NISTIR 6029

Electronics and Electrical Engineering Laboratory

J. M. Rohrbaugh
Compiler

Technical Progress Bulletin

97-1

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

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards
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Electronics and Electrical
Engineering Laboratory
Semiconductor Electronics Division
Gaithersburg, MD 20899-0001

July 1997

97-1

U.S. DEPARTMENT OF COMMERCE
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ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY
TECHNICAL PROGRESS BULLETIN, JULY 1997 ISSUE

INTRODUCTION

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

Organization of Bulletin: This issue contains abstracts for all relevant papers released for publication by NIST in the quarter and citations and abstracts for such papers published in the quarter. Entries are arranged by technical topic as identified in the Table of Contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication." This does not imply acceptance by any outside organization. Papers published in the quarter appear under the subheading "Recently Published." Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Laboratory conferences and workshops planned for calendar years 1997 through 1998 and a list of sponsors of the work.

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

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

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

Laboratory Sponsors: The Laboratory Programs are sponsored by the National Institute of Standards and Technology and a number of other organizations, in both the Federal and private sectors; these are identified on page 33.

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 30.

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

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

TO LEARN MORE ABOUT THE LABORATORY...

Two general documents are available that may be of interest. These are ***EEEL 1996 Technical Accomplishments, Advancing Metrology for Electrotechnology to Support the U.S. Economy*** and ***Measurements for Competitiveness in Electronics***. The first presents selected technical accomplishments of the Laboratory for the period October 1, 1995 through September 30, 1996. A brief indication of the nature of the technical achievement and the rationale for its undertaking are given for each example. The second identifies measurement needs for a number of technical areas and the general importance of measurements to competitiveness issues. The findings of each chapter dealing with an individual industry have been reviewed by members of that industry. A longer description of both documents follows:

EEEL 1996 Technical Accomplishments, Advancing Metrology for Electrotechnology to Support the U.S. Economy, NISTIR 5941 (December 1996).

The Electronics and Electrical Engineering Laboratory, working in concert with other NIST Laboratories, is providing measurement and other generic technology critical to the competitiveness of the U.S. electronics industry and the U.S. electricity-equipment industry. This report summarizes selected technical accomplishments and describes activities conducted by the Laboratory in FY 1996 in the field of semiconductors, magnetics, superconductors, low-frequency microwaves, lasers, optical fiber communications and sensors, video, power, electromagnetic compatibility, electronic data exchange, and national electrical standards. Also included is a profile of EEEL's organization, its customers, and the Laboratory's long-term goals.

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

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

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

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

TABLE OF CONTENTS

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Released for Publication

Zimmerman, N.M., Cobb, J.L., and Clark, A.F., **Distant Defects Can Modulate the Charge of a Single Electron Transistor**.

We have systematically measured two-level fluctuator (TLF) noise in a single electron tunneling transistor. From the amplitude, duty cycle and presence of intermediate states, we conclude that there is a cluster of triggered TLFs in this case. The systematic dependence of switching rate on the gate voltage, and the lack of rate dependence on a finer scale or on source-drain voltage, tell us unambiguously that the TLFs are not located in the tunnel barriers. We, thus conclude, as has been previously inferred, that noisy defects outside the barrier can lead to significant modulation of the transistor island charge.
[Contact: Neil M. Zimmerman, (301) 975-5887]

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Recently Published

Cage, M.E., and Jeffery, A.-M., **Intrinsic Capacitances and Inductances of Quantum Hall Effect Devices**, Journal of Research of the National Institute of Standards and Technology, Vol. 101, No. 6, pp. 733-744 (November–December 1996).

Analytic solutions are obtained for the internal capacitances, kinetic inductances, and magnet inductances of quantum Hall effect devices to investigate whether or not the quantized Hall resistance is the only intrinsic impedance of importance in measurements of the ac quantum Hall effect. The internal capacitances and inductances are obtained by using results of Cage and Lavine, who determined the current and potential distributions across the widths of quantum Hall effect devices. These intrinsic capacitances and inductances produce small out-of-phase impedance corrections to the quantized Hall resistance and the longitudinal resistance.
[Contact: Marvin E. Cage, (301) 975-4224]

SEMICONDUCTOR MICROELECTRONICS

Silicon Materials

Released for Publication

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

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

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

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

Compound Materials

Released for Publication

Amirtharaj, P.M., and Burnett, J., **Optical Properties of Mercury Cadmium Telluride**, to be published as a Book Chapter in Narrow-Gap II-IV Compounds for Opto-Electronic and Electro-Magnetic Applications, P. Capper, ed. (Chapman and Hall, London, 1997).

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

Compound Materials

Recently Published

Anderson, G.W., Kub, F.J., Carruthers, T.F., Papanicolaou, N.A., Frankel, M.Y., Katzer, D.S., Modolo, J.A., and Tseng, W.F., **Planar, $Al_{0.3}Ga_{0.7}As$-Passivated-Base, Heterojunction Bipolar Phototransistors**, Applied Optics, Vol. 36, No. 4, pp. 760-764 (1 February 1997).

New planar GaAs heterojunction bipolar phototransistors have been designed and demonstrated. The devices use a $GaAs/Al_{0.3}Ga_{0.7}As$ molecular-beam-epitaxy materials system with an $Al_{0.3}Ga_{0.7}As$ passivated, 10 nm thick base; a depleted, high-low emitter; and a low emitter-base capacitance. Electrical contact to the emitter is made by a set of parallel, ohmic fingers and to the collector by an ohmic contact formed in a large ~1.48 μm deep via. Rise times in response to impulse optical excitation at 810 nm measured at 810 nm and 850 nm were 0.67-19, depending on experimental conditions. These devices are promising for use in heterodyne photodetector arrays for coherent optical processing channelizers requiring a 100 MHz bandwidth.
[Contact: Wen F. Tseng, (301) 975-5291]

Tseng, W.F., Chandler-Horowitz, D., Papanicolaou, N.A., and Boos, J.B., **Interdigitated Hetero InGaAs/GaAs n-i-p-i Modulators**, Materials Letters, Vol. 29, pp. 249-253 (December 1996).

Interdigitated hetero InGaAs n-i-p-i InGaAs/GaAs modulators have been grown and fabricated by a shadow mask technique for selectively making contacts to n- and p-layers. Manipulations of exciton peak positions and intensities by external electrical bias and incident optical power have been demonstrated.
[Contact: Wen F. Tseng, (301) 975-5291]

Analysis and Characterization Techniques

Released for Publication

Wollman, D.A., Hilton, G.C., and Irwin, K.D., **High-Energy-Resolution Microcalorimeter Spectrometer for EDS X-Ray Microanalysis**, to be published in the Proceedings of the 1997 Microscopy and Microanalysis Conference, Cleveland, Ohio, August 10-14, 1997.

Si(Li) and Ge Energy Dispersive Spectroscopy (EDS) detectors are commonly used for X-ray microanalysis because they are easy to use, inexpensive to operate, and offer both rapid qualitative evaluation of chemical composition and accurate quantitative analysis.
[Contact: David A. Wollman, (303) 497-7457]

Device Physics and Modeling

Recently Published

Adams, V.H., Blackburn, D.L., Joshi, Y., and Berning, D.W., **Issues in Validating Package Compact Thermal Models for Natural Convection Cooled Electronic Systems**, Proceedings of the Thirteenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium - SEMITHERM XIII,

Austin, Texas, January 28-30, 1997, pp. 10-23.

[See Packaging.]

Insulators and Interfaces

Released for Publication

Belzer, B.J., and Blackburn, D.L., ***Semiconductor Measurement Technology*: The Results of an Interlaboratory Study of Ellipsometric Measurements of Thin Film Silicon Dioxide on Silicon**, to be published as NIST Special Publication 400-99.

The results of an interlaboratory study with nine participants for the measurement of thin film oxides on silicon are presented. The purpose of the study was to establish a baseline of agreement between laboratories for ellipsometric thin film measurements. The maximum standard deviations of the thickness calculated between laboratories using a common data reduction method were 0.22 nm for 10 nm oxides, 0.43 nm for 50 nm oxides, and 0.32 nm for 100 nm oxides.
[Contact: Barbara J. Belzer, (301) 975-2248]

Integrated-Circuit Test Structures

Released for Publication

Cresswell, M.W., Sniegowski, J.J., Ghoshtagore, R.N., Allen, R.A., Guthrie, W.F., and Linholm, L.W., **Electrical Linewidth Test Structures Fabricated in Mono-Crystalline Films for Reference-Material Applications**, to be published in the Proceedings of the 1997 IEEE International Conference on Microelectronic Test Structures, Monterey, California, March 18-20, 1997.

Electrical linewidth measurements have been extracted from test structures replicated in thin planar films of mono-crystalline silicon with feature widths down to 0.18 μm. The structures are electrically insulated from a bulk-silicon substrate by a layer of silicon dioxide provided by SIMOX (Separation by the IMplantation of OXygen) technology. The motivation is to facilitate the development of linewidth reference-materials for Critical-Dimension (CD) instrument calibration. An appropriate selection of the surface orientation of the starting silicon, the design and orientation of the structures' features, and patterning by a lattice-plane selective etch provides a unique set of reference-feature properties such as rectangular cross sections and atomically planar and smooth sidewalls. These properties are highly desirable for CD-reference applications where feature widths need to be certified with nanometer-level uncertainty for use by a diverse range of CD instruments. End-applications include the development and calibration of new generations of CD instruments directed at controlling processes for manufacturing devices having sub-quarter-micrometer features.
[Contact: Michael W. Cresswell, (301) 975-2072]

Lee, W.E., Guthrie, W.F., Cresswell, M.W., Allen, R.A., Sniegowski, J.J., and Linholm, L.W., **Reference-Length Shortening by Kelvin Voltage Tape in Linewidth Test Structures Replicated in Mono-Crystalline Silicon Films**, to the published in the Proceedings of the 1997 IEEE International Conference on Microelectronic Test Structures, Monterey, California, March 18-20, 1997.

Electrical test structures replicated in thin films of single-crystal material offer potential benefits as physical standards for CD and overlay metrology. However, the regions where Kelvin voltage taps are attached typically have three-dimensional geometries. These geometries are uniquely predictable, except for a small measurable feature which is constant over large areas, and therefore, offer an additional means for validating the linewidths of the bridge features. Current flow through these regions has been simulated, and the results have been compared with experimental measurements. A formulae has been calculated for the electrical length shortening effect of Kelvin-voltage taps, and this has been used to formulate a linewidth extraction algorithm.
[Contact: Michael W. Cresswell, (301) 975-2072]

Microfabrication Technology

Released for Publication

Milanović, V., Gaitan, M., Bowen, E.D., Tea, N.H., and Zaghloul, M.E., **Thermoelectric Power Sensor for Microwave Applications by Commercial CMOS Fabrication**.

[See Microwave and Millimeter-Wave Metrology.]

Tea, N.H., Milanović, V., Zincke, C., Suehle, J.S., Gaitan, M., Zaghloul, M.E., and Geist, J., **Hybrid Post-Processing Etching for CMOS-Compatible MEMS**.

A major limitation in the fabrication of microstructures as a post-CMOS process has been overcome by the development of this hybrid processing technique which combines an isotropic and an anisotropic etch step. Using this hybrid technique, microelectromechanical structures with sizes ranging from 0.05 mm to ~2 mm wide and arbitrary length can be fabricated in CMOS technology. Mechanical robustness of the microstructures determines the limit on their useful dimensions. Examples of an application of this hybrid technique to produce microwave coplanar transmission lines are presented. The performance of the micromachined microwave coplanar waveguides meets the design specifications. Various commonly used etchants were investigated for top-side maskless post micromachining of <100> silicon to obtain the microstructures. The isotropic etchant used is gas-phase xenon difluoride (XeF_2), while the wet anisotropic etchants are either ethylenediaminepyrocatechol or tetramethylammonium hydroxide. The advantages and disadvantages of these etchants with respect to selectivity, reproducibility, handling, and process compatibility are also described.
[Contact: Michael Gaitan, (301) 975-2070]

Microfabrication Technology

Recently Published

Cavicchi, R.E., Semancik, S., DiMeo Jr., F., Suehle, J.S., Tea, N., Kreider, K.G., Chaparala, P., and Gaitan, M., **Temperature-Modulated Micro-Hotplate Gas Sensors**, Proceedings of the Sixth International Meeting on Chemical Sensors, Gaithersburg, Maryland, July 22-25, 1996 (unpaged).

A considerable body of sensor research has been devoted to the miniaturization of the Taguchi or tin oxide solid state gas sensor into a thin film device. The motivations are threefold, 1) to improve the poor selectivity of this device by fabricating arrays in which the array elements are either different in composition or in fixed operating temperature; 2) to reduce the power consumption so that small portable devices become possible; and 3) to reduce cost by using the batch fabrication techniques of this film processing. A fourth key advantage has emerged from work on microsensors: the rapid thermal time constant (~1 ms) associated with small size allows rapid temperature modulation during operation. Temperature modulation can be used to change the time-constants for desorption, adsorption, and reaction of detected species during sensor operation. The temperature-dependence of the time-constants are different for different species. This produces a time-dependent response pattern which is characteristic of the species being detected.
[Contact: John S. Suehle, (301) 975-2247]

DeGroot, D.C., Rudman, D.A., Zhang, K., Ma, Q.Y., Kato, H., and Jaeger, N.A.F., **Planar Microwave Devices Fabricated by Ion-Implantation Patterning of High-Temperature Superconductors**, Applied Physics Letters, Vol. 69, No. 14, pp. 2119-2121 (30 September 1996).

[See Microwave and Millimeter-Wave Metrology.]

Gaitan, M., **Microheating Elements in CMOS Technology**, Proceedings of the 1996 IEEE International Symposium on Circuits and Systems, Atlanta, Georgia, May 12-15, 1996, pp. 5-8.

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 paper is an overview of CMOS-based microheating elements realized by an anisotropic chemical etch after the full CMOS process is complete.
[Contact: Michael Gaitan, (301) 975-2070]

Li, H.Q., Ono, R.H., Vale, L.R., Rudman, D.A., and Liou, S.H., **A Novel Multilayer Circuit Process Using $YBa_2Cu_3O_x$/Sr TiO_3 Thin Films Patterned by Wet Etching and Ion-Milling**, Applied Physics Letters, Vol. 69, No. 18, pp. 2752-2754 (28 October 1996).

[See Cryoelectronic Metrology.]

Tseng, W.F., Chandler-Horowitz, D., Papanicolaou, N.A., and Boos, J.B., **Interdigitated Hetero InGaAs/GaAs n-i-p-i Modulators**, Materials Letters, Vol. 29, pp. 249-253 (December 1996).

[See Compound Materials.]

Plasma Processing

Released for Publication

Christophorou, L.G., Olthoff, J.K., and Wang, Y., **Electron Interactions with CCl_2F_2**.

[See Power Systems Metrology.]

Olthoff, J.K., **Plasma Diagnostics on the Gaseous Electronics Conference Radio-Frequency Reference Cell**, to be published in the Proceedings of the Frontiers in Low Temperature Plasma Diagnostics II Conference, Bad Honnef, Germany, February 17-21, 1997.

A review and summary of plasma diagnostics applied to the GEC RF Reference Cell is presented. [Contact: James K. Olthoff, (301) 975-2431]

Plasma Processing

Recently Published

Bretagne, J., Šimko, T., Gousset, G., Rao, M.V.V.S., Van Brunt, R.J., Wang, Y., Olthoff, J.K., Peko, B.L., and Champion, R.L., **Distributions of H^+, H_2^+ H_3^+ Ions in Townsend Discharge and Determination of Their Collision Cross Sections**, Proceedings of the Thirteenth European Sectional Conference on the Atomic and Molecular Physics of Ionised Gases, Poprad, Slovakia, August 27-30, 1996, pp. 115-116.

[See Power Systems Metrology.]

Christophorou, L.G., Olthoff, J.K., and Rao, M.V.V.S., **Electron Interactions with CHF_3**, Journal of Physical and Chemical Reference Data, Vol. 26, No. 1, pp. 1-15 (1997).

In this paper, we assess and synthesize the available information on the cross sections and the rate coefficients for collisional interactions of trifluoromethane (CHF_3) with electrons in an effort to build up a database on electronic and ionic collision processes that will aid the understanding of the behavior of CHF_3 in its use in manufacturing semiconductor devices and other applications. The limited data on the total and partial electron impact ionization and dissociation cross sections, total and partial cross sections for electron impact dissociation of CHF_3 into neutral species, electron-impact-induced line and continuous light emission from CHF_3, negative ion states of CHF_3, and the energetics of ionization, dissociation, and attachment are summarized and discussed. To our knowledge, no measurements are available of the cross sections of any of the electron scattering processes (elastic, momentum, vibrational, inelastic, etc.) or the electron transport, attachment, and ionization coefficients. While the available information is meager, the synthesis of the existing knowledge and the background information provided in the paper can be helpful for modeling plasma reactors. Clearly, more measurements and calculations are needed of the cross sections for virtually all fundamental electron impact processes for this plasma processing gas. Measurements of the transport, attachment, and ionization coefficients over wide ranges of the density-reduced electric field are also needed.
[Contact: Loucas Christophorou, (301) 975-2432]

Christophorou, L.G., Olthoff, J.K., and Rao, M.V.V.S., **Electron Interactions with CF_4**, Journal of Physical and Chemical Reference Data, Vol. 25, No. 5, pp. 1341-2388 (September 1996).

Carbon tetrafluoride (CF_4) is one of the most widely used components of feed gas mixtures employed for a variety of plasma-assisted material-processing applications. It has no stable excited states and, in a plasma environment, is an ideal source of reactive species, especially F atoms. To assess the behavior of CF_4 in its use in manufacturing semiconductor devices and other applications, it is

necessary to have accurate information about its fundamental properties and reactions, particularly its electronic and ionic interactions and its electron collision processes at low energies (<100 eV).

In this article, we assess and synthesize the available information on the cross sections and/or the rate coefficients for collisional interactions of CF_4 with electrons. Assessed information is presented on: (i) cross sections for electron scattering (total, momentum, elastic, differential, inelastic), electron impact ionization (total, partial, multiple, dissociative), electron impact dissociation (total, and for dissociative excitation), and electron attachment (total, and for specific anions); (ii) coefficients for electron transport (electron drift velocity, transverse and longitudinal electron diffusion coefficients), electron attachment, and electron impact ionization; and (iii) cross-section sets derived from analyses of electron transport data. The limited ionization data on CF_4 radicals are also presented, and references are given to measurements of electron transport properties of CF_4 gas mixtures. Based upon the assessment of published experimental data, recommended values for various cross sections and coefficients are generated which are presented in graphical and tabular form.
[Contact: Loucas Christophorou, (301) 975-2432]

Packaging

Released for Publication

Adams, V., Joshi, Y., and Blackburn, D.L., **Application of Compact Model Methodologies to Natural Convection Cooling of an Array of Electronic Packages in a Low Profile Enclosure**, to be published in the Proceedings of the 1997 Intersociety Electronic and Photonic Packaging Conference, Hawaii, Hawaii, June 15-19, 1997.

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

Packaging

Recently Published

Adams, V.H., Blackburn, D.L., Joshi, Y., and Berning, D.W., **Issues in Validating Package Compact Thermal Models for Natural Convection Cooled Electronic Systems**, Proceedings of the Thirteenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium - SEMITHERM XIII, Austin, Texas, January 28-30, 1997, pp. 10-23.

A methodology is proposed for the validation of compact thermal models of electronic packages which utilizes data and simulations obtained from a simple, but realistic system containing the package. The test system is the enclosure specified by the JEDEC Subcommittee, JC15.1 for thermal measurements in a natural convection environment. Simulations for a detailed model and several different compact models for a 88-pin plastic quad flat-package in the enclosure are in good agreement with experimental measurements of junction temperature. The study shows that the system must be well characterized, including accurate knowledge of circuit board thermal conductivity and

accurate simulation of radiation heat transfer, to serve for validation purposes. For the package used in this study, system level considerations can outweigh package level considerations for predicting junction temperature. Given that the system is accurately modeled, the JEDEC enclosure can serve as a viable experimental validation tool for compact models.
[Contact: David L. Blackburn, (301) 975-2068]

Harman, G.G., **Wire Bonding to Multichip Modules and Other Soft Substrates**, Chapter in Multichip Modules with Integrated Sensors, W.K. Jones and G. Harsanyi, Eds. (Kluwer Academic Publishers, Dordrecht, The Netherlands, 1996), pp. 47-62.

Several classes of "soft substrates" can be difficult to wire bond. These include MCM-Ds, MCM-Ls, flex substrates, some complex IC chips with multilevel polymer-insulated metallization, and microwave hybrids made on PTFE substrates. The bonding solutions include: increasing the bond-pad metal thickness and area and applying a hard metal under-layer, a hard metal top-layer, or some combination of these, capped with a highly bondable metal. A summary is given of the bond-pad metallurgy and bonding machine parameters that have produced successful wire bonding to a wide variety of MCMs and other "soft substrates." Wire bonding yield is also generally correlated to the elastic modulus and T_g of the polymer or laminate, and to the yield strength of the metal pads. Thus, the choice of material properties for the substrate and bond pads is at least as important as the actual bonding machine setup in achieving high-yield wire bonding. Other considerations, such as the possible use of high-frequency ultrasonic bonding and high-clock-rate skin-effect losses on the multilayer bond pads, are discussed.
[Contact: George G. Harman, (301) 975-2097]

Reliability

Released for Publication

Martin, A., O'Sullivan, P., Mathewson, A., Suehle, J. S., and Chaparala, P., **Investigation of the Influence of Ramped Voltage Stress on Intrinsic t_{bd} of MOS Gate Oxides**.

This study investigates the influence of a pre-stressing ramped voltage stress prior to a constant voltage stress on the time to breakdown. Constant voltage stress and combined ramped/constant voltage stress measurements were performed on six MOS gate-oxide thicknesses. The time-to-breakdown distributions were compared, and an increase of the time to breakdown for pre-stressed oxides was observed in some cases. A further analysis of the current-time characteristics gave conclusions about the trapping properties of the oxide. It was found that the initial positive charge buildup in the oxide is an important indicator for degradation which must be considered for highly accelerated reliability measurements on pre-stressed oxides. Since common understanding of oxide breakdown and models for breakdown mechanisms cannot describe all of the experimental results, a qualitative model is proposed.
[Contact: John S. Suehle, (301) 975-2247]

Reliability

Recently Published

Suehle, J.S., and Chaparala, P., **Low Electric Field Breakdown of Thin SiO_2 Films Under Static and Dynamic Stress**, IEEE Transactions on Electron Devices, Vol. 44, No. 5, pp. 801-808 (May 1997).

A comprehensive study of Time-Dependent Dielectric Breakdown (TDDB) of 6.5, 9, 15, and 22 nm SiO_2 films under dc and pulsed bias has been conducted over a wide range of electric fields and temperatures. Very high temperatures were used at the wafer level to accelerate breakdown so tests could be conducted at electric fields as low as 4.5 MV/cm. New observations are reported for TDDB that suggest a consistent electric field and temperature dependence for intrinsic breakdown and a changing breakdown mechanism as a function of electric field. The results show that the logarithm of the median-test-time-to-failure log (t_{50}) is described by a linear electric field dependence, with a field acceleration parameter that is not dependent on temperature. It has a value of approximately 1 decade/MV/cm for the range of oxide thicknesses studied and shows a slight decreasing trend with decreasing oxide thickness. The thermal activation E_a ranged between 0.7 and 0.95 eV for electric fields below 9.0 MV/cm for all

oxide thicknesses. TDDB tests conducted under pulsed bias indicate that increased dielectric lifetime is observed under unipolar and bipolar pulsed stress conditions, but diminishes as the stress electric field and oxide thickness are reduced. This observation provides new evidence that low electric field aging and breakdown is not dominated by charge generation and trapping.
[Contact: John S. Suehle, (301) 975-2247]

SIGNAL ACQUISITION, PROCESSING AND TRANSMISSION

DC and Low-Frequency Metrology

Released for Publication

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

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

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

The most accurate root-mean-square measurements of ac voltage and current are made by comparing the heating effect of an unknown ac signal to that of a known dc signal using a thermal converter. The limiting factors for the ac-dc differences of the most accurate converters used at national laboratories are, to a large degree, thermal and thermoelectric effects which are temperature dependent. In order to reduce these effects, a thermal transfer device has been fabricated to operate at temperatures below 10 K, where the thermoelectric effects are expected to be small. Furthermore, the entire converter is mounted on a temperature-controlled platform to reduce thermal gradients. This paper details the design and fabrication of a transition-edge temperature sensor, and presents preliminary data for its sensitivity and response at cryogenic temperatures.
[Contact: Erich N. Grossman, (303) 497-5102]

Waveform Metrology

Released for Publication

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

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

Cryoelectronic Metrology

Released for Publication

Bluhm, H., Wadas, A., Wiesendanger, H., Roshko, A., Aust, J.A., and Nam, D., **Electrostatic Force Microscopy Imaging of Domain Inverted**

Gratings in $LiNbO_3$.

Ferroelectric domains in $LiNBO_3$ have been investigated by means of electrostatic force microscopy. Polarization-inverted gratings with 4 μm periodicity were fabricated by titanium diffusion into both +c and -c faces of single domain $LiNbO_3$ crystals. The distribution of electric field in the vicinity of the sample surface was measured using scanning probe microscopy. The electric force image was found to correlate with the shape of the domain inverted profile observed by scanning electron and optical microscopies.
[Contact: Alexana Roshko, (303) 497-5420]

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

[See DC and Low-Frequency Metrology.]

Wollman, D.A., Hilton, G.C., and Irwin, K.D., **High-Energy-Resolution Microcalorimeter Spectrometer for EDS X-Ray Microanalysis**, to be published in the Proceedings of the 1997 Microscopy and Microanalysis Conference, Cleveland, Ohio, August 10-14, 1997.

[See Analysis and Characterization Techniques.]

Cryoelectronic Metrology

Recently Published

Li, H.Q., Ono, R.H., Vale, L.R., Rudman, D.A., and Liou, S.H., **A Novel Multilayer Circuit Process Using $YBa_2Cu_3O_x$/Sr TiO_3 Thin Films Patterned by Wet Etching and Ion-Milling**, Applied Physics Letters, Vol. 69, No. 18, pp. 2752-2754 (28 October 1996).

A process combining hydrofluoric acid (HF) and Ar^+ ion-milling has been used to make $YBa_2Cu_3O_x/SrTiO_3/YBa_2Cu_3O_x$ (YBCO/STO/YBCO) multilayer test circuits. Low-angle steps can be readily etched in STO and YBCO films with this process. YBCO lines crossing 5^o steps have about the same critical temperature T_c (89 K to 90 K) and critical current density J_c (>1 x 10^6 A/cm^2 at 86 K) as lines on planar surfaces. Via connections have the same T_c as other circuit components and adequate critical currents for most circuit designs.
[Contact: Ronald H. Ono, (303) 497-3762]

Antenna Metrology

Released for Publication

Francis, M.H., **Comment on Aperture Sampling Requirements in Planar Near-Field and Pattern Calculations**.

This paper comments and relates the angle of coverage to the near-field sample spacing. However, if the near-field sampling does not contain at least two samples per period for the fastest varying near-field period, aliasing will occur. As a result, the periodically continued patterns begin to overlap and the measured pattern in this overlap region will be the complex sum of the overlapping patterns. We show the relation between the near-field sampling and the maximum angle of coverage when we also require that the effect of aliasing be negligible.
[Contact: Michael H. Francis, (303) 497-5873]

Muth, L.A., and Wittmann, R.C., **Calibration of Polarimetric Radar Systems**, to be published in the Proceedings of the 1997 IEEE Antenna Propagation Society International Symposium, Montréal, Canada, July 13-18, 1997.

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

of the target.
[Contact: Lorant A. Muth, (303) 497-3603]

Muth, L.A., and Wittmann, R.C., **Radar Cross Section Range Characterization**, to be published in the Proceedings of the 1997 IEEE Antenna Propagation Society International Symposium, Montréal, Canada, July 13-18, 1997.

Radar cross section (RCS) range characterization and certification are essential to improve the quality and accuracy of RCS measurements by establishing consistent standards and practices throughout the RCS industry. Comprehensive characterization and certification programs (to be recommended as standards) are being developed at the National Institute of Standards and Technology, together with the Government Radar Cross Section Measurement Working Group.

We discuss in detail the long-term technical program and the well-defined technical criteria intended to ensure RCS measurement integrity. The determination of significant sources of errors, and a quantitative assessment of their impact on measurement uncertainty is emphasized. We briefly describe ongoing technical work and present some results in the areas of system integrity checks, dynamic and static sphere calibrations, noise and clutter reduction in polarimetric calibrations, quiet-zone evaluation and overall uncertainty analysis of RCS measurement systems.
[Contact: Lorant A. Muth, (303) 497-3603]

Prickett, M.J., Bloomfield, R.A., Kinzel, G.A., Wittman, R.C., and Muth, L.A., **Uncertainty Analysis for NRaD Radar Cross Section Measurements**, to be published as NISTIR 5061.

The Naval Command, Control and Ocean Surveillance Center RDT&E Division (NRaD) conducts Radar Cross Section measurements on U.S. naval ships and other targets. This document discusses the assessment of measurement uncertainty and follows general guidelines proposed by the National Institute of Standards and Technology.
[Contact: Ronald C. Wittman, (303) 497-3326]

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

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

Wittmann, R.C., and Black, D.N., **Quiet-Zone Evaluation Using a Spherical Synthetic-Aperture Radar**, to be published in the 1997 IEEE Antenna Propagation Society International Symposium, Montréal, Canada, July 13-18, 1997.

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

Antenna Metrology

Recently Published

Will, J.E., Norgard, J.D., Sega, R.M., Seifert, M., Pesta, A., Cleary, J., Stubenrauch, C.F., and MacReynolds, K., **Near-Field to Far-Field Antenna Pattern Measurements Using Infrared Imaging and Fourier Iterative Plane-To-Plane Techniques**, Proceedings of the 1996 Sixth Annual Dual-Use Technologies and Applications Conference, Syracuse, New York, June 3-6, 1996, pp. 266-271.

This paper describes the application of the "plane-to-plane" (PTP) iterative Fourier processing technique to infrared thermographic images of microwave fields to calculate the near-field and far-

field patterns of radiating antennas. A resistive sheet is positioned in a radiating field, and a thermal "picture" is then taken of the heat pattern. Each pixel of this thermal image represents a measurement of the intensity (magnitude) of the field at the pixel location on the resistive sheet.

The PTP technique allows recovery of the phase by combining measurements made on two planes, both in the radiating near field of the antenna under test. Starting with an estimate of the phase and the measured magnitudes, Fourier processing techniques are used to iteratively "propagate" between the planes to determine the correct phase distribution at each plane. We describe the technique and show comparisons made between the predicted results and results from measured IR thermograms of the field of a 36-element patch array antenna operating at 4 GHz using the University of Colorado Springs (UCCS) Thermal Camera.
[Contact: Carl F. Stubenrauch, (303) 497-3927]

Will, J.E., Norgard, J., Stubenrauch, C.F., MacReynolds, K., Seifert, M., and Sega, R., **Phase Measurements of Electromagnetic Fields Using Infrared Imaging Techniques and Microwave Holography**, Proceedings of the SPIE, (The international Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Thermosense XVIII, Vol. 2766, pp. 323-333 (1996).

Complex (magnitude and phase) measurements of the near field of a radiating antenna over a known surface (usually a plane, cylinder, or sphere) can be used to determine its far-field radiation pattern using near-field to far-field Fourier transformations. Standard gain horn antennas are often used to probe the near field. Experimental errors are introduced into the near-field measurements by mechanical probe position inaccuracies and electrical probe interactions with the antenna under test and probe correction errors.

A minimally perturbing infrared (IR) imaging technique can be used to map the near fields of the antenna. This measurement technique is much simpler and easier to use than the probe method and eliminates probe position errors and probe correction errors. Current IR imaging techniques, which have been successfully used to rapidly map the relative magnitude of a radiating field at many locations (mXn camera pixels per image captured) over a surface, however, suffer from an inability to determine phase information.

Absolute magnitude and relative phase data can be obtained by empirical or theoretical calibration of the IR detector screens (used to absorb the radiated energy over the measurement plane) and by using techniques from microwave holography. For example, magnitude only measurements of the radiating field of an antenna at two different locations (over two different surfaces) in the near field of the antenna can be used to determine its complex (magnitude and phase) far-field radiation pattern using plane-to-plane iterative transformations.

This paper discusses the progress made to date in determining both magnitude and phase information from IR imaging data (IR Thermograms), thus, enabling near-field and far-field measurements of antenna patterns using IR thermal imaging techniques.
[Contact: Carl E. Stubenrauch, (303) 497-3927]

Noise Metrology

Released for Publication

Randa, J., **Noise Temperature Measurements on Wafer**, to be published as NIST Technical Note 1390.

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

temperature. The tests also confirm our ability to produce known noise temperatures on wafer.
[Contact: James Randa, (303) 497-3150]

Microwave and Millimeter-Wave Metrology

Released for Publication

Milanović, V., Gaitan, M., Bowen, E.D., Tea, N.H., and Zaghloul, M.E., **Implementation of Thermoelectric Microwave Power Sensors in CMOS Technology**, to be published in the Proceedings of the 1997 International Symposium on Circuits and Systems, Hong Kong, June 9-12, 1997.

This paper presents implementations of efficient microwave power measurement devices through commercial CMOS processes with additional maskless etching. Two types of detectors were fabricated and tested. Both types of thermocouple detectors measure true rms power of signals in the frequency range up to 20 GHz and input power range from -30 dBm to +10 dBm. The devices have linearity better than ±40% for output vs. input power over the 40 dB dynamic range. Measurements of the return loss, obtained using an automatic network analyzer, show an acceptable input return loss of less than -20 dB over the entire frequency range.
[Contact: Michael Gaitan, (301) 975-2070]

Milanović, V., Gaitan, M., Bowen, E.D., Tea, N.H., and Zaghloul, M.E., **Thermoelectric Power Sensor for Microwave Applications by Commercial CMOS Fabrication**.

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

Williams, D.F., Belquin, J.-M., Spisseer, A., and Cappy, A., **Microwave Epitaxial Layer Characterization**.

We examine the effect of thin AlInAs/GaInAs epitaxial layers on the propagation of electrical signals in coplanar waveguide transmission lines fabricated on indium phosphide substrates. We show that argon ion isolation implants effectively reduce conduction losses in these layers to negligible levels at rf, microwave, and millimeter-wave frequencies.
[Contact: Dylan F. Williams, (303) 497-3138]

Microwave and Millimeter Wave Metrology

Recently Published

DeGroot, D.C., Rudman, D.A., Zhang, K., Ma, Q.Y., Kato, H., and Jaeger, N.A.F., **Planar Microwave Devices Fabricated by Ion-Implantation Patterning of High-Temperature Superconductors**, Applied Physics Letters, Vol. 69, No. 14, pp. 2119-2121 (30 September 1996).

We have applied ion-implantation inhibit patterning as a new method of fabricating low-loss microwave transmission lines in high-temperature superconductor thin films. To determine the effectiveness of this technique, we fabricated coplanar waveguide transmission lines in $YBa_2Cu_3O_{7-\delta}$ thin films that had been deposited on $LaAlO_3$ substrates using pulsed laser deposition. Microwave characterizations of these lines are compared to a reference line fabricated with conventional ion milling. At 76 K and 12 GHz, the attenuation constants of the ion-implanted transmission lines are approximately 0.02 dB/mm, and the overall loss response is indistinguishable from that of the ion-milled device.
[Contact: Donald C. DeGroot (303) 497-7212]

DeGroot, D.C., Walker, D.F., and Marks, R.B., **Impedance Mismatch Effects on Propagation Constant Measurements**, Proceedings of the IEEE 5th Topical Meeting on Electrical Performance of Electronic Packaging, Napa, California, October 28-30, 1996, pp. 141-143.

By measuring propagation constants of coplanar waveguide transmission lines, we show the significant systematic errors of common measurement techniques when the characteristic impedance of the lines does not match the reference impedance of the instrument.
[Contact: Donald C. DeGroot, (303) 4978-7212]

Ginley, R.A., **Dual 6-Port ANA Calibration with a Single Impedance Standard**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 532-533.

A newly developed method allows dual 6-port ANAs 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]

Huang, D.-X., Rebuldela, G., and Harper, J., **RF-DC Differences of Micropotentiometers**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 460-461.

Various sources of rf-dc differences of a micropotentiometer (μpot) are analyzed and calculated, and the results agree well with the experiments. A new design reduces the rf-dc differences of μpot significantly. Observations show good stability over a long period, which makes μpots suitable as primary rf and audio standards in the microvolt and millivolt ranges.
[Contact: Gregorio Rebuldela, (303) 497-3561]

Marks, R.B., Jargon, J.A., and Juroshek, J.R., **Calibration Comparison Method for Vector Network Analyzers**, Proceedings of the 48th Automatic Radio Frequency Techniques Group, Clearwater, Florida, December 5-6, 1996, pp. 38-45.

We present a technique for comparing the scattering parameter measurements made with respect to two vector network analyzer calibrations. This method determines the worst-case measurement error bounds on any calibration from a benchmark calibration, assuming the two are similar to first order. We illustrate our method by examining the differences between an open-short-load-thru and a sliding load calibration, both of which are available commercially on a variety of vector network analyzers.
[Contact: Roger B. Marks, (303) 497-3037]

Williams, D.F., **Calibration in Multiconductor Transmission Lines**, Proceedings of the 48th Automatic Radio Frequency Techniques Group, Clearwater, Florida, December 5-6, 1996, pp. 46-53.

This paper presents a calibration and measurement method for circuits embedded in lossy printed multiconductor transmission lines. The experimental results illustrate the complexity of the modal representation and the utility of the conductor representation for circuit design.
[Contact: Dylan F. Williams, (303) 497-3138]

Williams, D.F., and Olyslager, F., **Modal Cross Power in Quasi-TEM Transmission Lines**, IEEE Microwave and Guided Letters, Vol. 6, No. 11, pp. 413-415 (November 1996).

This letter examines modal cross power in electromagnetic transmission lines. It shows that the cross powers of nearly degenerate modes may be large in quasi-TEM multiconductor transmission lines typical of modern electronic circuits at moderate and low microwave frequencies. The letter develops simple expressions to estimate the magnitude of these cross powers from the "power-normalized" conductor impedance and admittance matrices of the lines.
[Contact: Dylan F. Williams, (303) 497-3138]

Electromagnetic Properties

Released for Publication

Baker-Jarvis, J.R., Jones, C.A., and Janezic, M.D., **Shielded Open-Circuited Sample Holder for Very Broad Band Measurements of Solids and**

Liquids.

This paper presents a simple method of obtaining accurate permittivity measurements from 100 Hz to 10 GHz using a single coaxial sample. The method is based on a full-field model of a coaxial termination. The method requires the use of a LCR meter and network analyzer. Measurements indicate that good accuracy can be obtained over a very wide band of frequencies.
[Contact: James Baker-Jarvis, (303) 497-5621]

Janezic, M.D., and Williams, D.F., **Permittivity Characterization from Transmission-Line Measurement**, to be published in the Proceedings of the 1997 IEEE Microwave Theory and Techniques Conference, Denver, Colorado, June 8-12, 1997.

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

Johnk, R.T., and Ondrejka, A.R., **The Extraction of Electrical Material Properties Using a Free-Space Time Domain rf Absorber Reflectivity Measurement System**, to be published in the Proceedings of the 1997 IEEE Electromagnetic Compatibility Conference, Austin, Texas, August 18-22, 1997.

During the past several years, there has been much research conducted at NIST in the measurement of scattering characteristics of a wide variety of rf absorber structures using free-space, time-domain reflectometer systems. Recently, this technology has been applied to the nondestructive testing of low-loss, low-dispersion dielectric panels. The scattering information obtained from the measurements of selected test structures is used to extract the relative permittivities of the various dielectric layers. Tests have been successfully conducted on single and multiple-layer dielectric panels, from which reasonable estimates of material properties have been obtained. Good results have been obtained in tests performed at both normal and oblique incidence. In addition, an edge-effect removal algorithm has recently been developed that significantly improves the estimated dielectric constant for small panels.
[Contact: Robert T. Johnk, (303) 497-3737]

Krupka, J., Derzakowski, K., Abramowicz, A., Tobar, M., and Geyer, R., **Measurements of the Complex Permittivity of Extremely Low Loss Dielectric Materials Using Whispering Gallery Modes**, to be published in the Proceedings of the 1997 IEEE Microwave Theory and Techniques Conference, Denver, Colorado, June 8-12, 1997.

The whispering gallery mode technique may be used for very accurate complex permittivity measurements of both isotropic and uniaxially anisotropic dielectric materials. A mode-matching technique is used to find the relationship between the complex permittivity, resonant frequency, and the dimensions of a resonant structure. The total uncertainty in permittivity is smaller than 0.05 percent and is limited principally by uncertainty in sample dimensions.
[Contact: Richard G. Geyer, (303) 497-5852]

Electromagnetic Properties

Recently Published

Jones, C.A., Kantor, Y., and Grosvenor, J.H., **Permittivity Measurements of Low-Loss Dielectric Materials at 60 GHz**, Proceedings of the SPIE, (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Millimeter and Submillimeter Waves and Applications III, Vol. 2842, pp. 263-273 (1996).

The National Institute of Standards and Technology is developing a Fabry-Perot resonator to measure the permittivity of materials at 60 GHz. The system is designed to operate in a semi-confocal configuration with the ability to adapt the system for high-temperature measurements. This talk will focus on design of the system, mode, identification, and measurements of permittivity for three low-loss materials.
[Contact: Chriss A. Jones, (303) 497-5958]

Krupka, J., Geyer, R.G., Baker-Jarvis, J., and Ceremuga, J., **Measurements of the Complex**

Permittivity of Microwave Circuit Board Substrates Using Split Dielectric Resonator and Reentrant Cavity Techniques, Proceedings of the Seventh International Conference on Dielectric Materials Measurements and Applications, University of Bath, United Kingdom, September 23-26, 1996, pp. 21-24.

Dielectric properties of microwave circuit board materials are usually measured with stripline or microstripline resonator techniques. These techniques have two disadvantages. First, it is difficult to measure dielectric loss tangent of low-loss materials, because conductor losses in such resonators are large and are usually not known accurately. Second, it is difficult to measure particular tensor components of anisotropic materials. We propose a split dielectric resonator technique for measurements of the complex permittivity of isotropic materials and a combination of this method and the re-entrant cavity for characterization of the complex permittivity of anisotropic materials.
[Contact: Richard G. Geyer, (303) 497-5852]

Lewis, R.L., **Relative Permittivity Measurement of Square Copper-Laminated Substrates Using the Full-Sheet Resonance Technique**, NISTIR 5053 (January 1997).

A measurement program has been undertaken at NIST to evaluate the full-sheet resonance (FSR) technique from which consistent relative permittivity values have been obtained. Here, we present an analysis of the theory underlying the FSR technique, along with a theoretical formulation correcting full two-port scattering-matrix measurements of a resonant cavity for the effects of coupling between the external measurement circuit and the cavity. A circuit analysis modeling the resonant cavity and its external circuit is presented, along with a least-squares solution for the resonant cavity's primary resonance parameters. The least-squares analysis features a slight rearrangement of an earlier formulation leading to a more numerically stable solution. An even earlier solution for a resonant cavity's unloaded quality factor also using a least-squares solution to obtain a coupling correction is presented for comparison. The application of these coupling correction formulations to the FSR technique is discussed, and results from these two correction formulations are compared with uncorrected results for two sample FSR panels. Computed least-squares data-scatter uncertainties are obtained for each FSR permittivity measurement, which are then used to obtain overall uncertainty estimates for each panel's measured permittivity, including a repeatability uncertainty estimate. These overall uncertainty estimates are compared to our earlier uncorrected FSR uncertainty estimate, showing a tightening of the uncertainty interval for corrected measurements. Finally, our measured FSR permittivities are compared with re-entrant cavity substrate permittivity measurements, showing agreement within expected uncertainty limits between the two techniques.
[Contact: Richard L. Lewis, (303) 497-5196]

Paulter, N.G., **A Fast and Accurate Method for Measuring the Dielectric Constant of Printed Wiring Board Materials**, IEEE Transactions on Components, Packaging, and Manufacturing Technology, Part C, Vol. 19, No. 3, pp. 214-225 (June 1996).

A new time-domain-reflectometry measurement method is described that provides accurate measurements of the average high-frequency (0.1 GHz to 5 GHz) dielectric constant of printed wiring board materials and that is suitable for "factory-floor" usage. A parallel-plate transmission line is used for the sample geometry. A model is developed that describes the electrical behavior of the transmission line, thereby allowing the dielectric constant to be extracted from the observed signal. The data analysis and the sample preparation are both simple to accomplish.
[Contact: Nicholas G. Paulter, (301) 975-2405]

Weil, C.M., Janezic, M.D., and Vanzura, E.J., **Intercomparison of Permeability and Permittivity Measurements Using the Transmission/Reflection Method in 7 and 14 mm Coaxial Air Lines**, NIST Technical Note 1386 (March 1997).

We discuss a measurement intercomparison, designed as a follow-up to that reported by Vanzura et al. In this effort, 13 participants performed broadband (3 MHz to 10 GHz) measurements of the magnetic and dielectric properties of five different

ferrite samples using the transmission/reflection (T/R) method in 7 and 14 nm diameter coaxial air lines. Agreement within ±5 percent was obtained for the measured permeability data for frequencies between 50 and 100 MHz. However, consistent with the findings of the earlier study, significant variability (±15 percent) was found to exist in the permittivity data, due to air-gap effects.
[Contact: Claude M. Weil, (303) 497-5305]

OPTOELECTRONICS

Released for Publication

Amin, J., Aust, J.A., Veasey, D.L., and Sanford, N.A., **980 nm-Pumped Er- and Er/Yb-Doped Waveguide Lasers in $LiNbO_3$**, to be published in the Proceedings of the 1997 European Conference on Integrated Optics, Stockholm, Sweden, April 2-4, 1997.

We demonstrate a 980 nm-pumped Er- and the first Er/Yb-doped waveguide laser in Ti:$LiNbO_3$. The devices have been fabricated on x-cut $LiNbO_3$ using the z-propagation direction. This choice of waveguide orientation results in a reduced susceptibility to photorefractive damage, and allows CW room-temperature operation.
[Contact: Andrew J. Amin, (303) 497-3289]

Lehman, J.H., and Scott, T.R., **Optical Radiation Detectors for Laser Measurements**, to be published in the Proceedings of the 1997 International Laser Safety Conference, Orlando, Florida, March 17-21, 1997.

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

Mechels, S.E., Schlager, J.B., and Franzen, D.L., **High Resolution Differential Mode Delay Measurements in Optical Fibers Using a Frequency Domain Phase Shift Technique**.

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

Mirin, R.P., Gossard, A.C., and Bowers, J.E., **Characterization and Modeling of InGaAs Quantum Dot Lasers**, to be published in the Proceedings of the 1997 International Conference on Modulated Semiconductor Structures, Santa Clara, California, July 14-18, 1997.

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

Rochford, K.B., Rose, A.H., and Wang, C.M., **Accuracy of Optical Retardance Measurements**.

NIST recently performed an intercomparison of retardance measurements to sample current practice and found adequate measurement accuracy for the majority of current applications, but

possibly inadequate accuracy for the most critical retarder needs.
[Contact: Kenneth B. Rochford, (303) 497-5170]

Weil, C.M., Janezic, M.D., and Vanzura, E.J., **Intercomparison of Permeability and Permittivity Measurements Using the Transmission/Reflection Method in 7 and 14 mm Coaxial Air Lines**.

A measurement intercomparison, designed as a follow-up to that reported by Vanzura et al, is discussed. In this effort, thirteen participants performed broadband (3 MHz to 10 GHz) measurements of the magnetic and dielectric properties of five different ferrite samples using the transmission/reflection (T/R) method in 7 mm and 14 mm diameter coaxial air lines. Good agreement is evident in the measured permeability data for frequencies >50 MHz. However, following the findings of the earlier study, significant variability (+15%) was found to exist in the permittivity data, due to air-gap effects.
[Contact: Claude M. Weil, (303) 497-5305]

OPTOELECTRONICS

Recently Published

Amin, A.J., Aust, J.A., and Sanford, N.A., **Stable CW Operating Waveguide lasers at Room-Temperature in Rare-Earth-Diffused Lithium Niobate**. Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Rare-Earth-Doped Devices, Vol. 2996, pp. 166-170 (1997).

A means of reproducibly fabricating stable cw-channel waveguide lasers in rare-earth-doped Ti:$LiNbO_3$ is demonstrated, through careful choice of the light propagation direction. Z-propagating waveguides have been fabricated in Nd:$TiLiNbO_3$ and room-temperature cw laser operations has been obtained by pumping in the 800 nm band with greatly reduced photorefractive instability. The reduced photorefractive damage susceptibility in this waveguide configuration has been used to our advantage in the realization, for the first time, of a 980 nm-pumped laser Er:Ti:$LiNbO_3$. The device showed a lasing threshold of 10.5 mW of absorbed pump power and a slope efficiency of 8.5%.
[Contact: Andrew J. Amin, (303) 497-3289]

Amin, A.J., Veasey, D.L., Sanford, N.A., and Hayden, J.S., **Waveguide Lasers by Ion-Edge in Er-Doped Glass**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Rare-Earth-Doped Devices, Vol. 2996, pp. 135-142 (1997).

Erbium and erbium/ytterbium co-doped silicate glass waveguide lasers have been fabricated by silver ion-exchange and their characteristics analyzed. We report on measurements and comparisons made in the lasing properties of these devices, including thresholds, slope-efficiencies, and pump tuning ranges. The results presented show that through proper choice of host glass, it is possible to make low-threshold lasers both in singly and co-doped devices.
[Contact: Andrew J. Amin, (303) 497-3289]

Knopp, K.J., Christensen, D.H., and Hill, J.R., **Vertical-Cavity Surface-Emitting Lasers with Low-Ripple Optical Pump Bands**, Applied Physics Letters, Vol. 69, No. 26, pp. 3987-3989 (23 December 1996).

We have used multilayer mirror optimization methods to enhance the coupling of pump light into vertical-cavity surface-emitting lasers (VCSELs). With previously reported devices, pump light was coupled into VCSEL cavities through interference notches in the mirror reflectance spectrum. This approach is sensitive to temperature-dependent reflectance spectrum shifts. We have created devices with a wide pump-band window of low reflectance. We report the simulation, growth, and optically pumped lasing of such optimized low-ripple VCSELs. Further, broadband pump windows open the possibility of spectrally broad optical pumps, and they eliminate the need for costly tunable pump lasers.
[Contact: David H. Christensen, (303) 497-3354]

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)**, Proceedings of the International Conference on Metallurgical

Coatings and Thin Films, San Diego, California, April 22-26, 1996, pp. 783-787.

We have employed a novel approach to enhance the optical pump-coupling stability of vertical-cavity surface-emitting lasers (VCSELs). These structures are composed of thin-film semiconductor multilayers and are manufactured entirely by thin-film deposition. In the past, pump light was coupled into VCSEL cavities through the short wavelength interference notches in the reflectance spectrum. However, the steep slope and narrow width of the notches inherently makes pump-coupling sensitive to device temperature. We have employed traditional thin-film optimization to the multilayer etalon to create a low ripple, wideband pump region of low reflectance while maintaining cavity-mode field overlap at the quantum wells. We demonstrate a factor of 2.5 times better stability across a 35 nm spectral range.
[Contact: David H. Christensen, (303) 497-3354]

Rochford, K.B., Rose, A.H., and Day, G.W., **Magneto-Optic Sensors Based on Iron Garnets**, Proceedings of the 9th Annual IEEE Lasers and Electro-Optics Society 1996 Annual Meeting, Boston, Massachusetts, November 18-19, 1996, pp. 242-243. [Also published in IEEE Transactions on Magnetics, Vol. 32, No. 5, pp. 4113-4117 (September 1996).]

Large magneto-optic coefficients make iron garnets attractive transducers for magnetic field sensors. A typical response curve can be idealized as a Faraday rotation that is linear with applied field H up to a field that causes saturation, H_{sat}. Applying H_{sat} yields a saturation rotation Θ_{sat}. For sensor operation over the range of linear response, the slope, or magneto-optic sensitivity S, can be approximated by $S = \Theta_{sat}/H_{sat}$. The Faraday rotation Θ is equal to $S \cdot H$ in this approximation.
[Contact: Kenneth B. Rochford, (303) 497-5170]

Schaafsma, D.T., and Christensen, D.H., **Cavity Coupling in Vertical-Cavity Semiconductor Lasers**, NISTIR 5047 (January 1997).

The growing sophistication of vertical-cavity surface-emitting lasers, or VCSELs, has fostered questions which have previously lacked a certain relevance. In particular, the gain medium in the laser can now be confined to a very small region of space and moved about within the cavity, and the mode volume of the cavity itself can be reduced to a scale where coupling between the source medium and the emitted radiation and even the quantum nature of light can become significant. This work explores two types of coupling in planar cavities: emitter coupling, a light-matter interaction; and mode coupling, a light-only interaction. Technological applications of coupling effects are discussed, along with novel metrology designed for devices such as VCSELs. A novel experimental technique for probing the side-emission from VCSELs is also described and is used both to probe for coupling effects and to serve as a metrological tool.

Experiments designed to probe for emitter coupling in VCSELs are described, and their results show that the effect of the cavity on the emitter can, indeed, be seen in side emission studies. The results of this experiment show side emission to be a versatile tool, not only for examining cavity effects, but also for basic metrology and modeling of optical response.

The general effects of mode coupling are illustrated in a simplified experiment designed to show the strong redistribution of energy from a dipole inside an etalon, which is much more pronounced than the normal etalon redistribution effects for light originating outside the cavity. These tests also show that redistribution of intensity patterns does not indicate feedback to an emitter from its own radiation. This type of coupling to cavity modes is then examined in VCSEL structures and shown to be potent enough for device applications.
[Contact: David H. Christensen, (303) 497-3354]

Schaafsma, D.T., and Christensen, D.H., **Mode Splitting in Side Emission from Vertical-Cavity Surface-Emitting Lasers**, Physical Review B, Vol. 54, No. 20, 14 618-14 622 (15 November 1996).

We present side-emission (luminescence) data from vertical-cavity surface-emitting lasers which show cavity-induced effects on the emission spectrum. In particular, the heavy-hole luminescence spectrum contains two peaks when pumped in such a way as to excite electron-hole pairs well inside the cavity region, where coupling to free-space modes is minimized, and only one peak when pumped near

the edge of the cavity (near a cleaved facet), where coupling to free-space modes is maximized. This splitting can be distinguished as a cavity-induced effect with little ambiguity from other factors present in semiconductor quantum-well radiation, such as the light- and heavy-hole splitting. A fit to the data using Lorentzian line shapes gives a vacuum-field Rabi splitting of roughly 34 meV, which is consistent with theoretical calculations and with other reports on this phenomenon. We, therefore, conclude that the two peaks in the spectrum are due to Rabi oscillation in the cavity, and that they represent an actual change in the energy configuration of the quantum well.
[Contact: David H. Christensen, (303) 497-3354]

Schlager, J.B., Mechels, S.E., and Franzen, D.L., **Zero-Dispersion Wavelength Uniformity and Four-Wave Mixing in Optical Fiber**, Proceedings of the IEEE Laser and Electro-Optics Society Meeting (LEOS'96), Boston, Massachusetts, November 18-19, 1996, pp. 166-167.

Frequency-domain phase shift measurements of zero-dispersion wavelength in optical fibers cut from a single spool are compared with the maximum four-wave mixing efficiency wavelength. A 1.2 nm change in zero-dispersion wavelength over 10 km affects four-wave mixing behavior.
[Contact: John S. Schlager, (303) 497-3542]

Veasey, D.L., Gary, J.M., and Amin, J., **Rigorous Scalar Modeling of Er and Er/Yb-Doped Waveguide Lasers**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10. Bellingham, Washington 98227-0010), Rare-Earth-Doped Devices, Vol. 2996, pp. 109-120 (1997).

A rigorous scalar model for predicting the characteristics of rare-earth-doped waveguide lasers has been developed. The model consists of two nonhomogeneous wave equations: one for the forward-propagating laser signal power, the other for the backward-propagating laser signal. These equations are coupled with one forward-propagating nonhomogeneous wave equation representing the pump signal. The three wave equations are coupled with the space dependent laser rate equations to form a system of time-dependent differential equations. This large system of equations is solved, using appropriate initial and boundary conditions, by the method of lines using collocation for the spatial approximation. The solutions to this system yield data which predict the time- and position-dependent laser signal power, pump power, and population densities in a waveguide laser cavity supporting an arbitrary guided mode. The assumptions made in this new model are that the transverse field maintains the same shape as a function of longitudinal position in the laser cavity and that the effects of spatial hole burning and standing waves are neglected. We have used this model to predict continuous wave and Q-switched laser performance for Er and Er/Yb-doped lasers. We have achieved favorable comparisons with actual laboratory operation of cw Yb/Er-co-doped waveguide lasers. Results from simulations of Er-doped and Yb/Er-doped Q-switched lasers are presented which show that high-peak powers on the order of 500 W and 1 ns pulse widths can be achieved.
[Contact: David L. Veasey, (303) 497-5952]

Williams, P.A., **Accuracy in Polarization Mode Dispersion Measurements**, Proceedings of the IEEE Laser and Electro-Optics Society Meeting (LEOS'96), Boston, Massachusetts, November 18-19, 1996, pp. 170-171.

A description is given of ongoing work toward accuracy statements for polarization mode dispersion measurements. The work described here includes theoretical comparisons of methods, experimental and simulated accuracies, and round-robin comparison results.
[Contact: Paul A. Williams, (303) 497-3805]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Christophorou, L.G., Olthoff, J.K., and Van Brunt, R.J., **Sulfur Hexafluoride and the Electric Power Industry**.

Gas-insulated electrical equipment has a demonstrated value for society. Sulfur hexafluoride (SF_6) is the electric power industry's preferred gas for electrical insulation and arc quenching/current

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

Christophorou, L.G., Olthoff, J.K., and Wang, Y., **Electron Interactions with CCl_2F_2.**

In this article, we critically evaluate and synthesize the available information on the cross sections and rate coefficients for collisional interactions of dichlorodifluromethane (CCl_2F_2) with electrons. This gas has many industrial uses and is of atmospheric and environmental interest. The CCl_2F_2 molecule fragments rather extensively under electron impact, principally via dissociative ionization and dissociative attachment; the latter process is temperature dependent. Information is presented and discussed on: (1) electron scattering processes [cross sections for total electron scattering, momentum transfer, differential elastic electron scattering, integral elastic electron scattering, and inelastic electron scattering for rotational and for vibrational (direct and indirect) excitation]; (2) electron impact ionization (cross sections for total, partial, and double ionization and coefficients for electron impact ionization); (3) electron attachment (electron attachment cross sections and rate constants and their energy and temperature dependencies, electron attachment coefficients, dissociative attachment fragment anions, and negative ion states); (4) optical emission under electron impact, and (5) electron transport coefficients (electron drift velocity and ratio of transverse electron diffusion coefficient to electron mobility). Based upon the assessment of published experimental data, recommended values of various cross sections and rate coefficients are generated in graphical and tabular form. Areas where additional data are needed are identified, such as the measurement of the cross sections for momentum transfer and electron impact dissociation of CCl_2F_2 into neutral species.
[Contact: Loucas G. Christophorou, (301) 975-2432]

Mansoor, A., and Martzloff, F.D., **The Effect of Neutral Earthing Practices on Lightning Current Dispersion in a Low-Voltage Installation**,

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

Misakian, M., **ELF Electric and Magnetic Field Measurement Methods**, to be published in the Proceedings of the 1st Chilean Metrology Congress Conference, Santiago, Chile, April 2-4, 1997.

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

Misakian, M., **Vertical Cavity Polarized Extremely-Low Frequency Magnetic Fields and Induced Electric Fields in Culture Media**.

An examination is made of some properties of induced electric fields in cell culture media produced by vertical circularly polarized magnetic fields. The described geometry is not advantageous for determining effects that may be attributable to induced electric fields or currents.

[Contact: Martin Misakian, (303) 497-2426]

Olthoff, J.K., **Plasma Diagnostics on the Gaseous Electronics Conference Radio-Frequency Reference Cell**, to be published in the Proceedings of the Frontiers in Low Temperature Plasma Diagnostics II Conference, Bad Honnef, Germany, February 17-21, 1997.

[See Plasma Processing.]

Rao, M.V.V.S., Olthoff, J.K., and Van Brunt, R.J., **Negative Ion-Energy Distributions and Ion-Neutral Reactions in SF_6 Townsend Discharges at High Electric Field-To-Gas Density Ratios (E/N)**.

Knowledge of kinetic-energy distributions (KEDs) of both positive and negative ions in discharges are important in determining the reaction coefficients for modeling discharges. It is well known that stable SF_6^- ions are produced by electron-attachment to SF_6 with relatively large cross sections for thermal electrons. Other processes, such as collisional electron-detachment and collision-induced dissociation, are also important because they affect the density and identity of negative ions in the discharge. We report here measurements on relative concentrations and KEDs of SF_6^-, SF_5^-, F_2^-, and F^- ions produced in SF_6 Townsend discharges at high *E/N*. The F^- is the dominant ion, and is produced with relatively high kinetic energies. The KEDs of SF_6^- and SF_5^- are observed to be Maxwellian at 5.5 kTd, but begin to deviate from it with increasing *E/N*, while those of F^- are non-Maxwellian at all *E/N*. The F_2^- signal increases with increasing *E/N*; however, its signal is relatively weak compared to the other ions. The mean ion energies and relative abundances of these ions are derived from the measured KEDs, and are reported.
[Contact: James K. Olthoff, (301) 975-2431]

Power Systems Metrology

Recently Published

Bachl, H., Martzloff, F., and Nastasi, D., **Using Incandescent Lamp Failure Levels for Assessment of the Surge Environment**, Proceedings of the 1997 International Zurich Symposium on Electromagnetic Compatibility, Zurich, Switzerland, February 18-20, 1997, pp. 579-584.

This paper reports a joint investigation of the failure modes and levels of incandescent lamps ("light bulbs") exposed to surges occurring in low-voltage ac power systems. Tests were performed in one European laboratory and in one U.S. laboratory on typical 100 W bulbs used in the two environments, the North American 120 W systems, and the 230 V European systems. Through complementary tests and high-speed video observation of the flashes, more detailed understanding of the parameters has been obtained. Having determined what it takes to fail a light bulb by a surge, this information can be used to assess the surge environment by noting that frequent bulb failure does not occur; therefore, surges above the failure threshold must be infrequent.
[Contact: François Martzloff, (301) 975-2409]

Bretagne, J., Šimko, T., Gousset, G., Rao, M.V.V.S., Van Brunt, R.J., Wang, Y., Olthoff, J.K., Peko, B.L., and Champion, R.L., **Distributions of H^+, H_2^+ H_3^+ Ions in Townsend Discharge and Determination of Their Collision Cross Sections**, Proceedings of the Thirteenth European Sectional Conference on the Atomic and Molecular Physics of Ionised Gases, Poprad, Slovakia, August 27-30, 1996, pp. 115-116.

Experimental and theoretical investigations of hydrogen discharges are complicated by coexistence of three dominant ionic species (H^+, H_2^+ and H_3^+) and their mutual interconversion by collisions with neutral gas molecules. A recent cross-section set for collisions of H_n^+ and ions (n = 1,2,3) with H_2 based on extrapolations to low energies is highly uncertain, especially for H_3^+/H_2 and with moderate collision energies (10 to 1000 eV), and this uncertainty can be reflected in predicted ion-energy distributions.

In this work, an attempt is made to deduce a consistent set of H_n^+/H_2 cross sections by comparing experimental and theoretical investigations of ion-energy distributions and fluxes in low-pressure Townsend discharges.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Lindes, G., Mansoor, A., Martzloff, F.D., and

Vannoy, D., **Surge Recordings that Make Sense**, Proceedings of the Electrical Power Research Institute PQA'97 Conference, Columbus, Ohio, March 3-6, 1997, pp. 1-11.

This paper offers a rationale for avoiding attempts to characterize the surge environment in low-voltage end-user power systems by a single number -- the "energy in the surge" -- derived from a simple voltage measurement. Numerical examples illustrate the fallacy of this concept. Furthermore, based on the proliferation of surge-protective devices in low-voltage end-user installations, the paper draws attention to the need for changing focus from surge voltage measurements to surge current measurements.
[Contact: François Martzloff, (301) 975-2409]

Mansoor, A., Nastaski, D., and Martzloff, F.D., **Applying Reality Checks to Standards on the Surge Environment**, Proceedings of the 23rd International Conference on Lightning Protection, Florence, Italy, September 23-27, 1996, Vol. II, pp. 749-754.

The paper identifies several realities of surge environment and equipment survival that are sometimes ignored in surge-protection practices. It questions the quest for what could be overly conservative requirements for surge immunity or surge mitigation by presenting "reality checks" based on field experience or laboratory data. A first check focuses on the fact that some recent field recordings of surges may be misleadingly low in today's surge environment. Additional checks, aimed at moderating the overly conservative requirements, include the case history of a proposed high-stress 100/1300 μs surge test, data on failure levels of clock motors and light bulbs that can serve as benchmarks for severity levels, and measurements, validated by parametric modeling, showing that large currents cannot propagate into long cables without causing a flashover of the wiring devices at the beginning of the cable, effectively limiting the energy-delivery capability of a surge at the end of the cable.
[Contact: François D. Martzloff, (301) 975-2409]

Martzloff, F.D., **Surge Recordings that Make Sense: Shifting Focus from Voltage to Current Measurements**, Proceedings of the 1996 International Symposium on Electromagnetic Compatability, Rome, Italy, September 17-20, 1996, pp. 311-314.

The paper proposes to establish a program for characterizing surge events according to the capability of a surge event to deliver a surge current through the power system in end-user facilities. This characterization would replace the conventional, and by now misleading, monitoring of surge voltages. The new approach will use a current transducer including a silicon-avalanche diode with the lowest possible voltage to "attract" surges away from other surge-protective devices connected within the facility. The voltage signal from the current transducer will then be recorded using any power-quality-monitoring instrument available to the individual researchers, providing complete current waveform parameters.
[Contact: François D. Martzloff, (301) 975-2409]

Misakian, M., and Fenimore, C., **Distributions of Measurement Errors for Single-Axis Magnetic Field Meters During Measurements Near Appliances**, Bioelectromagnetics, Vol. 18, pp. 273-276 (1997).

Comparisons are made between the average magnetic flux density as it would be measured with a single-axis coil probe and the flux density at the center of the probe, assuming that the probe is oriented to measure the maximum field at that point. Probability distributions of the differences between the two quantities are calculated assuming a dipole magnetic field and are found to be asymmetric. The distributions are used to estimate the uncertainty for maximum magnetic field measurements at distances that are large compared with the dimensions of the field source.
[Contact: Martin Misakian, (303) 497-2426]

Van Brunt, R.J., and von Glahn, P., **Improved Monte-Carlo Simulator of Partial Discharge**, Proceedings of the 1996 Conference on Electrical Insulation and Dielectric Phenomena, San Francisco, California, October 20-23, 1996, pp. 504-509.

A previous introduced Monte-Carlo simulator of partial discharge (PD) has been extended and made

more versatile to allow simulation of a wider range of observed discharge behavior. The version of the simulator described here allows simulation of pulsating PD that can be represented as a point process and covers such properties as nonstationary behavior associated with PD-induced modifications of the discharge site and statistical characteristics of multi-site discharges. In the present work, it is shown how the simulator can be applied to gain insight into the physical basis for the previously reported anomalous stochastic behavior of PD generated by applying low-frequency alternating voltages to point electrodes that touch the surface of pure Al_2O_3.
[Contact: Richard Van Brunt, (301) 975-2425]

Van Brunt, R.J., Olthoff, J.K., Firebaugh, S.L., and Sauers, I., **Production of S_2F_{10}, S_2OF_{10}, and $S_2O_2F_{10}$ from Spark and Negative-Corona Discharges in SF_6 and SF_6/O_2 Gas Mixtures**, Transactions of the IEE of Japan, Vol. 116-A, No. 11, pp. 1014-1024 (November 1996).

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 mixture containing up to 10% oxygen by volume fraction. 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 $S_2O_2F_{10}$ 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]

Van Brunt, R.J., von Glahn, P., and Las, T., **Anomalous Stochastic Behavior of Partial Discharge on Aluminum Oxide Surfaces**, Journal of Applied Physics, Vol. 81, No. 2, pp. 840-854 (15 January 1997).

The stochastic properties of pulsating partial discharge (PD) generated by applying a low-frequency sinusoidal alternating voltage to a point electrode touching an aluminum oxide (Al_2O_3) surface in air have been investigated. The time dependence of such statistical characteristics as mean numbers of positive and negative PD pulses per half cycle and the amplitude and phase distributions of individual positive and negative PD pulses selected according to their order of occurrence in a cycle were extracted from records of the amplitudes and phases of all PD events that occurred while the voltage was applied for times up to 40 min. The discharge characteristics exhibit a dramatic sensitivity to the impurity content of Al_2O_3. In the case of high-purity (99.9%) Al_2O_3, the positive-PD pulses cease within 30 s after application of the voltage from which time the negative-PD pulses persist indefinitely in a relatively stationary pattern. The cessation of positive PD was not observed for Al_2O_3 samples of lower purity (96% or lower). A modified version of a previously developed Monte-Carlo simulator of ac-generated PD that includes effects of transport and decay of surface charge between PD events was used to gain insight into the conditions that could give rise to the observed long-term behavior of PD for high purity Al_2O_3.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Pulse Power Metrology

Released for Publication

Mansoor, A., and Martzloff, F.D., **The Effect of Neutral Earthing Practices on Lightning Current Dispersion in a Low-Voltage Installation**.

[See Power Systems Metrology.]

Magnetic Materials and Measurements

Released for Publication

Crawford, T.M., Rogers, C.T., Silva, T.J., and Kim, Y.K., **Second-Harmonic Magneto-Optic Kerr Effect from Spin-Valve Test Structures and Correlation with Magneto Resistance Response**.

We have simultaneously measured the second-harmonic magneto-optic Kerr effect and the magnetoresistance of patterned Ta/$Ni_{81}Fe_{19}$/Cu/$Ni_{81}Fe_{19}$/Ta spin-valve test structures. For applied fields transverse and longitudinal to the bias-current direction, we have observed correlated changes in magnetoresistance and in second-harmonic intensity. Irreversible magnetization switching and coherent magnetization rotation have been observed. Multilayer reflection theory modeling of the second-harmonic intensity from these structures indicates that the detected second-harmonic arises largely from the top $Ni_{81}Fe_{19}$/Ta interface.
[Contact: Thomas J. Silva, (303) 497-5619]

Misakian, M., **Vertical Cavity Polarized Extremely-Low Frequency Magnetic Fields and Induced Electric Fields in Culture Media**.

[See Power Systems Metrology.]

Oti, J.O., Kim, Y.K., and Suvarna, S., **A Personal Computer Based Semi-Analytical Micromagnetics Design Tool**.

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

Oti, J.O., and Russek, S.E., **Micromagnetic Simulations of Magnetoresistive Behavior of Submicrometer Spin-Valve MRAM Devices**.

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

Rice, P., Russek, S.E., Hoinville, J., and Kelley, M.H., **Optimizing the NIST Magnetic Imaging Reference Sample**.

We have further developed the NIST magnetic imaging reference sample to include a magnetic pattern which can indicate the magnetic polarity of a magnetic force microscope tip. Several samples cut from the same disk were measured with a single tip. We have also measured a single transition with several tips. Both of these measurements have shown the variability in images taken with different tips and different instrument configuration which underscores the need for a well-calibrated sample.
[Contact: Paul Rice, (303) 497-3841]

Russek, S.E., Oti, J.O., Kim, Y.K., and Cross, R.W., **Performance Optimization of Submicrometer Spin-Valves for Digital Applications**.

We have characterized the magnetoresistive response of giant magnetoresistive spin valve devices, designed for digital applications, as a function of current density and magnetic field angle. The devices are designed to have only two stable states and are characterized by their positive and negative switching fields. The variation in the switching fields of submicrometer devices is compared with a multilayer single-domain model to determine how accurately the switching fields can

be predicted. Significant deviation from single domain behavior is observed. The sensitivity of the switching fields to current density and field angle are examined in the context of applications to magnetoresistive random access memory and digital sensors.
[Contact: Steven E. Russek, (303) 497-5097]

Russek, S.E., Oti, J.O., Kim, Y.K., and Cross, R.W., **Submicrometer Scaling of Spin Valve Devices Designed for Digital Applications**.

The performance of spin-valve giant magnetoresistive devices, designed for digital applications, has been examined as a function of device line width and aspect ratio. NiFe-Co-Cu-Co-NiFe-FeMn devices have been fabricated with linewidths down to 0.4 μm and aspect ratios that varied from 10:1 to 1.5:1. As the device linewidth decreases, the switching fields and switching field asymmetry increase due to magnetostatic effects. As the aspect ratio decreases, the switching field asymmetry increases rapidly, and the devices become prone to domain noise. The experimentally observed switching fields are compared to single domain and micromagnetic models to determine the accuracy with which the switching fields can be predicted. In addition to the magnetostatic effects, there is a decrease in the magnetoresistive response due to a dead layer at the device edges.
[Contact: Stephen E. Russek, (303) 497-5097]

Magnetic Materials and Measurements

Recently Published

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**, IEEE Transactions on Magnetics, Vol. 32, No. 5, pp. 4087-4089 (September 1996).

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 of roughly a factor of 3 upon magnetization reversal. In the longitudinal geometry, the second harmonic Kerr angle is 32.6° for s-incidence and 6.8° for p-incidence. A simple theoretical treatment allows us to compare the relevant second-order susceptibility elements as measured in the two geometries: the element magnitudes and relative phase shifts agree within experimental error.
[Contact: Thomas J. Silva, (303) 497-7826]

Cross, R.W., Kim, Y.K., Oti, J.O., and Russek, S.E., **Magnetostatic Effects in Giant Magnetoresistive Spin-Valve Devices**, Applied Physics Letters, Vol. 69, No. 25, pp. 3935-3937 (16 December 1996).

We report on magnetotransport measurements of spin valve films that have been fabricated into rectangular stripes with Au current leads. The spin valve films consisted of two magnetic NiFe layers separated by a nonmagnetic Cu layer. The top NiFe layer was magnetically pinned by a FeMn layer with an effective pinning field of 12 kA/m (150 Oe). After device fabrication, the transport properties changed dramatically as the stripe-height of the device was decreased below 1 μm. Internal demagnetizing fields and magnetostatic interactions between the magnetic layers dominated the magnetic response. These interactions change the biasing point and the linearity, and cause a decrease in sensitivity to field changes. We have developed a simple single-domain rotation model that includes magnetostatic, anisotropy, and exchange interactions to describe the magnetic behavior, from which we calculate the transport response.
[Contact: Ralph W. Cross, (303) 497-5300]

Kirschenbaum, L.S., Rogers, C.T., Beale, P.D., Russek, S.E., and Sanders, S.C., **High Current Density Self-Field Effects and Low-Frequency Noise in NiFe/Ag Giant Magneto-Resistance Multilayers**, IEEE Transaction on Magnetics, Vol. 32, No. 5, pp. 4684-4686 (September 1996).

High current densities (10^6 to 10^7 A/cm^2) produce magnetic fields which can induce antiparallel magnetic alignment in large (16 μm and 8 μm) NiFe/Ag thin film multilayer devices. We induce Giant Magneto-Resistance (GMR) in unannealed devices which normally do not display GMR. We find multiple peaks in the magnetoresistance curves of annealed and unannealed devices. Analysis of the positions and shapes of these

magnetoresistance peaks provides a new set of tools for determining the micromagnetic structure of the multilayers. Our magneto-optical Kerr effect data and low frequency noise data correlate with the magnetoresistance peaks and may yield further information about layer-layer interactions and domain structure.
[Contact: Stephen E. Russek, (303) 497-5097]

Liou, S.H., Malhotra, S.S., Moreland, J., and Hopkins, P.F., **High Resolution Imaging of Thin-Film Recording Heads by Superparamagnetic Magnetic Force Microscopy Tips**, Applied Physics Letters, Vol. 70, No. 1, pp. 135-137 (6 January 1997).

We have used superparamagnetic force microscopy (MFM) tips to obtain high-spatial resolution MFM images of recording heads. Profiles of magnetic field gradient above a thin-film recording head under 3 mA bias current to the head and various tip-head distance conditions are presented. At a low tip-head distance, the gap width, gap location, and gap-field structure can be well resolved in these MFM images. Superparamagnetic tips show promise for the magnetic imaging of recording heads with gap widths below 200 nm.
[Contact: John Moreland, (303) 497-3641]

Misakian, M., and Fenimore, C., **Distributions of Measurement Errors for Single-Axis Magnetic Field Meters During Measurements Near Appliances**, Bioelectromagnetics, Vol. 18, pp. 273-276 (1997).

[See Power Systems Metrology.]

Rice, P., and Hoinville, J., **Correlating Magnetic Force Microscopy Images and Recording Head Output**, Data Storage Magazine, pp. 35-40 (January 1997).

The preferred instrument for studying magnetization on recording media has been the spin-stand. Although the magnetization on a disk exists in two dimensions, the read-back head reduces the two-dimensional magnetic signal to one dimension and outputs a one-dimensional electrical waveform. We have combined output from the spin-stand and images obtained from the Magnetic Force Microscopy (MFM), to provide a more complete picture of the magnetic fields read by the head. This technique allows us to study effects such as how transition shape is affected by media noise and the corresponding effect on the read-back waveform. We can also see features left behind from previous data which cannot be distinguished from media noise as read back by the recording head. We have demonstrated that the response of an MFM tip to the disk's magnetic fields is almost identical to the output signal from an inductive read-back head. This implies that the MFM can be used to measure the two-dimensional magnetization that a transition contains to more fully understand the response of the read head.
[Contact: Paul Rice, (303) 497-3841]

Rice, P., and Hoinville, J., **Spatial Correlation Between Magnetic Force Microscope Images and Recording Head Output**, IEEE Transactions on Magnetics, Vol. 32, No. 5, pp. 3563-3565 (September 1996).

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. As one of the examples of this technique, 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., and Russek, S.E., **Magnetic Imaging Reference Sample**, IEEE Transactions on Magnetics, Vol. 32, No. 5, pp. 4133-4137 (September 1996).

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 designed to explore certain aspects of magnetic imaging. Disks are then cut into coupons, cleaned, and patterned with a reference grid of numbered 20 μm × 20 μm 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**, Proceedings of the 9th Annual IEEE Lasers and Electro-Optics Society 1996 Annual Meeting, Boston, Massachusetts, November 18-19, 1996, pp. 242-243. [Also published in IEEE Transactions on Magnetics, Vol. 32, No. 5, pp. 4113-4117 (September 1996).]

[See OPTOELECTRONICS.]

Superconductors

Released for Publication

Ovchinnikov, Yu.N., Ivlev, B.I., Soulen, R.J., Jr., Classen, J.H., Fogle, W.E., and Cowell, J.H., **The Temperature and Magnetic Field Dependence of the Induced Magnetization in Macroscopic Samples Due to the Proximity Effect**.

We have applied the Ginzburg-Landau equations to calculate the behavior of the diamagnetism of macroscopic samples consisting of a normal metal in contact with a superconductor. In particular, the calculation focuses on the temperature region above the superconductive transition temperature T_{cN} of the normal metal. We have compared these calculations with experimental measurements of the temperature (0.006 K to 1 K) and magnetic field (10^{-9} to 10^{-6} T) dependence of the diamagnetism for several samples of Be (T_{cN} ~23 mK) and W (T_{cN} ~15.5 mK) in contact with the superconductor AL (T_{cS} = 1.18 K). The agreement between the predictions and measurement is quite good and confirms the approach of using the Ginzburg-Landau model to calculate the proximity effect in macroscopic normal systems above their superconductive transitions.
[Contact: Alan F. Clark, (301) 975-2139]

Superconductors

Recently Published

DeGroot, D.C., Rudman, D.A., Zhang, K., Ma, Q.Y., Kato, H., and Jaeger, N.A.F., **Planar Microwave Devices Fabricated by Ion-Implantation Patterning of High-Temperature Superconductors**, Applied Physics Letters, Vol. 69, No. 14, pp. 2119-2121 (30 September 1996).

[See Microwave and Millimeter Wave Metrology.]

Wiejaczka, J.A., and Goodrich, L.F., **Interlaboratory Comparison on High-Temperature Superconductor Critical-Current Measurements**, Journal of Research of the National Institute of Standards and Technology, Vol. 102, No. 1, pp. 29-52 (January–February 1997).

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

Other Electrical Systems Topics

Recently Published

Stricklett, R.L., and Vangel, M., **Electric Motor**

Efficiency Testing Under the New Part 431 of Chapter II of Title 10, Code of Federal Regulations: Enforcement Testing, NIST Technical Note 1422 (January 1997).

The provisions for electric motor efficiency testing under the proposed new Part 431 of Chapter II of Title 10, Code of Federal Regulations, as published for public comment in the *Federal Register*, Vol. 61, No. 230, Wednesday, November 27, 1996, pp. 60439-60475, are discussed. The criteria for demonstration of compliance with the energy efficiency requirements established by Energy Policy and Conservation Act of 1975, as amended, are presented. The operating characteristics, i.e., the estimated probability of demonstrating compliance based on the mean efficiency, standard deviation, and number of units tested, of the Sampling Plan for Enforcement Testing recommended by the new Part 431 are evaluated by model calculations.
[Contact: Kenneth L. Stricklett, (301) 975-3955]

ELECTROMAGNETIC INTERFERENCE

Conducted EMI

Recently Published

Bachl, H., Martzloff, F., and Nastasi, D., **Using Incandescent Lamp Failure Levels for Assessment of the Surge Environment**, Proceedings of the 1997 International Zurich Symposium on Electromagnetic Compatibility, Zurich, Switzerland, February 18-20, 1997, pp. 579-584.

[See Power Systems Metrology.]

Lindes, G., Mansoor, A., Martzloff, F.D., and Vannoy, D., **Surge Recordings that Make Sense**, Proceedings of the Electrical Power Research Institute PQA'97 Conference, Columbus, Ohio, March 3-6, 1997, pp. 1-11.

[See Power Systems Metrology.]

Mansoor, A., Nastaski, D., and Martzloff, F.D., **Applying Reality Checks to Standards on the Surge Environment**, Proceedings of the 23rd International Conference on Lightning Protection, Florence, Italy, September 23-27, 1996, Vol. II, pp. 749-754.

[See Power Systems Metrology.]

Martzloff, F.D., **Surge Recordings that Make Sense: Shifting Focus from Voltage to Current Measurements**, Proceedings of the 1996 International Symposium on Electromagnetic Compatability, Rome, Italy, September 17-20, 1996, pp. 311-314.

[See Power Systems Metrology.]

Radiated EMI

Released for Publication

Hill, D.A., and Kanda, M., **Measurement Uncertainty of Radiated Emissions**, to be published as NIST Technical Note 1389.

We present a summary of current knowledge and techniques for evaluating measurement uncertainty of radiated emissions. The important quantity for compliance testing is the expanded uncertainty (typically for a coverage factor k = 2), and we discuss the validity of obtaining the combined uncertainty from an RSS sum of separate uncertainties. A generic uncertainty model includes the following separate sources of measurement uncertainty: setup of equipment under test, measurement procedures, facility, antenna, and receiver. Measurement uncertainties for radiated emissions are large and not well quantified, and recommendations are made for further study.
[Contact: David A. Hill, (303) 497-3472]

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

We present methods for improving the reliability of measurements made in a mode-stirred chamber. The combination of improved instrumentation and a larger paddle resulted in measurements that were significantly more reproducible (+1 dB) than previous measurements. We also give a simple

model that is capable of describing the characteristics of a mode-stirred chamber at any frequency using only two parameters.
[Contact: John M. Ladbury, (303) 497-5372]

VIDEO TECHNOLOGY

Released for Publication

Boynton, P.A., and Kelley, E.F., **Accurate Contrast Ratio Measurements Using a Cone Mask**, to be published in the Proceedings of the 1997 Society for Information Display International Symposium, Boston, Massachusetts, May 12-16, 1997.

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

Kelley, E.F., and Jones, G.R., **Utilizing the Bidirectional Reflection Distribution Function to Predict Reflections from Flat Panel Displays**, to be published in the Proceedings of the 1997 Society for Information Display International Symposium, Boston, Massachusetts, May 12-16, 1997.

A method is presented which accurately predicts the reflected luminance from a flat panel display from known lighting conditions using the bidirectional reflection distribution function (BRDF) of the display. The BRDF reflection model employed separates the reflection into three components; diffuse (lambertian), specular, and haze. Calculated values for the reflected luminances are compared to measured values for several lighting conditions with good agreement. Attempts to parameterize the BRDF of a flat panel display are discussed.
[Contact: Edward F. Kelley, (301) 975-3842]

ADDITIONAL INFORMATION

Announcements

Yaney, D.S., and Settle-Raskin, A.D., **National Semiconductor Metrology Program, Project Portfolio, FY 1996**, NISTIR 5851 (June 1996).

The National Semiconductor Metrology Program (NSMP) is a NIST-wide effort designed to meet the highest priority measurement needs of the semiconductor industry as expressed by the *National Technology Roadmap for Semiconductors* and other authoritative industry sources. The NSMP was established in 1994 with a strong focus on mainstream silicon CMOS technology and an ultimate funding goal of $25 million annually. Current annual funding of approximately $11 million supports the 23 internal projects which are summarized in this Project Portfolio booklet.

The NSMP is operated by NIST's Office of Microelectronics Programs, which also manages NIST's relationships with the Semiconductor Industry Association (SIA), SEMATECH, and the Semiconductor Research Corporation. These include NIST's memberships on the SIA committees that develop the *Roadmap* and numerous SRC technical management committees. In addition, NIST is active in the semiconductor standards development activities of ASTM, Deutsches Institut für Normung, Electronic Industries Association, International Organization for Standardization, and Semiconductor Equipment and Materials International. <http://www.eeel.nist.gov/omp>
[Contact: Alice D. Settle-Raskin, (301) 975-4400]

Lists of Publications

Bradford, A.G., **Metrology for Electromagnetic Technology: A Bibliography of NIST Publications**, NISTIR 5051 (September 1996).

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

bibliography to this publication is NISTIR 5052.
[Contact: Ann G. Bradford, (303) 497-3678]

Lyons, R.M., **A Bibliography of the NIST Electromagnetic Fields Division Publications**, NISTIR 5050 (August 1996).

This bibliography lists the publications by the staff of the National Institute of Standards and Technology's Electromagnetic Fields Division for the period January 1970 through July 1996. It supersedes NISTIR 5039 which listed the publications of the Electromagnetic Fields Division from January 1970 through July 1995. Selected earlier publications from the Division's predecessor organizations are included.
[Contact: Ruth Marie Lyons, (303) 497-3132]

Schmeit, R.A., **Electrical and Electronic Metrology: A Bibliography of NIST Electricity Division's Publications, NIST List of Publication 94** (March 1997).

This bibliography covers publications of the Electricity Division (and predecessor organizational units), Electronics and Electrical Engineering Laboratory, National Institute of Standards and Technology, for the period of January 1968 through December 1996. A brief description of the Division's technical program is given in the introduction.
[Contact: Ruth A. Schmeit, (301) 975-2401]

Smith, A.J., **A Bibliography of Publications of the NIST Optoelectronics Division**, NISTIR 5052 (September 1996).

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

Walters, E.J., **NIST List of Publications 103, National Semiconductor Metrology Program and the Semiconductor Electronics Division, 1990-1996**. (March 1997).

This List of Publications includes all papers relevant to semiconductor technology published by NIST staff, including work of the National Semiconductor Metrology Program and the Semiconductor Electronics Division, and other parts of NIST having independent interests in semiconductor metrology. Bibliographic information is provided for publications from 1990 through 1996. Indices by topic area and by author are provided. Earlier reports of work performed by the Semiconductor Electronics Division (and its predecessor divisions) during the period from 1962 through December 1989 are provided in NIST List of Publications 72.
[Contact: E. Jane Walters, (301) 975-2050]

1997-1998 Calendar of Events

July 14-16, 1997 (San Francisco, California)

SEMICON West 97, Moscone Center. The NIST National Semiconductor Metrology Program will continue its government-industry liaison support role by exhibiting at SEMICON West in 1997. NIST personnel has provided expertise on semiconductor-related issues to industry, government agencies, and academia at SEMICON West for 27 years.

Due to tremendous industry growth and exhibitors' need for more space, SEMICON West is expanding to San Jose. Wafer Processing (process equipment, chemicals, gases, gas handling equipment, and clean room and materials) exhibits are at the Moscone Center, July 14-16. Test Assembly and Packaging exhibits are at San Jose Convention Center, July 16-18.

NIST's booth is located in the Gateway Hall, Booth 3706, Moscone Center. Please stop by and see us!
[Contact: Alice Settle-Raskin, (301) 975-4400]

July 24, 1997 (Gaithersburg, Maryland)

Ion Implant Users Group Meeting. One of the topics to be discussed will be Charging, Charging Damage and Test Structures. Additional topics will be announced at a later date.
[Contact: John Albers, (301) 975-2075]

August 12-15, 1997 (Boulder, Colorado)

Laser Measurements Short Course. Co-sponsored by NIST and University of Colorado, the course will provide training on laser management 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 16, 1997 (Austin, Texas)

Ion Implant Users Group Meeting. The meeting is in conjunction with SEMICON SW95. This meeting provides a forum for the informal exchange of information and ideas of ion-implant related issues, their future trends and applications. This year's meeting, "Opportunities and Challenges in Ion Implantation," is organized by the Ion Implant Users Group (East Coast), the Greater Silicon Valley Implant Users Group and the Greater Southwest Implant/RTP Users Group. The topics for this meeting will be Nitrogen Implants for Defect Engineering, High-Dose Hydrogen Implants for SOI Applications, the Use of Indium and Antimony as Alternatives to Boron, Phosphorus for Shallow-Junction Formation, Trends in Ultra-Low Energy Implantation, High-Energy Implantation, and other relevant topics.
[Contact: John Albers, (301) 975-2075]

October 30-31, 1997 (Gaithersburg, Maryland)

Workshop on Thin Dielectric Films. The Semiconductor Electronics Division of NIST will be conducting a two-day workshop on thin dielectric film metrology. This workshop will include invited speakers and discussion groups focused on issues pertinent to the setup and calibration for optical metrology tools (primarily ellipsometers and reflectometers), the use of standards, traceability of standards to NIST, and ways to address related evolving industry requirements for thin dielectric films. This workshop will be particularly beneficial for manufacturers of such optical metrology tools, those in integrated circuit manufacturers' calibration laboratories, and those involved with NIST-traceable or secondary thin dielectric film standards. The workshop will conclude with a round-table discussion of closely related issues such as metrology for developing thin-gate dielectrics, the relationship between optical, electrical, and other film characterization techniques, and what the projected necessary standards are for developing technologies.
[Contact: Barbara J. Belzer, (301) 975-2248]

November 4-7, 1997 (Shanghai, China)

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

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

Fourteenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM) 1998. Co-sponsored by NIST and IEEE, the symposium will present papers on current thermal management, modeling and measurement work on electronic components and systems in the following areas: thermal characterization - component through system; analytical and computational modeling and simulation; experimental methods and applications; thermal design and testing for reliability; and thermal aspects of high temperature electronics.
[Contact: David L. Blackburn, (301) 975-2068]

March 23-27, 1998 (Gaithersburg, Maryland)

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

The Workshop provides a forum to present and discuss critical issues; problems and limits; evolving requirements and analysis needs; future directions; and key measurement principles, capabilities, applications, and limitations. It will be comprised of

formal invited presentation sessions and poster sessions for contributed papers. This Workshop is the second in a series. The first was held at NIST January 30 to February 2, 1995. Papers from that Workshop were published in *Semiconductor Characterization: Present Status and Future Needs* (AIP Press, New York, 1996), W. M. Bullis, D. G. Seiler, and A. C. Diebold, editors. This Workshop is sponsored by NIST, SEMATECH, Semiconductor Research Corporation, and American Vacuum Society - Manufacturing Science and Technology Group.
[Contact: David G. Seiler, (301) 975-2074]

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NIST SILICON RESISTIVITY SRMs

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

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

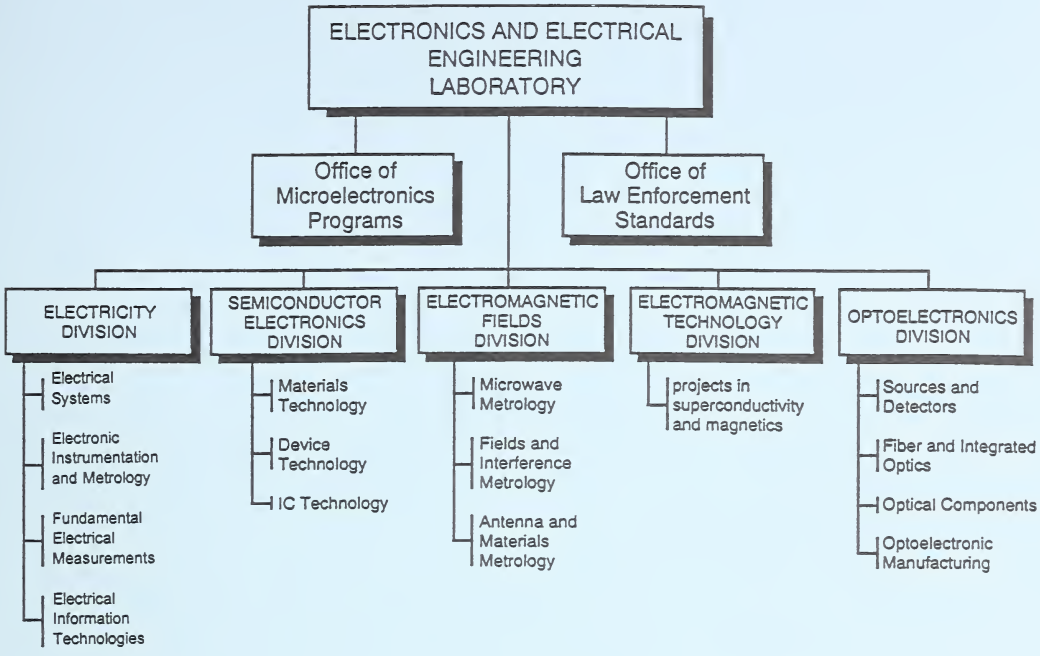
Technical insights presented by the rigorous certification process are available in NIST Special Publication 260-131, *Standard Reference Materials: The Certification of 100 mm Diameter Silicon Resistivity SRMs 2541 through 2547 Using Dual-Configuration Four-Point Probe Measurements.* Individual data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

NIST SILICON BULK RESISTIVITY STANDARD REFERENCE MATERIALS

DATE UPDATED: 30 JUNE 1997

NOMINAL RESISTIVITY (ohm·cm)	NEW SRMs	AVAILABILITY
0.01	2544	8/1/97
0.1	2542	8/15/97
1	2543	To be announced
10	2544	To be announced
25	2545	8/1/97
100	2546	9/2/97
200	2547	8/15/97

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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