optical loss and combustion products of the jacket were measured. Fibers heated with the jacket showed an OH absorption at 1390 nm which peaked around 950 °C. Fibers heated with the jacket removed did not show any OH absorption. Fibers held at or above at 1200 °C began to devitrify.
[Contact: Allen H. Rose, (303) 497-5599]

OPTOELECTRONICS

Recently Published

Gilbert, S.L., and Swann, S.C., **NIST Special Publication 260-133, *Standard Reference Materials*: $^{12}C_2H_2$ Absorption Reference for 1510-1540 nm Wavelength Calibration - SRM 2517**, NIST Special Publication 260-133, (January 1998).

Standard Reference Material (SRM) 2517 is an optical-fiber-coupled absorption cell containing acetylene ($^{12}C_2H_2$) gas. It is intended for use in calibrating the wavelength scale of wavelength measuring instruments in the 1500 nm region. About 50 accurately measured absorption lines of the R and P branch of the $v_1 + v_3$ rotational-vibrational band of $^{12}C_2H_2$ are located between 1510-1540 nm. We have measured the pressure-induced shift of the lines and certify the SRM wavelengths with an expanded uncertainty (coverage factor $k = 2$) of ± 0.0006 nm. This publication describes the SRM, the NIST measurement procedure, and the uncertainty determination for SRM certification.
[Contact: Sarah L. Gilbert, (303) 497-3120]

Silva, T.J., and Kos, A.B., **Nonreciprocal Differential Detection Method for Scanning Kerr-Effect Microscopy**, Journal of Applied Physics, Vol. 81, No. 8, pp. 5015-5017 (15 April 1997).

We describe an optical detection scheme for

scanning Kerr-effect microscopy (SKEM) which does not require modification of the magnetic state of a sample for domain observation. The scheme exploits the nonreciprocal nature of the magneto-optic Kerr effect (MOKE) to distinguish polarization rotation due to sample magnetization from other spurious sources, such as sample roughness and birefringence of the microscope optics. We present SKEM images of domain structures in lithographically patterned $Ni_{81}Fe_{19}$ elements which demonstrate the imaging capabilities of the new detection scheme for materials with typical MOKE magnitudes.
[Contact: Thomas J. Silva, (303) 497-7826]

VIDEO TECHNOLOGY

Released for Publication

Boynton, P.A., and Kelley, E.F., **Small-Area Black Luminance Measurements on White Screen Using Replica Masks**, to be published in the Digest of Technical Papers, Society for Information Display International Symposium, Anaheim, California, May 17-22, 1998.

Luminance measurements of small areas of black pixels on white-screen backgrounds are often used as metrics in display measurements, such as character-stroke contrasts or deep modulation transfer functions. Serious errors may be made in measurements and subsequent ergonomic conclusions if glare contributions of the measurement are not considered. We show a simple method for accounting for glare corruption of luminance measurements by using replica masks.
[Contact: Paul A. Boynton, (301) 975-3014]

Kelley, E.F., **Flat Panel Display Measurements and Standards**, to be published in the Proceedings of the 1998 International Symposium Applications Seminar, Anaheim, California, May 17-22, 1998.

Display metrology is discussed as applied to flat panel displays. Topics include the importance of proper setup, expected measurement uncertainty vs. repeatability, and problems in making accurate light measurements. The role played by measurement diagnostics is considered and encouragement is given to employ such diagnostics routinely. A review of the status of international display standards is provided.
[Contact: Edward F. Kelley, (301) 975-3828]

X-RAY SPECTROMETRY

Released for Publication

Martinis, J.M., Irwin, K.D., Wollman, D.A., Hilton, G.C., Dulcie, L.L., and Bergren, N.F., **The next Generation of EDS: Microcalorimeter EDS with 3 eV Energy Resolution**, to be published in the 1998 Microscopy and Microanalysis Meeting, Atlanta, Georgia, July 12-16, 1998.

Semiconductor energy dispersive spectrometers, the most commonly used detectors for X-ray microanalysis, have after 30 years matured in technological development such that significant improvements in energy resolution are not expected in the future. We believe a revolutionary advance in X-ray microanalysis will occur in the next few years due to the development of new X-ray spectrometers based on microcalorimeters. Energy resolution comparable with wavelength dispersive spectrometers, 3 eV to 10 eV, has already been achieved; future detectors may reach a fundamental limit as low as 0.5 eV to 1 eV.
[Contact: John M. Martinis, (303) 497-3597]

Wollman, D.A., Irwin, K.D., Hilton, G.C., Dulcie, L.L., Bergren, N.F., Newbury, D.E., and Martinis, J.M., **Microcalorimeter EDS with 3 eV Energy Resolution**, to be published in the Proceedings of the 14th International Congress on Electron Microscopy, Cancun, Mexico, August 31-September 4, 1998.

We believe that a revolutionary advance in X-ray microanalysis will occur in the next few years due to the development of the microcalorimeter energy dispersive spectrometer (EDS), which combines the excellent energy resolution of a wavelength dispervise spectrometer (WDS) with the parallel energy detection of an EDS. The energy resolution of the microcalorimeter (3 eV to 10 eV) is now comparable to that of WDS; future microcalorimeter detectors may reach fundamental energy resolution limits as low as 0.5 eV to 1 ev.
[Contact: David A. Wollman, (303) 497-7457]

Wollman, D.A., Newbury, D.E., Hilton, G.C., Irwin, K.D., Dulcie, L.L., Bergren, N.F., and Martinis, J.M., **Measurement of Chemical Shifts Using a Microcalorimeter Energy-Dispersive Spectrometer**, to be published in the Proceedings of the 1998 Microscopy and Microanalysis Meeting, Atlanta, Georgia, July 12-16, 1998.

We report measurements of chemical shifts in the Fe L-lines of different Fe compounds obtained using a microcalorimeter energy dispersive spectrometer (EDS). The observed changes in peak position and relative intensity of the Fe-Lines are in agreement with measurements obtained using a wavelength dispersive spectrometer, demonstrating the usefulness of microcalorimeter EDS for high-resolution microanalysis.
[Contact: David A. Wollman, (303) 497-7457]

X-RAY SPECTROMETRY

Recently Published

Wollman, D.A., Irwin, K.D., Hilton, G.C., Dulcie, L.L., Newbury, D.E., and Martinis, J.M., **High-Resolution, Energy-Dispersive Microcalorimeter Spectrometer for X-Ray Microanalysis**, Journal of Microscopy, Vol. 188, Pt. 3, pp, 196-223 (December 1997).

We have developed a prototype X-ray microcalorimeter spectrometer with high-energy resolution for use in X-ray microanalysis. The microcalorimeter spectrometer system consists of a superconducting transition-edge sensor X-ray microcalorimeter cooled to an operating temperature near 1000 mK by a compact adiabatic demagnetization refrigerator, a superconducting quantum interference device current amplifier followed by pulse-shaping amplifiers and pileup rejection circuitry, and a multichannel analyser with computer interface for the real-time acquisition of X-ray spectra. With the spectrometer mounted on a scanning electron microscope, we have achieved an instrument response energy resolution of better than 10 eV full width at half-maximum (FWHM) over a broad energy range at real-time output count rates up to $105 s^{-1}$. Careful analysis of digital X-ray pulses yields an instrument-response energy resolution of $7 \cdot 2 \pm 0 \cdot 4$ eV FWHM at $5 \cdot 89$ keV for Mn $K\alpha_{1,2}$ X-rays from a radioactive ^{55}Fe source, the best reported energy resolution for any energy-dispersive detector.
[Contact: David A. Wollman, (303) 497-7457]

ADDITIONAL INFORMATION

Announcements

Knight, S., and Settle-Raskin, A., **Project Portfolio FY 1997 - The National Semiconductor Metrology Program**, NISTIR 5851 (May 1997).

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 24 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 5051 (September 1998).

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 5050 (August 1998).

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 5039 which listed the publications of the Electromagnetic Fields Division from January 1970 through July 1995. 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 1997).

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 5077 (September 1998).

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 1996. 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: Erick M. Secula, (301) 975-2050]

1997-1998 Calendar of Events

November 4-7, 1997 (Shanghai, China)

International Conference on Materials and Process Characterization for VLSI, 1997 (ICMPC'97). Co-sponsored by NIST and Institute of Microelectronics in Singapore, this course will provide an international forum for the exchange of information on materials and process characterization for semiconductor and integrated circuit technology with emphasis on diagnostics and control of materials and processes, failure and reliability analysis, and new analytical methods. The Shanghai location will provide good opportunities to establish contacts with a large number of scientists and technologies from the Pacific Rim and China.
[Contact: David G. Seiler, (301) 975-2054]

March 10-12, 1998 (San Diego, California)

Fourteenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM) 1998. Co-sponsored by NIST and IEEE, the symposium will present papers on current

thermal management, modeling and measurement work on electronic components and systems in the following areas: thermal characterization - component through system; analytical and computational modeling and simulation; experimental methods and applications; thermal design and testing for reliability; and thermal aspects of high temperature electronics.
[Contact: David L. Blackburn, (301) 975-2068]

March 23-27, 1998 (Gaithersburg, Maryland)

1998 International Conference on Characterization and Metrology for ULSI Technology. The purpose of this workshop is to bring together scientists and engineers interested in all aspects of the technology and characterization techniques for semiconductor device research, development, manufacturing, and diagnostics: chemical and physical, electrical, optical, in-situ, and real-time control and monitoring.

The Workshop provides a forum to present and discuss critical issues; problems and limits; evolving requirements and analysis needs; future directions; and key measurement principles, capabilities, applications, and limitations. It will comprise of formal invited presentation sessions and poster sessions for contributed papers. The Workshop is the second in a series. The first was held at NIST January 30 to February 2, 1995. Papers from that Workshop were published in *Semiconductor Characterization: Present Status and Future Needs* (AIP Press, New York, 1996), W. M. Bullis, D. G. Seiler, and A. C. Diebold, editors. The Workshop is sponsored by NIST, Semiconductor Electronics Division, National Semiconductor Metrology Program, Electronics and Electrical Engineering Laboratory; SEMATECH; Semiconductor Research Corporation; American Vacuum Society - Manufacturing Science and Technology Division; and Semiconductor Equipment and Materials International (SEMI).
[Contact: David G. Seiler, (301) 975-2074]

July 20-21, 1998 (Breckenridge, Colorado)

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

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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.

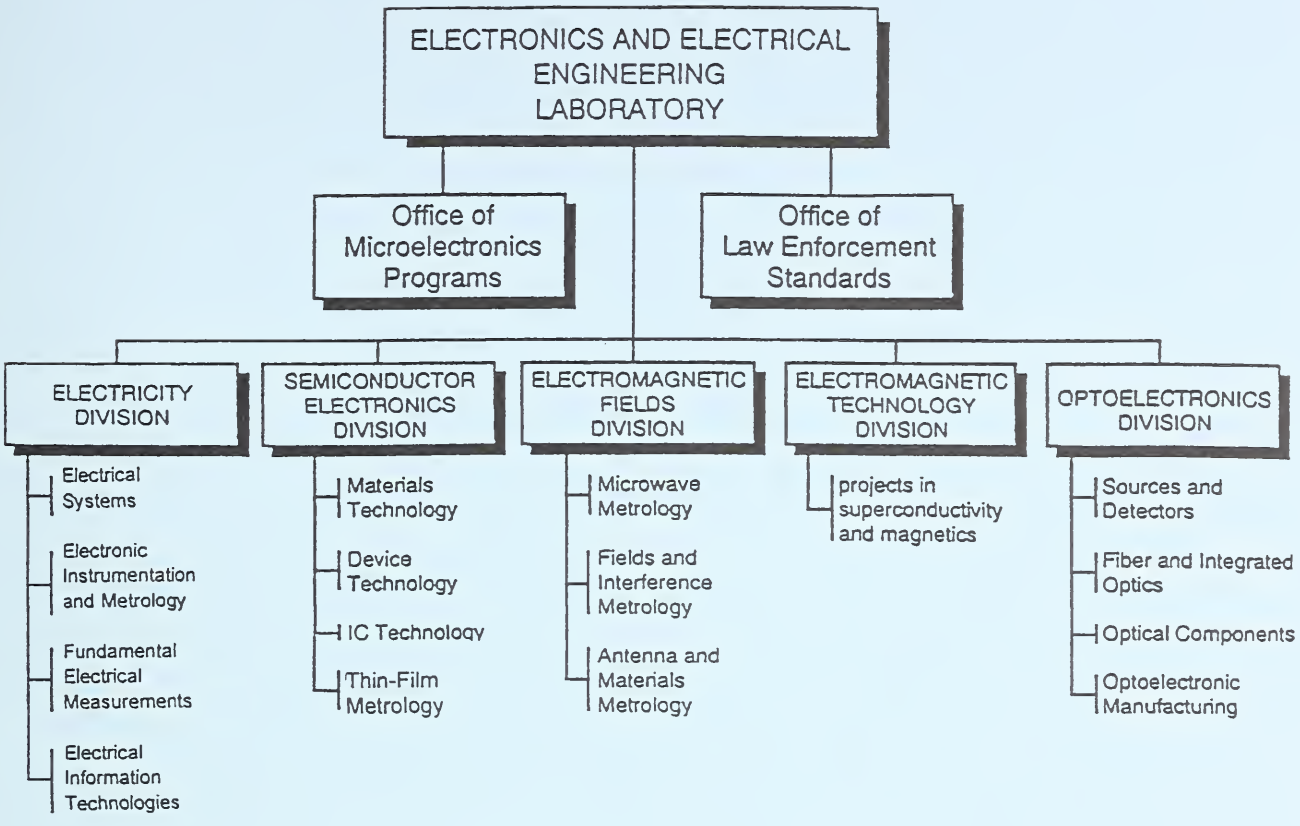
Technical insights presented by the rigorous certification process are available in NIST Special Publication 260-131, *Standard Reference Materials:* The Certification of 100 mm Diameter Silicon Resistivity SRMs 2541 through 2547 Using Dual-Configuration Four-Point Probe Measurements. Individual data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

NIST SILICON BULK RESISTIVITY STANDARD REFERENCE MATERIALS

DATE UPDATED: 30 JUNE 1997

NOMINAL RESISTIVITY (ohm·cm)	NEW SRMs	AVAILABILITY
0.01	2541	NOW!
0.1	2542	NOW!
1	2543	begining 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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