NISTIR 5853

Electronics and Electrical Engineering Laboratory

J. M. Rohrbaugh
Compiler

Technical Progress Bulletin

96-1

Covering Laboratory Programs,
January to March 1996,
with 1996 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

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U.S. DEPARTMENT OF COMMERCE
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ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY
TECHNICAL PROGRESS BULLETIN, JUNE 1996 ISSUE

INTRODUCTION

This is the fifty-fourth issue of a quarterly 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 first quarter of calendar year 1996.

Organization of Bulletin: This issue contains abstracts for all relevant papers released for publication by NIST in the quarter and citations and abstracts for such papers published in the quarter. Entries are arranged by technical topic as identified in the Table of Contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication." This does not imply acceptance by any outside organization. Papers published in the quarter appear under the subheading "Recently Published." Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Laboratory conferences and workshops planned for calendar year 1996 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 and the Electromagnetic Technology Divisions, and the newly formed Optoelectronics Division 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 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 34.

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 32.

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.

TABLE OF CONTENTS

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

TO LEARN MORE ABOUT THE LABORATORY...

Two general documents are available that may be of interest. These are ***Measurements for Competitiveness in Electronics*** and ***EEEL 1995 Technical Accomplishments, Advancing Metrology for Electrotechnology to Support the U.S. Economy***. The first presents selected technical accomplishments of the Laboratory for the period October 1, 1994 through September 30, 1995. 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 1995 Technical Accomplishments, Advancing Metrology for Electrotechnology to Support the U.S. Economy, NISTIR 5818 (December 1995).

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 1995 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.

This document is a successor to NISTIR 90-4260, *Emerging Technologies in Electronics ... and their measurement needs* [Second Edition].
[Contact: Ronald M. Powell, (301) 975-2220]

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Released for Publication

Avramov-Zamurovic, S., Zimmerman, N.M., Clark, A.F., and Jeffery, A., **Tests to Evaluate the Frequency Dependent Capacitor Ratio for Single Electron Tunneling Experiment**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

A precise measurement of the ratio of two cryogenic capacitors is needed for a capacitor charging experiment using Single Electron Tunneling phenomena. To support the capacitor charging metrology, a frequency characterization of the capacitors is required. To cover the frequency range from 1 Hz to 1 kHz, resistive and inductive voltage divider bridges are proposed. Preliminary tests suggest that the uncertainty with which the capacitor ratio can be evaluated is less than one part per million.
[Contact: Svetlana Avramov-Zamurovic, (301) 975-2414]

Benz, S.P., and Hamilton, C.A., **A Pulse-Driven Programmable Josephson Voltage Standard**.

A voltage standard based on a series array of pulsed-biased, non-hysteretic Josephson junctions is proposed. The output voltage can be rapidly and continuously programmed over a wide range by changing the pulse repetition frequency. Simulations relate the circuit margins to pulse height, width, and frequency. Experimental results on a prototype circuit confirm the expected behavior.
[Contact: Samuel P. Benz, (303) 497-5258]

Clark, A.F., **Cryogenic Devices for Precision Electrical Measurements**, to be published in the Conference Bulletin of the International Cryogenic Materials Conference, Kitakyushu, Japan, May 20-24, 1996.

Cryogenic devices are now used for the precise realization of the base electrical units of voltage and resistance through the Josephson effect and the quantum Hall effect. With the recently discovered single electron tunneling (SET) effect, soon the units for capacitance and current may also be available in low-temperature devices. New developments may also yield Josephson arrays for programmable voltage standards and quantum Hall devices that operate at higher temperatures and lower magnetic fields. Several of these advances will also allow precise determinations of fundamental constants. These new developments are described and the materials and device needs summarized, ranging from nanoscale SET devices operating at a few millikelvin to Josephson junctions operating at liquid nitrogen temperatures.
[Contact: Alan F. Clark, (301) 975-2139]

Clark, A.F., **State-of-the-Art of Precision Electrical Measurements**, to be published in the Conference Digest, American Society for Engineering Education, Washington, D.C., June 23-25, 1996.

The basis for all electrical measurements is the system of electrical units for the ampere, volt, ohm, henry, and farad. The limits for the smallest uncertainties in our electrical measurements are the precision with which we can realize these units in the laboratory. The state of the art for these precision electrical measurements is reviewed and the relationship with commercially available instruments explored. The need in engineering education for understanding this connection between the fundamental units and electrical measurements is stressed.
[Contact: Alan F. Clark, (301) 975-2139]

Elmquist, R.E., and Dziuba, R.F., **Loading Effects in Resistance Scaling**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

Power loading effects in dc resistance references are not well understood even for the most commonly used high-precision standards. This paper examines loading effects and their contribution to the uncertainty of recent NIST comparisons of the quantum Hall effect and calculable capacitor.
[Contact: Randolph E. Elmquist, (301) 975-6591]

Fujii, K., Williams, E.R., and Steiner, R.L., **A New Refractometer by Combining a Variable Length Vacuum Cell and a Double-Pass Michelson**

Interferometer, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

A new refractometer with a variable length vacuum cell has been developed, where 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 accuracy of 4×10^{-9} has been achieved.
[Contact: Edwin R. Williams, (301) 975-4206]

Gillespie, A.D., Fujii, K., Newell, D., Olsen, P.T., Picard, A., Steiner, R., Stenbakken, G., and Williams, E., **Measurement and Reduction of Alignment Errors of the NIST Watt Experiment**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunuschweig, Germany, June 17-20, 1996.

The effects of uncertainties in the alignment of the NIST watt balance with local gravity and the balance's magnetic field have been analyzed, and techniques for measuring all misalignment parameters have been developed. The systematic uncertainty in the watt measurement due to alignment uncertainties has been reduced to 0.04 μW/W.
[Contact: Aaron D. Gillespie, (301) 975-4056]

Hamilton, C.A., Burroughs, C.J., and Benz, S.P., **Progress toward an AC Josephson Voltage Standard**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

Progress toward a Josephson voltage standard for fast dc measurements and ac waveform synthesis is described, including a version with SNS junctions operated at 11 GHz. A bias control circuit that achieves milliampere drive capability, transient suppression, and submicrosecond settling time is used for fast, automated measurements of A/D converter linearity, squarewave synthesis at 400 Hz, and a test for subnanovolt accuracy.
[Contact: Clark A. Hamilton, (303) 497-3740]

Jeffrey, R.A., 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**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Branuschweig, Germany, June 17-20, 1996.

The latest NIST results from the comparison of the quantized Hall resistance (QHR), based on Ω-90, with the realization of the SI ohm obtained from the calculable capacitor measurement are reported. Various systematic checks have been performed and examined.
[Contact: Randolph A. Jeffrey, (301) 975-4056]

Keller, M.W., Martinis, J.M., and Zimmerman, N.M., **Design and Operation of a 7-Junction Electron Pump**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

We report progress in the development of a seven-junction electron pump for use in a new capacitance standard. Cross-capacitance in the pump has been reduced with a new geometry of islands and gates. Stray capacitance and charge noise have been reduced by using a quartz substrate. With these and other improvements, the pump has become a relatively easy-to-operate cryoelectronic device.
[Contact: John M. Martinis, (303) 497-3597]

Lee, K.C., **Quantum Hall Effect-Based Resistance Standard**, to be published in the Proceedings of the 19th NASA Metrology Workshop, Cocoa Beach, Florida, February 26—March 3, 1996.

In order to support modern 8.5 digit digital multimeters and high-end calibrators capable of delivering uncertainties of the order of parts per million (ppm), primary standards laboratories must be able to provide calibration uncertainties less than 0.1 ppm. Quantum hall Effect (QHE)-based resistance standards can provide these low uncertainties, but at present require very sophisticated and costly equipment. This talk describes the quantum Hall effect, the equipment necessary to use it as a resistance standard, and some of the challenges in making a QHE-based

resistance standard commercially viable.
[Contact: Kevin C. Lee, (301) 975-4236]

Steinbach, A., Martinis, J.M., and Devoret, M.H., **Observation of Hot-Electron Shot Noise in a Metallic Resistor**.

We have measured the current noise of silver thin-film resistors as a function of current and temperature and for resistor lengths of 7000, 100, 30, and 1 μm. As the resistor becomes shorter than the electron-phonon interaction length, the current noise for large current increases from a nearly current independent value to the interacting hot-electron value (3/4)2eI. However, the further reduction in length below the electron-electron interaction length decreases the noise to a value approaching the independent hot-electron value (1/3)2eI first predicted for mesoscopic resistors.
[Contact: John M. Martinis, (303) 497-3597]

Steiner, R.L., Gillespie, A., Fujii, K., Williams, E., Newell, D., Picard, A., Stenbakken, G., and Olsen, P.T., **The NIST Watt Balance: Progress Towards Monitoring the Kilogram**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

Random uncertainty of 0.08 μW/W in the NIST watt balance has been achieved by improvements in a velocity measurement using three laser interferometers and by the elimination of filter delays and electrical noise. The latest results of this experiment are presented.
[Contact: Richard L. Steiner, (301) 975-4226]

Zimmerman, N.M., Clark, A.F., and Williams, E.R., **Results of Capacitance Ratio Measurements for the Single Electron Pump-Capacitor Charging Experiment**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

We report on a metrological application of the single electron tunneling (SET) phenomena: a precise measurement of the ratio of two cryogenic capacitors. Our measurement used a superconducting SET electrometer as the null detector for a capacitance bridge. We have achieved a 3 ppm level of imprecision in the measurement of capacitance ratio from 100 Hz to 1000 Hz. We used custom-made cryogenic vacuum-gap capacitors, which have a leakage resistance of no less than 10^{19} Ω. Further improvements can be made in the attempt to obtain an imprecision of 10^{-8} at lower frequencies, sufficient for the metrological measurement of capacitance or the fine-structure constant using an SET pump.
[Contact: Neil M. Zimmerman, (301) 975-5887]

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Recently Published

Kautz, R.L., and Benz, S.P., **Metallic-Barrier Junctions for Programmable Josephson Voltage Standards**, Proceedings of the European Conference on Applied Superconductivity, Edinburgh, Scotland, July 3-6, 1995, pp. 1407-1410.

The current amplitudes of Shapiro steps are studied in large-area metallic-barrier Josephson junctions by simulation and experiment. In the absence of a ground plane, simulations show that junctions larger than about four times the Josephson penetration depth are of limited utility because the microwave power required to induce Shapiro steps increases rapidly with junction size. Experimentally, step amplitudes as large as 7 mA are observed in Nb-PdAu-Nb sandwich junctions.
[Contact: Richard L. Kautz, (303) 497-3391]

SEMICONDUCTOR MICROELECTRONICS

Silicon Materials

Released for Publication

Krska, J.-H.Y., Yoon, J.U., Nee, J., Chung, J.E., Roitman, P., Campisi, G., and Brown, G., **A Model for SIMOX Buried-Oxide High-Field Conduction**.

[See Device Physics and Modeling.]

Silicon Materials

Recently Published

Rennex, B.G., Ehrstein, J.R., and Scace, R.I., **Methodology for the Certification of Reference Specimens for Determination of Oxygen Concentration in Semiconductor Silicon by Infrared Spectrophotometry**, Journal of the Electrochemical Society, Vol. 143, No. 1, pp. 258-263 (1996).

The methodology and experiment for certification of reference specimens for determining interstitial oxygen concentration in semiconductor silicon are reported. These reference specimens are intended for calibration of infrared spectrophotometers which measure the 1107 cm^{-1} oxygen peak in silicon to enable users to improve their measurement agreement. Based on an earlier international Grand Round Robin study, this measurement agreement is at best 5.4% (2σ). Industry requirements for measurement comparison are much more demanding, and a methodology to satisfy those requirements is described. The most important aspect of this methodology is to reduce interlaboratory variation by the use of a single infrared instrument for certification. The certification uncertainty depends primarily on the improved repeatability of this instrument. Other sources of uncertainty were nonuniformity in both oxygen concentration and thickness over the specimen area, and variations in residual oxygen among the float-zone specimens which provided zero-oxygen reference for the reference sets. These various sources were combined in quadrature to arrive at 2σ estimates of uncertainty under 0.2% at three oxygen levels.
[Contact: Brian G. Rennex, (301) 975-2108]

Compound Materials

Released for Publication

Bennett, H.S., **Majority and Minority Electron and Hole Mobilities in Heavily Doped Gallium Aluminum Arsenide**.

[See Device Physics and Modeling.]

Compound Materials

Recently Published

Bennett, H.S., **Report on Workshop on Planning for Compound Semiconductor Technology**, NIST Journal of Research, Vol. 101, pp. 89-94 (1996).

This report describes the motivation for and the results of the Workshop on Planning for Compound Semiconductor Technology. This Workshop, sponsored by NIST and Semiconductor Equipment and Materials International, was held at Gaithersburg, Maryland on February 3, 1995, in conjunction with the International Workshop on Semiconductor Characterization: Present Status and Future Needs, January 30—February 2, 1995. The purposes of the Workshop on Planning for Compound Semiconductor Technology were to: (1) assess whether agreement exists in the compound semiconductor industry for the need of a consensus-based planning effort to support its future goals for materials, processes, devices, interconnects, and packages, and (2) foster the free exchange of information and ideas that might be used to create a more competitive compound semiconductor industry by a mutual understanding of its common problems and of ways to solve them. Without some consensus-based planning on the part of the North American compound semiconductor industry, future economic opportunities in this industry may be limited.
[Contact: Herbert S. Bennett, (301) 975-2079]

Burnett, J.H., Amirtharaj, P.M., Cheong, H.M., Paul, W., Koteles, E.S., and Elman, B., **Use of Pressure for Quantum-Well Band Structure Characterization**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis D.G. Seiler, and A.C. Diebold, Eds. (AIP, New York, 1996), pp. 634-638.

[See Analysis and Characterization Techniques.]

Chandler-Horowitz, D., Berning, D.W., Pellegrino, J.G., Burnett, J.H., Bour, D.P., and Treat, D.W., **Double-Modulation and Selective Excitation Photoreflectance for Wafer-Level Characterization of Quantum-Well Laser Structures**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A.C. Diebold, Eds. (AIP, New York, 1996), pp. 639-643.

[See Analysis and Characterization Techniques.]

Richter, C.A., Seiler, D.G., Pellegrino, J.G., Tseng, W.F., and Thurber, W.R., **Novel Magnetic Field Characterization Techniques for Compound Semiconductor Materials and Devices**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A.C. Diebold, Eds. (AIP, New York, 1996), pp. 673-677.

[See Analysis and Characterization Techniques.]

Sha, W., Smirl, A.L., and Tseng, W.F., **Coherent Plasma Oscillations in Bulk Semiconductors**, Physical Review Letters, Vol. 74, No. 21, pp. 4273-4276 (22 May 1995).

Coherent subpicosecond electron-hole charge oscillations that result from ballistic transport in the presence of a constant built-in field are observed in a bulk GaAs p-i-n sample by using differential electroabsorption techniques.
[Contact: Wen F. Tseng, (301) 975-5291]

Analysis and Characterization Techniques

Released for Publication

Amirtharaj, P.M., Chandler-Horowitz, D., and Bour, D.P., **Double Modulation and Selective Excitation Photoreflectance for Characterizing Highly Luminescent Semiconductor Structures and Samples with Poor Surface Morphology**, to be published in the Proceedings of the Materials Research Society, Boston, Massachusetts, November 25-29, 1995.

Photoreflectance (PR) is a powerful, contactless, and nondestructive technique capable of probing interband electronic transitions and built-in electric-fields at the surface and in interface regions in semiconductor materials and microstructures. It has been widely used as a characterization tool. However, its application to highly luminescent systems, such as quantum-well (QW) lasers and samples with poor surface morphology, has been limited because of the difficulty in minimizing the interference from the luminescence and the pump beam that is scattered from the surface. We present a double modulation procedure where both the probe and pump beams are modulated which allows the PR component to be completely separated from the luminescence and scattered contributions. The separation is achieved through the appropriate choice of modulation frequencies and specially designed tuned amplifiers. A complete PR system, along with the necessary circuits, is presented. In addition, we have also exploited the freedom provided by the system to choose any pump wavelength to selectively modulate specific regions of the multilayer structure (QW, barrier, and cladding layer) and extract detailed information regarding the properties of each layer. The applicability of the procedure is demonstrated by fully characterizing a GaInP-based QW laser structure used for visible emitters and by measurements on a saw-cut and chemically etched back surface of a commercial GaAs wafer. Finally, procedures attempted in the past to overcome difficulties with the luminescence and surface scattering are discussed and compared to the double modulation PR technique.
[Contact: Paul M. Amirtharaj, (301) 975-5974]

Analysis and Characterization Techniques

Recently Published

Burnett, J.H., Amirtharaj, P.M., Cheong, H.M., Paul, W., Koteles, E.S., and Elman, B., **Use of Pressure for Quantum-Well Band Structure Characterization**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A.C. Diebold, Eds. (AIP, New York, 1996), pp. 634-638.

We present a technique to determine unambiguously the origin of the peaks in absorption spectra (and related spectra) of semiconductor heterostructures, using external hydrostatic and uniaxial pressure. This technique depends on the different effective mass dependencies of the various types of heterostructure energy levels involved in absorption transitions, such as electron, heavy hole, light hole, exciton, and defect levels, and the dissimilar pressure dependencies of the various masses. Measurements of the hydrostatic or uniaxial pressure dependencies of the spectral peaks, thus, distinguish peaks associated with these different types of energy levels. The approach is demonstrated for GaAs/AlGaAs quantum wells and HgTe/HgCdTe superlattices using hydrostatic pressure. Heavy- and light-hole-related peaks have

large differences in external uniaxial pressure coefficients, so not only is externally applied uniaxial pressure a convenient and reliable method to distinguish heavy- and light-hole levels, but also the heavy-hole/light-hole splitting can be used to determine quantitatively the amount of built-in uniaxial strain in the heterostructure layers.
[Contact: John H. Burnett, (301) 975-5974]

Chandler-Horowitz, D., Berning, D.W., Pellegrino, J.G., Burnett, J.H., Bour, D.P., and Treat, D.W., **Double-Modulation and Selective Excitation Photoreflectance for Wafer-Level Characterization of Quantum-Well Laser Structures**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A.C. Diebold, Eds. (AIP, New York, 1996), pp. 639-643.

A double-modulation photoreflectance (PR) procedure is presented, where both the probe and pump beams are modulated, and the photoreflectance signal can be isolated from the luminescence and the scattered pump beam signals. The PR signal is separated from the other two signals through detection at the sum frequency. A careful choice of frequencies and specially designed filters and tuned amplifiers were needed to achieve optimum operation. A complete system, along with the necessary circuits, is presented and applied to the characterization of a highly luminescent quantum-well laser structure. The freedom allowed by such a system to easily accommodate any pump wavelength is an important feature. We have exploited this added versatility, and the ordering of the bandgap of the multiple layers required in complex laser structures, to extract the bandgap and alloy composition of each of the constituent regions as well as the built-in strain in the pseudomorphic quantum-well.
[Contact: Deane Chandler-Horowitz, (301) 975-2084]

Diebold, A.C., Kump, M.R., Kopanski, J.J., and Seiler, D.G., **Characterization of Two-Dimensional Dopant Profiles: Status and Review**, Journal of Vacuum Science and Technology B, Vol. 14, No. 1, pp. 196-201 (January/February 1996).

The National Technology Roadmap for Semiconductors calls for development of two- and three-dimensional dopant profiling methods for calibration of technology computer-aided design process simulators. We have previously reviewed 2D dopant profiling methods. In this article, we briefly review methods used to characterize etched transistor cross sections by expanding our previous discussion of scanned probe microscopy methods. We also mention the need to participate in our ongoing comparison of analysis results for test structures that we have provided the community.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Kopanski, J.J., Marchiando, J.F., and Lowney, J.R., **Scanning Capacitance Microscopy Measurements and Modeling: Progress Towards Dopant Profiling of Silicon**, Journal of Vacuum Science and Technology B, Vol. 14, No. 1, pp. 242-247 (January/February 1996).

A scanning capacitance microscope (SCM) has been implemented by interfacing a commercial contact-mode atomic force microscope with a high-sensitivity capacitance sensor. The SCM has promise as a next-generation dopant-profiling technique because the measurement is inherently two dimensional, has a potential spatial resolution limited by tip diameter of at least 20 nm, and requires no current-carrying metal-semiconductor contact. Differential capacitance images have been made with the SCM of a variety of bulk-doped samples and in the vicinity of pn junctions and homojunctions. Also, a computer code has been written that can numerically solve Poisson's equation for a model SCM geometry by using the method of collocation of Gaussian points. Measured data and model output for similar structures are presented. How data and model output can be combined to achieve an experimental determination of dopant profile is discussed.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Neubauer, G., Erickson, A., Williams, C.C., Kopanski, J.J., Rodgers, M., and Adderton, D., **2D-Scanning Capacitance Microscopy Measurements of Cross-Sectioned VLSI Teststructures**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A.C. Diebold, Eds. (AIP, New York, 1996), pp. 318-321.

We have developed a setup which uses scanning capacitance microscopy (SCM) to obtain electrical data of cross-sectioned samples while simultaneously acquiring conventional topographical atomic force microscopy data. The results presented here include 2D SCM maps of cross-sections of blanket implanted, annealed Si wafers as well as test structures on Si. We found the technique to be sensitive over several orders of magnitude of carrier density concentrations $<10^{15}$ to 10^{20} atoms/cm^3, with a lateral resolution of 20 nm to 150 nm, depending on probe tip and dopant level. We find excellent agreement of total implant depth obtained from SCM signals of cross-sectioned samples with conventional Secondary Ion Mass Spectrometry profiles of the same sample.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Neubauer, G., Erickson, A., Williams, C.C., Kopanski, J.J., Rodgers, M., and Adderton, D., **Two Dimensional Scanning Capacitance Microscopy Measurements of Cross-Sectioned Very Large Scale Integration Test Structures**, Journal of Vacuum Science and Technology B, Vol. 14, No. 1, pp. 426-432 (January/February 1996).

Scanning probe technology, with its inherent two-dimensionality, offers unique capabilities for the measurement of electrical properties on a nanoscale. We have developed a setup which uses scanning capacitance microscopy (SCM) to obtain electrical information of cross-sectioned samples while simultaneously acquiring conventional topographical atomic force microscopy (AFM) data. In an extension of our work on very large scale integration cross sections, we have now obtained one-dimensional and two-dimensional SCM data of cross sections of blanket-implanted, annealed Si wafers, as well as special test structures on Si. We find excellent agreement of total implant depth obtained from SCM signals of these cross-sectioned samples with conventional secondary ion mass spectrometry (SIMS) profiles of the same samples. Although no modeling for a direct correlation between signal output and absolute concentration has yet been attempted, we have inferred quantitative dopant concentrations from correlation to SIMS depth profiles obtained on the same sample. By these means of indirect modeling, we have found that our SCM technique is sensitive to carrier density concentrations varying over several orders of magnitude, i.e., $<1 \times 10^{15}$ to 1×10^{20} atoms/cm^3, with a lateral resolution of 20 nm to 150 nm, depending on tip and dopant level.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Nguyen, N.V., Chandler-Horowitz, D., Pellegrino, J.G., and Amirtharaj, P.M., **High-Accuracy Principal-Angle Scanning Spectroscopic Ellipsometry of Semiconductor Interfaces**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A.C. Diebold, Eds. (AIP, New York, 1996), pp. 438-442.

A high-performance spectroscopic ellipsometer has been custom built, in-house at NIST, based on the commonly used rotating-analyzer configuration. The data accuracy was highly enhanced by using the principal-angle scanning technique. This technique requires an accurate setting of the angle of incidence which is accomplished by an interferometer and high-precision goniometers for the sample stage and the polarizer. For each wavelength, the principal angle of incidence was automatically searched to obtain a 90° phase shift of the polarized light upon reflection, i.e., $\Delta = 90°$, and the polarizer azimuth was set to Ψ. At this condition, the ac component of detected intensity is near a null. With zone averaging, systematic errors such as the detector nonlinearity, and the analyzer and polarizer calibration constants are minimized.
To illustrate the use and capability of this system, we use the results of a recent study of the optical properties of SiO_2/Si system and, in particular, the transitional region, defined as an interlayer between the thermally grown SiO_2 film and the Si substrate. In this study, the complex dielectric function and the thickness of the interlayer was determined. From the dielectric function, the existence of both strain and microroughness at this region was inferred, and the strain was seen to induce a redshift of 0.042 eV of the critical point E_1.
[Contact: Nhan V. Nguyen, (301) 975-2044]

Perkowitz, S., Seiler, D.G., Bullis, W.M., **Optical Characterization of Materials and Devices for the Semiconductor Industry: Trends and Needs**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A.C. Diebold, Eds. (AIP, New York, 1996), pp.

422-424.

Contactless, nondestructive optical methods are used to characterize materials, processes, and devices in the semiconductor industry. In response to industrial needs, the Semiconductor Electronics Division of the National Institute of Standards and Technology conducted a survey of the needs for and use of optical characterization methods within the semiconductor industry. Data from forty-two firms were analyzed to show the impact of the methods, what they measure, their range and precision, and their cost. A significant finding of the study is the need expressed by many industrial users for improved standards and test methods for optical characterization.
[Contact: David G. Seiler, (301) 975-2054]

Richter, C.A., Seiler, D.G., Pellegrino, J.G., Tseng, W.F., and Thurber, W.R., **Novel Magnetic Field Characterization Techniques for Compound Semiconductor Materials and Devices**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A.C. Diebold, Eds. (AIP, New York, 1996), pp. 673-677.

Quantum-mechanical effects observed in the magnetoresistance of semiconductor devices and materials give important information such as carrier density, scattering rates, and band structure parameters. However, the small size of these effects often limits their observation and subsequently their practical use. The purpose of this paper is to show how these quantum mechanical effects can be more easily observed and used as characterization tools by modulating the applied magnetic field, which can increase the sensitivity of magnetotransport measurements.
[Contact: Curt A. Richter, (301) 975-2082]

Shaffner, T.J., Diebold, A.C., McDonald, R.C., Seiler, D.G., and Bullis, W.M., **Business and Manufacturing Motivations for the Development of Analytical Technology and Metrology for Semiconductors**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A.C. Diebold, Eds. (AIP, New York, 1996), pp. 1-10.

Semiconductor characterization is an indispensable enabler of all modern microelectronics and optoelectronic circuits, and is in the critical path for maintaining the steady decline in cost-per-function of silicon integrated circuit technology. It is also driving new developments in compound semiconductor materials and devices (III-V and II-VI). In this overview, we present a perspective on measurement technology relative to business and economic challenges of the semiconductor industry, and illustrate the key role metrology plays in modern process development and manufacturing. We also describe how new characterization techniques evolve for semiconductor applications.
[Contact: David G. Seiler, (301) 975-2054]

Device Physics and Modeling

Released for Publication

Bennett, H.S., **Majority and Minority Electron and Hole Mobilities in Heavily Doped Gallium Aluminum Arsenide**.

The majority electron and minority hole mobilities have been calculated in $Ga_{1-y}Al_yAs$ for donor densities between 10^{16} cm^{-3} and 10^{19} cm^{-3}. Similarly, the majority hole and minority electron mobilities have been calculated for acceptor densities between 10^{16} and 10^{20} cm^{-3}. The mole fraction for aluminum, *y*, varies between 0.0 and 0.3 in these calculations. All the important scattering mechanisms have been included. The ionized impurity and carrier-carrier scattering processes have been treated with a quantum-mechanical, phase-shift analysis. These calculations are the first to use a phase-shift analysis for minority carriers scattering from majority carriers in ternary compounds such as $Ga_{1-y}Al_yAs$. The results are in good agreement with experiment for majority mobilities and predict that at high dopant densities, minority mobilities should increase with increasing dopant density for a short range of densities. This effect occurs because of the reduction of plasmon scattering and the removal of carriers from carrier-carrier scattering because of the Pauli exclusion principle. These calculations do not treat the density-of-states modifications due to heavy doping, which should have only a small effect on the mobility at room temperature. The results are important for device modeling because of the need to have physically reasonable values for minority

mobilities when simulating the electrical behavior of heterojunction bipolar transistors.
[Contact: Herbert S. Bennett, (301) 975-2079]

Krska, J.-H.Y., Yoon, J.U., Nee, J., Chung, J.E., Roitman, P., Campisi, G., and Brown, G., **A Model for SIMOX Buried-Oxide High-Field Conduction**.

A new model for SIMOX BOX (buried oxide) high-field conduction which incorporates the role of silicon islands and BOX non-stiochiometry is presented. For single-implant SIMOX BOX high-field conduction, the onset E-field for both positive and negative applied bias is much lower than the expected onset E-field for that of thermal oxide. In addition, the onset E-field for injection from the substrate is lower than for injection from the top-silicon. We propose that conduction by electron injection from the top interface is due to Fowler-Nordheim tunneling with oxide-non-stoichiometry-induced modification of the effective barrier-height. Conduction by electron injection from the bottom interface is due to a two-step Fowler-Nordheim tunneling mechanism with cathode E-field enhancement caused by the presence of silicon islands located near the oxide-substrate interface of single-implant SIMOX. These mechanisms were verified using numerical simulation, electrical, and physical measurements. A modified Fowler-Nordheim equation can be used to model BOX conduction through the addition of three parameters, k_e, k_α, and ϕ_{BOX}. The E-field enhancement factors (k_e and k_α) can be directly correlated to silicon island shape, location, and density, while the effective barrier-height (ϕ_{BOX}) can be correlated to BOX non-stoichiometry. Monitoring these parameters has potential use as a simple method for SIMOX BOX quality control.
[Contact: Peter Roitman, (301) 975-2077]

Insulators and Interfaces

Recently Published

Nguyen, N.V., Chandler-Horowitz, D., Pellegrino, J.G., and Amirtharaj, P.M., **High-Accuracy Principal-Angle Scanning Spectroscopic Ellipsometry of Semiconductor Interfaces**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A.C. Diebold, Eds. (AIP, New York, 1996), pp. 438-442.

[See Analysis and Characterization Techniques.]

Dimensional Metrology

Released for Publication

Lowney, J.R., Vladar, A.E., and Postek, M.T., **High-Accuracy Critical-Dimension Metrology Using a Scanning Microscope**, to be published in the Proceedings of SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Metrology, Inspection, and Process Control for Microlithography X, Santa Clara, California, March 10-15, 1996.

Two Monte Carlo computer codes have been written to simulate the transmitted-, backscattered-, and secondary-electron signals from targets in a scanning electron microscope. The first discussed, MONSEL-II, is applied to semi-infinite lines produced lithographically on multi-layer substrates. The second discussed, MONSEL-III, is an extension to fully three-dimensional targets. Results are given for a 1 μm step etched in a silicon substrate and compared with experimental data. The comparisons show that it is possible to obtain edge location to an uncertainty of less than 10 nm. Simulations are also given for photoresist lines on a silicon substrate coated with a layer of photoresist. Techniques are developed for simulating signals for finite beam diameter from those for zero beam diameter, and for extracting signals approximating zero beam diameter from those with finite beam diameter.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

Dimensional Metrology

Recently Published

Drapela, T.J., Franzen, D.L., and Young, M., **Optical Fiber, Fiber Coating, and Connector Ferrule Geometry: Results of Interlaboratory Measurement Comparisons**, NIST Technical Note 1378 (November 1995).

[See Optical Fiber/Waveguide Sensors.]

Integrated-Circuit Test Structures

Released for Publication

Cresswell, M.W., Sniegowski, J.J., Ghoshtagore, R.N., Allen, R.A., Linholm, L.W., and Villarrubia, J.S., **Electrical Test Structures Replicated in Silicon-on-Insulator Material**, to be published in the Proceedings of SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), 1996 International Symposium on Microlithography: Metrology, Inspection, and Process Control for Microlithography X, Santa Clara, California, March 10-15, 1996.

Measurements of the linewidths of submicrometer features made by different metrology techniques have frequently been characterized by differences of up to 90 nm. The purpose of the work reported here is to address the special difficulties that this phenomenon presents to the certification of reference materials for enabling the calibration of linewidth-measurement instruments. Accordingly, a new test structure has been designed, fabricated, and undergone preliminary tests. Its distinguishing characteristics are assured cross-sectional profile geometries with known side-wall slopes, surface planarity, and compositional uniformity when it is formed in mono-crystalline material at selected orientations to the crystal lattice. To allow the extraction of electrical linewidth, the structure is replicated in a silicon film of uniform conductivity which is separated from substrate silicon by a buried oxide layer. The utilization of a silicon-on-insulator substrate further allows the selective removal of substrate material from local regions below the reference features, thus facilitating measurements by optical and electron-beam transmission microscopy. The combination of planar feature surfaces having known side-wall slopes is anticipated to eliminate factors which are believed to be responsible for methods divergence in linewidth measurements, a capability which is a prerequisite for reliable certification of the linewidths of features on reference materials.
[Contact: Michael W. Cresswell, (301) 975-2072]

Integrated-Circuit Test Structures

Recently Published

Allen, R.A., Cresswell, M.W., Ellenwood, C.H., and Linholm, L.W., **The Enhanced Voltage-Dividing Potentiometer for High-Precision Feature Placement**, IEEE Transactions on Instrumentation and Measurement, Vol. 45, No. I, pp. 136-141 (February 1996).

Enhancements to the voltage-dividing potentiometer, an electrical test structure for measuring the spatial separations of pairs of conducting features, are presented and discussed. These enhancements reduce or eliminate systematic errors which can otherwise lead to uncertainties as large as several hundred nanometers. These systematic errors, attributed by modeling to asymmetries at certain intersections of conducting features in the test structure, are eliminated by modifications to the test structure and test procedures.
[Contact: Richard A. Allen, (301) 975-5026]

Microfabrication Technology

Released for Publication

Gaitan, M., **Microheating Elements in CMOS Technology**, to be published in the Proceedings of the 1996 International Symposium on Circuits and Systems, Atlanta, Georgia, May 12-15, 1996.

The miniaturization of heating elements offers two distinct advantages over conventional heaters: their small size allows the rapid temperature transient control of a small surface, on the order of 1 ms, and array integration, enabling the configuration of a temperature programmable surface. Since many physical, biological, and chemical phenomena can be controlled by temperature, microheating elements have many interesting and potential applications. Integration of microheating elements with CMOS technology allows the monolithic circuit integration with the heaters for control, sensing, and signal processing. This manuscript is an overview of CMOS-based microheating elements realized by a anisotropic chemical etch after the full CMOS process is complete.
[Contact: Michael Gaitan, (301) 975-2070]

Johnson, R.B., Chung, R., and Gaitan, M., **Real-Time Thermal Infrared Scene Generation Technology and Its Application in the Test and Calibration of Infrared Sensors and Seekers**, to

be published in the Proceedings of the 1996 Government Microcircuit Applications Conference, Orlando, Florida, March 18-21, 1996.

For over two decades, researchers have investigated a wide variety of technologies for use as a real-time infrared scene generator. During the past several years, the most promising technology to meet the myriad of applications appears to be the silicon micromachined resistive-array approach. Each thermal pixel is created by a micro-scale resistor. The present investigation reports the recent results achieved by using the standard commercial CMOS foundry process, rather than a costly custom CMOS process, to produce the chip and the subsequent post-foundry etching. Both chip-level and pixel-specific electronics are readily included on the chip since IC technology is employed.
[Contact: Michael Gaitan, (301) 975-2070]

Milanović, V., Gaitan, Marshall, J.C., and Zaghloul, M.E., **CMOS Foundry Implementation of Schottky Diodes for RF Detection**.

Schottky diodes were designed and fabricated using a commercial *n*-well CMOS foundry process through the MOSIS service. The Schottky diodes were implemented by modifying the SCMOS technology file of the public-domain graphics layout editor, MAGIC. Current-voltage measurements showed that only the *n*-type devices had rectifying properties with a barrier height of 0.78 eV. The diodes were tested in an RF detector circuit. The cut-off frequency of the detector was shown to be 600 MHz.
[Contact: Michael Gaitan, (301) 975-2070]

Plasma Processing

Released for Publication

Foest, R., Olthoff, J.K., Van Brunt, R.J., Benck, E., and Roberts, J.R., **Optical and Mass Spectrometric Investigations of Ions and Neutrals in SF_6 Radio-Frequency Discharges**.

[See Power Systems Metrology.]

Rao, M.V.V., Van Brunt, R.J., and Olthoff, J.K., **Resonant Charge Exchange and the Transport of Ions at High Electric Field-to-Gas Density Ratios (*E/N*) in Argon, Neon, and Helium**.

Translational kinetic-energy distributions of singly and doubly charged ions have been measured at high electric field-to-gas density ratios (*E/N*) up to 5.0×10^{-17} Vm^2 (50 kTd) in diffuse, parallel-plate Townsend discharges in Ar, Ne, and He using an ion energy analyzer-mass spectrometer. For Ar^+ in Ar and Ne^+ in Ne when $E/N < 2.0 \times 10^{-17}$ Vm^2, and for He^+ in He when $E/N < 0.8 \times 10^{-17}$ Vm^2, the energy distributions are Maxwellian and consistent with predictions based on the assumption that resonant symmetric charge exchange is the dominant ion-neutral collision process. At higher *E/N* values, the kinetic-energy distributions for Ar^+, Ne^+, and He^+ show departures from the Maxwellian form that may be indicative of deviations from equilibrium. The mean ion energies (effective ion temperatures) are consistent in the low *E/N* range with the drift-velocity data of Hornbeck from pulsed Townsend discharge experiments, and in the case of Ar^+, with recent results of Radovanov and coworkers. The charge-exchange cross sections derived from Maxwellian fits to the energy distribution data for $Ar^+ + Ar$, $Ne^+ + Ne$, and $He^+ + He$ agree with available data. The relative contributions of the doubly charged ions Ar^{++}, Ne^{++}, and He^{++} to the total ion flux were found to be small (less than 3%) and to decrease at high *E/N*. The mean energies of the doubly charged ions are much higher than those for the corresponding singly charged ions, and the results suggest that double-charge transfer could be the dominant process affecting the transport of Ar^{++} and Ne^{++}.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Plasma Processing

Recently Published

Hwang, H.H., Olthoff, J.K., Van Brunt, R.J., Radovanov, S.B., and Kushner, M.J., **Evidence for Inelastic Processes for N_3^+ and N_4^+ from Ion Energy Distributions in He/N_2 Radio Frequency Glow Discharges**, Journal of Applied Physics, Vol. 79, No. 1, pp. 93-98 (1 January 1996).

The ion energy distributions (IEDs) striking surfaces in rf glow discharges are important in the context of plasma etching during the fabrication of

microelectronics devices. In discharges sustained in molecular gases or multicomponent gas mixtures, the shape of the IED and the relative magnitudes of the ion fluxes are sensitive to ion-molecule collisions which occur in the presheath and sheath. Ions which collisionlessly traverse the sheaths or suffer only elastic collisions arrive at the substrate with a measurably different IED than do ions which undergo inelastic collisions. In this article, we present measurements and results from parametric calculations of IEDs incident on the grounded electrode of a rf glow discharge sustained in a HeN_2 gas mixture while using a Gaseous Electronics Conference Reference Cell (33.3 Pa, 13.56 MHz). We found that the shape of the IEDs for H_3^+ and H_4^+ provide evidence for inelastic ion-molecule reactions which have threshold energies of <10 eV.
[Contact: James K. Olthoff, (301) 975-2431]

Power Devices

Recently Published

Adams, V.H., Joshi, Y., and Blackburn, D.L., **Natural Convection from an Array of Electronic Packages Mounted on a Narrow Aspect Ratio Enclosure**, Proceedings of the Thirteenth National Heat and Mass Transfer Conference, Surathkal, India, December 28-30, 1995, pp. 911-917.

Three-dimensional natural convection flow and heat transfer were numerically studied for a 3 x 3 array of discretely heated electronic packages mounted on a horizontal circuit board in an air-filled, narrow aspect ratio rectangular enclosure with length, width, and height ratio of 6:6:1. The governing equations for natural convection in air, coupled with conjugate conduction within the electronic packages surfaces and maximum chip temperatures for Rayleigh numbers of 10^4, 10^6, and 10^7 were compared with corresponding results from an analysis involving only heat conduction. It was found that conduction-only analysis underpredicts heat transfer from the top surfaces of the electronic packages by a factor of 1.5 to 4.4, with a resultant overprediction of the maximum chip to ambient temperature difference of 235%.
[Contact: David L. Blackburn, (301) 975-2068]

Photodetectors

Released for Publication

Hale, P.D., Wang, C.M., Park, R., and Lau, W.Y., **Photoreceiver Frequency Response Transfer Standard: Calibration Using a Swept Heterodyne Method**.

[See Integrated Optics.]

Reliability

Recently Published

Chaparala, P., Suehle, J.S., Messick, C., and Roush, M., **Time-Dependent Dielectric Breakdown of Intrinsic SiO_2 Films under Dynamic Stress**, Final Report of the IEEE 1995 Integrated Reliability Workshop, Lake Tahoe, California, October 22-25, 1995, pp. 104-112.

We present time-dependent dielectric breakdown (TDDB) characteristics for 9, 15, and 22 nm silicon dioxide films stressed under dc, unipolar, and bipolar pulsed bias conditions. Our results indicate that the increased lifetime observed under pulsed stress conditions diminishes as the stress electric-field and oxide thickness are reduced. TDDB data under pulse bias conditions exhibit similar field and temperature dependencies as under static stress. C-V measurements indicate that lifetime enhancement only occurs for electric fields and thickness where charge trapping is significant.
[Contact: John S. Suehle, (301) 975-2247]

Erhart, D.L., Schafft, H.A., and Gladden, W.K., **On the Road to Building-In Reliability**, Final Report of the IEEE 1995 International Integrated Reliability Workshop, Lake Tahoe, California, October 22-25, 1995, pp. 5-10 (1996).

The cycle-time pressures to reduce the time required to introduce new products, and the continued demands for decreasing product failure rates are pushing our existing reliability risk management methodology to its limits. These issues have stimulated the reassessment of our strategy and the development of an alternate approach. In this presentation, we explore the implementation of building-in-reliability (BIR). We develop working definitions for BIR and the present reliability risk assessment methodology, testing-in

reliability (TIR). We contrast the TIR and BIR approaches in the context of a new product introduction process, as well as in the context of day-to-day manufacturing. We examine the TIR and BIR approaches to metallization reliability, and develop a strawman proposal for the implementation of BIR.
[Contact: Harry A. Schafft, (301) 975-2234]

Martin, A., Suehle, J.S., Chaparala, P., O'Sullivan, P., Mathewson, A., and Messick, C., **Assessing MOS Gate Oxide Reliability on Wafer Level with Ramped/Constant Voltage and Current Stress**, Final Report of the IEEE 1995 Integrated Reliability Workshop, Lake Tahoe, California, October 22-25, 1995, pp. 81-91 (1996).

In this study, time-to-breakdown distributions are compared for MOS gate oxides which were stressed with a constant voltage (or current) stress or a pre-stressing voltage (or current) ramp followed by a constant voltage (or current) stress. Results show clearly that a pre-stress can increase time-to-breakdown. This increase is discussed, and it is shown that it is dependent on oxide thickness, pre-stressing ramp rate and the processing conditions. The current-time (or voltage-time) characteristics of the constant stress are investigated, and it is observed that charge trapping in the oxide is the reason for the time-to-breakdown increase. The pre-stressed oxide clearly shows a different initial charge trapping characteristic than the nonpre-stressed oxide. The measurement results are discussed, and it is demonstrated that the common understanding of oxide breakdown cannot explain the observed results. Therefore, a new parameter is proposed which is related to oxide degradation and breakdown and which has to be considered in combined ramped/constant stress measurements.
[Contact: John S. Suehle, (301) 975-2247]

Schlund, B., Suehle, J.S., Messick, C., and Chaparala, P., **A New Physics-Based Model for Time-Dependent-Dielectric Breakdown**, Final Report of the IEEE Integrated Reliability Workshop, Lake Tahoe, California, October 22-25, 1995, pp. 72-80 (1996).

A new, physics-based model for time-dependent-dielectric breakdown has been developed, and is presented along with test data obtained by NIST on oxides provided by an industrial firm. Testing included fields from 5.6 MV/cm to 12.7 MV/cm, and temperatures ranging from 60 °C to 400 °C. The physics, mathematical model, and test data all confirm a linear, rather than an inverse field dependence. The primary influence on oxide breakdown was determined to be due to the dipole interaction energy of the field with the orientation of the molecular dipoles in the dielectric. The resultant failure mechanism is shown to be the formation and coalescence of vacancy defects, similar to that proposed by Dumin et al.
[Contact: John S. Suehle, (301) 975-2247]

Other Semiconductor Metrology Topics

Recently Published

Shaffner, T.J., Diebold, A.C., McDonald, R.C., Seiler, D.G., and Bullis, W.M., **Business and Manufacturing Motivations for the Development of Analytical Technology and Metrology for Semiconductors**, Semiconductor Characterization: Present Status and Future Needs, W.M. Bullis, D.G. Seiler, and A.C. Diebold, Eds. (AIP, 1996), pp. 1-10.

[See Analysis and Characterization Techniques.]

SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

DC and Low-Frequency Metrology

Released for Publication

Chang, Y.M., **NIST Measurement Assurance Program for Capacitance Standards at 1 kHz**, to be published as a NIST Technical Note.

This document describes the capacitance Measurement Assurance Program (MAP) service at the National Institute of Standards and Technology. This service, which uses a commercial digital capacitance meter as the transport standard, provides calibration for capacitance standards at both the 1000 pF and 100 pF levels, at a frequency of 1 kHz. In contrast to the normal MAP, where the transport standards are measured by the client laboratory, the capacitance MAP involves measurements performed on "dummy" standards

by both the meter (1 kHz digital capacitance meter used as the transport standard) and the laboratory capacitance measuring system. Measurement procedures and requirements for client laboratories are included. Also presented are error analysis, assigned values, and equations to estimate the combined uncertainties of the assigned values.
[Contact: Y. May Chang, (301) 975-4237]

Dziuba, R.F., **Resistors**, to be published in the Encyclopedia of Applied Physics.

Resistors are important components in electrical and electronic circuits. The first resistors were specified lengths of wire made out of pure metals which exhibited large temperature dependencies. Later resistance alloys, notably manganin and Evanohm®, were developed for the construction of wirewound resistors with zero temperature coefficients of resistance near room temperature. This article begins with a brief historical account of the evolution of the different types of resistors starting with wirewounds and proceeding to carbon composition and the various film-type resistors. The concept of resistance is briefly described along with Ohm's Law and the unit of resistance. By international agreement, since January 1, 1990, the unit of resistance has been expressed in terms of the quantum Hall effect which occurs in suitable semiconductors operating at high magnetic fields and low temperatures and is based on fundamental constants. The importance of resistors in the measurement of current, voltage ratios, temperature, and displacement is also discussed. The article describes, in more detail, resistor fabrication including the main constructural elements of base material, resistive element, terminations, and protective enclosure. Then separate categories of carbon composition, wirewound, metal foil, thin film, and thick film resistors are characterized. The article next discusses the key characteristics of the different types of resistors, including accuracy, stability, power rating, temperature coefficient, load coefficient, voltage coefficient, humidity effects, pressure effects, and frequency effects. Finally, the common classification of resistors, according to their intended use and inherent performance, is described. This classification includes standard resistors, resistors in electronic circuits, integrated-circuit resistors, high current resistors, and high-voltage resistors.
[Contact: Ronald F. Dziuba, (301) 975-4239]

Elmquist, R.E., and Dziuba, R.F., **Loading Effects in Resistance Scaling**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

[See Fundamental Electrical Measurements.]

Jarrett, D.G., **Automated Guarded Bridge for Calibration of Multimegohm Standard Resistors**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

The implementation of an automated guarded bridge for calibrating multimegohm standard resistors is described. A guarded Wheatstone bridge has been assembled with programmable dc calibrators in two of the arms allowing multiple ratios and test voltages to be remotely selected. Preliminary measurements are reported along with the balancing algorithm.
[Contact: Dean G. Jarrett, (301) 975-4240]

Jeffery, A.M., Shields, J.Q., and Lee, L.H., **Conversion of a 2-Terminal-Pair Bridge to a 4-Terminal-Pair Bridge for Increased Range and Precision in Impedance Measurements**, Proceedings of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

A new four-terminal-pair bridge, capable of a relative uncertainty of 1 in 10^9, has been constructed at NIST by converting a two-terminal pair bridge. The conversion requires only addition of components which are easily removed if two-pair measurements are to be made. The design and testing of this bridge are described.
[Contact: Ann Marie Jeffery, (301) 975-4246]

Kinard, J.R., Lipe, T.E., Childers, C.B., Novotny, D.B., and Huang, D.-X., **High-Current Thin Film Multijunction Thermal Converters and Multi-Converter Modules**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig,

Germany, June 17-20, 1996.

High-current, thin-film multijunction thermal converters (HCTFMJTCs) have been fabricated at NIST with heater ranges from a few milliamperes to 1 A. Multi-converter modules containing HCTFMJTCs have also been constructed to measure currents up to several amperes.
[Contact: Joseph R. Kinard, (301) 975-4250]

Kupferman, S.L., Hamilton, C.A., Naujoks, G., and Vickery, A., **A Compact Transportable Josephson Voltage Standard**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

[See Cryoelectronic Metrology.]

Marshall, J.A., Jarrett, D.G., Dziuba, R.F., and Marshall, T.A., **A Low Thermal Guarded Scanner for High Resistance Measurement Systems**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

The design and testing of a low thermal guarded scanner developed to provide completely guarded switching when used with guarded resistance bridge networks is described.
[Contact: Dean G. Jarrett, (301) 975-4240]

Oldham, N.M., Parker, M., Bell, B., and Avramov-Zamurovic S., **Exploring the Low-Frequency Performance of Thermal Converters Using Circuit Models and a Digitally Synthesized Source**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

Low-frequency tracking errors of thermal voltage converters are described and estimated using circuit models. A digitally synthesized source is used to confirm ac-dc differences in the 0.001 Hz to 40 Hz range.
[Contact: Nile M. Oldham, (301) 975-2408]

Oldham, N.M., Parker, M., and Avramov-Zamurovic, S., **Low-Voltage Standards in the 10 Hz - 1 MHz Range**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

A stepdown procedure for establishing voltage standards in the 1 to 100 mV range at frequencies between 10 Hz and 1 MHz is described. The stepdown employs low-voltage thermal voltage converters and micropotentiometers. Techniques for measuring input impedance and equations describing loading errors are given.
[Contact: Nile M. Oldham, (301) 975-2408]

Souders, T.M., Waltrip, B.C., Laug, O.B., and Deyst, J.P., **A Wideband Sampling Voltmeter**, to be published in the Proceedings of the 1996 IEEE Instrumentation and Measurement Technology Conference, Brussels, Belgium, June 4-6, 1996.

A high-accuracy sampling voltmeter, designed to span the frequency range of 10 Hz to 200 MHz, is described. The instrument operates autonomously, at a measurement update rate of at least one per second. A novel quasi-equivalent time sampling process is used, with a custom strobed comparator as the sampling device and decision element. The architecture and control are presented, along with the time-base design principles. Major error sources associated with the time-base are also discussed.
[Contact: T. Michael Souders, (301) 975-2406]

Waltrip, B.C., and Oldham, N.M., **DC-1MHz Wattmeter Based on RMS Voltage Measurements**, to be published in the Proceedings of the 1996 IEEE Instrumentation and Measurement Technology Conference, Brussels, Belgium, June 4-6, 1996.

[See Power Systems Metrology.]

Waveform Metrology

Released for Publication

Nahman, N., Andrews, J., Baldwin, E., and Gans, W., **Pulse Transition Duration Measurements and Standards at NIST - 1975 to 1988**, to be published as a NIST Technical Note.

The techniques employed by NIST from the mid 70s

through 1988 for the calibration of the *pulse transition duration* (TD) of a fast, step-like, electrical pulse generator are described along with the artifact requirements on the pulse generator. The fundamental definitions and measurement and generation methods relevant to the calibration of *pulse transition duration* are presented. Subjects discussed include the IEEE Pulse Standards 181-77 and 194-77, deconvolution as applied in (1) time-domain waveform measurements of a pulse and (2) in network impulse response characterization, and the NBS 50, 100, and 200 ps Transition Duration Transfer Standards which are based upon a tunnel diode step-like generator (TD about 20 ps), and Debye liquid-dielectric coaxial line filters. The Appendices contain electronic circuit diagrams and mechanical drawings for the Transition Duration Transfer Standards.
[Contact: William L. Gans, (301) 975-2502]

Cryoelectronic Metrology

Released for Publication

Benz, S.P., and Hamilton, C.A., **A Pulse-Driven Programmable Josephson Voltage Standard**.

[See Fundamental Electrical Measurements.]

Hamilton, C.A., Burroughs, C.J., and Benz, S.P., **Progress toward an AC Josephson Voltage Standard**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

[See Fundamental Electrical Measurements.]

Kupferman, S.L., Hamilton, C.A., Naujoks, G., and Vickery, A., **A Compact Transportable Josephson Voltage Standard**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

The development of a compact, portable 10 V Josephson calibration system is described. Its accuracy at 10 V is expected to be 0.02 ppm. Its weight and volume are reduced by more than a factor of three compared to laboratory systems. The new system will replace travelling voltage standards used within several NASA and DOE standards laboratories.
[Contact: Clark A. Hamilton, (303) 497-3740]

Cryoelectronic Metrology

Recently Published

Booi, P.A.A., and Benz, S.P., **Design of High-Frequency, High-Power Oscillators Using Josephson-Junction Arrays**, Proceedings of the European Conference on Applied Superconductivity, Edinburgh, Scotland, July 3-7, 1995, pp. 1479-1482.

We analyze the limitations imposed by junction capacitance and the parasitic inductance associated with shunt resistors, on the performance of Nb/Al-AlO_x/Nb-junction-array oscillators. We use wide junctions that are in-situ deposited on top of PdAu resistor films (to minimize inductance) and are situated above Nb ground planes to ensure uniform current injection. From the measured parasitics, we infer the maximum power and frequency that can be obtained for critical-current densities $J_c \leq 100$ kA/cm^2. We illustrate these findings with experimental results of 1,968-junction arrays having $J_c \approx 10$ kA/cm^2 that was found to couple 0.1 to 0.8 mW to a 56-Ω load in the range 100 to 300 GHz.
[Contact: Peter A. A. Booi, (303) 497-5910]

Kautz, R.L., and Benz, S.P., **Metallic-Barrier Junctions for Programmable Josephson Voltage Standards**, Proceedings of the European Conference on Applied Superconductivity, Edinburgh, Scotland, July 3-6, 1995, pp. 1407-1410.

[See Fundamental Electrical Measurements.]

Roshko, A., Goodrich, L.F., Rudman, D.A., Moerman, R., and Vale, L.R., **Magnetic Flux Pinning in Epitaxial $YBa_2Cu_3O_{7-\delta}$ Thin Films**, Journal of Electronic Materials, Vol. 24, No. 12, pp. 1919-1922 (1995).

The influence of microstructure on the critical current density of laser ablated $YBa_2Cu_3O_{7-\delta}$ thin films has been examined. Scanning tunneling microscopy was used to examine the morphologies of $YBa_2Cu_3O_{7-\delta}$ films and the morphology data

were then correlated with measurements of the critical current density. The films were found to grow by an island nucleation and growth mechanism. The critical current densitites of the films are similar to those of films with screw dislocation growth, indicating that screw dislocation growth is not necessary for good pinning. The data suggest that the critical current density in applied magnetic field may be higher in films with higher densities of growth features.
[Contact: Alexana Roshko, (303) 497-5420]

Antenna Metrology

Recently Published

Guerrieri, J., Canales, N., MacReynolds, K., and Tamura, D., **Planar Near-Field Measurements and Microwave Holography for Measuring Aperture Distribution on a 60 GHz Active Array Antenna**, Proceedings of the 17th Annual Meeting and Symposium, Antenna Measurement Techniques Association, Williamsburg, Virginia, November 13-17, 1995, pp. 295-299.

This paper discusses results of a recent attempt to measure aperture distribution of a small active steerable array antenna at 60 GHz using planar near-field measurements and the back transform. Using a procedure which exercises every phase shifter without steering the antenna beam, it is possible to isolate problems with individual bits in the phase shifters. From calculation of the aperture fields for each case, we hope to infer the individual phase shifter bit loss. We also discuss problems which arose in the measurement because of the short wavelength, signal-to-noise ratio and small number of elements.
[Contact: Jeffrey J. Guerrieri, (303) 497-3863]

Microwave and Millimeter-Wave Metrology

Released for Publication

Ginley, R.A., **Calibrating a Dual Six-Port with a Single Impedance Standard**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Branuschweig, Germany, June 17-20, 1996.

A newly developed method allows dual six-port automatic network analyzers to be calibrated with a single, known one-port termination instead of air line standards. This technique is especially useful for low frequency calibrations below 30 MHz where air lines cannot be adequately characterized.
[Contact: Ronald A. Ginley, (303) 497-3634]

Microwave and Millimeter-Wave Metrology

Recently Published

Marks, R.B., Jargon, J.A., Pao, C.K., and Wen, C.P., **Microwave Characterization of Flip-Chip MMIC Components**, Proceedings of the 45th Electronic Components & Technology Conference, Las Vegas, Nevada, May 21-24, 1995, pp. 343-350.

We apply custom calibration standards and software to the accurate on-wafer measurement of metal-insulator-metal capacitors and spiral inductors on flip-chip coplanar-waveguide MMICs. We suggest equivalent circuit models and document their deficiencies. The results are applicable to the development of an accurate CAD database.
[Contact: Roger B. Marks, (303) 497-3037]

Marks, R.B., Jargon, J.A., Pao, C.K., and Wen, C.P., **Microwave Characterization of Flip-Chip MMIC Interconnections**, Proceedings of the IEEE 1995 International Microwave Symposium, Orlando, Florida, May 14-19, 1995, Vol. 3, pp. 1463-1466.

We report accurate on-wafer measurements of transmission lines on flip-chip coplanar-waveguide MMICs. The effects are difficult to predict theoretically, and without custom standards and unique calibration software, measurements would be intractable. The results are applicable to the development of an accurate CAD database. We also report and apply a new technique for the measurement of transmission line capacitance.
[Contact: Roger B. Marks, (303) 497-3037]

Weidman, M.P., **Direct Comparison Transfer of Microwave Power Sensor Calibrations**, NIST Technical Note 1379 (January 1996).

This report describes a basic, but potentially accurate, transfer technique for comparing

microwave power sensors. The technique is not new, but the specific applications are. This report is written to supplement the existing literature. The method transfers the effective efficiency of a standard power sensor to an unknown (uncalibrated) power sensor. The power sensors may be bolometric (thermistor mounts), thermoelectric, or diode types, and each type will have inherent limitations. The technique can be implemented with a variety of commercial coaxial and rectangular waveguide components. Measurement uncertainty is discussed in this report so that a potential user can quantify transfer uncertainties.
[Contact: Manly P. Weidman, (303) 497-3516]

Williams, D.F., and Schappacher, J.B., **Line Reflect-Match Calibrations with Nonideal Microstrip Standards**, Proceedings of the 46th Automatic Radio Frequency Techniques Group, Scottsdale, Arizona, November 30—December 1, 1995, pp. 35-38.

We apply a previously developed Line-Reflect-Match calibration that compensates for the nonideal electrical behavior of the match standard to microstrip transmission lines and investigate impedance definitions, standard parasitics, and calibration accuracy.
[Contact: Dylan F. Williams, (303) 497-3138]

Electromagnetic Properties

Released for Publication

Crawford, T.M., Rogers, C.T., Silva, T.J., and Kim, Y.K., **Transverse and Longitudinal Second Harmonic Magneto-Optic Kerr Effect Observed from $Ni_{81}Fe_{19}$ Thin Film Structures**.

We report measurements of the second harmonic magneto-optic Kerr effect in both transverse and longitudinal geometries from 100 nm thick $Ni_{81}Fe_{19}$ films. For the transverse geometry, we observe intensity changes >3 upon magnetization reversal. In the longitudinal geometry, the second harmonic Kerr angle is 32.6 degrees for s-incidence and 6.8 degrees for p-incidence. The second-order susceptibility elements, χ_{xxx} and χ_{zxx}, are measured in both the p-transverse and in the s-longitudinal geometry. A simple theoretical treatment allows us to compare the elements as measured in the two geometries: the element magnitudes and relative phase shifts agree to >90%.
[Contact: Thomas J. Silva, (303) 497-7826]

Geyer, R.G., and Krupka, J., **Microwave Behavior of Ferrites: Theory and Experiment**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

The relative magnetic permeability and loss factor of microwave ferrites in the demagnetized state are determined near and above gyromagnetic resonance using low-loss dielectric ring resonators. This technique allows complex permeability determination on a single ferrite sample from 2 GHz to 25 GHz. The measured real parts of the initial permeability are compared with theoretical predictions of the permeability of a sample in the demagnetized state.
[Contact: Richard G. Geyer, (303) 497-5533]

Hu, X., **Magnetization Reversal and Coercive Force in Ultrathin Films with Perpendicular Surface Anisotropy: Micromagnetic Theory**.

Quasi-static magnetization reversals in ultrathin magnetic films with perpendicular surface anisotropy are studied micromagnetically. Reversal processes such as nucleations, coherent and incoherent rotations, domain-wall motion, and abrupt jumps are found in films of different shape anisotropy, surface anisotropy, exchange stiffness, and film thickness. The coercivity of ultrathin magnetic films in fields perpendicular to the film plane is shown to decrease with the square of the reciprocal of the film thickness, which coincides very well with experimental observations. Magnetization reversal processes resulting from applying in-plane external fields are also studied.
[Contact: Xiao Hu, (303) 497-3701]

Jargon, J.A., and Janezic, M.D., **Measuring Complex Permittivity and Permeability Using Time Domain Network Analysis**, to be published in the Proceedings of the 1996 IEEE Microwave and Technique Society International Microwave Symposium, San Francisco, California, June 17-21, 1996.

We use a time-domain network analyzer along with a recent improvement to the transmission/reflection method to determine the complex permittivity and permeability of a sample in a coaxial line. Our data show that accurate measurements can be made without a conventional frequency domain network analyzer.
[Contact: Jeffrey A. Jargon, (303) 497-3596]

Krupka, J., Pietruszko, S., Geyer, R.G., Baker-Jarvis, J., and Derzakowski, K., **Semiconductor Resistivity Measurements Using a Split-Dielectric Resonator Technique**, to be published in the Proceedings of the MIKON XI International Microwave Conference, Warsaw, Poland, May 27-30, 1996.

A split-dielectric resonator technique is employed for microwave resistivity and permittivity measurements of semiconductors. Rigorous Rayleigh-Ritz and mode-matching methods are used for resistivity and permittivity analysis and to determine resolvable upper and lower resistivity measurement bounds. Both bulk semiconductor wafers and thin amorphous silicon films deposited on fused silica substrates were measured. The measurement data for the semiconducting wafers compare well with data taken by the conventional four-point probe method and demonstrate that the split dielectric resonator is useful for noncontacting, nondestructive resistivity measurements of bulk semiconductor wafers. Thin silicon films deposited on low-loss dielectric substrates may also be measured by this technique provided the film resistivity is greater than 0.01 Ω·m but less than 10 Ω·m.
[Contact: Richard G. Geyer, (303) 497-5852]

Electromagnetic Properties

Recently Published

Baker-Jarvis, J., and Grosvenor, J.H., **Dielectric and Magnetic Measurements from -50 °C to 200 °C and in the Frequency Band 50 MHz to 2 GHz**, NISTIR 5045 (March 1996).

This is an overview of techniques for dielectric and magnetic measurements of low-loss through high-loss materials in the frequency range from 50 MHz to 2 GHz and over a temperature range of -50 °C to 200 °C. We conclude that a single fixture is not adequate to satisfy the measurement objectives. The necessary measurements can be met using a combination of reentrant cavity, coaxial line, and dielectric resonator fixtures. In order to minimize heat loss, the coaxial line fixture should be milled from stainless steel stock and then gold plated. The reentrant cavity and split post resonator fixtures should be fitted with high-temperature coaxial cables and temperature control obtained from an environmental furnace.
[Contact: James Baker-Jarvis, (303) 497-5621]

Baker-Jarvis, J., and Janezic, M.D., **Analysis of a Two-Port Flanged Coaxial Holder for Shielding Effectiveness and Dielectric Measurements of Thin Films and Thin Materials**, IEEE Transactions on Electromagnetic Compatibility, Vol. 38, No. I, pp. 67-70 (February 1996).

A two-port flanged coaxial probe for measuring the dielectric and magnetic properties of thin material sheets is analyzed. Closed form solutions for the two-port scattering parameters are presented. The solution assumes an incident TEM wave together with evanescent TM_{0n} modes. Numerical results are obtained for both the forward and inverse problem. Computations indicate that at low frequencies the incident waves are almost totally reflected. As the frequency is increased, transmission through the sample increases. Experimental results compare closely with theory. The inverse solution yielded good permittivity determination for the cases tested. The technique should prove useful for nondestructive testing of circuit boards or substrates.
[Contact: James-Baker Jarvis, (303) 497-5621]

Mantese, J.V., Micheli, A.L., Dungan, D.F., Geyer, R.G., Baker-Jarvis, J., and Grosvenor, J., **Applicability of Effective Medium Theory to Ferroelectric/Ferrimagnetic Composites with Composition and Frequency-Dependent Complex Permittivities and Permeabilities**, Journal of Applied Physics, Vol. 79, No. 3, pp. 1655-1660 (February 1996).

High-frequency (1 MHz to 1 GHz) transmission line measurements were used to determine the composition and frequency-dependent complex permittivities and complex permeabilities of ferroelectric/ferrimagnetic (barium titanate and a

magnesium-copper-zinc ferrite) composites. The effective medium rules of Maxwell-Garnett give both lower and upper bounds for the effective permittivities and permeabilities and yield accurate estimates of the bulk electric and magnetic properties at low volume fill fraction of either component provided the proper host matrix is chosen. Bruggeman theory yielded the best predictive values for the permittivity and permeability over the entire composition range. In all cases, these complex quantities were shown to be constrained by Bergman-Milton bounds.
[Contact: Richard G. Geyer, (303) 497-5852]

Laser Metrology

Released for Publication

Obarski, G.E., Larson, D.R., and Phelan, R.J., **Relative Intensity Noise of an InGaAsP Laser over a 22 GHz Bandwidth at Cryogenic and Room Temperature**, to be published in the Proceedings of the Optical Society of America/Topical Meeting, Boston, Massachusetts, April 29—May 3, 1996.

We show that cryogenic operation of a commercial InGaAsP laser significantly reduces its relative intensity noise within a measurement bandwidth of 22 GHz, indicating its potential for ultrahigh-speed optical communications.
[Contact: Gregory E. Obarski, (301) 975-5747]

Laser Metrology

Recently Published

Vayshenker, I., Yang, S., Li, X., and Scott, T.R., **Automated Measurements of Nonlinearity of Optical Fiber Power Meters**, Proceedings of SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Photodetectors and Power Meters II, Vol. 2550, pp. 12-19 (1995).

[See Optical Fiber Metrology.]

Optical Fiber Metrology

Recently Published

Vayshenker, I., Yang, S., Li, X., and Scott, T.R., **Automated Measurements of Nonlinearity of Optical Fiber Power Meters**, Proceedings of SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Photodetectors and Power Meters II, Vol. 2550, pp. 12-19 (1995).

We have developed a system for measuring the nonlinearity of optical power meters or detectors over a dynamic range of more than 60 dB at telecommunications wavelengths. This system uses optical fiber components and is designed to accommodate common optical power meters and optical detectors. It is based on the triplet superposition method. The system also measures the range discontinuity between neighboring power ranges or scale settings of the optical power meter. We have developed an algorithm to treat both the nonlinearity and the range discontinuity in a logically consistent manner. Measurements with this system yield correction factors for powers in all ranges. The measurement system is capable of producing results which have standard deviations as low as 0.02%. With slight modification, the system can operate over a 90 dB dynamic range at telecommunications wavelengths. This measurement system provides accurate determination of optical power meter or detector nonlinearity; the characterized detectors then can be used for such applications as absolute power and attenuation measurements.
[Contact: Thomas R. Scott, (303) 497-3651]

Optical Fiber/Waveguide Sensors

Released for Publication

Day, G.W., Rochford, K.B., and Rose, A.H., **Fundamentals and Problems of Fiber Current Sensors**, to be published in the Proceedings of the 1996 International Conference on Optical Fiber Sensors, Sapporo, Hokkaido, Japan, May 21-24, 1996.

This paper briefly reviews the history and present commercial status of optical fiber sensors, and then summarizes recent research aimed at improved performance, lower cost, and wider areas of application.
[Contact: Gordon W. Day, (303) 497-5204]

Deeter, M.N., and Bon, S., **Molecular Field Theory Analysis of Magneto-Optic Sensitivity of Gallium-Substituted Yttrium Iron Garnets**.

The temperature dependence of the magneto-optic sensitivity of gallium-substituted yttrium iron garnets was measured at 1.3 μm and compared with a model based on molecular field theory. The model incorporates results of measurements of both the saturation magnetization and saturation Faraday rotation versus temperature. These measurements were analyzed in the context of molecular field theory to extract the fundamental molecular field coefficients and the magneto-optical coefficients as functions of gallium content. The model and direct sensitivity measurements both indicate that the magneto-optic sensitivity of garnet compositions with gallium substitution levels near 0.8 should exhibit a vanishing first-order temperature sensitivity.
[Contact: Merritt N. Deeter, (303) 497-5400]

Rochford, K.B., Rose, A.H., and Day, G.W., **Magneto-Optic Sensors Based on Iron Garnets**.

The use of iron-garnet bulk and film single crystals in optical sensors is reviewed. Magneto-optic sensitivity, and its stability, are important parameters that depend on a variety of factors, including optical design. Polarimetric and diffractive sensor technologies are summarized, and several recent demonstrations of magnetic field, current, and rotation sensing using garnets are described. Garnets also find application as important non-sensing components in sensor systems.
[Contact: Kenneth B. Rochford, (303) 497-5170]

Optical Fiber/Waveguide Sensors

Recently Published

Deeter, M.N., **Fiber-Optic Faraday-Effect Magnetic-Field Sensor Based on Flux Concentrators**, Applied Optics, Vol. 35, No. 1, pp. 154-157 (1 January 1996).

[See Magnetic Materials and Measurements.]

Drapela, T.J., Franzen, D.L., and Young, M., **Optical Fiber, Fiber Coating, and Connector Ferrule Geometry: Results of Interlaboratory Measurement Comparisons**, NIST Technical Note 1378 (November 1995).

Interlaboratory measurement comparisons, dealing with geometrical parameters of optical fibers, fiber coating, and fiber connector ferrules (including steel pin gages used to determine ferrule inside diameter), have been coordinated by NIST. The international fiber (glass) geometry comparison showed better agreement among participants, for all measured parameters, than in previous comparisons. Many participants' test sets were calibrated for fiber cladding diameter measurements by means of calibration artifacts from NIST or other national standards laboratories; there was significantly better agreement among those participants than among participants who were not calibrated. In the other comparisons, some parameters showed large systematic offsets between participants' data; accurate calibration, for those parameters, would lead to better interlaboratory agreement. NIST is developing ferrule, pin gage, and coating calibration artifacts.
[Contact: Timothy J. Drapela, (303) 497-5858]

Rose, A.H., and Wyss, J.C., **Self Calibrating Optical Thermometer**, Proceedings of SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Self-Calibrated Intelligent Optical Sensors and Systems, Vol. 2594, pp. 142-148 (1996).

A computer-controlled optical thermometer has been built to demonstrate a self-calibrating optical sensor. The self-calibrating thermometer records the temperatures with a fiber-optic polarimetric temperature sensor. The wavelength sensitivity of the polarimetric sensor is used to facilitate the recalibration. The system contains an optical source which can be tuned over approximately a 9 nm wavelength range, and a monochromator to measure any shifts in the wavelength of the laser. The monochromator is calibrated with the spectrum of a neon discharge lamp.
[Contact: Allen H. Rose, (303) 497-5599]

Integrated Optics

Released for Publication

Christensen, D.H., Hill, J.R., Hickernell, R.K.,

Matney, K., and Goorsky, M.S., **Characterization of Layer-Thickness Variations in Distributed Bragg Reflectors for Evaluation of Epitaxial Growth Stability**, to be published in the Proceedings of the Third International Workshop on Expert Evaluation and Control of Compound Semiconductor Materials and Technologies, Freiburg, Germany, May 12-16, 1996.

Variations of epitaxial layer thicknesses from uniform periodicity in compound semiconductor Bragg-reflectors are investigated experimentally and theoretically. In prior work, we evaluated the average layer-thickness uniformity across the wafer using a number of X-ray, electron-beam, and optical metrologies. Here, the variation of individual layer thicknesses in the growth direction at a given point on the wafer is characterized, thereby assessing the growth stability in time. The characterization is based on the correlation of experimental reflectance spectroscopy and high-resolution X-ray diffractometry measurements and precisely-fitted simulations made on growth runs which include both random and systematic variations from perfect periodicity. We find good agreement between the measurement techniques and between the measurements and their simulations.
[Contact: David H. Christensen, (303) 497-3354]

Hale, P.D., Wang, C.M., Park, R., and Lau, W.Y., **Photoreceiver Frequency Response Transfer Standard: Calibration Using a Swept Heterodyne Method**.

We have developed a photoreceiver frequency response transfer standard which can be used to measure the optical modulation transfer function of a modulated optical source. It combines a photodiode with a RF power sensor or an amplified receiver with a RF power sensor. It is calibrated with an expanded uncertainty of 0.06 dB (coverage factor = 2) using a heterodyne technique at 1.319 μm. Theory is presented which allows use of the transfer standard with arbitrary source modulation depth. The calibration is transferred to a SDH/SONET test equipment manufacturer giving a final uncertainty well below the 0.3 dB uncertainty specified by ITU-TS (formerly CCITT) recommendation G.957. The transfer standard may have other applications including calibration of CATV test equipment, lightwave component analyzers, and lightwave spectrum analyzers.
[Contact: Paul D. Hale, (303) 497-5367]

Knopp, K.J., Christensen, D.H., Hill, J.R., and Masterson, K.D., **Thin-Film Design for Enhanced Stability of Optically Pumped Vertical-Cavity Surface-Emitting Lasers (VCSELs)**.

We have employed a novel approach to enhance the stability of optically pumped Vertical-Cavity-Surface-Emitting-Lasers (VCSELs). This work was stimulated by our investigation of the output characteristics of optically powered PIN microcavity LEDs and VCSELs for their use in sensor applications. These structures are comprised of thin-film semiconductor multilayers and are manufactured entirely by thin-film deposition. In the past, optically pumped VCSELs used the short wavelength interference notches in the DBR reflectance spectrum to couple pump light into the cavity. However, the steep slope and narrow width of the notches inherently make pump-coupling stability highly sensitive to device temperature. Typically the resonance wavelength and pump notch wavelength will red shift with a rate of 0.056 nm/°C. We have investigated a novel structure for enhanced pump-coupling stability. We have employed traditional thin film design optimization to the multilayer etalon structure to create a low ripple, wideband pump region of low reflectance while maintaining cavity-mode field overlap at the quantum wells. Detailed experimental and simulation results are presented, demonstrating that a factor of 2.5 times improved stability has been achieved across a 35 nm spectral range.
[Contact: David H. Christensen, (303) 497-3354]

Integrated Optics

Recently Published

Kumar, A., Jindal, R., and Gallawa, R.L., **Bending Induced Phase Shifts in Arbitrarily Bent Rectangular-Core Dual-Mode Waveguides**, Journal of Lightwave Technology, Vol. 14, No. 2, pp. 196-201 (February 1996).

We examine the variation of the effective indexes of the two modes of an arbitrarily bent dual-mode rectangular-core waveguide. We find that under the large bending radius approximation, which is indeed

the practical case for most of the devices, the waveguide bent with bending radius p in a plane at an angle Θ with the major axis is almost equivalent to bending it simultaneously in the plane of major and minor axes with bending radii p sec Θ and p cosec Θ, respectively. The bending-induced phase difference between the two modes is found (a) to be maximum when the waveguide is bent along the major axis, and (b) to decrease first and then increase in the opposite direction as the V-number is decreased. The results of our study can be used to improve the sensitivity of the dual-mode optical waveguide sensors and devices based on the bending of fiber.
[Contact: Robert L. Gallawa, (303) 497-3761]

Complex System Testing

Released for Publication

Deyst, J.P., Souders, T.M., and Blair, J.J., **Uncertainties of Frequency Response Estimates Derived from Responses to Uncertain Step-Like Inputs**, to be published in the Proceedings of the 1996 IEEE Instrumentation and Measurement Technology Conference, Brussels, Belgium, June 4-6, 1996.

The frequency response of a linear time-invariant system can be estimated from the measurement of its response to an ideal step input. However, an ideal step is unrealizable, and various other error sources affect the accuracy of such estimates. This paper investigates the effect of using an uncertain (inexactly known), step-like test signal. An approach is developed here for determining the systematic uncertainties of the frequency response estimate of a device under test (DUT), when it is estimated from the response of the DUT to the uncertain, step-like test signal. The time-domain uncertainties of the test signal, and those of the DUT response, are converted to the frequency domain and processed, resulting in uncertainties for the frequency response of the DUT. Also, a mathematical proof is provided for the "envelope-modulation" method of calculating the systematic uncertainties of a frequency response estimate of a device, as derived from the uncertain response of the device to an ideal step.
[Contact: John P. Deyst, (301) 975-2437]

Other Signal Topics

Released for Publication

Fujii, K., Williams, E.R., and Steiner, R.L., **A New Refractometer by Combining a Variable Length Vacuum Cell and a Double-Pass Michelson Interferometer**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

[See Fundamental Electrical Measurements.]

Gilbert, S.L., and Wieman, C.E., **Laser Cooling**, MacMillen Encyclopedia of Physics.

This encyclopedia article describes the physics and technology of laser cooling and trapping of atoms. It is geared toward high school seniors and college undergraduates. A bibliography of articles for the non-specialist on this subject is included.
[Contact: Sarah L. Gilbert, (303) 497-3120]

Other Signal Topics

Recently Published

Young, M., and Hale, P.D., **Off-Axis Illumination and Its Relation to Partial Coherence**, American Journal of Physics, Vol. 63, No. 12, pp. 1136-1141 (1996).

We calculate the partially coherent of an edge in one dimension by the method of adding intensities, that is, by modeling the illumination as an array of mutually incoherent plane waves incident over a range of angles. In order to visualize the transition between coherent and incoherent imaging, we display images that result from such off-axis plane waves; these images change considerably as the angle of illumination changes. The calculations are easily carried out on a microcomputer with a high-level mathematics program. The results shed light on off-axis and dark-field illumination as well. Finally, we elucidate a distinction between imaging with the aperture stop in the transform plane and imaging with the aperture stop distant from the transform plane.
[Contact: Matt Young, (303) 497-3223]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Day, G.W., Rochford, K.B., and Rose, A.H., **Fundamentals and Problems of Fiber Current Sensors**, to be published in the Proceedings of the 1996 International Conference on Optical Fiber Sensors, Sapporo, Hokkaido, Japan, May 21-24, 1996.

[See Optical Fiber/Waveguide Sensors.]

Foest, R., Olthoff, J.K., Van Brunt, R.J., Benck, E., and Roberts, J.R., **Optical and Mass Spectrometric Investigations of Ions and Neutrals in SF_6 Radio-Frequency Discharges**.

Radio-frequency (rf) discharges at 13.56 MHz were generated in pure SF_6 using a capacitively coupled, parallel-plate GEC Reference Cell for gas pressures in the range of 4 Pa to 33 Pa (~30 mTorr to ~250 mTorr) and for peak-to-peak applied rf voltages in the range of 100 V to 300 V. The following measurements were made during operation of the discharge: 1) electrical characteristics which included power dissipation, voltage-current phase angle, and the dc self bias; 2) time-averaged vertical and horizontal profiles of the optical emissions from neutral atomic fluorine for the $2p^4 3p'\ ^2F^0_{7/2} \rightarrow 2p^4 3s'\ ^2D_{5/2}$ and $2p^4 3p\ ^2P^0_{3/2} \rightarrow 2p^4 3s\ ^2P_{3/2}$ transitions; 3) spatially-resolved, laser-induced fluorescence (LIF) utilizing the $2p^4 3s\ ^4P_{5/2}$ metastable level of atomic fluorine; 4) mass spectra of neutral species in the plasma; and 5) kinetic-energy distributions and relative fluxes of mass-selected positive ions extracted from the plasma through a 0.1 mm diameter orifice in the grounded electrode. The dependence of the electrical characteristics on gas pressure confirm previous observations and model predictions which indicate, for example, that the plasma becomes more resistive as pressure increases. The optical-emission and LIF results are also consistent with previously reported pronounced peaks in emission intensity in front of the powered electrode and a complex double layer formation at the plasma-sheath boundary, which can be attributed to the strong electron-attaching properties of the gas. From the mass spectrometric observations of the neutral gas constituents, it can be inferred that a significant fraction (as much as 80% in some cases) of the SF_6 in the cell can be dissociated or decomposed when the discharge is on for an input gas flow rate of 1.5×10^{-6} mol s^{-1} (2.0 sccm). The measured ion energy distributions exhibit deviations from the simple "rf-saddle structure" that become more pronounced with decreasing ion mass. The ion-energy distributions also exhibit pronounced dependences on pressure and applied voltage that appear to be consistent with corresponding changes in the electrical characteristics and LIF. Changes in electrode-surface conditions produced by the discharge were found to dramatically affect the ion-energy distributions, LIF, and electrical characteristics.
[Contact: James K. Olthoff, (301) 975-2431]

Waltrip, B.C., and Oldham, N.M., **DC-1MHz Wattmeter Based on RMS Voltage Measurements**, to be published in the Proceedings of the 1996 IEEE Instrumentation and Measurement Technology Conference, Brussels, Belgium, June 4-6, 1996.

A wideband wattmeter for measuring active power over a frequency range of dc to 1 MHz is described. The wattmeter is based on the three-voltmeter method in which three rms voltage measurements are used to calculate power.
[Contact: Bryan C. Waltrip, (301) 975-2438]

Van Brunt, R.J., Olthoff, J.K., Firebaugh, S.L., and Sauers, I., **Production of S_2F_{10}, S_2OF_{10}, and $S_2O_2F_2$ from Spark and Negative Corona Discharges in SF_6 and SF_6/O_2 Gas Mixtures**.

The rates for production of the compounds S_2F_{10}, S_2OF_{10}, and $S_2O_2F_{10}$ have been measured both in spark and continuous, constant-current negative glow corona discharges generated using point-to-plane electrode gaps in "pure" SF_6 and SF_6/O_2 gas mixtures containing up to 10% oxygen. In the case of corona discharges in pure SF_6, the S_2F_{10} concentrations were measured as a function of time during discharge operation using a gas chromatograph-mass spectrometer for gas pressures in the range of 100 kPa to 500 kPa and at discharge currents between 2 μA and 80 μA. The charge rate-of-production of S_2F_{10} from

negative corona is observed to drop with decreasing discharge current, and the yield curves exhibit nonlinearities in the early stages of the discharge associated with "conditioning" of the point electrode. The initial nonlinearities become more pronounced with increasing gas pressure. The absolute yields of S_2OF_{10} and $S_2O_2F_{10}$ were measured as a function of O_2 content in SF_6 for both negative glow corona (40 μA and 200 kPa) and spark discharge (80 J/spark and 100 kPa). The gas analysis in the case of spark discharges was performed after each spark using a cryogenic enrichment chromatographic technique. When O_2 is added to the gas, there is a dramatic drop in the S_2F_{10} yield from both types of discharges with a corresponding increase in S_2OF_{10} yield from the spark and $S_2O_2F_{10}$ yield from the corona discharge. The results can be explained within the framework of a plasma-chemical model from considerations of the competition among the reactions of SF_5 radicals produced by dissociation of SF_6 in the discharge with SF_5 itself as well as with O_2 and O, and the relative degree of O_2 dissociation in the two types of discharges.
[Contact: Richard J. Van Brunt, (301) 975-2425]

von Glahn, P., Stricklett, K.L., Van Brunt, R.L., and Cheim, A.V., **Correlations between Electrical and Acoustic Detection of Partial Discharge in Liquids and Implications for Continuous Data Recording**, to be published in the Proceedings of the 1996 IEEE International Symposium on Electrical Insulation, Montreal, Canada, June 16-19, 1996.

Simultaneous measurements were made of electrical and acoustic signals from partial discharge (PD) produced by applying an alternating voltage at a frequency of 70 Hz to a point-plane electrode gap immersed in transformer oil. Both internally and externally mounted acoustic sensors were tested, and in all cases the intensity of the acoustic PD signal was found, on average, to increase with the amplitude of the electrical PD signal. The correlation between acoustic and electrical PD signals was found to be consistent with results reported from previous investigations. It is shown here that, because of this strong correlation, it is possible to extract statistical information from continuously recorded acoustic PD data, such as pulse phase (time) and amplitude distributions that are in agreement with those obtained from the electrical data. It is demonstrated that by having continuous records of *all* PD events that occur during a test, it is possible to uncover new statistical information that is useful in attempts to understand the physical basis for the phenomenon.
[Contact: Peter von Glahn, (301) 975-2427]

Power Systems Metrology

Recently Published

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]

Stricklett, K.L., and Altafim, R.A.C., **Electrohydrodynamic Instability and Electrical Discharge Initiation in Hexane**, Proceedings of the Conference on Electrical Insulation and Dielectric Phenomena, Virginia Beach, Virginia, October 22-25, 1995, pp. 163-166.

An experimental technique is described that tests the hydrodynamic stability of the fluid boundary in a fluid-insulated system: A quasi-uniform field configuration is used, and a pulsed, Nd:YAG laser is employed to create a micro-bubble at the surface of one electrode. The gap is pulse-charged, and the laser is synchronized with the time-of-application of the voltage pulse. Under appropriate experimental conditions of voltage and laser pulse energy, the bubble evolves to produce full electrical breakdown by the onset and propagation of instabilities in the bubble surface. Experimental data obtained in hexane are presented.

[Contact: Kenneth L. Stricklett, (301) 975-3955]

Magnetic Materials and Measurements

Released for Publication

Kirschenbaum, L.S., Rogers, C.T., Beale, P.D., Russek, S.E., and Sanders, S., **High Current Density Self-Field Effects and Low-Frequency Noise in NiFe/Ag GMR Multilayers**.

High current densities (10^6 to 10^7 A/cm^2) produce magnetic fields which can induce antiparallel magnetic alignment in large (20 μm, 16 μm, and 8 μm) NiFe/Ag thin-film multilayer devices. Giant magneto-resistive (GMR) may be induced in unannealed devices which normally do not display GMR. Annealed and unannealed devices display multiple peaks in their magnetoresistance curves. Analysis of the positions and shapes of these magnetoresistance peaks provides a new set of tools for determining the micromagnetic structure of the multilayers. Linear Kerr effect data and low-frequency noise data correlate with the magnetoresistance peaks and may yield further information about layer-layer interactions.
[Contact: Stephen E. Russek, (303) 497-5097]

Rice, P., and Hoinville, J., **Spatial Correlation Between Magnetic Force Microscope Images and Recording Head Output**.

We have developed a technique which directly compares magnetic force microscope (MFM) images and recording head read-back signals on longitudinal thin-film disks with exact spatial correlation. To get exact spatial correlation, we had to perform three important operations at the same position on the disk. We wrote data with an inductive recording head; we read back the data with the same head; and we imaged the data with an MFM. Using this technique, we show that MFM images are related directly to the read-back signal. For example, we saw a signal anomaly which could have been mistaken for media noise which from the MFM image was proven to be incomplete overwrite.
[Contact: Paul Rice, (303) 497-3841]

Rice, P., Russek, S.E., and Haines, B., **Development of a Magnetic Imaging Reference Sample**.

We propose a reference sample for magnetic imaging. We have chosen a thin-film magnetic hard disk as a representative sample because the domains are very stable magnetically and thermally. This type of sample is also of fundamental interest to the disk drive industry, currently the largest user of magnetic force microscopy. Disk samples are prepared by writing a special magnetic pattern consisting of various transition spacings which were designed to explore certain aspects of magnetic imaging. Disks can then be cut into coupons, cleaned, and patterned with a reference grid of numbered 20 m x 20 m Au frames. These frames allow easy navigation around the sample. We believe a sample of this type can help define limits, expectations, and claims of resolution, as well as instrument sensitivity and ease of operation.
[Contact: Paul Rice, (303) 497-3841]

Rochford, K.B., Rose, A.H., and Day, G.W., **Magneto-Optic Sensors Based on Iron Garnets**.

[See Optical Fiber/Waveguide Sensors.]

Magnetic Materials and Measurements

Recently Published

Crawford, T.M., Rogers, C.T., Silva, T.J., and Kim, Y.K., **Observation of the Transverse Second Magneto-Optic Kerr Effect from $Ni_{81}Fe_{19}$ Thin Film Structures**, Applied Physics Letters, Vol. 68, No. 11, pp. 1573-1575 (11 March 1996).

We report measurements of the second-harmonic magneto-optic Kerr measurements on air-exposed, polycrystalline $Ni_{81}Fe_{19}$ thin films, ranging from 1 nm to 2 μm, on Al_2O_3-coated Si (001). For samples thicker than 20 nm, in the transverse Kerr geometry, we observe a factor of four change in second-harmonic intensity upon magnetization reversal. For thin samples, we observe interference between second-harmonic fields from the various interfaces and deterioration of ferromagnetism in the 1 and 2 nm films. Modeling suggests that the $Ni_{81}Fe_{19}/Al_2O_3$ interface has a larger second-order susceptibility than the air/$Ni_{81}Fe_{19}$ surface.
[Contact: Thomas J. Silva, (303) 497-7826]

Deeter, M.N., **Fiber-Optic Faraday-Effect Magnetic-Field Sensor Based on Flux**

Concentrators, Applied Optics, Vol. 35, No. 1, pp. 154-157 (1 January 1996).

[See Optical Fiber/Waveguide Sensors.]

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.]

Oti, J.O., Russek, S.E., Sanders, S.C., and Cross, R.W., **Models of Granular Giant Magnetoresistance Multilayer Thin Films**, IEEE Transactions on Magnetics, Vol. 32, No. 2, pp. 590-598 (March 1996).

Phenomenological micromagnetic and large-scale magnetization-dependent models of resistivity that produce giant magnetoresistance in granular multilayer magnetic thin films are described. Included in the models are intralayer and interlayer scattering components formulated explicitly in terms of the microstructural properties and characteristic transport lengths of the medium. The micromagnetic model provides insight into the influence of the magnetization distribution on the giant magnetoresistance response of the medium. The large-scale model, which is derived from the micromagnetic model, is useful for obtaining media transport parameters from experimental data. Both models are used to study a set of annealed NiFe/Ag multilayer films.
[Contact: John O. Oti, (303) 497-5557]

Superconductors

Recently Published

Roshko, A., Goodrich, L.F., Rudman, D.A., Moerman, R., and Vale, L.R., **Magnetic Flux Pinning in Epitaxial $YBa_2Cu_3O_{7-\delta}$ Thin Films**, Journal of Electronic Materials, Vol. 24, No. 12, pp. 1919-1922 (1995).

[See Cryoelectronic Metrology.]

ELECTROMAGNETIC INTERFERENCE

Conducted EMI

Recently Published

Martzloff, F.D., Mansoor, A., Phipps, K.O., and Grady, W.M., **Surging the Upside-Down House: Measurements and Modeling Results**, Proceedings of the Fourth International Conference on Power Quality: Applications and Perspectives, New York, New York, May 9-11, 1995, unpaged.

Electronic equipment with two input ports, power and communications, can be exposed to damaging differences of voltage between the two ports during surge events. To demonstrate real-world scenarios, a replica of the wiring system in a typical residence was installed in the laboratory. This paper reports selected results from many measurements, and presents the corresponding numerical modeling, thereby leading to mutual validation of the two processes. Two exposure scenarios for producing differences of voltages between the power and data ports of appliances are illustrated. Additional measurements and parametric variations are reported here to characterize the impedance of the various components of the wiring system and the source impedance of the resulting overvoltages appearing between the ports.
[Contact: François D. Martzloff, (301) 975-2409]

Radiated EMI

Released for Publication

Camell, D., Koepke, G., Smith, R., and Rakoski, B., **A Standard Source Method for Reducing Antenna Factor Errors in Shielded Room Measurements**, to be published as a NIST Technical Note.

In this report, we will examine the use of a well-characterized standard source of electromagnetic radiation as a means to calibrate the effects of the shielded room on a receiving antenna used for MIL-STD 461/462 RE102 emissions measurement. The goal was to compensate for the shielded room environment such that radiated emissions measurements can be more accurately compared from one room to another. This was accomplished by using a characterized spherical dipole source to

calibrate an antenna's response in the location that it was used. An interlaboratory comparison was made of the detected emissions from a simulated equipment under test at three sites to see how this in-situ calibration of the receive antenna helped the shielded room test repeatability.
[Contact: Dennis G. Camell, (303) 497-3214]

Johnk, R., and Randa, J., **Low-Frequency Representation of Radio-Frequency Absorbers**, to be published in the Proceedings of the 1996 IEEE International Symposium on Electromagnetic Compatibility, Santa Clara, California, August 19-23, 1996.

We present a simple model to characterize the behavior of radio-frequency absorbers at low frequency. The absorber is represented by a flat, homogeneous, isotropic slab of lossy material, with effective constitutive parameters. These parameters are determined by a fit to measured data. Excellent fits are obtained in the two applications considered. The model is intended for use in the characterization of absorber-lined chambers at low frequency. It could also be used to predict the low-frequency performance of partially loaded shielded enclosures.
[Contact: Robert T. Johnk, (303) 497-3737]

Ladbury, J.M., Johnk, R.T., and Ondrejka, A.R., **Rapid Evaluation of Mode-Stirred Chambers Using Impulsive Waveforms**, to be published as NIST Technical Note 1381.

In this paper, we present an experimental technique for the rapid evaluation of mode-stirred (or reverberation) chambers. The measurement provides an estimate of the average chamber quality factor (Q) by measuring the chamber impulse response and observing the decay of the spectral components of the response. The results show good agreement with those obtained using conventional CW techniques. The measurement is well suited for low-frequency analysis of a chamber, where costly and time-consuming mode-tuned approaches are generally employed. Since this technique does not use paddle stirring, the time savings can be considerable.
[Contact: Robert T. Johnk, (303) 497-3737]

Radiated EMI

Recently Published

Camell, D.G., and Ma, M.T., **Data Evaluation of a Linear System by a Second-Order Transfer Function**, Conference Record of the 1995 IEEE Electro-Magnetic Compatibility Symposium, Atlanta, Georgia, August 14-18, 1995, pp. 511-515.

A recently developed technique for predicting the response of a linear system to an electromagnetic pulse, based only on the measured continuous-wave (cw) magnitude, is applied to a particular system as a case study. The measured magnitude representing the system's transfer function is deduced first from the measured response to a known cw source, supplied by the Naval Surface Warfare Center. Then, an analytic expression is derived for the magnitude square of the transfer function to approximate the measured data, and a system transfer function in terms of the complex frequency is obtained. Finally, the system's cw phase characteristics and its multiple solutions due to a given impulse source are predicted.
[Contact: Dennis G. Camell, (303) 497-3214]

Crawford, M.L., **Alternative Electromagnetic Compatibility Compliance Test Facilities**, Book Chapter in Handbook of Electromagnetic Compatibility Academic Press, San Diego, California (1995), pp. 681-710.

A number of test facilities exist that can be used as alternatives to open field sites or shielded anechoic chambers for electromagnetic compatibility (EMC) compliance testing. The most common include various transverse electromagnetic (TEM) transmission line facilities. These operate as TEM transducers to either establish a known test field for radiated immunity testing or they serve as a receptor for measuring the radiated emissions from the equipment under test. Another alternative facility is the mode-stirred or reverberating chamber. This facility is essentially a large microwave oven. Tests are performed by measuring appropriate input, output, and statistical test field parameters for either radiated immunity or emissions testing. Procedures for performing radiated immunity and emission tests using TEM and reverberation chamber facilities are described. Recent work to combine TEM cell EMC measurement technology with reverberating

chamber EMC measurements into a single, hybrid facility is also described.
[Contact: Myron L. Crawford, (301) 975-5497]

Crawford, M.L., Riddle, B.F., and Camell, D.G., **TEM/Reverberating Chamber Electromagnetic Radiation Test Facility at Rome Laboratory**, NISTIR 5002 (January 1996).

This report summarizes the measurement and evaluation of a TEM/reverberating chamber. This chamber was developed as a single, integrated facility for testing radiated electromagnetic compatibility/vulnerability (EMC/V) of large systems of a large shielded enclosure configured as a transverse electromagnetic (TEM) transmission line-driven reverberating chamber. TEM mode test fields are generated at frequencies below multimode cutoff, and mode-stirred test fields are generated at frequencies above multimode cutoff. The report discusses the basis for such a development including the theoretical concepts, the advantages and limitations, the experimental approach for evaluating the operational parameters, and the procedures for using the chamber to perform EMC/V measurements. Both the chamber's cw and pulsed rf characteristics are measured and analyzed.
[Contact: Myron L. Crawford, (303) 497-5497]

Hill, D.A., Camell, D.G., Cavcey, K.H., and Koepke, G.H., **Radiated Emissions and Immunity of Microstrip Transmission Lines: Theory and Measurements**, NIST Technical Note 1377 (July 1995).

We analyze radiation from a microstrip transmission line and calculate total radiated power by numerical integration. Reverberation chamber methods for measuring radiated emissions and immunity are reviewed and applied to three microstrip configurations. Measurements from 200 to 2000 MHz are compared with theory, and excellent agreement is obtained for two configurations that minimize feed cable and finite ground plane effects. Emissions measurements are found to be more accurate than immunity measurements because the impedance mismatch of the receiving antenna cancels when the ratio of the microstrip and reference radiated power measurements is taken. The use of two different receiving antenna locations for emissions measurements illustrates good field uniformity within the chamber.
[Contact: David A. Hill, (303) 497-3472]

Kanda, M., **Methodology for Electromagnetic Interference Measurements**, Book Chapter in Handbook of Electromagnetic Compatibility, Academic Press, San Diego, California (1995), pp. 599-625.

Establishing standards for electromagnetic (EM) field measurements is a multifaceted endeavor which requires measurements made (1) in anechoic chambers, (2) at open sites, and (3) within guided-wave structures and the means of transferring these measurements from one situation to another. The underlying principles of these standard measurements and transfer standards fall into one of two categories: measurements and theoretical modeling. That is, either a parameter or a set of parameters is measured, or a parameter is calculated by established physical and mathematical principles. The three measurement topics and field transfer standards are discussed, with the guided-wave structures restricted to the transverse electromagnetic cell and the waveguide chamber. Throughout the discussion, the interplay between measured quantities and predicted (modeled) quantities are seen. The frequencies considered here range from 10 kHz to 40 GHz (and upward) and are determined by our ability to make an actual measurement and the restrictions imposed by rigorous theoretical analysis of a given model.
[Contact: Motohisa Kanda, (303) 497-5320]

Kanda, M., **Standard Probes for Electromagnetic Field Measurements**, Book Chapter in Handbook of Electromagnetic Capability Academic Press, San Diego, California (1995), pp. 627-648.

This tutorial paper discusses various standard antennas for measuring radio-frequency electric and magnetic fields. A theoretical analysis of each antenna's receiving characteristics is summarized and referenced. The standard probes described are an electrically short dipole, a resistively-loaded dipole, a half-wave dipole, an electrically small loop, and a resistively-loaded loop. A single-turn loop designed for simultaneous measurement of the electric and magnetic components of near-fields and other complex electromagnetic environments is also

described. Each type of antenna demonstrates a different compromise between broadband frequency response and sensitivity.
[Contact: Motohisa Kanda, (303) 497-5320]

VIDEO TECHNOLOGY

Released for Publication

Boynton, P.A., Ohno, Y., and Kelley, E.F., **Characterization of Spectroradiometers and Colorimeters Using Interference Filters**, to be published in the Digest of the 1996 Society for Information Display Symposium, San Diego, California, May 12-17, 1996.

Spectroradiometers and colorimeters are used in display measurements to measure color in one of several color space coordinate systems. How accurately these instruments can measure the color coordinates can be simply tested by using interference filters. Error sources within the measuring system are identified which could explain several observed anomalies.
[Contact: Paul A. Boynton, (301) 975-3014]

ADDITIONAL INFORMATION

Announcements

Characterization Workshop Proceedings Published

The Proceedings of the International Workshop on Semiconductor Characterization: Present Status and Future Needs is now available through AIP Press. The book *Semiconductor Characterization* covers the unique characterization requirements of both silicon IC development and manufacturing and compound semiconductor materials, devices, and the National Technology Roadmap for Semiconductors. Additional sections discuss technology trends and future requirements for compound semiconductor applications. Recent developments in characterization, including in-situ, in-FAB, and off-line analysis methods are also highlighted. The book provides useful insights on the capabilities of different characterization techniques, gives perspectives on industrial metrology requirements, and explores critical needs and issues in semiconductor metrology research. This book will serve as a base-line reference in this rapidly growing field for the next decade.

In the foreword, **Craig Barrett**, Chief Operating Officer at Intel, and **Arati Prabhakar**, Director of NIST, stated that "characterization and modeling of semiconductors are increasingly becoming a crucial part of semiconductor manufacturing. This book provides a concise and effective portrayal of industry characterization needs and the problems that must be addressed by industry, government, and academia to continue the dramatic progress in semiconductor technology."

The work is based on papers given at the International Workshop, held the week of January 30, 1995 at NIST in Gaithersburg, Maryland. Sponsors were: The Advanced Research Projects Agency, SEMATECH, the National Institute of Standards and Technology, The Army Research Office, the U.S. Department of Energy, the National Science Foundation, Semiconductor Equipment and Materials International (SEMI), the Manufacturing Science and Technology Division of the American Vacuum Society, and the Working Group on Electronic Materials of the Committee on Civilian Industrial Technologies.

To order the Proceedings, call the American Institute of Physics toll free at 1-800-809-2247.
[Contact: David G. Seiler, (301) 975-2054]

Lists of Publications

Bradford, A.G., **Metrology for Electromagnetic Technology: A Bibliography of NIST Publications**, NISTIR 5040 (September 1995).

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 4041.
[Contact: Ann G. Bradford, (303) 497-3678]

Lyons, R.M., **A Bibliography of the NIST Electromagnetic Fields Division Publications**, NISTIR 5039 (August 1995).

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 1995. It supersedes NISTIR 5028 which listed the publications of the Electromagnetic Fields Division from January 1970 through July 1994. 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** (July 1995).

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 1994. A brief description of the Division's technical program is given in the introduction.
[Contact: Ruth A. Schmeit, (301) 975-2401]

Smith, A.J., and Derr, L.S., **A Bibliography of Publications of the NIST Optoelectronics Division**, NISTIR 5041 (September 1995).

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, 1990-1995**. (March 1996).

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 1995. 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]

1996 Calendar of Events

July 16-18, 1996 (San Francisco, California)

SEMICON/West '96, Moscone Center. The NIST National Semiconductor Metrology Program will continue its government-industry liaison support role by exhibiting at SEMICON/West in 1996. For over 40 years, NIST and its predecessor, the National Bureau of Standards, have provided expertise on semiconductor-related issues to industry, government agencies, and academia. Since SEMICON/West's inception 26 years ago, NIST personnel have provided the same expertise to the show's attendees. NIST's booth is located in Hall 4, Booth 6547. Please stop by and see us!
[Contact: Alice Settle-Raskin, (301) 975-4400]

August 19-23, 1996 (Boulder, Colorado)

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

October 1-3, 1996 (Boulder, Colorado)

Symposium on Optical Fiber Measurements. This Symposium, held at NIST in Boulder, provides a forum for reporting the results of recent measurement research in the area of lightwave communications, including optical fibers. Aspects of optical fiber metrology will be discussed, including attenuation, dispersion, geometry, reflectometry,

and connectors; integrated optic devices; laser diode sources and detectors; and system measurements.
[Contact: Douglas L. Franzen, (303) 497-3346]

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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. The existing SRMs (on 50 mm wafers) shown in the table below will be augmented with an improved set (on 100 mm wafers) during CY 96-97. NIST efforts to produce the new SRMs have recently received increased emphasis. The earlier set will continue to be available until the supply is exhausted.

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. While it is expected that these wafers will offer considerable utility in calibrating contactless gauges, certification has been performed solely with four-point probe methods. Technical insights presented by the rigorous certification process will be presented in a NIST Special Publication. Individual data for each wafer will be supplied along with the SRM Certificate.

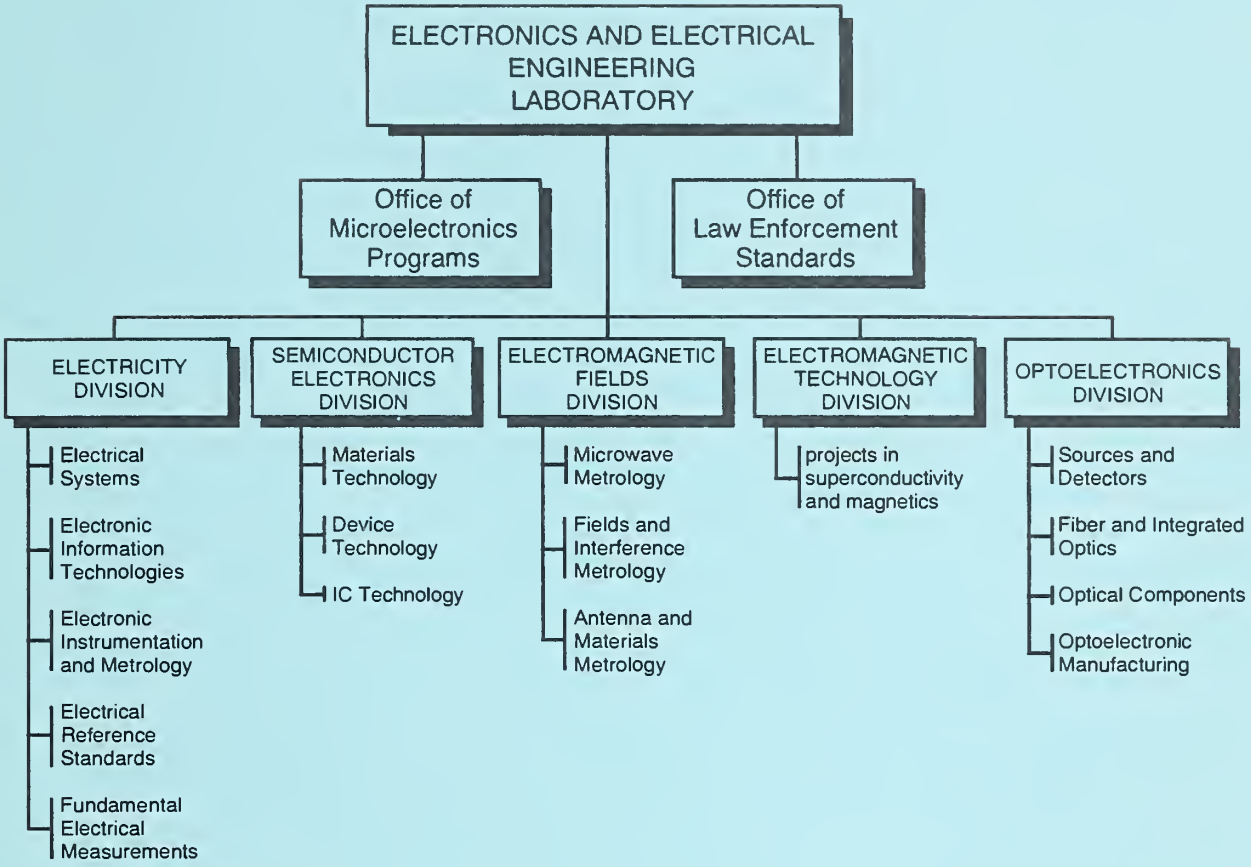
It is expected that the higher resistivity SRMs (2547, 2546) will be available first during CY 96 and be followed closely by SRM 2545. The low resistivity material (SRMs 2542, 2541) is expected to be available by year end. A limited number of SRM 2543 may also be available by year end, with the remainder in early CY 97. Technical issues associated with SRM 2544 will preclude its availability until CY 97.

NIST SILICON BULK RESISTIVITY STANDARD REFERENCE MATERIALS

DATE UPDATED: 23 JANUARY 1996

NOMINAL RESISTIVITY (ohm · cm)	OLD SRMs	AVAILABILITY	NEW SRMs (ohm · cm)	ANTICIPATED AVAILABILITY
0.01	1523 (one of set of two wafers)	limited supply	2541	CY 96
0.1	1521 (one of set of two wafers)	limited supply	2542	CY 96
1	1523 (one of set of two wafers)	limited supply	2543	CY 96-97
10	1521 (one of set of two wafers)	limited supply	2544	CY 97
25	1522	set of three wafers no longer available	2545	CY 96
75	1522		2546 (100)	CY 96
180	1522		2547 (200)	CY 96

The above table will be updated in future issues to reflect changes in availability. Every effort will be made to provide accurate statements of availability; 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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