NISTIR 6100

Electronics and Electrical Engineering Laboratory

J. M. Rohrbaugh
Compiler

Technical Progress Bulletin

97-3

Covering Laboratory Programs,
July to September 1997,
with 1997-1998 EEEL Events Calendar

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

NIST

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Semiconductor Electronics Division
Gaithersburg, MD 20899-0001

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U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary
TECHNOLOGY ADMINISTRATION
Gary Bachula, Acting Under Secretary
for Technology
NATIONAL INSTITUTE OF STANDARDS
AND TECHNOLOGY
Raymond G. Kammer, Director

ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY
TECHNICAL PROGRESS BULLETIN, DECEMBER 1997 ISSUE

INTRODUCTION

This is the fifty-seventh 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 Unpublished papers appear under the subheading "Released for Publication."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, 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 32.

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 29.

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

GENERAL INFORMATION

Released for Publication

Zimmerman, N.M., **A Primer on Electrical Units in the Si**.

I examine the dissemination of the electrical units, from basic physical laws to commercial calibrations. I discuss the important distinction between realization and representation of units, which refers back to the basic coherency of the SI (Le Système International d'Unités) through the difference between practical units and SI units. I then outline the current dissemination of electrical units, heavily based on the fundamental quantum standards (Josephson voltage and quantized Hall resistance standards), as well as on a classic metrology experiment, the calculable capacitor. We will see that this dissemination is one way physicists test the accuracy of the basic physical laws. As an example of the dissemination, I also outline the chain from the primary voltage standard to the factory floor. Finally, I briefly discuss some areas of current research which have the potential to induce permanent changes in the definition of the SI units, in particular, the kilogram.
[Contact: Neil M. Zimmerman, (301) 975-5887]

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Released for Publication

Benz, S.P., Hamilton, C.A., Burroughs, C.J., Christian, L.A., and Przybysz, J.X., **Pulse-Driven Josephson Digital/Analog Converter**.

We have designed and demonstrated a pulse-driven Josephson digital/analog converter. When used as a programmable voltage standard, this device can synthesize metrologically accurate ac waveforms as well as stable dc voltages. We show through simulations that Josephson quantization produces a nearly ideal quantization noise spectrum when a junction is driven with a typical waveform produced by a digital code generator. This technique has been demonstrated in preliminary experiments with arrays of 1000 junctions clocked at frequencies up to 12 Gbit/s where sine waves of a few millivolts in amplitude were synthesized at frequencies up to 1 MHZ.
[Contact: Samuel P. Benz, (303) 497-5258]

Jeffery, A.M., Elmquist, R.E., Shields, J.Q., Lee, L.H., Cage, M.E., Shields, S.H., and Dziuba, R.F., **Determination of the Von Klitzing Constant and the Fine-Structure Constant through a Comparison of the Quantized Hall Resistance and the Ohm Derived from the NIST Calculable Capacitor**.

This paper describes a recent determination of the von Klitzing constant and the fine-structure constant by means of intercomparisons of values of the ohm as defined in the Système International d'Unités (SI), derived from the NIST calculable cross-capacitor, and values of the international practical unit of resistance derived from the integral quantum Hall effect. In this determination, the intercomparisons were made in a series of measurements lasting three years. A small difference is observed between this determination and a similar intercomparison at this same laboratory which was reported in 1988. The most recent value of the fine structure constant based on the experimental value and theoretical expression for the magnetic moment anomaly of the electron, which has the smallest uncertainty of any value currently available, is consistent with both of these results. The new value exceeds the 1990 conventional value of the von Klitzing constant $R_{K\text{-}90}$ by slightly more than twice the relative standard uncertainty of the present measurement, which is 2.4×10^{-8}.
[Contact: Ann Marie Jeffery, (301) 975-4246]

Kim, J., Sosso, A., and Clark, A.F., **Dynamics of a Pulse-Driven Josephson Junction**.

The periodic solutions and the step boundaries of a non-hysteretic Josephson junction driven by a square-wave pulse were found. The non-step region vanishes exponentially with the pulse repetition rate. The maximum value of any non-zero step width approaches to $2I_c$, where I_c is the critical current, with decreasing either the pulse repetition rate or the pulse duration time.
[Contact: Alan F. Clark, (301) 975-2139]

Lee, K.C., **Degradation of GaAs/AlGaAs Quantized Hall Resistors with AuGe/Ni Contacts**, to be published in the Journal of Research of the National Institute of Standards and Technology.

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 coatings, 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 a 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 conduction path in parallel with the two-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 are 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 contacts and the heterostructure are protected from corrosion and oxidation.
[Contact: Kevin C. Lee, (301) 975-4236]

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Recently Published

Gillespie, A.D., Fujii, K., Newell, D.B., Olsen, P.T., Picard, A., Steiner, R.L., Stenbakken, G.N., and Williams, E.R., **Alignment Uncertainties of the NIST Watt Experiment**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 605-608 (April 1997).

The effects of alignment uncertainties of the NIST watt balance with respect to local gravity and the magnetic-flux density of the balance have been analyzed. Techniques for measuring all quantities relevant to misalignment have been developed. The components of the relative combined standard uncertainty of the measured value of the watt due to alignment uncertainties have been reduced to 20 nW/W, and potential improvements in the balance design have been identified which could ultimately lead to a reduction of that uncertainty to below 10 nW/W.
[Contact: Aaron D. Gillespie, (301) 975-4056]

Jeffery, A.-M., **Obtaining the Unit of Capacitance from the Calculable Capacitor at the National Institute of Standards and Technology**, Proceedings of the 1997 National Conference of Standards Laboratories Workshop and Symposium, Atlanta, Georgia, July 27-31, 1997, Vol. 2, Sec. 6E, p. 745.

The capacitance unit at NIST is determined from a calculable cross capacitor. Its value of 0.5 pF is determined from the change in displacement of one screening electrode relative to another. This International System of units (Si) value is then transferred via a 10 pF fused silica capacitor to the bank of five 10 pF capacitors that maintains the U.S. capacitance unit. This bank is used to assign values to transfer standards used in NIST capacitance calibrations and for international comparisons. The calculable capacitor measurement is one of the most direct ways to obtain a capacitance unit in terms of the Si, but is an extremely difficult experiment to perform. Other alternatives are discussed including obtaining a capacitance unit via a dc quantum Hall effect device.
[Contact: Anne-Marie Jeffery, (301) 975-4246]

Jeffery, A.-M., Elmquist, R.E., Lee, L.H., Shields, J.Q., and Dziuba, R.F., **NIST Comparison of the Quantized Hall Resistance and the Realization of the Si OHM through the Calculable Capacitor**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 264-268 (April 1997).

The latest NIST result from the comparison of the quantized Hall resistance with the realization of the Si ohm obtained from the NIST calculable capacitor is reported. A small difference between the 1988 result and the present result has led to a re-evaluation of the sources and magnitudes of possible systematic errors.
[Contact: Ann-Marie Jeffery, (301) 975-4246]

Newell, D.B., Fujii, K., Gillespie, A.D., Olsen, P.T., Picard, A., Steiner, R.L., Stenbakken, G.N., and Williams, E.R., **The NIST Electronic Kilogram**, Proceedings of the 1997 Measurement Science Conference Symposium and Workshop, Pasadena, California, January 23-24, 1997 (unpaged).

The SI system's unit of mass is the last standard defined in terms of an artifact: *The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.* That

prototype is a century-old platinum-iridium alloy cylinder stored in a vault at the Bureau International des Poids et Mesures in Sèvres, France. The long-term stability of the kilogram and national prototypes with respect to each other, however, has a relative uncertainty of several parts times 10^{-8}, most likely due to the adsorption of airborne particulate matter increasing their mass or the subsequent cleaning process that is meant to return the masses to their previous values. It is, therefore, highly desirable to monitor, and ultimately re-define, the kilogram in terms of invariant quantities. To this end, the National Institute of Standards and Technology Watt Balance has been designed to measure the ratio of mechanical to electrical work, linking the meter, the artifact kilogram, and the second to the practical realizations of the ohm and the volt derived from the quantum Hall effect and the Josephson effect.
[Contact: David B. Newell, (301) 975-4228]

Reintsema, C.D., Grossman, E.N., Koch, J.A., Kinard, J.R., and Lipe, T.E., **AC-DC Transfer at Cryogenic Temperatures Using a Superconducting Transition-Edge Temperature Sensor**, Proceedings of the 1997 IEEE Instrumentation and Measurement Technology Conference, Ottawa, Ontario, Canada, May 19-21, 1997, pp. 726-727.

[See DC and Low-Frequency Metrology.]

Steiner, R.L., Gillespie, A.D., Fujii, K., Williams, E.R., Newell, D.B., Picard, A., Stenbakken, G.N., and Olsen, P.T., **The NIST Watt Balance: Progress Toward Monitoring the Kilogram**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 601-604 (April 1997). [Also published in the Digest of the 19996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 6-7.]

The National Institute of Standards and Technology watt balance is an experiment to compare measurements of the watt using electrical references (volt, ohm) to those using mechanical references (length, time, mass). A coil within a radial magnetic field has a dual use of: 1) generating a voltage by moving at some velocity to calibrate the magnetic flux density, and, 2) generating a force with electrical current to balance the gravitational force of a mass. This experiment has had several improvements made to it in the last year. These include the incorporation of three-laser interferometry and a refractometer to improve the velocity measurements, temperature control, and coil rotation damping to reduce drifts and stabilize laser and mechanical alignments, and a gravimeter to determine local gravity. Systematic errors and scatter in long-term measurements have been greatly reduced in the last year, but statistically significant deviations relative to within-run uncertainty still persist. The source of these deviations has not yet been identified. Recent within-run standard deviations are generally near 0.1 μW/W, which is the target precision of this present design.
[Contact: Richard L. Steiner, (301) 975-4226]

Zimmerman, N.M., Cobb, J.L., and Clark, A.F., **Recent Results and Future Challenges for the NIST Charged-Capacitor Experiment**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 294-298 (April 1997).

This paper reports on recent results of some of the work towards developing a new capacitance standard using single electron tunneling (SET) devices. In particular, we plan on using a SET pump to charge a cryogenic standard capacitor and measuring the voltage that develops. In this paper, we first briefly summarize recent results on 1) measurements of the ratio of two capacitors in a bridge configuration, using a SET transistor as the null detector, and 2) stability and leakage measurements on the cryogenic capacitors. We then discuss in some detail several of the as-yet unanswered challenges in this project, including the effects of stray capacitances and line impedance, and resulting requirements on the sensitivity of the SET null detector.
[Contact: Neil M. Zimmerman, (301) 975-5887]

SEMICONDUCTOR MICROELECTRONICS

Silicon Materials

Recently Published

Ehrstein, J.R., and Croarkin, M.C., ***Standard Reference Materials*: The Certification of 100 Diameter Resistivity SRMs 2541 through 2547 Using Dual-Configuration Four-Point Probe Measurements, NIST Special Publication 260-131** (August 1997).

This report documents the selection of material, the certification procedure and its control, and the analysis of measurement uncertainty for a family of new and improved Standard Reference Materials for

sheet resistance and resistivity of silicon wafers, SRMs 2541 through 2547, covering the resistivity range 0.01 Ω·cm through 200 Ω·cm. These SRMs, made from 100 mm silicon, replace previous SRM sets 1521 through 1523, which used 50.8 mm (2 in) diameter silicon at the same nominal resistivity levels.

The certification of the new SRMs uses a dual-configuration four-point probe procedure rather than the single-configuration procedure of ASTM F84, as used for previous SRMs. The new SRMs offer better handling compatibility with current user instrumentation, better uniformity of wafer thickness and of resistivity, more extensive spatial characterization of the near-center wafer resistivity, and reduced measurement uncertainty compared to the SRMs they replace.

The general procedures for the certification measurements, the control of the certification process, and the analysis of the results are based on experience gained from numerous preliminary experiments that allowed evaluation of the importance and relative magnitude of many possible measurement effects. The validity and effectiveness of the resulting certification and control procedures were tested during the analysis of results from the first of the SRMs to be certified, that at 200 Ω·cm. The body of this report details the background and principles of the certification process and the approach to analyzing the experimental data needed to calculate the uncertainty of the certified values. This report details the evaluation of underlying components of uncertainty that apply to all SRM levels. Additional components derived from statistical analyses of the actual certification data are done separately for each SRM level and certification for these latter two SRMs have not been completed at this time and will be documented in supplements to this report when available.
[Contact: James R. Ehrstein, (301) 975-2060]

McMarr, P.J., Mrstik, B.J., Twigg, M.E., Hughes, H.L., Anc, H.L., Roitman, P., and Garcia, G.A., **Optimization of the Electrical Properties of Low-Dose SIMOX Wafers**, Proceedings of the 1997 Government Microcircuit Applications Conference (GOMAC), Las Vegas, Nevada, March 10-13, 1997, pp. 314-317.

The purpose of this study was to determine if high-quality silicon-on-insulator substrates could be manufactured using a low-cost, commercially viable process. The manufacturing technology chosen for study was the SIMOX process. Current-voltage measurements were performed on the insulator and breakdown field values determined. Spectroscopic ellipsometry and cross-section transmission electron microscopy measurements were used to characterize the insulator. The results of these measurements were correlated with the breakdown field values of the insulator.
[Contact: Peter Roitman, (301) 975-2077]

Roitman, P., Bagchi, S., Krause, S., Garcia, G.A., McMarr, P.J., Mrstik, B.J., and Hughes, H.L., **Buried Oxide Defects in Low Dose SIMOX Processing Conditions, Precipitates and Defects, and Detection Methods**, Proceedings of the 1997 Government Microcircuit Applications Conference (GOMAC), Las Vegas, Nevada, March 10-13, 1997, pp. 318-321.

Two procedures for low-defect density, low-dose SIMOX have been developed: optimized dose and room temperature implant. The localized microscopic nature of defect structures in low-dose SIMOX is reviewed. The effect of process variables on defects in investigated using electron microscopy and capacitor current-voltage measurement. Both process approaches show promise.
[Contact: Peter Roitman, (301) 975-2077]

Compound Materials

Released for Publication

Bennett, H.S., **High Dopant and Carrier Concentration Effects in Gallium Aluminum Arsenide: Densities of States and Effective Intrinsic Carrier Concentrations**.

The changes in carrier densities of states and effective intrinsic carrier concentrations due to high dopant and carrier concentration effects in $Ga_{1-y}Al_yAs$ are calculated at 300 K for donor densities between 10^{16} cm^{-3} and for acceptor densities between 10^{16} cm^{-3} and 10^{20} cm^{-3}. The mole fraction of AlAs, y, varies between 0.0 and 0.3 in these calculations. The Klauder self-energy method (fifth level of approximation) is used to describe the effects of carrier-dopant ion interactions on the conduction and valence bands and their densities of states. The effects of carrier-carrier interactions (majority-carrier exchange and minority-carrier correlation) are calculated by extending the work of Abram *et al.* to

include both finite wave numbers and finite temperatures. This paper is the first reported use of one theory to treat both sides of the Mott transition. Namely, solutions of the very non-linear integral equations that result from the Klauder fifth-level approximation are obtained for low-dopant densities that involve both bound and continuum states and for high-dopant densities that involve primarily continuum states. The results show that quantitatively changes occur in densities of states, locations of band-edges, and effective intrinsic-carrier concentrations from the values usually used by researchers, particularly, from those values found in most device simulators. These results are important for predictive simulations of optoelectronic, microwave, and electronic devices because such computer simulations require physically reasonable values of the changes in the locations of band-edges, densities of states, and effective intrinsic carrier concentrations. These changes, as functions of carrier density, dopant density, and mole fraction of AlAs, may be readily incorporated into existing simulators through the use of "look-up tables" based on the results reported in this paper.
[Contact: Herbert S. Bennett, (301) 975-2079]

Mirin, R.P., Gossard, A.C., and Bowers, J.E., **Characterization of InGaAs Quantum Dot Lasers with a Single Quantum Dot Layer as an Active Region**, to be published in the Proceedings of the 8th International Conference on Modulated Semiconductor Structures, Santa Barbara, California, July 13-18, 1997.

[See OPTOELECTRONICS.]

Richter, C.A., and Pellegrino, J.G., **Quantum Measurements of Interface Roughness in High-Mobility GaAs/AlGaAs Device Structures**.

We illustrate that quantum interference effects can be used to quantitatively measure interface roughness at semiconductor interfaces. The properties of two-dimensional electron systems are utilized to measure microroughness at buried interfaces by using an electrical measurement technique based on the physics of weak localization. In addition to providing quantitative values, this method is nondestructive, measuring the interface roughness *in situ*; and due to its fundamental nature, is insensitive to modeling. We use this measurement method to quantitatively measure interface roughness in GaAs/AlGaAs heterostructures. We observe that growth conditions affect roughness, and that larger values of roughness as measured by this weak localization technique lead to lower mobility devices. A second measurement method is presented in this work to measure interface roughness in very high mobility material systems that is based upon quantum interference in small ring structures.
[Contact: Curt A. Richter, (301) 975-2082]

Compound Materials

Recently Published

Bluhm, H., Wadas, A., Wiesendanger, R., Roshko, A., Aust, J.A., and Nam, D., **Imaging of Domain-Inverted Gratings in $LiNbO_3$ by Electrostatic Force Microscopy**, Applied Physics Letters, Vol. 71, No. 1, pp. 146-148 (7 July 1997).

[See OPTOELECTRONICS.]

Analysis and Characterization Techniques

Released for Publication

Richter, C.A., and Pellegrino, J.G., **Quantum Measurements of Interface Roughness in High-Mobility GaAs/AlGaAs Device Structures**.

[See Compound Materials.]

Analysis and Characterization Techniques

Recently Published

Bluhm, H., Wadas, A., Wiesendanger, R., Roshko, A., Aust, J.A., and Nam, D., **Imaging of Domain-Inverted Gratings in $LiNbO_3$ by Electrostatic Force Microscopy**, Applied Physics Letters, Vol. 71, No. 1, pp. 146-148 (7 July 1997).

[See OPTOELECTRONICS.]

Knopp, K.J., Ketterl, J.R., Christensen, D.H., Pearshall, T.P., and Hill, J.R., **Simultaneous Monitoring of Wafer- and Environment-States During Molecular Beam Epitaxy**, Proceedings of the Materials Research Society Symposium, Boston, Massachusetts, December 2-6, 1996, pp. 761-766.

[See OPTOELECTRONICS.]

Marchiando, J.F., Kopanski, J.J., and Lowney, J.R., **A Model Database for Determining Dopant Profiles from Scanning Capacitance Microscope Measurements**, Proceedings of the 4th International Workshop on Measurement, Characterization, and Modeling of Ultra-Shallow Doping Profiles in Semiconductors, Research Triangle Park, North Carolina, April 6-9, 1997, pp. 65.1-65.3.

To help correlate scanning capacitance microscope measurements with dopant concentrations, model capacitance curves are calculated for uniformly doped silicon and stored in a database that depends on the probe-tip radius of curvature, the oxide thickness, and the dopant density. The oxide thicknesses range from 5 nm to 20 nm, the dopant concentrations range from 10^{17} cm^{-3} to 10^{20} cm^{-3}, and the probe-tip radius of curvature is set to 10 nm. The cone-shaped probe-tip 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 ambient regions. The equations are solved within the semi-classical quasi-static approximation, where the capacitance measurement depends only on the majority charge carriers, and inversion and charge trapping may be ignored. Comparison with one-dimensional-related models differs as much as 200% over the given doping range. For shallow gradient profiles satisfying quasi-uniformity conditions, the database is used directly to find the doping profile. Converting a 512 x 512 image takes less than 2 min. Comparison with a measured capacitance-voltage curve is briefly discussed.
[Contact: Jay F. Merchant, (301) 975-2088]

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 Spring Meeting, Montreal, Canada, May 4-9, 1997, pp. 183-193.

[See Insulators and Interfaces.]

Devices Physics and Modeling

Released for Publication

Adams, V., Joshi, Y., and Blackburn, D.L., **Package Geometry Considerations in Thermal Compact Modeling Strategies**, to be published in the Proceedings of the Thermal Management of Electronic Systems EUROTHERM Seminar N° 58 Conference, Nantes, France, September 24-26, 1997.

[See Power Devices.]

Bennett, H.S., **High Dopant and Carrier Concentration Effects in Gallium Aluminum Arsenide: Densities of States and Effective Intrinsic Carrier Concentrations**.

[See Compound Materials.]

Device Physics and Modeling

Recently Published

Mantooth, H.A., and Hefner, A.R., Jr., **Electrothermal Simulation of an IGBT PWM Inverter**, IEEE Transactions on Power Electronics, Vol. 12, No. 3, pp. 474-484 (May 1997).

[See Power Devices.]

Marchiando, J.F., Kopanski, J.J., and Lowney, J.R., **A Model Database for Determining Dopant Profiles from Scanning Capacitance Microscope Measurements**, Proceedings of the 4th International Workshop on Measurement, Characterization, and Modeling of Ultra-Shallow Doping Profiles in Semiconductors, Research Triangle Park, North Carolina, April 6-9, 1997, pp. 65.1-65.3.

[See Analysis and Characterization Techniques.]

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 Spring Meeting, 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 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 than 100 Å can be as large as 23% and 13%, respectively.
[Contact: Nhan V. Nguyen, (301) 975-2044]

Microfabrication Technology

Released for Publication

Lee, K.C., **Degradation of GaAs/AlGaAs Quantized Hall Resistors with AuGe/Ni Contacts**, to be published in the Journal of Research of the National Institute of Standards and Technology.

[See FUNDAMENTAL ELECTRICAL MEASUREMENTS.]

Pauza, A.J., Booij, W.E., Hermann, K., Moore, D.F., Blamire, M.G., Rudman, D.A., and Vale, L., **Electron Beam Damaged High-T_c Josephson Junctions**.

[See Cryoelectronic Metrology.]

Microfabrication Technology

Recently Published

Milanović, V., Gaitan, M., Bowen, E.D., Tea, N.H., and Zaghloul, M.E., **Thermoelectric Power Sensor for Microwave Applications by Commercial CMOS Fabrication**, IEEE Electron Device Letters, Vol. 18, No. 9, pp. 450-452 (September 1997).

[See Microwave and Millimeter-Wave Metrology.]

Zimmerman, N.M., **A Simple Fabrication Method for Nanometer-Scale Thin-Metal Stencils**, Journal of Vacuum Science and Technology B, Vol. 15, No. 2, pp. 369-372 (March 1997).

We describe a simple fabrication method for the production of thin-metal stencils using the overlayer film from lift-off patterning. While such stencils have been fabricated before using other techniques, this method has several advantages. The advantages include the fact that this method requires only the capability to perform standard lithography and thin-film deposition, but does not require any dry etching or other sophisticated capabilities. In addition, by using the negative of the lithographically defined pattern, we show that a small number of trenches of lateral size down to 100 nm, in an otherwise continuous stencil, can be produced using electron-beam lithography with very little beam rastering necessary (i.e., small exposure times). We also argue that any group with access to simple photolithography and thin-film deposition facilities should be able to make these stencils, with openings much smaller than the lithography resolution limit.
[Contact: Neil M. Zimmerman, (301) 975-5887]

Plasma Processing

Released for Publication

Christophorou, L.G., and Olthoff, J.K., **Electron Interactions with C_2F_6.**

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 the critical parameters 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 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 each of these cross sections, additional

measurements are needed for each of them, especially for inelastic electron scattering and momentum transfer. No 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 *E / N* values are indicated.
[Contact: Loucas G. Christophorou, (301) 975-2432]

Wang, Y., Van Brunt, J.K., and Olthoff, J.K., **Mass Spectrometric Measurement of Molecular Dissociation in Inductively-Coupled Plasmas**.

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 o 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 were less than 2% for all plasma conditions studied.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Plasma Processing

Recently Published

Christophorou, L.G., Olthoff, J.K., and Wang, Y., **Electron Interactions with CCl_2F_2**, Proceedings of the 23rd International Conference on Phenomena in Ionized Gases, Toulouse, France, July 16-22, 1997, pp. I-68-I-69.

We have completed a critically evaluated synthesis of the available information on cross sections and rate coefficients for collisional interactions of low energy electrons with dichlorodifluoromethane. This gas has many industrial uses and is of significant atmospheric and environmental interest, particularly for electron collision cross sections, a reasonably complete set of cross sections and transport data are assembled.
[Contact: Loucas Christophorou, (301) 975-2432]

Rao, M.V.V.S., Olthoff, J.K., Christophorou, L.G., and Van Brunt, R.J., **Negative Ion Kinetic-Energy Distributions and Ion-Neutral Reactions in O_2 and CO_2 Townsend Discharges at High *E/N***, Proceedings of the 1997 International Symposium on Electron Molecule Collisions and Ion and Electron Swarms, Engelberg, Switzerland, July 18-22, 1997, pp. P60/1-P60/2.

Electron attaching gases, such as O_2, CO_2, and SF_6, are commonly used ingredients in various gaseous discharges employed in plasma processing techniques. Negative ions formed in such gas discharges are known to influence the electrical discharge characteristics by altering the electron density. An understanding of the role played by negative ions in gas discharges and other applications requires a knowledge of their kinetics because negative ions can be converted to other charge carriers either by electron transfer or by electron detachment in collisions with neutrals. In this paper, we report measurements of kinetic-energy distributions (KEDs) of O_2^- and O^- ions in O_2 and O^- in CO_2 discharges at high electric field-to-gas density ratios (*E/N*). The KEDs of the negative ions are explained by the possible electron-molecule collisions and ion-neutral reaction mechanisms. The mean ion energies are derived from the ion energy distributions and the relative abundance of the negative ions are determined from the flux measurements.
[Contact: James K. Olthoff, (301) 975-2431]

Rao, M.V.V.S., Olthoff, J.K., and Van Brunt, R.J., **Negative Ion-Energy Distributions and Ion-Neutral Reactions in SF_6 Townsend Discharges at High Electric Field-To-Gas Density Ratios (E/N)**, Proceedings of the 20th International Conference on the Physics of Electronic and Atomic Collisions, Vienna, Austria, July 23-29, 1997, p. MO 202.

Knowledge of kinetic-energy distributions (KEDs) of both positive and negative ions in discharges are important in determining the reaction coefficients for modeling discharges. It is well known that stable SF_6^- ions are produced by electron-attachment to SF_6 with relatively large cross sections for thermal electrons. Other processes, such as collisional electron-detachment and collision-induced dissociation, are also important because they affect the density and

identity of negative ions in the discharge. We report here measurements on relative concentrations and KEDs of SF_6^-, SF_5^-, F_2^-, and F^- ions produced in SF_6 Townsend discharges at high *E/N*. The F^- is the dominant ion, and is produced with relatively high kinetic energies. The KEDs of SF_6^- and SF_5^- are observed to be Maxwellian at 5.5 kTd, but begin to deviate from it with increasing *E/N*, while those of F^- are non-Maxwellian at all *E/N*. The F_2^- signal increases with increasing *E/N*; however, its signal is relatively weak compared to the other ions. The mean ion energies and relative abundances of these ions are derived from the measured KEDs, and are reported.
[Contact: James K. Olthoff, (301) 975-2431]

Rao, M.V.V.S., Olthoff, J.K., and Van Brunt, R.J., **Translational Kinetic-Energy Distributions of Positive Ions Produced in Townsend Discharges of SF_6 at High Electric Field-to-Gas Density Ratios (*E/N*)**, Proceedings of the Twentieth International Conference on the Physics of Electronic and Atomic Collisions, Vienna, Austria, July 23-29, 1997, p. MO 203.

Gas discharges, in which ions possess a broad energy distribution due to gas-phase collision processes, are commonly used for etching of semiconductors. In order to model plasmas and to understand the etching phenomena, it is necessary to have information on kinetics of both charged particles and neutral species, e.g., reaction products and radicals. For practical reasons, electron attaching gases are of interest because the difference between the ionization and attachment rate increases strongly with the applied electric-field strength. For example, in the case of SF_6, the lowest attainable electric field-to-gas density ratio (*E/N*) for a self-sustained stable dc discharge in the Townsend region is about 5×10 Vm^2 (5 kTd), below which the discharge remains oscillatory. To our knowledge, no data have been reported on ion kinetic energies and relative abundances of ions at high *E/N* for SF_6 in the Townsend discharges. This paper is concerned with the measurements of kinetic-energy distributions and relative concentrations of ions produced in stable dc discharge in SF_6.
[Contact: James K. Olthoff, (301) 975-2431]

Rao, M.V.V.S., Van Brunt, R.J., and Olthoff, J.K., **Kinetic-Energy Distributions of Positive Ions Produced in Townsend Discharges of Oxygen at High Electric Field-to-Gas Density Ratios**, Proceedings of the 1997 International Symposium on Electron Molecule Collisions and Ion and Electron Swarms, Engelberg, Switzerland, July 18-22, 1997, pp. 61/1-P61/2.

Understanding the details of ion production and transport in electrical gas discharges is of importance to both the semiconductor industry, which uses gas-phase discharges for microelectronic device production, and the electric equipment industry, which uses electronegative gases as high-voltage insulation. Oxygen is a gas of interest in these areas because of its common usage in plasma discharges for etching and for cleaning processes, and also its nearly universal presence in high-voltage insulation systems as an impurity. In this report, we present measurements of kinetic-energy distributions (KEDs) for positive ions (O_2^+ and O^+) in oxygen, for dc Townsend discharges with electric field-to-gas density ratios (*E/N*) comparable to what may be found in the sheaths of radio-frequency plasmas. Analysis of these KEDs provided an insight into the production mechanisms of these ions, the dominant processes affecting the transport of the ions, and the validity of assuming equilibrium ion distributions at high values of *E/N*. From the measured KEDs, the mean ion energies are derived, and the relative ion intensities are obtained.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Power Devices

Released for Publication

Adams, V., Joshi, Y., and Blackburn, D.L., **Package Geometry Considerations in Thermal Compact Modeling Strategies**, to be published in the Proceedings of the Thermal Management of Electronic Systems EUROTHERM Seminar N° 58 Conference, Nantes, France, September 24-26, 1997.

Computational fluid dynamics simulations are performed for a Plastic Quad Flat Package in a standard enclosure for natural convection thermal measurements to assess the impact of compact thermal modeling strategies on solution run time and temperature prediction. The effect of package die and pad size, relative to the package dimensions, is examined to determine their effect on the adequacy of the predicted thermal behavior from these compact

thermal models. Simulation results using a simple block on lead model and a thermal resistance model are compared to those from a detailed model of the package. For large die size where heat transfer within the package is nearly one-dimensional, these compact models adequately predict the thermal behavior of the electronic package. The results also show that, for the packages studied, die size has a dominant effect over pad size on temperature predictions from compact models.
[Contact: David L. Blackburn, (301) 975-2068]

Power Devices

Recently Published

Mantooth, H.A., and Hefner, A.R.,Jr., **Electrothermal Simulation of an IGBT PWM Inverter**, IEEE Transactions on Power Electronics, Vol. 12, No. 3, pp. 474-484 (May 1997).

A recently developed electrothermal network simulation methodology is used to analyze the behavior of a full-bridge, pulse-width-modulated, voltage-source inverter, which uses insulated gate bipolar transistors (IGBTs) as the switching devices. The electrothermal simulations are performed using the Saber circuit simulator and include control logic circuitry, IGBT gate drivers, the physics-based IGBT electrothermal model, and thermal network component models for the power-device silicon chips, packages, and heat sinks. It is shown that the thermal response of the silicon chip determines the IGBT temperature rise during the device switching cycle. The thermal response of the device TO247 package and silicon chip determines the device temperature rise during a single phase of the 60 Hz sinusoidal output. Also, the thermal response of the heat sink determines the device temperature rise during the system startup and after load-impedance changes. It is also shown that the full electrothermal analysis is required to accurately describe the power losses and circuit efficiency.
[Contact: Allen R. Hefner, Jr., (301) 975-2071]

SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

DC and Low-Frequency Metrology

Recently Published

Dziuba, R.F., and Kile, L.L., **An Automated Guarded Bridge System for the Comparison of 10 kΩ Standard Resistors**, Proceedings of the 1997 IEEE Instrumentation and Measurement Technology Conference, Ottawa, Ontario, Canada, May 19-21, 1997, pp. 394-396.

An automated guarded resistance bridge has been specifically developed at the National Institute of Standards and Technology for the calibration of high-quality 10 kΩ standard resistors. The system is designed to intercompare up to 30 nominally-equal, four-terminal resistors with a resolution and combined relative standard uncertainty of 0.01 μΩ/Ω and 0.02 μΩ/Ω, respectively. With a few minor modifications, the system is capable of comparing other nominally-equal resistors in the range 100 Ω to 1 MΩ.
[Contact: Ronald F. Dziuba, (301) 975-4239]

Elmquist, R.E., and Dziuba, R.F., **Loading Effects in Resistance Scaling**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 322-324 (April 1997). [Also published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 334-335.]

Reference resistors are affected by the heating of the resistor element caused by the measurement current. The effects of such loading are complex and can change in magnitude as a function of the initial state of the resistor and the external environment. This paper describes a method for determining relative load coefficients by using cryogenic current comparator ratio measurements in a two-step scaling process. Previously undiscovered loading effects are analyzed using a resistance element made from copper, which has an easily measured change of resistance with temperature. The magnitude of loading effects in several types of resistors is listed.
[Contact: Richard E. Elmquist, (301) 975-6591]

Jarrett, D.G., **Automated Guarded Bridge for Calibration of Multimegohm Standard Resistors from 10 MΩ to 1 TΩ**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 325-328 (April 1997).

The implementation of an automated guarded bridge for calibrating multimegohm standard resistors is described. A guarded multimegohm bridge has been assembled with programmable dc calibrators in two of

the arms allowing multiple ratios and test voltages to be remotely selected. A programmable electrometer with a resolution of ± 3 fA in the current mode is used to measure the difference in currents flowing through the remaining two arms of the bridge consisting of unknown and standard resistors. The balancing algorithm used to estimate the calibrator setting required to obtain a null is described along with a graphical user interface that has been written to provide flexibility to the measurement system and improve control of the instrumentation. Evaluation of the multimegohm bridge from 10 MΩ to 1 TΩ is reported along with a comparison of the multimegohm bridge performance to that of the existing manual and semi-automated systems that the multimegohm bridge will replace.

Kinard, J.R., Lipe, T.E., and Childers, C.B., **Extension of the NIST AC-DC Difference Calibration Service for Current to 100 kHz**, Journal of Research of the National Institute of Standards and Technology, Vol. 102, No. 1, pp. 75-83 (January-February 1997).

The NIST calibration service for ac-dc difference of thermal current converters relies on multijunction thermal converters as the primary standards, and various thermal converters and thermoelements as the reference and working standards. Calibrations are performed by comparing the ac-dc difference of a customer's thermal current converter to the ac-dc difference of a NIST standard current converter. Typical artifacts accepted for calibration include single-junction thermoelements, multijunction thermal converters, and transfer shunts for use with thermoelements. This paper describes the standards on which the calibration service is based, and the results of the study to characterize the NIST standards over the extended frequency range from 50 kHz to 100 kHz at current from 1 mA to 20 A. The general method for the frequency extension at high frequency involves the use of thermoelements in the 5 mA range, with small frequency dependence, as the starting point for build-up and build-down chains to cover the whole range from 1 mA to 20 A.
[Contact: Joseph R. Kinard, (301) 975-4250]

Kinard, J.R., Lipe, T.E., Childers, C.B., Novotny, D.B., and Huang, D.-X., **High-Current Thin-Film Multijunction Thermal Converters and Multiconverter Modules**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 391-394 (April 1997). [Also published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 594-595.]

High-current, thin-film multijunction thermal converters (FMJTCs) have been fabricated at NIST with heater ranges from a few milliamperes to 1 A. Multiconverter modules containing high-current FMJTC's have also been constructed to measure currents up to 6 A at frequencies up to 100 kHz.
[Contact: Joseph R. Kinard, (301) 975-4250]

Kinard, J.R., Novotny, D.B., Lipe, T.E., and Huang, D.-X., **Development of Thin-Film Multijunction Thermal Converters at NIST**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 347-351 (April 1997). [Also published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 493-494.]

This paper gives an overview of the development of thin-film multijunction thermal converters (FMJTC's) at the National Institute of Standards and Technology (N). A historical perspective of film thermal converters is presented, followed by descriptions of the motivation, fabrication processes, physical characteristics, and the electrical properties of the FMJTC's produced at N. Integrated micropotentiometers that incorporate FMJTC's and thermal converters, produced by an alternative fabrication technology using a CMOS foundry, are also described. The paper concludes with a report on the present status of the FMJTC project and future directions.
[Contact: Joseph R. Kinard, (301) 975-4250]

Oldham, N.M., Avramov-Zamurovic, S., and Parker, M.E., **Exploring the Low-Frequency Performance of Thermal Converters Using Circuit Models and a Digitally Synthesized Source**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 352-355 (April 1997).

Low-frequency errors of thermal-voltage converters are described and estimated using a circuit model that includes easily measured parameters. A digitally synthesized source is used to confirm the estimated ac-dc differences in the 0.01 Hz to 40 Hz range.
[Contact: Nile M. Oldham, (301) 975-2408]

Oldham, N.M., Avramov-Zamurovic, S., Parker, M.E., and Waltrip, B.C., **Low-Voltage Standards in the 10 Hz to 1 MHz Range**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 395-398 (April 1997).

A step-down procedure is described for establishing voltage standards in the 2 mV to 200 mV range at frequencies between 10 Hz and 1 MHz. The step-down employs low-voltage thermal voltage converters and micropotentiometers. Techniques are given for measuring input impedance and calculating loading errors.
[Contact: Nile M. Oldham, (301) 975-2408]

Reintsema, C.D., Grossman, E.N., Koch, J.A., Kinard, J.R., and Lipe, T.E., **AC-DC Transfer at Cryogenic Temperatures Using a Superconducting Transition-Edge Temperature Sensor**, Proceedings of the 1997 IEEE Instrumentation and Measurement Technology Conference, Ottawa, Ontario, Canada, May 19-21, 1997, pp. 726-727.

A prototype, cryogenic thermal transfer device has been constructed and tested using a superconducting transition-edge thermal sensor.
[Contact: Erich N. Grossman, (303) 497-5102]

Waveform Metrology

Recently Published

Stenbakken, G.N., and Deyst, J.P., **Timebase Distortion Measurements Using Multiphase Sinewaves**, Proceedings of the 1997 IEEE Instrumentation and Measurement Technology Conference, Ottawa, Ontario, Canada, May 19-21, 1997, pp. 1003-1008.

Distortions in the timebases of equivalent-time oscilloscopes and digitizers cause nonlinear distortions of waveforms samples by them. This paper reports on a comparison of two methods of characterizing timebase distortion, using pure sinewave inputs of known frequency: the "sinefit" and the "analytic signal" methods. Simulations are used to compare the performance of the two methods versus different types of timebase distortion, different sinewave frequencies, number of different sinewave phases, levels of random noise, and levels of random jitter. The performance of the two methods varies considerably, dependent upon the input signal frequency and type of timebase distortion. Each method does much better than the other for certain cases.
[Contact: Gerard N. Stenbakken, (301) 975-2440]

Cryoelectronic Metrology

Released for Publication

Benz, S.P., Hamilton, C.A., Burroughs, C.J., Christian, L.A., and Przybysz, J.X., **Pulse-Driven Josephson Digital/Analog Converter**.

[See FUNDAMENTAL ELECTRICAL MEASUREMENTS.]

Booth, J.C., Beall, J.A., Ono, R.H., Stork, F.J.B., Rudman, D.A., and Vale, L.R., **Third-Order Harmonic Generation in High-Temperature Superconducting Coplanar Waveguides at Microwave Frequencies**.

We use third-harmonic measurements of coplanar waveguide (CPW) transmission lines to explore the behavior of nonlinearities in microwave devices fabricated from high-T_c superconductors. Our measurements focus on the effect of varying the CPW geometry, including center linewidth, line length, and film thickness, on the nonlinearity of the transmission line circuit as measured by the third-order intercept. The third-order intercepts decrease (indicating more nonlinearity) with increasing line length for all geometries studied. Also, differences in the third-order intercepts between lines of different linewidth and film thickness can be explained quantitatively by appropriately scaling the incident microwave power. These observations demonstrate that the sources of nonlinearity in our CPW transmission lines are distributed along the line length, and depend on the detailed form of the current distribution within the superconductor.
[Contact: David A. Rudman, (303) 497-5081]

Huber, M.E., Cory, A.M., Lumpkins, K.L., Nafe, F.N., Ranschler, J.O., Hilton, G.C., Martinis, J.M., and Steinbach, A.H., **DC SQUID Series Arrays with Intracoil Damping to Reduce Resonance Distortions**.

We report on low-noise dc Superconducting Quantum Interference Device (SQUID) series arrays with smooth dc characteristics incorporating intracoil

damping. The voltage-flux characteristics of these devices are reproducible upon repeated cool-down and do not require multiple heating/cooling cycles to eliminate trapped flux. The devices consist of 100 SQUIDs with individual signal and feedback coils connected in series. The total input inductance is 600 nH, and the peak-to-peak output modulation is 4 mV with a transfer function of 350 V/A. The equivalent input current noise is approximately 2 pA/$\sqrt{\text{Hz}}$. With these characteristics, these devices are useful as preamplifiers in microcalorimeter X-ray detectors.
[Contact: Gene C. Hilton, (303) 497-5679]

Leitner, A., Rogers, C.T., Price, J.C., Rudman, D.A., and Herman, D.R., **Semiconducting Properties of Nb-Doped Strontium Titanate Thin-Films Grown by Pulsed Laser Deposition**.

We report on the growth of epitaxial Nb-doped strontium titanate thin films on lanthanum aluminate substrates using pulsed laser deposition. X-ray diffraction and atomic force microscopy indicate that the films grow in the (100) orientation with surface roughness of ≈5 nm. The transport properties were measured from 300 K to 4 K. We find optimum doping and mobility for growth near 870 °C and chamber pressures below 2 × 10^{-6} Torr. Oxygen partial pressures above 1 × 10^{-7} Torr cause dramatic decreases in the film conductivity. The most highly doped samples display metallic behavior down to 4 K.
[Contact: David A. Rudman, (303) 497-5081]

Li, H.Q., Ono, R.H., Rudman, D.A., Vale, L.R., and Liou, S.H., **Multilayer Processing of High-T_c Films and Stacked Bicrystal Josephson Junctions**.

A new process for making high-temperature superconducting multilayer circuits is reported in detail. Proximity exposure was used to form controllable shallow edges which are required for the crossovers and interconnects. Small features with shallow edges can be achieved by the combination of contact exposure and proximity exposure. Stacked Josephson junctions on STO bicrystal substrates were prepared using this process and tested. A multilayer low-inductance dc-SQUID fabricated using this process shows large voltage modulation.
[Contact: Ronald H. Ono, (303) 497-3762]

Pauza, A.J., Booij, W.E., Hermann, K., Moore, D.F., Blamire, M.G., Rudman, D.A., and Vale, L., **Electron Beam Damaged High-T_c Josephson Junctions**.

Results are presented on the fabrication and characterization of high-T_c Josephson junctions in thin films of $YBa_2Cu_3O_{7-\delta}$ produced by the process of focused electron beam irradiation at 350 keV. The junctions produced using this technique have all the properties of an RSJ-like junction, with a uniform spatial current density profile, and a current density which can be tailored for a given operating temperature. The physical properties of the damaged layer (barrier) can be described as a superconducting material, of reduced T_c, which can be produced with a length of ≈15 nm. The properties of the barrier can be calculated using an SNS junction model with no boundary resistance. From the SNS model we can predict the scaling of the critical current-normal resistance (I_cR_n) product and gain insight into the factors controlling junction reproducibility. Measured I_cR_n scaling data allow us to estimate the I_cR_n product of a junction given its current density and operating temperature. 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 of less than 1.4. Stability over several months has been demonstrated at room and fridge temperatures (297 K and 281 K) for junctions which have been initially over-damaged and then annealed at temperatures around 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. The production of 100 of these stabilized junctions could be accomplished in around 4 h of irradiation time. The I_cR_n scaling also indicates that junctions suitable for high sensitivity SQUIDs ($I_c \approx 100\ \mu A$) can be made with I_cR_n products of ≈120 μV.
[Contact: David A. Rudman, (303) 497-5081]

Cryoelectronic Metrology

Recently Published

Li, H.Q., Ono, R.H., Vale, L.R., Rudman, D.A., and Liou, S.H., **High Temperature Superconducting Josephson Junctions in a Stacked Bicrystal Geometry**, Applied Physics Letters, Vol. 71, No. 8, pp. 1121-1123 (August 1997).

Bicrystal grain boundary Josephson junctions were fabricated in a stack of two layers of $YBa_2Cu_3O_x$

separated by epitaxial $SrTiO_3$. Weak-link behavior was observed in the bridges formed in both layers that had similar shunted-junction characteristics, but significantly different critical currents. Characteristic voltages up to 1.9 mV were measured at 4.5 K. The resonant structure was seen in the current-voltage characteristics of the upper-layer junctions, and interactions between junctions in the two layers were evident.
[Contact: Ronald H. Ono, (303) 497-7705]

Morris-Hotsenpiller, P.A., Roshko, A., Lowekamp, J.B., and Rohrer, G.S., **Growth Morphologies of Heteroepitaxial Rutile Films on Sapphire Substrates**, Journal of Crystal Growth, Vol. 174, pp. 424-433 (July 1997).

The growth morphologies of (100), (101) and (001) rutile films grown on sapphire substrates by the ion-beam sputter deposition technique have been examined as a function of film/substrate orientation, film thickness, substrate surface preparation, growth rate, and growth temperature. The rutile films of each orientation appear to grow via island (Volmer-Weber) type growth. At the early stages of growth (≤100 Å) on as-polished substrates, the roughnesses of the films grown at 725 °C and 3 Å/min are correlated to their lattice mismatches and inversely related to the calculated surface energies of their sapphire substrates. Thicker films (≥700 Å) have morphologies which are orientation dependent, appear to minimize their surface energies and are stable with respect to annealing. Rougher and slightly less crystallographically aligned (100) and (001) rutile films result from the more three-dimensional growth found on annealed sapphire substrates. Relatively small increases in the growth rate, at very low rates, can change the details of the surface structures present. The changes in the morphologies observed on films grown at lower temperatures indicate that the processes controlling their development have a strong temperature dependence at all stages. Comparisons were also made between (100) and (101) rutile films grown by the ion-beam sputter deposition and metalorganic chemical vapor deposition techniques under similar conditions. The chemical-vapor-deposited films have morphologies which are similar to the ion-beam sputtered films with comparable thicknesses, but grown at lower temperatures.
[Contact: Alexana Roshko, (303) 497-5420]

Ono, R.H., Li, H.Q., Vale, L.R., Rudman, D.A., and Liou, S.H., **Multilayer Processing of High-T_c Films and Josephson Devices**, Extended Abstracts of the 6th International Superconductive Electronics Conference, Berlin, Germany, June 25-28, 1997, pp. 34-36.

We present the results of a novel fabrication process that produces bicrystal junctions stacked one above the other. These high-temperature superconducting devices show conventional weak-link Josephson behavior and intriguing new phenomena, such as capacitively-coupled high-frequency interactions between junctions.
[Contact: Ronald H. Ono, (303) 497-3762]

Roshko, A., Stork, F.J.B., Rudman, D.A., Aldrich, D.J., and Morris-Hotsenpiller, P.A., **Comparison of Heteroepitaxial $YBa_2Cu_3O_{7-\delta}$ and TiO_2 Thin Film Growth**, Journal of Crystal Growth, Vol. 174, pp. 398-408 (July 1997).

The growth of heteroepitaxial $YBa_2Cu_3O_{7-\delta}$ and TiO_2 thin films has been investigated as a function of deposition rate, film thickness, and deposition temperature. In spite of the fact that the two materials are grown at very different rates and undercoolings, the films are found to have similar growth mechanisms and dependences on film thickness and deposition temperature. Both types of films were found to have an island growth morphology, as shown by STM and AFM. The diameter of the islands was found to increase with the film thickness through a power law dependence. It is shown that this is not the result of a grain growth mechanism, but is consistent with that predicted for a coarsening mechanism. The density of the islands decreased exponentially with increasing substrate temperature. The temperature dependence is consistent with those of homogeneous nucleation and of a diffusion-controlled process. The similar characteristics of the films of these two different materials suggest that $YBa_2Cu_3O_{7-\delta}$ may be useful as a model system for studying heteroepitaxial oxide film growth.
[Contact: Alexana Roshko, (303) 497-5420]

Antenna Metrology

Released for Publication

Kent, B.M., and Muth, L.A., **On the Establishment of a Common RCS Range Documentation**

Standards Based on American National Standards Institute ANSI Z-540 and International Standards Organization ISO25.

The signature measurement community is well aware of the complexities of a modern Radar Cross Section (RCS) measurement range. These electromechanical systems, regardless of range type, contain a myriad of hardware and software in order to operate the range within its intended design parameters. Naturally, operating the range as designed helps assure that the range produces consistently high-quality data. Often, the job of keeping current range documentation may seem overwhelming, especially since there are currently no standards or guidelines for organizing such documentation.

This paper presents overview of ANSI/NCSL standard Z-540. ANSI/NCSL standard Z-540 in its simplest form offers a straightforward way to organize range documentation. We briefly discuss the major points and sections of ANSI Z-540, as well as how to organize a format-universal "range book." Since ANSI/NCSL Z-540 is the U.S. equivalent of International Standard (ISO) 25, it is especially useful for two reasons; (1) it appears to be applicable to RCS ranges, and (2) its quality control requirements are entirely consistent with the ISO 9002 series of quality standards. Properly executed, ANSI/NCSL Z-540 may greatly assist a range in producing, managing, and reporting technical RCS data where such ISO quality compliance is mandated by contractual commitments.
[Contact: Lorant A. Muth, (303) 497-3603]

Lieberman, A.G., and Vanderau, J.M., **Fixed and Base Station Antennas**, to be published as National Institute of Justice (NIJ) Standard-0204.02.

NIJ Standard-0204.02, Fixed and Base Station Antennas, establishes minimum structural, environmental, and radio frequency (rf) performance requirements and test methods for antennas that are used at base stations or other fixed sites by law enforcement agencies. It is intended that this standard is used as an aid to the selection and procurement of such antennas operating in the following law enforcement frequency bands: 25 MHZ to 50 MHZ, 150 MHZ to 174 MHZ, 406 MHZ to 512 MHZ, and 806 MHZ to 930 MHZ.
[Contact: A. George Lieberman, (301) 975-2757]

Muth, L.A., Wittmann, R.C., and Kent, B.M., **Interlaboratory Comparisons in Radar Cross Section Measurement Assurance**, to be published in the Proceedings of the 1997 Annual Meeting and Symposium, Antenna Measurement Techniques Association, Boston, Massachusetts, November 17-21, 1997.

The National Institute of Standards and Technology (NIST) is coordinating a radar cross section (RCS) interlaboratory comparison study using a family of standard cylinders developed at Wright Laboratories. As an important component of measurement assurance and of the proposed RCS certification program, interlaboratory comparisons can be used to establish repeatability (within specified uncertainty limits) of RCS measurements within and between measurement ranges. We discuss the importance of intercomparison studies in global standards metrology programs, examine recently conducted comparison studies at NIST, and give a status report on the first national RCS intercomparison study in progress. We also consider future plans.
[Contact: Lorant A. Muth, (303) 497-3603]

Skinner, J.P., Kent, B.M., Wittmann, R.C., Mensa, D.L., and Andersh, D., **Radar Image Normalization and Interpretation**, to be published in the Proceedings of the 1997 Annual Meeting and Symposium, Antenna Measurement Techniques Association, Boston, Massachusetts, November 17-21, 1997.

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. Wittmann, (303) 497-3326]

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**, to be published in the Proceedings of the 1997 Annual Meeting and Symposium, Antenna Measurement Techniques Association, Boston, Massachusetts, November 17-21, 1997.

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 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 antenna 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) 497-3972]

Antenna Metrology

Recently Published

Muth, L.A., and Wittmann, R.C., **Calibration of Polarimetric Radar Systems**, Digest of the 1997 IEEE Antenna Propagation Society International Symposium, Montréal, Canada, July 13-18, 1997, pp. 830-833.

The calibration of nonreciprocal radars has been studied extensively. A brief review of known calibration techniques points to the desirability of a simplified calibration procedure. Fourier analysis of scattering data from a rotating dihedral allows rejection of noise and background contributions. Here, we derive a simple set of nonlinear equations in terms of the Fourier coefficients of the data that can be solved analytically without approximations or simplifying assumptions. We find that independent scattering data from an additional target such as a sphere are needed to accomplish this. We also derive mathematical conditions that allow us to check calibration data integrity and the correctness of the mathematical model of the scattering matrix of the target.
[Contact: Lorant A. Muth, (303) 497-3603]

Wittmann, R.C., Alpert, B.K., and Francis, M.H., **Nonideal Measurement Locations in Planar Near-Field Antenna Metrology**, Digest of the 1997 IEEE Antenna Propagation Society International Symposium, Montréal, Canada, July 13-18, 1997, pp. 168-171.

We introduce a near-field to far-field transformation algorithm that relaxes the usual restriction that data points be located on a plane-rectangular grid. Computational complexity is $O(N\log N)$, where N is the number of data points. (Calculation times depend on the numerical precision specified and on the condition number of the problem.) This algorithm allows efficient processing of near-field data with known probe position errors. Also, the algorithm is applicable to other measurement approaches, such as plane-polar scanning, where data are collected on a nonrectangular grid.
[Contact: Ronald C. Wittmann, (303) 497-3326]

Wittmann, R.C., and Black, D.N., **Quiet-Zone Evaluation Using a Spherical Synthetic-Aperture Radar**, Digest of the 1997 IEEE Antenna Propagation Society International Symposium, Montréal, Canada, July 13-18, 1997, pp. 148-151.

We describe an imaging technique which allows the isolation of sources of unwanted radiation on an antenna/radar cross-section range. The necessary data may be collected by using a roll-over azimuth mount to scan a probe over a spherical measurement surface.
[Contact: Ronald C. Wittmann, (303) 497-3326]

Noise Metrology

Released for Publication

Randa, J., and Terrell, L.A., **Noise-Temperature Measurement System for the WR-28 Band**.

The NIST Noise Project has constructed and tested a radiometer for the measurement of noise source 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]

Noise Metrology

Recently Published

Randa, J., **Noise Temperature Measurements on Wafer**, NIST Technical Note 1390 (March 1997).

The NIST Noise Project has developed the theoretical formalism and experimental methods for performing accurate noise-temperature measurements on wafer. This report presents 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 was performed, which resulted in an estimated standard uncertainty (1 δ) of 1.1% or less for most values of noise temperature. The tests also confirm our ability to produce known noise temperature on wafer.
[Contact: James Randa, (303) 497-3150]

Microwave and Millimeter-Wave Metrology

Released for Publication

Booth, J.C., Beall, J.A., Ono, R.H., Stork, F.J.B., Rudman, D.A., and Vale, L.R., **Third-Order Harmonic Generation in High-Temperature Superconducting Coplanar Waveguides at Microwave Frequencies**.

[See Cryoelectronic Metrology.]

Randa, J., **Noise Temperature Measurements on Wafer**, NIST Technical Note 1390 (March 1997).

[See Noise Metrology.]

Williams, D.F., Janezic, M.D., and Ralston, A., **Quasi-TEM Model for Coplanar Waveguide on Silicon**, to be published in the Digest of the 1997 Electrical Performance of Electronic Packaging Conference, San Jose, California, October 27-29, 1997.

This paper compares a simple quasi-TEM model for coplanar waveguide fabricated on silicon substrates to measurement. It demonstrates that, 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]

Microwave and Millimeter-Wave Metrology

Recently Published

Milanović, V., Gaitan, M., Bowen, E.D., Tea, N.H., and Zaghloul, M.E., **Thermoelectric Power Sensor for Microwave Applications by Commercial CMOS Fabrication**, IEEE Electron Device Letters, Vol. 18, No. 9, pp. 450-452 (September 1997).

This letter describes an implementation of a thermoelectric microwave power sensor fabricated through commercial CMOS process with additional maskless etching. The sensor combines micromachined coplanar waveguides and contact pads, a microwave termination which dissipates heat proportionally to input microwave power, and many aluminum-polysilicon thermocouples. The device was designed and fabricated in standard CMOS technology, including the appropriate glass-cuts for post-fabrication micromachining. By removing the bulk silicon located beneath the device through micromachining, thermal and electromagnetic losses are minimized. The sensor measures true rms power of signals in the frequency range up to 20 GHz with input power range in the -30 dBm to +10 dBm range. Over this 40 dB dynamic range, output voltage vs. input power is linear with less than ±0.16%. Automatic network analyzer data show an acceptable input return loss of less than -20 dB over the entire frequency range.
[Contact: Michael Gaitan, (301) 975-2070]

Electromagnetic Properties

Released for Publication

Holloway, C.L., Baker-Jarvis, J.R., Johnk, R.T., and Geyer, R.G., **Electromagnetic Ferrite Tile Absorber.**

Anechoic chambers have been used for over 40 years to simulate different operating environments for a wide range of frequencies. These chambers provide an accurate and convenient environment for electromagnetic compatibility (EMC) testing, and are important cost-effective tools for achieving EMC compliance. In order to perform tests in anechoic chambers in the 30 MHZ to 1000 MHZ frequency range, good low-frequency electromagnetic absorbers are needed. Magnetic materials, such as ferrite tile absorbers, offer the type of low-frequency performance needed for EMC testing inside shielded rooms (or chambers).

The first anechoic chambers or "dark rooms" were constructed in the early 1950s to perform antenna measurements. These chambers were equipped with bats of loosely spun animal hair coated with carbon. This broadband "hair" absorber was 5.08 cm (2 in) thick and provided -20 dB of reflectivity (20 log [reflected wave/incident wave]) at normal incidence from 2.4 GHz to 10 GHz. Later in the decade, the hair absorber was replaced by a new generation of absorber that offered -40 dB of reflectivity at normal incidence. Unlike the hair absorber, the new absorber was equipped with a shaped or convoluted front surface.

In this paper, we overview the theory behind ferrite tile and foam absorbers. We also review material measurement methods.
[Contact: James R. Baker-Jarvis, (303) 497-5621]

Weil, C.M., Geyer, R.G., and Sengupta, L., **Microwave Dielectric Characterization of Bulk Ferroelectrics.**

This paper discusses two of the measurement techniques used at NIST for dielectric characterization of bulk high-permittivity ferroelectrics in the microwave spectrum. Permittivity data are presented for barium titanate (ϵ'_r = 125 at 10 GHz) using both transmission line and cavity resonator techniques. The advantages and disadvantages of each method are discussed in detail. We also discuss some high-accuracy (±0.5%) permittivity measurements for a composite of barium strontium titanate (BSTO) and nonferroelectric oxide at 24 °C using an X-band (8 GHz to 11 GHz) mode-filtered cylindrical cavity. Data are presented on the variation of permittivity properties with the fractional barium/strontium stoichiometric ratio.
[Contact: Richard G. Geyer, (303) 497-5852]

Electromagnetic Properties

Recently Published

Janezic, M.D., and Williams, D.F., **Permittivity Characterization from Transmission-Line Measurement**, Digest of the 1997 IEEE Microwave Theory and Techniques Conference, Denver, Colorado, June 8-12, 1997, pp. 1343-1345.

We analyze three accurate broadband techniques for measuring the complex permittivity of dielectric substrates using coplanar waveguide transmission line measurements and demonstrate good agreement with single-frequency cavity measurements.
[Contact: Michael D. Janezic, (303) 497-3656]

Other Signal Topics

Recently Published

Fujii, K., Williams, E.R., Steiner, R.L., and Newell, D.B., **A New Refractometer by Combining a Variable Length Vacuum Cell and a Double-Pass Michelson Interferometer**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 191-195 (April 1997). [Also published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 128-129.]

A new refractometer with a variable length vacuum cell has been developed to eliminate errors caused by deformations in optical windows of the cell. The refractive index of air is determined by measuring the changes in the optical path difference between the air of interest and a vacuum as a function of the changes in the cell length. An optical phase modulation technique and a dark fringe detection method are used to a high resolution in measuring the optical path difference by a double-pass Michelson interferometer. A combined standard uncertainty of 5×10^{-5} in the measurement of the refractive index of

air has been achieved.
[Contact: Richard L. Steiner, (301) 975-4206]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Bray, S.L., Ekin, J.W., and Niles, M.J., **Fatigue-Induced Electrical Degradation of Composite High-Purity/High-Strength Aluminum Rings at 4 K**.

[See Superconductors.]

Christophorou, L.G., and Olthoff, J.K., **Electron Interactions with C_2F_6**.

[See Plasma Processing.]

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

We have measured the pulsating 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 discharge pulses have been determined.
[Contact: Yicheng Wang, (301) 975-4278]

Wang, Y., Van Brunt, J.K., and Olthoff, J.K., **Mass Spectrometric Measurement of Molecular Dissociation in Inductively-Coupled Plasmas**.

[See Plasma Processing.]

Power Systems Metrology

Recently Published

Christophorou, L.G., Olthoff, J.K., and Van Brunt, R.J., **Sulfur Hexafluoride and the Electric Power Industry**, IEEE Electrical Insulation Magazine, Vol. 13, No. 5, pp. 20-24 (September/October 1997).

Gas-insulated electrical equipment has a demonstrated value for society. Sulfur hexafluoride (SF_6) is the electric power industry's preferred gas for electrical insulation and arc quenching/current interruption equipment used in the transmission and distribution of electrical energy. However, SF_6 is a potent greenhouse gas, and this has led to concerns regarding its long-range environmental impact. The problems relating to the use of SF_6 by the electric industry are not without solution and can actually lead to new opportunities. To this end, besides the current efforts to curtail the releases of SF_6 into the environment, a comprehensive and focused program is indicated to develop alternative gaseous insulators and alternative high voltage technology.
[Contact: Loucas G. Christophorou, (301) 975-2432]

Key, T., Mansoor, A., and Martzloff, F., **No Joules for Surges: Relevant and Realistic Assessment of Surge Stress Threats**, Proceedings of the 7th International Conference on Harmonics and Quality of Power, Las Vegas, Nevada, October 16-18, 1996, pp. 67-72.

This paper challenges attempts to characterize the surge environment in low-voltage end-users power systems by a single number -- the "energy in the surge" -- derived from a simple voltage measurement. Our thesis is that such attempts are neither realistic nor relevant. This paper shows that these erroneous attempts, based on the classical formula for computing the energy dissipated in a linear load of known resistance, cannot be applied to characterize the environment per se, but only to a well-defined combination of source and load. In particular, there is no meaningful relationship between the "energy" in a surge event and the energy actually deposited in a varistor by this surge event. A review of equipment failure or upset mechanisms related to the occurrence of a surge voltage reveals that none of these mechanisms are related to this so-called "energy in the surge." Several failure mechanisms other than energy-related are identified, pointing out the need to describe the surge events with a more comprehensive set of parameters in conducting future surveys.
[Contact: François Martzloff, (303) 975-2409]

Mansoor, A., and Martzloff, F.D., **Driving High Surge Currents into Long Cables: More Begets Less**, IEEE Transactions on Power Delivery, Vol. 12, No. 2, pp.1176-1183 (July 1997).

Reality checks can and should be applied to

proposals for characterizing the surge environment and application of surge-protective devices (SPDs) to end-user, low-voltage power systems. One such check is the fact that driving a large current with steep front toward an SPD installed at the far end of a branch circuit cable could require such a high voltage that the connections at the near end of the cable will flashover, limiting the stress applied to the far-end SPD. Tests and numerical modeling were performed to support this thesis. The results of real-world measurements and modeling, presented in this paper, are in good agreement and validate each other. From that point on, the model allows parametric variations of cable length and surge current amplitude and waveform, of which several examples are presented.
[Contact: François Martzloff, (301) 975-2409]

Mansoor, A., and Martzloff, F.D., **The Effect of Neutral Earthing Practices on Lightning Current Dispersion in a Low-Voltage Installation**, Proceedings of the 1997 IEEE Summer Power Meeting, Berlin, Germany, July 15-18, 1997 (unpaged).

Computer modeling with the EMTP code has been applied to several configurations and earthing practices in use in various countries to show the effect of any differences in the dispersion (sharing) of a lightning stroke current. Simplifying assumptions have been made to some details of the configurations to focus on the main difference -- earthing practices. Identifying such differences provides the necessary perspective on their significance and the strong need to take them into consideration when developing international standards on surge-protective device applications.
[Contact: François D. Martzloff, (301) 975-2409]

Martzloff, F.D., **Electromagnetic Immunity of Single-Phase Personnel Protection Devices for Electric Vehicle Battery Chargers**, NISTIR 6013 (May 1997).

This document is based on a synthesis of several sources including primarily Basic Standards and Product Standards of the IEC, complemented by other documents such as IEEE Standards, and perceptions on the evolving consensus among the EMC community. Electromagnetic phenomena which can create electromagnetic disturbances have been classified in 18 categories in several IEC publications. A review of these phenomena within the context of personnel protection devices (PPD) allows a further classification to establish whether they will require tests to demonstrate electromagnetic compatibility: essential, optional, or immaterial. The essential category includes those phenomena with quasi-certainty of their occurrence and potentially disruptive or destructive effects. The optional category includes those phenomena with some probability of occurrence, but low risk of producing adverse effects. The immaterial category includes phenomena not occurring in the PPD environment or those for which a PPD can be deemed inherently immune.
[Contact: François D. Martzloff, (301) 975-2409]

Misakian, M., **ELF Electric and Magnetic Field Measurement Methods**, Proceedings of the 1st Chilean Metrology Congress, Santiago, Chile, April 2-4, 1997, pp. 39-48.

This paper surveys the instrumentation, calibration procedures, measurement techniques, and standards which can be used to characterize extremely low frequency (ELF) electric and magnetic fields. While the focus of the paper is on power frequency and power frequency harmonic fields, the measurement methods discussed are appropriate in principle for other ELF frequencies.
[Contact: Martin Misakian, (303) 497-2426]

Misakian, M., **Vertical Circularly Polarized ELF Magnetic Fields and Induced Electric Fields in Culture Media**, Bioelectromagnetics, Vol. 18, pp. 524-526 (1997).

Some properties of induced electric fields in cell culture media produced by vertical circularly polarized magnetic fields are examined. The described geometry is not advantageous for determining effects that may be attributable to induced electric fields or currents.
[Contact: Martin Misakian, (301) 975-2426]

Misakian, M., and Fenimore, C., **Distributions of Measurement Error for Three-Axis Magnetic Field Meters During Measurements near Appliances**, IEEE Transactions on Instrumentation and Measurement, Vol. 45, No. 1, pp. 244-249 (February 1996).

Comparisons are made between the average magnetic flux density as would be measured with a

three-axis coil probe and the flux density at the center of the probe. Probability distributions of the differences between the two quantities are calculated assuming a dipole magnetic field and are found to be asymmetric. The distributions allow estimates of uncertainty for resultant magnetic field measurements made near some electrical appliances and other electrical equipment.
[Contact: Martin Misakian, (301) 975-2426]

Petersons, O., FitzPatrick, G.J., and Simmon, E., **An Active High-Voltage Divider with 20 μV/V Uncertainty**, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, pp. 430-434 (April 1997).

A voltage divider has been developed consisting of an external compressed-gas capacitor, a group of stable solid-dielectric capacitors, and special electronic circuitry. A developmental prototype divider has been constructed and test results obtained to verify the operating principle and accuracy target. The new critical items enabling the desired performance are the solid-dielectric capacitors in the low-voltage arm, approaching the short-term stability of gas-insulated capacitors, and the active circuit consisting of a feedback amplifier, complemented with a controlled source, which essentially removes the error contribution from the feedback amplifier.
[Contact: Gerald J. FitzPatrick, (301) 975-2737]

Rao, M.V.V.S., Olthoff, J.K., Christophorou, L.G., and Van Brunt, R.J., **Negative Ion Kinetic-Energy Distributions and Ion-Neutral Reactions in O_2 and CO_2 Townsend Discharges at High *E/N***, Proceedings of the 1997 International Symposium on Electron Molecule Collisions and Ion and Electron Swarms, Engelberg, Switzerland, July 18-22, 1997, pp. P60/1-P60/2.

[See Plasma Processing.]

Rao, M.V.V.S., Olthoff, J.K., and Van Brunt, R.J., **Negative Ion-Energy Distributions and Ion-Neutral Reactions in SF_6 Townsend Discharges at High Electric Field-To-Gas Density Ratios (E/N)**, Proceedings of the Twentieth International Conference on the Physics of Electronic and Atomic Collisions, Vienna, Austria, July 23-29, 1997, p. MO 202.

[See Plasma Processing.]

Rao, M.V.V.S., Olthoff, J.K., and Van Brunt, R.J., **Translational Kinetic-Energy Distributions of Positive Ions Produced in Townsend Discharges of SF_6 at High Electric Field-to-Gas Density Ratios (*E/N*)**, Proceedings of the Twentieth International Conference on the Physics of Electronic and Atomic Collisions, Vienna, Austria, July 23-29, 1997, p. MO 203.

[See Plasma Processing.]

Rao, M.V.V.S., Van Brunt, R.J., and Olthoff, J.K., **Kinetic-Energy Distributions of Positive Ions Produced in Townsend Discharges of Oxygen at High Electric Field-to-Gas Density Ratios**, Proceedings of the 1997 International Symposium on Electron Molecule Collisions and Ion and Electron Swarms, Engelberg, Switzerland, July 18-22, 1997, pp. 61/1-P61/2.

[See Plasma Processing.]

Pulse Power Metrology

Recently Published

Mansoor, A., and Martzloff, F.D., **The Effect of Neutral Earthing Practices on Lightning Current Dispersion in a Low-Voltage Installation**, Proceedings of the 1997 IEEE Summer Power Meeting, Berlin, Germany, July 15-18, 1997 (unpaged).

[See Power Systems Metrology.]

Magnetic Materials and Measurements

Recently Published

Misakian, M., **Vertical Circularly Polarized ELF Magnetic Fields and Induced Electric Fields in Culture Media**, Bioelectromagnetics, Vol. 18, pp. 524-526 (1997).

[See Power Systems Metrology.]

Misakian, M., and Fenimore, C., **Distributions of Measurement Error for Three-Axis Magnetic Field Meters During Measurements Near Appliances**, IEEE Transactions on Instrumentation and Measurement, Vol. 45, No. 1, pp. 244-249 (February 1996).

[See Power Systems Metrology.]

Russek, S.E., Oti, J.O., Young, K.K., and Cross, R.W., **Field Angle and Current Density Effects in Submicrometer Spin Valves for Digital Applications**, IEEE Transactions on Magnetics, Vol. 33, No. 5, pp. 3292-3294 (September 1997).

We have characterized the magnetoresistive response of giant magnetoresistive spin valve devices, designed for digital applications, as a function of current density and magnetic field angle. The devices are designed to have only two stable states and are characterized by their positive and negative switching fields. The variations in the switching fields of submicrometer devices are compared with a multilayer single-domain mode to determine how accurately the switching fields can be predicted. Significant deviation from single domain behavior is observed. Structure in the magnetoresistive response curve, indicating stable micro-domains, is seen in devices with small-line widths and small-aspect ratios. At large-field angles, the micro-domains are stable to high-field values and can dramatically affect the switching process. The variation of the switching fields with bias current and field angle departs considerably from the single domain model predictions.
[Contact: Stephen E. Russek, (303) 497-5097]

Superconductors

Released for Publication

Bray, S.L., Ekin, J.W., and Niles, M.J., **Fatigue-Induced Electrical Degradation of Composite High-Purity/High-Strength Aluminum Rings at 4 K**.

Composite aluminum (Al) rings were fabricated from high-purity (99.995%) Al and high-strength Al alloy (6061-T6) for fatigue testing in liquid helium. The composite rings were designed to simulate the mechanical and electrical characteristics of the Al stabilizer system designed for the Anchorage Municipal Light & Power SMES magnet. To simulate the magnet operating conditions, as the coil is periodically charged and discharged, one test was conducted where a composite ring, at 4 K, was subjected to fatigue where the peak hoop *stress* was held constant during the test, and the ring's electrical resistance was periodically measured at 0 T and 4 T. For comparison, a second fatigue test was conducted on a similar ring where peak hoop *strain* was held constant. In both tests, the initial peak stain was 0.21%. In the constant-strain test, the increase in resistivity at 4 T after 4000 fatigue cycles was 56% greater than for the constant-stress test, indicating a significant strengthening of the composite through work hardening of the high-purity Al. These results, applied to the design of the SMES coil, allow a substantial reduction in the required quantity of high-purity-Al stabilizer and in the project's cost.
[Contact: Steven L. Bray, (303) 497-5631]

Goodrich, L.F., Medina, L.T., and Stauffer, T.C., **Comparisons of High-Current I_c Measurements Made in Liquid and Gaseous Helium**.

We compared variable-temperature critical-current, $I_c(T)$, measurements up to 200 A on samples immersed in liquid helium to those on samples in flowing helium gas. Multifilamentary Nb-Ti and Nb_3Sn samples were used in this study. $I_c(T)$ measurements above 5 K are difficult because these measurements need to be done in helium gas, and the heat generated during the measurement and conducted down high-current leads can raise the sample temperature significantly. This creates a large uncertainty and perhaps a sample-dependent bias in the sample temperature that occurs even if the measurements are meticulously made. $I_c(T)$ measurements at a constant magnetic field are needed to determine the temperature margin of magnet applications and performance data for applications designed to operate at various temperatures. The comparison of $I_c(T)$ data in liquid helium to data in gaseous helium, over the temperature range of 4 K to 5 K, allows for the inference of sample temperature uncertainty and biases. Agreement to within 30 mK was obtained.
[Contact: Loren F. Goodrich, (303) 497-3143]

Superconductors

Recently Published

Roshko, A., Stork, F.J.B., Rudman, D.A., Aldrich, D.J., and Morris-Hotsenpiller, P.A., **Comparison of Heteroepitaxial $YBa_2Cu_3O_{7-\delta}$ and TiO_2 Thin Film Growth**, Journal of Crystal Growth, Vol. 174, pp. 398-408 (July 1997).

[See Cryoelectronic Metrology.]

ELECTROMAGNETIC INTERFERENCE

Conducted EMI

Recently Published

Key, T., Mansoor, A., and Martzloff, F., **No Joules for Surges: Relevant and Realistic Assessment of Surge Stress Threats**, Proceedings of the 7th International Conference on Harmonics and Quality of Power, Las Vegas, Nevada, October 16-18, 1996, pp. 67-72.

[See Power Systems Metrology.]

Mansoor, A., and Martzloff, F.D., **Driving High Surge Currents into Long Cables: More Begets Less**, IEEE Transactions on Power Delivery, Vol. 12, No. 2, pp.1176-1183 (July 1997).

[See Power Systems Metrology.]

Radiated EMI

Released for Publication

Johnk, R.T., and Ondrejka, A.R., **Time-Domain Calibrations of D-Dot Sensors**.

This Technical Note covers in detail the procedures that are necessary to measure the receive transfer function of a broadband electric-field sensor using direct-pulse, time-domain methods. The calibration techniques presented here are applicable to a cone and ground plane system in the 50 MHz to 14 GHz frequency range, as well as to TEM cells in the 10 MHz to 100 MHz range. Measurement results that were obtained using both types of facilities are presented for a selected D-Dot sensor. In addition to a comparison of results from the two measurement facilities in the overlapping frequency ranges, thorough combined uncertainty analysis (Type-A and Type-B) uncertainties are presented.
[Contact: Robert T. Johnk, (303) 497-3737]

LAW ENFORCEMENT STANDARDS

Released for Publication

Higgins, K.M., **Forensic Laboratories: Handbook for Facility Planning, Design, Construction, and Moving**, to be published as National Institute of Justice (NIJ) Report 600-97.

This document, "Forensic Laboratories: Handbook for Facility Planning. Design, Construction, and Moving," is the product of two workshops sponsored by the Office of Law Enforcement Standards/NIST in 1996, where 23 professionals met and created this handbook. This handbook is not a standard, but a resource for those faced with building a new facility or the redesign of an existing facility. It is our hope that this document will help laboratory managers maximize organizational efficiency, ensure the economical expenditure of resources, and develop a safe, secure, and well-designed facility which will provide adequate space for forensic scientists to perform their tasks today and will include adaptability for tomorrow as technologies change.
[Contact: Kathleen M. Higgins, (301) 975-2757]

Lieberman, A.G., and Vanderau, J.M., **Fixed and Base Station Antennas**, to be published as National Institute of Justice (NIJ) Standard-0204.02.

[See Antenna Metrology.]

OPTOELECTRONICS

Released for Publication

Ata, E.P., Gökkavas, M., Onat, B., Islam, M.S., Tuttle, G., Mirin, R., Knopp, K.J., Christensen, D.H., Ünlü, M.S., and Özbay, E., **Resonant Cavity Enhanced High Speed Schottky Photodiodes**, to be published in the Proceedings of the 1997 International Semiconductor Device Research Symposium, Charlottesville, Virginia, December 11-13, 1997.

The bandwidth capabilities of optical-fiber telecommunication systems are still not fulfilled with present performances of optoelectronic devices, and high-speed photodetectors has been an active research area for the past two decades. It has been shown that Schottky photodiode, with 3 dB operating bandwidth exceeding 200 GHz, is one of the best candidates for high-speed photo detection. However, like the p-i-n photodiode, the Schottky photodiode also suffers from bandwidth-efficiency tradeoff. A recent family of photodetectors, resonant cavity enhanced (RCE) photodetectors, has the potential to

overcome this tradeoff as compared to conventional photodetectors. The RCE detector operation is principally same as the conventional one, with the main difference of increased internal optical field by virtue of a Fabry-Perot resonant cavity. The higher field enables high efficiencies with thinner absorbing layers, resulting in high-quantum efficiency with low-photo carrier transmit times. Schottky photodiode has its advantages in its simplicity, compatiblity with monolithic integration processes, and use of thin Schottky metal as top mirror of the resonant cavity. However, high-speed RCE photodetector research has mainly concentrated on p-i-n type photodiodes, where near 100% quantum efficiencies along with a 3 dB bandwith of 17 GHz have been reported. There are only a few reports on RCE Schottky photodiodes. We briefly report our work on design, fabrication, and testing of high-speed RCE Schottky photodiodes for operation at 840 nm.
[Contact: Kevin J. Knopp, (303) 497-7368]

Craig, R.M., **Interlaboratory Comparison of Polarization Crosstalk Measurement Methods in Terminated High Birefringence Optical Fiber**, to be published in the Technical Digest of Optical Fiber Communication Conference, San Jose, California, February 22-27, 1998.

Results of preliminary interlaboratory comparisons of polarization crosstalk in terminated PM fiber are presented for nominally identical patch cables using two different techniques. Bulk-optic polarizer and polarimeter methods are compared, yielding some disagreement.
[Contact: Rex M. Craig, (303) 497-3359]

Craig, R.M., Gilbert, S.L., and Hale, P.D., **A High-Resolution Non-Mechanical Approach to Polarization Dependent Transmission Measurements**.

We have implemented an automated, non-mechanical approach to the measurement of polarization-dependent loss (and, equivalently, gain). We use a deterministic fixed-states method to derive Mueller matrix elements from intensity measurements at specific polarization states. Voltage-modulated liquid-crystal variable retarders set the polarization states. Synchronous detection is employed to increase the signal-to-noise ratio of the system, and thereby allow measurement resolution to better than 0.001 dB. We present polarization-dependent loss measurements from 0.0016 dB to 0.56 dB at 1550 nm to verify performance.
[Contact: Sarah L. Gilbert, (303) 497-3120]

Leonhardt, R.W., **Calibration Service for Laser Power and Energy at 248 nm**, to be published as NIST Technical Note 1394.

This document describes the calibration service provided by the National Institute of Standards and Technology 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 measurement uncertainties range from 1.6% to 2.0%. 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 which 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]

Mioc, S.L., Therisod, S., Gilbert, S.L., and Mackie, N., **Fiber-Grating Stabilized Diode Laser Characteristics**, to be published in the Proceedings of the Conference on Bragg Gratings, Photosensitivity and Poling in Glass Fibers and Waveguides: Applications and Fundamentals, Williamsburg, Virginia, October 26-28, 1997.

We have conduced a detailed characterization of an 830 nm fiber-grating extended-cavity diode laser. The laser has regions of single-frequency operation interspersed with multimode operation.
[Contact: Sarah L. Gilbert, (303) 497-3120]

Mirin, R.P., Gossard, A.C., and Bowers, J.E., **Characterization of InGaAs Quantum Dot Lasers with a Single Quantum Dot Layer as an Active Region**, to be published in the Proceedings of the 8th International Conference on Modulated Semiconductor Structures, Santa Barbara, California, July 13-18, 1997.

Quantum dot lasers with an active region consisting of just a single quantum dot layer have been grown using molecular beam epitaxy and characterized from 80 K to 300 K. The quantum dot lasers lase from excited states over the entire temperature range. The characteristic temperature is 185 K over the temperature range 80 K to 141 K and decreases to 111 K from 141 K to 304 K. The effects of scattering by the quantum dots have also been analyzed and shown to be unimportant in these quantum dot lasers.
[Contact: Richard P. Mirin, (303) 497-7955]

Munroe, M.J., Blansett, E., Raymer, M.G., and Alphonse, G.A., **Intensity Stabilization Using a Double-Pass, Saturated Semiconductor Optical Amplifier**.

We demonstrate optical intensity stabilization, or smoothing, using a double-pass, traveling-wave semiconductor amplifier system operating in the saturated regime with nonsaturable losses present. We report the steady-state, time-domain and frequency-domain behavior of the system, and find total-intensity stabilization for an input intensity dynamic range greater than 10 dB. A 2 dB reduction in intensity noise is observed for an input noise frequency range from several kHz to 1.5 GHz except at certain discrete frequencies corresponding to the odd, half-integer multiples of the inverse double-pass round-trip time. We suggest design considerations to eliminate the observed noise enhancement at these discrete frequencies.
[Contact: Michael J. Munroe, (303) 497-7948]

Munroe, M.J., Cooper, J., and Raymer, M.G., **Spectrum of Stochastic Light, Intensity-Smoothed by a Saturated Semiconductor Optical Amplifier**.

We present calculations of the intensity-smoothing of stochastic light by a semiconductor optical amplifier (SOA). We predict spectral changes of the light that are due to amplitude-to-phase coupling in the gain medium. The intensity smoothing of noisy pulses with a SOA carries a penalty of spectral broadening (increased phase noise) which increases with increasing alpha parameter. The spectral broadening also increases with increasing strength of the intensity fluctuations being smoothed.
[Contact: Michael J. Munroe, (303) 497-7948]

Williams, P.A., and Wang, C.M., **Sampling Density and Extrema Thresholding Effects on Fixed Analyzer Measurements of Polarization Mode Dispersion**.

We report computer simulation results of polarization mode dispersion measurements using the fixed analyzer technique. We find a new value for the polarization mode coupling factor of 0.805 (a 2% discrepancy with the old value of 0.824). Systematic biases due to sampling density and extrema thresholding are quantified (6% to 12% for typical measurement conditions), and a simple correction algorithm is presented which removes the effects of these biases to within ±1.7%.
[Contact: Paul A. Williams, (303) 497-3805]

OPTOELECTRONICS

Recently Published

Bluhm, H., Wadas, A., Wiesendanger, R., Roshko, A., Aust, J.A., and Nam, D., **Imaging of Domain-Inverted Gratings in $LiNbO_3$ by Electrostatic Force Microscopy**, Applied Physics Letters, Vol. 71, No. 1, pp. 146-148 (7 July 1997).

Ferroelectric domains in $LiNbO_3$ have been investigated by means of electrostatic force microscopy. Polarization-inverted gratings with 4 μm periodicity were fabricated by titanium diffusion into both + *c* and - *c* faces of single-domain $LiNbO_3$ crystals. The distribution of the electric field in the vicinity of the sample surface was measured using scanning probe microscopy. The electrostatic force image was found to correlate with the shape of the domain-inverted profile observed by scanning electron and optical microscopies.
[Contact: Alexana Roshko, (303) 497-5420]

Knopp, K.J., Christensen, D.H., and Hill, J.H., **Vertical-Cavity Surface-Emitting Lasers with Low-Ripple Optical Pumping Windows**, IEEE Journal of Selected Topics in Quantum Electronics, Vol. 3, No. 2, pp. 366-371 (April 1997).

A general technique for numerically optimizing the optical admittances in vertical-cavity structures is used to suppress the interference ripple in the typical reflectance/transmittance spectra. This technique is applicable to any vertical-cavity device whose photonic properties at various wavelengths requires modification for specific applications. In this paper,

we report the use of this optimization method to enhance the coupling of pump light into 850 nm vertical-cavity surface-emitting lasers. We have designed and fabricated novel lasers which contain a wideband window of low reflectance amidst the typical interference fringe spectrum. The 750 nm to 800 nm region for the low-ripple design has an average reflectance of 5%; the peak-to-peak amplitude of the ripple is 0.25%. The sensitivity of these devices to temperature variations and layer-thickness manufacturing variations is also studied. The low-ripple pump window shifts at a rate of 0.036 nm/°C, the peak-to-peak ripple of the reflectance varies less than 2%, and the pump bandwidth remains constant, over temperatures ranging from 0 °C to 100 °C. The low-ripple structure substantially reduces the temperatures and wavelength variation of the pump-field overlap by creating a window of nearly constant reflectance.
[Contact: David H. Christensen, (303) 497-3354]

Knopp, K.J., Ketterl, J.R., Christensen, D.H., Pearshall, T.P., and Hill, J.R., **Simultaneous Monitoring of Wafer- and Environment-States during Molecular Beam Epitaxy**, Proceedings of the Materials Research Society Symposium, Boston, Massachusetts, December 2-6, 1996, pp. 761-766.

We report the simultaneous monitoring of the environment-state and wafer-state during epitaxial crystal growth using a single real-time measurement. Atomic absorption spectroscopy (AAS) is used to monitor the incident molecular beam flux, while UV reflectance (UVR) at 395 nm with an incident angle of 78° is used to monitor growth on the wafer. We have studied the utility of AAS/UVR monitoring of $Al_xGa_{1-x}As$ deposition: AlAs growing on GaAs, GaAs on AlAs, and superlattice growth. Additionally, optical multichannel spectroscopy (OMS) data were acquired throughout the growth of a distributed Bragg reflector (DBR). The relationship of the structure of the real-time OMS data to absorption, optical path length variation, and differential layer thickness variations is also discussed. Numerical simulations of the real-time wafer-state monitors using pseudodielectric constants, appropriate at a growth temperature of 579 °C, show good agreement with measured spectra.
[Contact: David H. Christensen, (303) 497-3354]

Lehman, J.H., and Scott, T.R., **Optical Radiation Detectors for Laser Measurements: Survey and Tutorial**, Proceedings of the 1997 International Laser Safety Conference, Orlando, Florida, March 17-20, 1997, pp. 279-288.

This paper provides an overview of currently available detectors for optical radiation measurements. In addition, detector parameters such as noise equivalent power, detectivity, wavelength range, detector speed, and spatial uniformity are briefly discussed. The magnitude of input power or energy, radiation wavelength, and pulse duration among other variables must be considered in order to select the most appropriate detector for laser safety hazard analysis and classification.
[Contact: John H. Lehman, (303) 497-3654]

Mechels, S.E., Schlager, J.B., and Franzen, D.L., **High Resolution Differential Mode Delay Measurements in Optical Fibers Using a Frequency Domain Phase Shift Technique**, IEEE Photonics Technology Letters, Vol. 9, No. 6, pp. 794-796 (June 1997).

A frequency-domain phase-shift technique, with a temporal resolution of 0.2 ps, is used to obtain differential mode delay measurements in graded-index multimode fibers. This resolution is a significant improvement over previously reported time-domain methods. As a consequence, useful results can be obtained from fibers as short as 15 m. Measurements performed at 850 nm, on 62.5 μm core diameter fibers from several different manufacturers, indicate a rich variety of mode delay profiles. Measurements on lengths ranging from 3 m to 500 m, indicate that delay profiles are established in the first few meters of fiber, and the general characteristics are retained over long distances.
[Contact: Steven E. Mechels, (303) 497-5409]

Munroe, M.J., Knopp, K.J., and Christensen, D.H., **Ultrafast Optical Excitation of Vertical-Cavity Surface-Emitting Lasers**, Technical Digest of the Optical Society of America 1997 Quantum Electronics and Laser Science Conference (QELS'97), Baltimore, Maryland, May 18-23, 1997, Vol. 12, p. 49.

We introduced a novel design for a vertical-cavity surface-emitting laser (VCSEL), which eliminates the ripple in the transmission over a very broad bandwidth (50 nm), thus allowing direct excitation of the quantum well by ultrashort (sub-100 fs) pulses.

Examples of this design are presented, including simulations of the ultrafast temporal response of the VCSEL cavity.
[Contact: Michael J. Munroe, (303) 497-7948]

Schaafsma, D.T., and Christensen, D.H., **Mode Splitting in Vertical-Cavity Microlasers from Side-Emission Measurements**, Technical Digest of the Optical Society of America 1997 Lasers and Electro-Optics Society Meeting (CLEO'97), Baltimore, Maryland, May 18-23, 1997, Vol. 11, pp. 271-272.

We presented polarization-analyzed side-emission luminescence data from vertical-cavity semiconductor lasers with shoe changes in the emission spectrum due to Rabi oscillation in the cavity.
[Contact: David T. Schasfsma, (303) 497-7281]

Svalgaard, M., and Gilbert, S.L., **Stability of Short, Single-Mode Erbium-Doped Fiber Lasers**, Journal of Research of the National Institute of Standards and Technology, Vol. 102, No. 3, pp. 333-347 (May-June 1997).

We have developed a frequency-domain phase shift system for measuring the zero-dispersion wavelength and the dispersion slope of single-mode optical fibers. A differential phase-shift method and nonlinear four-wave mixing technique were also investigated. The frequency-domain phase shift method is used to produce Standard Reference Materials that have their zero dispersion wavelengths characterized with an expanded uncertainty ($k = 2$) of ± 0.060 nm.
[Contact: Sarah L. Gilbert, (303) 497-3120]

Young, M., **Cladding Standard Improves Fiberoptic Measurements**, Laser Focus World, Vol. 31, No. 10, pp. 26-32 (October 1995).

A new standard of optical fiber cladding diameter developed by the National Institute of Standards and Technology in Boulder, Colorado, has led most major U.S. fiber manufacturers to recalibrate their fiber drawing towers. The standard is important to companies that manufacture or install connectors or connector parts in that accurate diameter measurements permit low-loss connections to be made with minimal effort.
[Contact: Matt Young, (303) 497-3223]

PRODUCT DATA SYSTEMS

Recently Published

Stewart, S.L., and St. Pierre, J.A., **Experience with a Manufacturing Framework**, Proceedings of the 1995 Object Oriented Programming Systems Languages and Applications Workshop, Austin, Texas, October 16, 1995, pp. 135-150 (1997).

This paper describes the first year of a joint project between the National Institute of Standards and Technology and SEMATECH. After studying the SEMATECH CIM Framework, we present a roadmap for adoption and use of manufacturing frameworks with four components: developing a specification, reaching consensus, standardization, and testing and certification. Results of our study include numerous recommendations about online specifications, supplier involvement, standards organizations, usage scenarios, reference implementations, and a testing and certification plan.
[Contact: James A. St. Pierre, (301) 975-4124]

VIDEO TECHNOLOGY

Recently Published

Boynton, P.A., and Kelley, E.F., **Accurate Contrast Ratio Measurements Using a Cone Mask**, Digest of the 1997 Society for Information Display International Symposium, Boston, Massachusetts, May 12-16, 1997, Sec. 32.1/pp. 823-826.

Display contrast ratios are often derived from luminance measurements of black and white patterns. Erroneous contrasts are obtained if veiling-glare contributions of the optical system are not considered. We present a method for avoiding glare corruption of luminance measurements utilizing a cone-shaped mask.
[Contact: Paul A. Boynton, (301) 975-3014]

Fenimore, C.P., Field, B.F., and Van Degrift, **Test Patterns and Quality Metrics for Digital Video Compression**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Symposium on Human Vision and Electronic Imaging II, Vol. 3016, pp. 269-276 (February 1997).

Lossy video compression systems such as MPEG2 introduce picture impairments such as image blocking, color distortion, and persistent color

fragments, "mosquito noise," and blurring in their outputs. While there are video test clips which exhibit one or more of these distortions upon coding, there is need of a set of well-characterized test patterns and video quality metrics. Digital test patterns can deliver calibrated stresses to specific features of the encoder, much as the test patterns for analog video stress critical characteristics of that system. Metrics quantify the error effects of compression by a computation.

NIST is developing such test patterns and metrics for compression rates that typically introduce perceptually negligible artifacts, i.e., for high-quality video. The test patterns are designed for subjective and objective evaluation. The test patterns include a family of computer-generated spinning wheels to stress luminance-based macro-block motion estimation algorithms and images with strongly directional high-frequency content to stress luminance-based macro-block motion estimation algorithms and images with strongly directional high-frequency content to stress quantization algorithms. In this paper, we discuss the spinning wheel test pattern. It has been encoded at a variety of bit rates near the threshold for the perception of impairments. We have observed that impairment perceptibility depends on the local contrast. For the spinning wheel, we report the contrast at the threshold for perception of impairments as a function of the bit rate. To quantify perceptual image blocking, we have developed a metric which detects "flats": image blocks of constant (or near constant) luminance. The effectiveness of this metric is appraised.
[Contact: Charles P. Fenimore, (301) 975-2428]

Kelley, E.F., and Jones, G.R., **Utilizing the Bidirectional Reflection Distribution Function to Predict Reflections from Flat Panel Displays**, Digest of the 1997 Society for Information Display International Symposium, Boston, Massachusetts, May 12-16, 1997, Sec. 32.3, pp. 831-834.

A method is presented which 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 (lambertian), specular, and haze. Calculated values for the reflected luminances are compared to measured values for several lighting conditions with good agreement. Attempts to parameterize the BRDF of a flat panel display are discussed.
[Contact: Edward F. Kelley, (301) 975-3842]

X-RAY SPECTROMETRY

Recently Published

Martinis, J.M., Wollman, D., Irwin, K., and Hilton, G.C., **Microcalorimeter X-Ray Spectrometers**, Future FAB International, pp. 333-337 (1997).

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. These detectors will be similar in operation to commonly-used energy dispersive spectrometers, but will improve upon the energy resolution by at least a factor of 10, thus rivaling or possibly exceeding the resolution achievable with wavelength dispersive spectrometers. We discuss the basic operating principle of this new technology and present microanalysis data taken with the detector on a scanning electron microscope to demonstrate the utility of the microcalorimeter spectrometer. Its primary impact on semiconductor process metrology will be improved analysis of low energy (100 eV to 2 keV) X-rays. This capability is important for detection of light elements, resolving interferences in important materials such as WSi_2 and TiN, and defect review.
[Contact: John M. Martinis, (303) 497-3597]

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 1996).

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 1996).

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 1996. 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 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, 1990-1996** (March 1997).

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: E. Jane Walters, (301) 975-2050]

*****CALL FOR PAPERS*****

1998 IEEE Radio and Wireless Conference (RAWCON'98)

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

Deadline for submission of papers: March 1, 1998

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.

RAWCON'98 offers authors an outstanding venue with a sophisticated audience of your customers, suppliers, and competitors. Publication in the IEEE Conference Proceedings ensures wide distribution of your archival paper. The conference will offer significant registration discounts to speakers.

RAWCON'98 starts on Sunday, August 9, 1998, with an all-day workshop on "Modeling and Simulation of Circuits for Wireless Communication Systems," organized by John Sevic of Spectrian Corporation. A Monday morning workshop entitled, "Overview of Coding and Modulation for Wireless Communications" and led by Professor Rodger Ziemer of the University of Colorado, will be followed by two and a half days of single track technical sessions. A Tuesday evening panel discussion, organized by Dr. Sanjay Kasturia of Lucent Technologies, rounds out the technical program. An exhibition, beginning on Tuesday, accompanies the conference.

We seek original, practical technical presentations in these wireless technologies: *System Architecture*, including third-generation wireless systems, LMDS, wireless LANs, wireless local loop, PCS, cellular, paging, etc. *System Performance*, including base stations, mobiles, signal processing, digital modulation, linearization, etc. *Active Devices*, including RFICs, MMICs, modeling, linearity, characterization, etc. *Passive Components*, including integrated passives, filters, packaging technology, package design, etc.

The program committee is particularly interested in papers on the following topics: Wireless data systems, software radio architectures, infrastructure equipment design for wireless communications, active device technologies for wireless communications, and applications of advanced antennas to mobile communications.

Authors are asked to submit five copies of a two-page summary (including figures) to the Technical Program Chair (TPC), Dr. Michael S. Heutmaker, Lucent Technologies, telephone: (609) 639-3116/fax (609)-639-3197, email: heutmaker@ieee.org, by March 1, 1998. The summary must contain complete contact information (including email) for the corresponding author. Please contact the TPC for information about electronic submission of the summary, if desired.

Submissions will be evaluated for originality, significance of the work, technical soundness, and interest to a broad audience. Authors will be notified of acceptance by April 24, 1998. Final accepted papers (3 to 5 pages in length) must be received by the TPC in camera-ready form by June 12, 1998, to be included in the published Proceedings.
[Contact: Roger B. Marks, (303) 497-3037]

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.

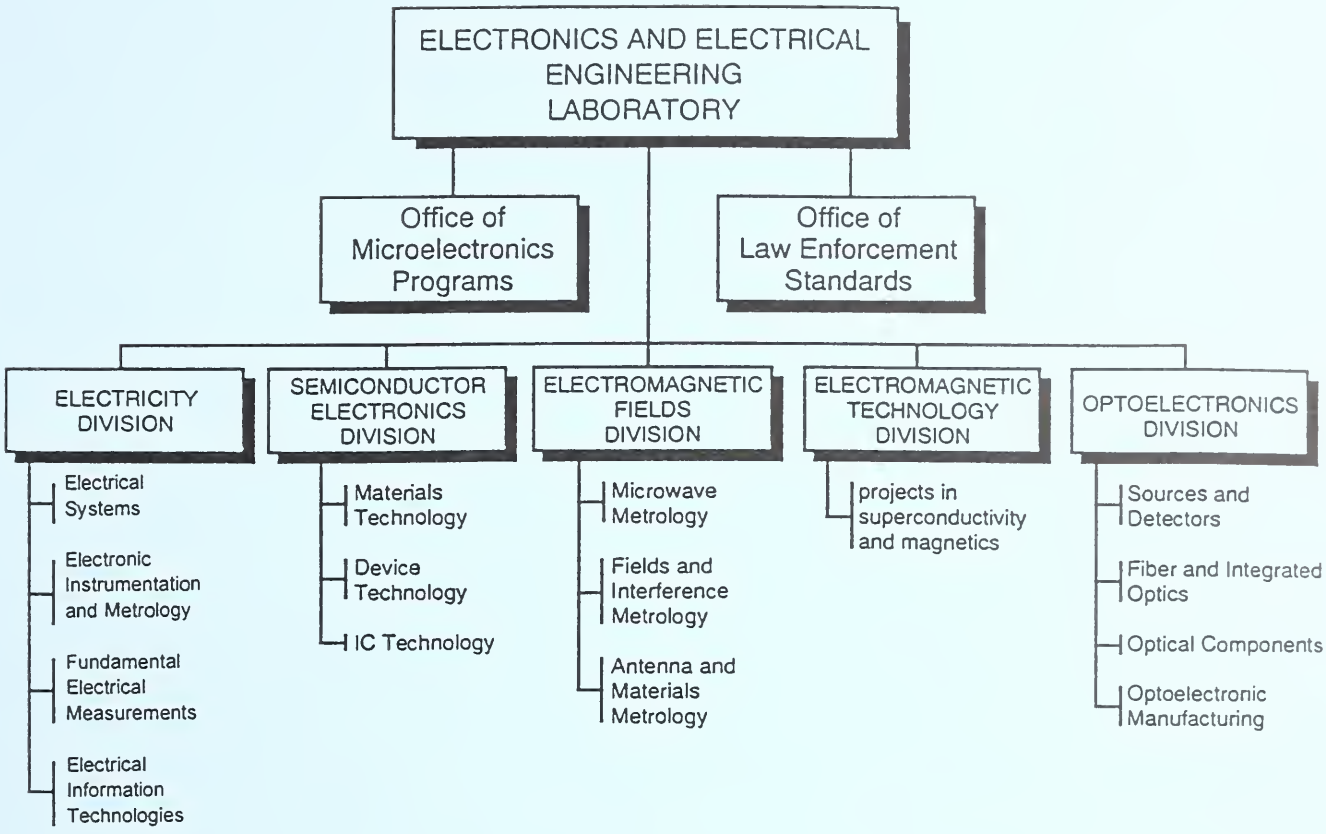
Technical insights presented by the rigorous certification process are available in NIST Special Publication 260-131, *Standard Reference Materials:* The Certification of 100 mm Diameter Silicon Resistivity SRMs 2541 through 2547 Using Dual-Configuration Four-Point Probe Measurements. Individual data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