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Electronics and Electrical Engineering Laboratory

J. M. Rohrbaugh
Compiler

Technical Progress Bulletin

96-4

Covering Laboratory Programs,
October to December 1996,
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

April 1997

96-4

U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary
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ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY
TECHNICAL PROGRESS BULLETIN, APRIL 1997 ISSUE

INTRODUCTION

This is the fifty-sixth issue of a publication providing information on the technical work of the National Institute of Standards and Technology Electronics and Electrical Engineering Laboratory (EEEL). This issue of the EEEL Technical Progress Bulletin covers the fourth quarter of calendar year 1996.

Organization of Bulletin: This issue contains abstracts for all relevant papers released for publication by NIST in the quarter and citations and abstracts for such papers published in the quarter. Entries are arranged by technical topic as identified in the Table of Contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication." This does not imply acceptance by any outside organization. Papers published in the quarter appear under the subheading "Recently Published." Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Laboratory conferences and workshops planned for calendar 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 and the Electromagnetic Technology Divisions, and the Optoelectronics Division in Boulder, Colo. The Office of Law Enforcement Standards conducts research and provides technical services to the U.S. Department of Justice and State and local governments, and other agencies in support of law enforcement activities. In addition, the Office of Microelectronics Programs (OMP) coordinates the growing number of semiconductor-related research activities at NIST. Reports of 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 28.

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 26.

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 ***Measurements for Competitiveness in Electronics*** and ***EEEL 1995 Technical Accomplishments, Advancing Metrology for Electrotechnology to Support the U.S. Economy***. The first presents selected technical accomplishments of the Laboratory for the period October 1, 1994 through September 30, 1995. A brief indication of the nature of the technical achievement and the rationale for its undertaking are given for each example. The second identifies measurement needs for a number of technical areas and the general importance of measurements to competitiveness issues. The findings of each chapter dealing with an individual industry have been reviewed by members of that industry. A longer description of both documents follows:

EEEL 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.

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

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FUNDAMENTAL ELECTRICAL MEASUREMENTS

Released for Publication

Cage, M.E., and Jeffery, A.-M., **Intrinsic Capacitances and Inductances of Quantum Hall Effect Devices**, to be published in the Journal of Research of the National Institute of Standards and Technology.

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]

Jeffery, A.-M., **Obtaining the Unit of Capacitance from the Calculable Capacitor at the National Institute of Standards and Technology**, to be published in the Proceedings of the 1997 National Conference of Standards Laboratories Workshop and Symposium, Atlanta, Georgia, July 27-31, 1997.

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

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

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

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Recently Published

Keller, M.W., Martinis, J.M., Zimmerman, N.M., and Steinbach, A.H., **Accuracy of Electron Counting Using a 7-Junction Electron Pump**, Applied Physics Letters, Vol. 69, No. 12, pp. 1804-1806 (16 September 1996).

We have operated a 7-junction electron pump as an electron counter with an error per pumped electron of 15 parts in 10^9 and an average hold time of 600 s. The accuracy and hold time are sufficient to enable a new fundamental standard of capacitance. We compare the measured accuracy of the pump as a function of pumping speed and temperature

with theoretical predictions based on a model which includes stray capacitance.
[Contact: John M. Martinis, (303) 497-3597]

SEMICONDUCTOR MICROELECTRONICS

Silicon Materials

Recently Published

Kim, J.S., Seiler, D.G., and Ehrstein, J.R., **Determination of Densities and Mobilities of Heavy and Light Holes in P-Type Si Using Reduced-Conductivity-Tensor Analyses of Magnetic-Field Dependent Hall and Resistivity Measurements**, Journal of Applied Physics, Vol. 80, No. 8, pp. 4425-4428 (15 October 1996).

The densities and mobilities of the individual heavy- and light-hole carriers have been simultaneously determined at various temperatures (40 K to 130 K) in three p-type, single-crystal Si samples. The separation of the two-hole components is achieved by multicarrier analyses of magnetic-field-dependent Hall and resistivity measurements within the two-carrier approximation of the reduced-conductivity-tensor scheme. The explicit experimental values for the densities and mobilities of the two-hole components obtained in this work should be considered as a valuable addition to the existing database for silicon material parameters. They should also be useful to silicon device physics and modeling.
[Contact: Jin S. Kim, (301) 975-2238]

Krska, J.-H. Y., Yoon, J.U., Nee, J.T., Roitman, P., Campisi, G.J., Brown, G.A., and Chung, J.E., **A Model for SIMOX Buried-Oxide High-Field Conduction**, IEEE Transactions on Electron Devices, Vol. 43, No. 11, pp. 1956-1964 (November 1996).

[See Device Physics and Modeling.]

Compound Materials

Recently Published

Bennett, H.S., **Majority and Minority Electron and Hole Mobilities in Heavily Doped Gallium Aluminum Arsenide**, Journal of Applied Physics, Vol. 80, No. 7, pp. 3844-3853 (1 October 1996).

[See Device Physics and Modeling.]

Analysis and Characterization Techniques

Released for Publication

Aust, J.A., Steiner, B., Sanford, N.A., Fogarty, G., Yang, B., Roshko, A., Amin, J., and Evans, C., **Examination of Domain-Reversed Layers in Z-Cut LiNbO Using Maker Fringe Analysis, Atomic Force Microscopy, and High-Resolution X-Ray Diffraction Imaging**, to be published in the Proceedings of the 1997 Conference on Lasers and Electro-Optics, Baltimore, Maryland, May 18-23, 1997.

[See **OPTOELECTRONICS**.]

Kopanski, J.J., Marchiando, J.F., and Alvis, R., **Practical Metrology Aspects of Scanning Capacitance Microscopy for Silicon 2-D Dopant Profiling**, to be published in the Proceedings of the Electrochemical Society Spring 1997 Meeting, Montreal, Canada, May 4-9, 1997.

A scanning capacitance microscope (SCM) acquires images of differential capacitance by either maintaining constant-voltage change, dV, or constant-capacitance change, dC, while simultaneously acquiring a topographic image with an atomic force microscope. When applied to prepared cross sections of silicon transistors, SCM images are acquired with contrast related to the two-dimensional (2-D) dopant distribution in the transistor. To convert SCM raw data to quantitative 2-D dopant profiles, the SCM's operating parameters must be selected to be in the regime that results in data that can be related simply to a model of the measurement. In this regime, SCM images can be converted to dopant profiles using a formalism that is both fast and accurate.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Device Physics and Modeling

Released for Publication

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, to be published in the Proceedings of the Thirteenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium - SEMITHERM XIII, Austin, Texas, January 28-30, 1997.

A methodology is proposed for the validation of compact thermal models of electronic packages which utilizes data and simulations obtained from a simple but realistic system containing the package. The test system is the enclosure specified by the JEDEC JC15.1 Subcommittee for thermal measurements in a natural-convection environment. Simulations for a detailed model and several different compact models for a 88-pin PQFP 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]

Device Physics and Modeling

Recently Published

Bennett, H.S., **Majority and Minority Electron and Hole Mobilities in Heavily Doped Gallium Aluminum Arsenide**, Journal of Applied Physics, Vol. 80, No. 7, pp. 3844-3853 (1 October 1996).

The majority electron and minority hole mobilities have been calculated in $Ga_{1-y}Al_yAs$ for donor densities between 10^{16} cm^{-3} and 10^{19} cm^{-3}. Similarly, the majority hole and minority electron mobilities have been calculated for acceptor densities between 10^{16} and 10^{20} cm^{-3}. The mole fraction of AlAs, *y*, varies between 0.0 and 0.3 in these calculations. All the important scattering mechanisms have been included. The ionized impurity and carrier-carrier scattering processes were treated with a quantum-mechanical, phase-shift analysis. These calculations are the first to use a phase-shift analysis for minority carriers scattering from majority carriers in ternary compounds such as $Ga_{1-y}Al_yAs$. The results are in good agreement with experiment for majority mobilities and predict that at high-dopant densities, minority mobilities should increase with increasing dopant density for a short range of densities. This effect occurs because of the reduction of plasmon scattering and the removal of carriers from carrier-carrier scattering because of the Pauli exclusion principle. These calculations do not treat the density-of-state modifications due to heavy doping, which should have only a small effect on the mobility at room temperature. The results are important for device modeling because of the need to have physically reasonable values for minority mobilities when simulating the electrical behavior of heterojunction bipolar transistors.
[Contact: Herbert S. Bennett, (301) 975-2079]

Bennett, H.S., **Report on the International Conference on Simulation of Semiconductor Processes and Devices**, [On-Line] Available: <<http://tcad.stanford.edu/tcad-journal/reports/sispad96.html>>

The International Conference on Simulation of Semiconductor Processes and Devices (SISPAD) provided an open forum for presentations of the latest results and trends in process and device simulation. The number of registered attendees set a record with over 212 attendees. This SISPAD96 was the first unified conference from the three preceding conferences, namely, the International Workshop on Numerical Modeling of Processes and Devices (NUPAD), the International Workshop on VLSI Process and Device Modeling (VPAD); and the International Conference on Simulation of Semiconductor Devices and Processes (SISDEP), which had been held in the U.S., Japan, and Europe, respectively. SISPAD is now the leading forum for Technology for Computer-Assisted Design (TCAD). The strong international nature of SISPAD96 was reflected in its program of seven invited papers, 46 accepted papers for oral presentations, and 29 poster papers. Authors from 20 countries had submitted 126 papers for consideration by the SISPAD96 Program Committee. Of the papers, 26 were from the U.S.,

14 from Japan, and the remainder from Austria, Belgium, France, Germany, Italy, Korea, Russia, Switzerland, Taiwan, and the United Kingdom. The conference had eight sessions on the following topics: Transport Models, Process Modeling, Impurity Modeling, Future Device Models, Advanced Silicon Device Models, Equipment and Topography Modeling, TCAD Applications, and Mesh Generation and Circuit Models. New topics were added. They included equipment modeling, new measurement techniques, and the use of the INTERNET for electronic publications and for remote collaborations. The Proceedings of this conference (ISBN Number 0-7803-2745-4) are available upon request and may be purchased from either the Business Center for Academic Societies Japan or the IEEE Service Center Single Publications Sales Unit.
[Contact: Herbert S. Bennett, (301) 975-2079]

Kim, J.S., Seiler, D.G., and Ehrstein, J.R., **Determination of Densities and Mobilities of Heavy and Light Holes in P-Type Si Using Reduced-Conductivity-Tensor Analyses of Magnetic-Field Dependent Hall and Resistivity Measurements**, Journal of Applied Physics, Vol. 80, No. 8, pp. 4425-4428 (15 October 1996).

[See Silicon Materials.]

Krska, J.-H. Y., Yoon, J.U., Nee, J.T., Roitman, P., Campisi, G.J., Brown, G.A., and Chung, J.E., **A Model for SIMOX Buried-Oxide High-Field Conduction**, IEEE Transactions on Electron Devices, Vol. 43, No. 11, pp. 1956-1964 (November 1996).

A new model for SIMOX buried-oxide (BOX) high-field conduction which incorporates the role of silicon islands and BOX nonstoichiometry is presented. For single-implant SIMOX BOX high-field conduction, the onset E-field for both positive and negative applied bias is much lower than the expected onset E-field for that of thermal oxide. In addition, the onset E-field for injection from the substrate is lower than for injection from the top-silicon.

We propose that conduction by electron injection from the top interface is due to Fowler-Nordheim tunneling with oxide-nonstoichiometry-induced modification of the effective barrier height. Conduction by electron injection from the bottom interface is due to a two-step Fowler-Nordheim tunneling mechanism with cathode E-field enhancement caused by the presence of silicon islands located near the oxide-substrate interface of single-implant SIMOX. These mechanisms were verified using numerical simulation, electrical, and physical measurements.

A modified Fowler-Nordheim equation can be used to model BOX conduction through the addition of three parameters, k_c, K_α, and ϕ_{BOX}. The E-field enhancement factors (k_c and k_α) can be directly correlated to silicon island shape, location and density, while the effective barrier-height (ϕ_{BOX}) can be correlated to BOX nonstoichiometry. Monitoring these parameters has potential use as a simple method for SIMOX BOX quality control.
[Contact: Peter Roitman, (301) 975-2077]

Marchiando, J.F., **On Calculating the Reflectance and Transmittance of Light for a Simple Thick Grating Structure**, Journal of Modern Optics, Vol. 43, No. 12, pp. 2493-2501 (1996).

This paper presents a formulation for calculating the reflectance and transmittance of classical light for a simple structure that contains a rectangularly shaped line grating layer that lies atop a thick transparent or weakly absorbing substrate layer. It is assumed that the substrate thickness is sufficiently large and non-uniform that when the light traverses it is averaged over a large surface area, the averaged field is considered as losing phase coherence and intensities can be added. It is assumed that the optical properties of the media in the various homogeneous regions of the structure are complex, local, linear, isotropic, and non-magnetic. This kind of structure has important applications in the metrology of linewidths for the semiconductor integrated circuit industry.
[Contact: Jay F. Marchiando, (301) 975-2088]

Dimensional Metrology

Recently Published

Allen, R.A., and Marshall, J.C., **Critical Dimension Metrology for MEMS Processes Using Electrical Techniques**, Proceedings of the SPIE

(The International Society for Optical Engineering), Microlithography and Metrology in Micromachining II, Vol. 2880, pp. 152-157 (1996).

Electrical critical dimension (ECD) test structures have been adapted for use in a surface micromachining environment and fabricated alongside various MicroElectroMechanical Systems (MEMS) structures. These freestanding ECD test structures, which are exposed to air on all surfaces (that is, no encompassing oxide), provide the ability to measure two key metrological process parameters, sheet resistance and feature width that can affect the threshold at which released fixed-fixed beam MEMS structures experience deflection due to residual compression strain.
[Contact: Richard A. Allen, (301) 975-5026]

Microfabrication Technology

Released for Publication

Knopp, K.J., Ketterl, J.R., Christensen, D.H., Pearsall, T.P., and Hill, J.R., **Simultaneous Monitoring of Wafer- and Environment-States during Molecular Beam Epitaxy**, to be published in the Proceedings of the Materials Research Society Symposium, Boston, Massachusetts, December 5-8, 1996.

[See **OPTOELECTRONICS**.]

Microfabrication Technology

Recently Published

Allen, R.A., and Marshall, J.C., **Critical Dimension Metrology for MEMS Processes Using Electrical Techniques**, Proceedings of the SPIE (The International Society for Optical Engineering), Microlithography and Metrology in Micromachining II, Vol. 2880, pp. 152-157 (1996).

[See Dimensional Metrology.]

Marshall, J.C., Read, D.T., and Gaitan, M.G., **Analysis of Fixed-Fixed Beam Test Structures**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), 1996 Symposium on Microlithography and Metrology in Micromachining II, Vol. 2880, pp. 46-55 (1996).

This paper presents recent NIST MicroElectroMechanical Systems fixed-fixed beam test structure data and analysis. These test structures show the most promise in measuring the compressive strain due to simplicity of the test structure design, simplicity of test and analysis, ability to isolate compressive strain values as a function of geometry, and most importantly, capability to record process variability data.
[Contact: Janet C. Marshall, (301) 975-2049]

Milanović, V., Gaitan, M., Bowen, E.D., and Zaghloul, M.E., **Micromachined Coplanar Waveguides in CMOS Technology**, IEEE Microwave and Guided Wave Letters, Vol. 6, No. 10, pp. 380-382 (October 1996).

Coplanar waveguides were fabricated in standard complementary metal-oxide semiconductor with post-processing micromachining. ICs were designed with commercial CAD tools, fabricated through the MOSIS service, and subsequently suspended by maskless top-side etching. Absence of the lossy silicon substrate after etching results in significantly improved insertion loss characteristics, dispersion characteristics, and phase velocity. Measurements were performed at frequencies from 1 to 40 GHz, before and after micromachining. These show improvement in loss characteristics of orders of magnitude. For the micromachined line, loss does not exceed 4 dB/cm. Before etching, loss as high as 38 dB/cm is measured. Phase velocity $v_p \approx 0.8 \cdot c$ is achieved for the micromachined line.
[Contact: Michael Gaitan, (301) 975-2070]

Milanović, V., Gaitan, M., Marshall, J.C., and Zaghloul, M.E., **CMOS Foundry Implementation of Schottky Diodes for RF Detection**, IEEE Transactions on Electron Devices, Vol. 43, No. 12, pp. 2210-2214 (December 1996).

Schottky diodes for rf power measurement were designed and fabricated using a commercial n-well CMOS foundry process through the MOSIS service. The Schottky diodes are implemented by modifying the SCMOS technology file of the public-domain graphics layout editor, MAGIC, or by explicitly implementing the appropriate Caltech Intermediate Form layers. The modifications allow direct contact

of first-layer metal to the low-doped substrate. Current-voltage measurements showed that only the n-type devices had rectifying properties with a barrier height of 0.78 eV. The *I-V* results were verified by performing capacitance-voltage measurements on diodes of different contact-areas. The diodes were tested in an rf detector circuit. The cut-off frequency of the detector was shown to be 600 MHz.
[Contact: Michael Gaitan, (301) 975-2070]

Read, D.T., and Marshall, J.C., **Measurements of Fracture Strength and Young's Modulus of Surface-Micromachined Polysilicon**, Proceedings of the SPIE (The International Society for Optical Engineering), Microlithography and Metrology in Micromachining II, Vol. 2880, pp. 46-55 (1996).

Polycrystalline silicon (polysilicon) is widely used as a mechanical layer in MicroElectroMechanical Systems (MEMS). Mechanical elements within MEMS structures are, by design, microscopic in size. Because the thickness of the polysilicon layer is typically around 2 μm and the width and length of the freed area is a few to hundreds of micrometers, standard techniques and apparatus for measurements of mechanical properties are not applicable. Furthermore, the deposition techniques for polysilicon cannot be adapted to make specimens big enough to test by conventional techniques. Therefore, special structures were designed to facilitate measurements of Young's modulus and fracture strength: cantilever beams and dog-bone tensile specimens. Here, we report first experiences with these structures. These experiences include successes and failures in manipulating and testing the special structures. While no definitive results for either fracture strength or Young's modulus are reported here, some plausible values for both quantities were obtained. Test methods and preliminary results to date are discussed.
[Contact: David T. Read, (303) 497-3853]

Plasma Processing

Recently Published

Rao, M.V.V., Van Brunt, R.J., and Olthoff, J.K., **Resonant Charge Exchange and the Transport of Ions at High Electric-Field to Gas-Density Ratios (*E/N*) in Argon, Neon, and Helium**, Physical Review E, Vol. 54, No. 5, pp. 5641-5656 (November 1996).

Translational kinetic-energy distributions of singly and doubly charged ions have been measured at high electric-field to gas-density ratios (*E/N*) up to 5.0×10^{-17} V m^2 (50 kTd) in diffuse, parallel-plate Townsend discharges in Ar, Ne, and He using an ion energy analyzer-mass spectrometer. For Ar^+ in Ar and Ne^+ in Ne when $E/N < 2.0 \times 10^{-17}$ V m^2, and for He^+ in He when $E/N < 1.0 \times 10^{-17}$ V m^2, the energy distributions are Maxwellian and consistent with predictions based on the assumption that resonant symmetric charge exchange is the dominant ion-neutral-species collision process. At higher *E/N* values, the kinetic-energy distributions for Ar^+, Ne^+, and He^+ show departures from the Maxwellian form that are indicative of deviations from the charge-transfer model. The mean ion energies (effective ion temperatures) are consistent in the low *E/N* range with the available drift-velocity data and in the case of Ar^+ with recent results of Radovanov et al. from Townsend discharge experiments. The charge-exchange cross sections derived from Maxwellian fits to the energy distribution data for Ar^+ + Ar, Ne^+ + Ne, and He^+ + He agree with available data. The relative contributions of the doubly charged ions Ar^{2+}, Ne^{2+}, and He^{2+} to the total ion flux were found to be small (less than 3%) and tend to decrease initially with increasing *E/N*. The mean energies of the doubly charge ions are higher than those for the corresponding singly charged ions, and the results suggest that double charge transfer could be the dominant process affecting the transport of Ar^{2+} and Ne^{2+} for *E/N* below about 1.5×10^{-17} V m^2. The observed He^{2+} kinetic-energy distributions are not consistent with a charge-transfer model.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Packaging

Recently Published

Harman, G.G., **Critical Issues in Wire-Bonded Chip Interconnections to the Year 2001**, Proceedings of the Second International Symposium on Electronic Packaging Technology,

Shanghai, China, December 9-12, 1996, pp. 79-84.

The current and future issues of materials, reliability, and yield of wire bonded interconnections used in microelectronics are described. Many of the critical issues affecting wire bonding over the next five years are discussed. These include the thrust towards fine pitch (towards 70 μm for ball bonding), lack of a quantitative understanding of the ultrasonic bonding mechanism, the use of high frequency for US bondings, new metallizations for bond pads, and the need for high yield and reliability for MCM production.
[Contact: George G. Harman, (301) 975-2097]

Power Devices

Recently Published

Berning, D.W., and Hefner, A.R., **IGBT Half-Bridge Shoot-Through Characterization for Model Validation**, Proceedings of the 1996 IEEE Industry Applications Society Meeting, San Diego, California, October 5-10, 1996, pp. 1491-1499.

A circuit is described for making a variety of measurements on half-bridge Insulated Gate Bipolar Transistor (IGBT) pairs for validating IGBT models. The circuit incorporates two robust isolated gate drives for the IGBTs. Each IGBT is driven with an eight-cycle square-wave burst with a long dead-time between bursts so that heat-sinking requirements are greatly reduced. The circuit incorporates a delay for one of the gate drives so that a variable amount of gate overlap or dead-time can be obtained. Switching events are studied that contain intervals where one IGBT is turned on before the other is turned off, as well as intervals where one is turned off before the other is turned on. The former situation applies to shoot-through faults and also emulates IGBT turn-on with diode recovery, while the latter situation represents desirable transition of current between devices. Results are related to suggested model validation procedures.
[Contact: David W. Berning, (301) 975-2069]

Photodetectors

Released for Publication

Lehman, J.H., and Aust, J.A., **A Bi-Cell Pyroelectric Detector Made from a Single $LiNbO_3$ Domain-Reversed Electret**.

[See **OPTOELECTRONICS**.]

Photodetectors

Recently Published

Berkowitz, S.J., Hirahara, A.S., Char, K., and Grossman, E.N., **Low Noise High-Temperature Superconducting Bolometers for Infrared Imaging**, Applied Physics Letters, Vol. 69, No. 14, pp. 2125-2127 (30 September 1996).

[See Cryoelectronic Metrology.]

Hale, P.D., Wang, C.M., Park, R., and Lau, W.I., **A Transfer Standard for Measuring Photoreceiver Frequency Response**, Journal of Lightwave Technology, Vol. 14, No. 11, pp. 2457-2466 (November 1996).

[See **OPTOELECTRONICS**.]

Park, R., and Hale, P.D., **Frequency Response Measurement of Digital Communications Analyzer Plug-In Modules**, Hewlett-Packard Journal, Vol. 47, No. 6, pp. 37-40 (December 1996).

[See **OPTOELECTRONICS**.]

Reliability

Recently Published

Suehle, J.S., and Chaparala, P., **Characterization of Time-Dependent Dielectric Breakdown in Intrinsic Thin SiO_2**.

Time-dependent dielectric breakdown data collected from 6.5, 9, 15, 20, and 22.5 nm thick SiO_2 films are presented. The failure distributions are of single mode with no apparent extrinsic population. The logarithm of the median-test-time-to-failure, $\log(t_{50})$, is described by a linear electric field dependence. Contrary to reports in earlier studies, the field acceleration parameter is observed to be insensitive to temperature and has a value of approximately

1.0 decade MV^{-1} cm^{-1} for the range of oxide thicknesses studied. Capacitance-voltage studies indicate that there is no strong correlation between oxide-trapped charges and time-to-failure under constant voltage stress conditions.
[Contact: John S. Suehle, (301) 975-2247]

SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

DC and Low-Frequency Metrology

Released for Publication

Kinard, J.R., Lipe, T.E., and Childers, C.B., **Extension of the NIST AC-DC Difference Calibration Service for Current to 100 kHz**, to be published in the Journal of Research of the National Institute of Standards and Technology.

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

DC and Low-Frequency Metrology

Recently Published

Chang, Y.M., **NIST Measurement Assurance Program for Capacitance Standards at 1 kHz**, NIST Technical Note 1417 (March 1996).

This document describes the capacitance Measurement Assurance Program (MAP) service at the National Institute of Standards and Technology. This service, which uses a commercial digital capacitance meter as the transport standard, provides calibration for capacitance standards at both the 1000 pF and 100 pF levels, at a frequency of 1 kHz. In contrast to the typical MAP where the transport standards are measured by the client laboratory, the capacitance MAP involves measurements performed on "dummy" standards by both the Meter (1 kHz digital capacitance meter used as the transport standard) and the laboratory capacitance measuring system. Measurement procedures and requirements for client laboratories are included. Also presented are error analysis, assigned values, and equations to estimate the combined uncertainties of the assigned values.
[Contact: Y. May Chang, (301) 975-4237]

Lipe, T.E., **A Reevaluation of the NIST Low-Frequency Standards for AC-DC Difference in the Voltage Range 0.6-100 V**, IEEE Transactions on Instrumentation and Measurement, Vol. 45, No. 6, pp. 913-917 (December 1996).

A reevaluation of the NIST standards of ac-dc difference was undertaken in an effort to reduce the calibration uncertainty offered by NIST for thermal voltage converters at frequencies below 100 Hz. This paper describes the measurements taken in support of this effort, as well as the devices used for the reevaluation process and the analysis of the uncertainty of the measurements. This reevaluation of the NIST low-frequency standards will permit a significant reduction in uncertainty for ac-dc difference calibrations at 10 Hz in the voltage range from 0.6 V to 100 V.
[Contact: Thomas E. Lipe, (301) 975-4151]

Stenbakken, G.N., and Dolev, A., **NIST High Accuracy Sampling Wattmeter**, NIST Technical Note 1420 (August 1996).

A high-accuracy sampling wattmeter was developed at the National Institute of Standards and Technology (NIST) to investigate the feasibility of using waveform sampling techniques for making very accurate power measurements at frequencies from 50 Hz to 1000 Hz. The goal of this effort was to develop an instrument having a full scale

measurement uncertainty over these frequencies of less than ±50 μW/W. The prototype instrument that came out of the development was used to demonstrate the accuracy achievable with the digital sampling method. The new high-accuracy sampling wattmeter was built around a wideband instrument developed earlier at NIST. The new wattmeter uses 16-bit analog-to-digital (A/D) converters and includes a two-stage current transformer in one of the input modules. This wattmeter operates with asynchronous sampling as did the previous wattmeter. The high accuracy is achieved by approximately synchronizing the interval over which samples are taken with the period of the input signal. Special care was taken to design input stages with a flat-frequency response and low-temperature sensitivity. The wattmeter has been calibrated using the NIST Audio-Frequency Power Bridge. The two instruments agreed to better than ±50 μW/W, of full scale, over the 50 Hz to 1000 Hz frequency range at all power factors.
[Contact: Gerard N. Stenbakken, (301) 975-2440]

Waveform Metrology

Released for Publication

Paulter, N.G., **Low Jitter Trigger System for Pulse Calibration and Intercomparison of High-Speed Samplers**.

A low jitter (<1 ps) trigger system for pulse-waveform-based calibration and intercomparison for high-speed samplers is described. The system uses a commercially available pulse generator and pulse splitter/delay line.
[Contact: Nicholas G. Paulter, (301) 975-2405]

Waveform Metrology

Recently Published

Paulter, N.G., **Selecting a Short-Pulse Laser System for Photoconductive Generation of High-Speed Electrical Pulses**, Optical Engineering, Vol. 35, pp. 3296-3300 (November 1996).

The selection of a short-pulse laser is important in electrical pulse metrology applications where the electrical pulses are generated photoconductively. Not only is the duration of the generated electrical pulse important, but so is the peak amplitude of that pulse. Insufficient pulse amplitude may cause excessive uncertainty in measurement results. An approximation is presented that can provide guidelines to selecting the optimal short-pulse laser according to photoconductor, laser and measurement system characteristics.
[Contact: Nicholas G. Paulter, (301) 975-2405]

Cryoelectronic Metrology

Released for Publication

Roshko, A., Stork, F.J.B., Rudman, D.A., Aldrich, D.J., and Morris-Hotsenpiller, P.A., **Comparison of Heteroepitaxial $YBa_2Cu_3O_{7-\delta}$ and TiO_2 Thin Film Growth**.

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

Stork, F.J.B., Beall, J.A., Roshko, A., DeGroot, D.C., Rudman, D.A., Ono, R.H., and Krupka, J., **Surface Resistance and Morphology of YBCO Films as a Function of Thickness**.

[See Superconductors.]

Vale, L.R., Ono, R.H., and Rudman, D.A.,

$YBa_2Cu_3O_{7-\delta}$ Josephson Junctions on Bicrystal Al_2O_3 and $SrTiO_3$ Substrates.

Bicrystal grain-boundary junctions (bi-GBJs) have been reproducibly fabricated on $SrTiO_3$ (STO) and r-plane Al_2O_3 (sapphire) bicrystal substrates. Sapphire bicrystals are candidates for high-frequency applications due to their low dielectric constant and loss tangent. The sapphire bi-GBJs demonstrated resistively shunted junction (RSJ)-like current-voltage characteristics, with junction parameters comparable to the STO bi-GBJs and critical-current densities $J_c \sim 10^5$ A/cm^2. Independent control of junction resistance (R_N) was demonstrated with the use of Au shunt layers. In addition, overlayers such as Au or STO may act to passivate the GBJs and improve long-term stability. [Contact: Ronald H. Ono, (303) 497-3762]

Cryoelectronic Metrology

Recently Published

Berkowitz, S.J., Hirahara, A.S., Char, K., and Grossman, E.N., **Low Noise High-Temperature Superconducting Bolometers for Infrared Imaging**, Applied Physics Letters, Vol. 69, No. 14, pp. 2125-2127 (30 September 1996).

High-temperature superconducting bolometric infrared detectors offer the promise of matching the sensitivity of HgCdTe detectors, but with an extended detection range to longer wavelengths (λ > 15 μm). We fabricated high-temperature superconducting bolometers using an all-epitaxial micromachining technology based upon a $YBa_2Cu_3O_x$ thin film on a yttria-stabilized zirconia free standing 50 x 50 μm^2 membrane supported on a $LaAlO_3$ substrate. This structure has simultaneously a low thermal conductance and a low heat capacity. Using this technology, we have made array-compatible pixels for infrared camera applications with optical noise equivalent powers as low as 6.3 x 10^{-13} W/$\sqrt{\text{Hz}}$ at 32 Hz. Over more than 1 octave of frequency range, these bolometers are limited by fundamental (chiefly phonon) noise sources rather than excess film noise.
[Contact: Eric N. Grossman, (303) 497-5102]

Castellano, M.G., Torrioli, G., Cosmelli, C., Costantini, A., Chiarello, F., Carelli, P., Rotoli, G., Cirillo, M., and Kautz, R.L., **Thermally Activated Escape from the Zero-Voltage State in Long Josephson Junctions**, Physical Review B., Vol. 54, No. 21, pp. 15 417-15 428 (1 December 1996).

We have measured the rate of thermally induced escape from the zero-voltage state in long Josephson junctions of both overlap and in-line geometry as a function of applied magnetic field. The statistical distribution of switching currents is used to evaluate the escape rate and derive an activation energy ΔU for the process. Because long junctions correspond to the continuum limit of multidimensional systems, ΔU is in principle the difference in energy between stationary states in an infinite-dimensional potential. We obtain good agreement between calculated and measured activation energies for junctions with lengths a few times the Josephson penetration depth λ_J.
[Contact: Richard L. Kautz, (303) 497-3391]

Antenna Metrology

Released for Publication

Masterson, K.D., Novotny, D.R., and Cavcey, K.H., **Standard Antennas Designed with Electrooptic Modulators and Optical-Fiber Linkage**, to be published in the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), 1996 Symposium on Intense Microwave Pulses IV, Denver, Colorado, August 4-9, 1996.

We described the design of standard reference antennas that utilizes an electro-optic transducer together with optical-fiber linkage to preserve the amplitude and phase information of the received signal. They will be used over a range from 10 MHz to 2 GHz at our open area test site in order to reduce measurement uncertainties attributable to the ambient electromagnetic spectrum. The transducer consists of an optical-fiber directional coupler with unbalanced legs and $LiNbO_3$ phase environments. The complementary rf signal is modeled to determine the design and operating parameters required for good repeatability and accuracy. The results show that spurious reflections in the modulator legs need to be less than -50 dB in order to obtain the desired stability.

[Contact: Keith D. Masterson, (303) 497-3756]

Muth, L.A., Wittmann, R.C., Kent, B., and Tuttle, J.D., **Radar Cross Section Range Characterization**, to be published in the Proceedings of the Eighteenth Annual Meeting and Symposium of the Antenna Measurement Techniques Association, Seattle, Washington, September 30—October 3, 1996, pp. 267-278.

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 are 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]

Muth, L.A., Wittmann, R.C., and Parnell, W., **Polarimetric Calibration of Nonreciprocal Radar Systems**, Proceedings of the Eighteenth Annual Meeting and Symposium of the Antenna Measurement Techniques Association, Seattle, Washington, September 30—October 3, 1996, pp. 389-383.

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]

Skinner, J.P., Kent, B.M., Wittmann, R.C., Mensa, D.L., and Andersh, D., **Normalization and Interpretation of Radar Images**.

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

Wittmann, R.C., Alpert, B.K., and Francis, M.H., **Near-Field Antenna Measurements Using Nonideal Measurement Locations**.

In this paper, 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]

Antenna Metrology

Recently Published

Guerrieri, J.R., MacReynolds, K., Canales, N., and Tamura, D.T., **Mismatch Errors in Insertion-Loss Measurements Using Harmonic Mixers**, Proceedings of the Eighteenth Annual Meeting and Symposium of the Antenna Measurement

Techniques Association, Seattle, Washington, September 30—October 3, 1996, pp. 377-382.

[See Microwave and Millimeter-Wave Metrology.]

Stubenrauch, C.F., MacReynolds, K., Newell, A.C., Cormack, R.H., Will, J.E., and Norgard, J.D., **Phaseless Measurements of Antenna Near Fields Employing Holographic Phase Retrieval**, Proceedings of the Eighteenth Annual Meeting and Symposium of the Antenna Measurement Techniques Association, Seattle, Washington, September 30—October 3, 1996, pp. 20-24.

We describe a technique which employs amplitude-only measurements of an unknown antenna combined with a synthetic reference wave to produce a hologram of a near-field antenna distribution. The hologram, which may be recorded by amplitude-only receiving equipment, is digitally processed using an enhanced theory which allows complete removal of the spurious images normally encountered with optical hologram reconstruction. The recovered near-field data are then processed using standard algorithms to calculate antenna far-fields. We present the theoretical formulation and results of measurements obtained on an 1.2 m reflector antenna.
[Contact: Carl F. Stubenrauch, (303) 497-3927]

Wittmann, R.C., Alpert, B.K., and Francis, M.H., **Planar Near-Field Antenna Measurements Using Nonideal Measurement Locations**, Proceedings of the Eighteenth Annual Meeting and Symposium of the Antenna Measurement Techniques Association, Seattle, Washington, September 30—October 3, 1996, pp. 74-79.

The standard planar near-field to far-field transformation method requires data points on a plane-rectangular lattice. In this paper, we introduce a transformation algorithm in which measurements are neither required to lie on a regular grid nor are strictly confined to a plane. Computational complexity is $O(N\log N)$, where N is number of data points. (Actual 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 for other measurement approaches, such as plane-polar scanning, where data are collected on a nonrectangular grid.
[Contact: Ronald C. Wittmann, (303) 497-3326]

Wittman, R.C., and Black, D.N., **Antenna/RCS Range Evaluation Using a Spherical Synthetic-Aperture Radar**, Proceedings of the Eighteenth Annual Meeting and Symposium of the Antenna Measurement Techniques Association, Seattle, Washington, September 30—October 3, 1996, pp. 406-410.

We describe an imaging technique which allows the isolation of sources of unwanted radiation on an antenna/RCS 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]

Microwave and Millimeter-Wave Metrology

Released for Publication

Booth, J.C., Beall, J.A., DeGroot, D.C., Rudman, D.A., Ono, R.H., Zhang, K., Hong, S., and Ma, Q.Y., **Microwave Characterization of Coplanar Waveguide Transmission Lines Fabricated by Ion Implantation Patterning of $YBa_2Cu_3O_{7-\delta}$**.

We report on the application of Si and Al ion-implantation patterning to the fabrication of low-loss microwave transmission lines in high-temperature superconductor (HTS) thin films. Using this technique, we have fabricated coplanar waveguide transmission lines in $YBa_2Cu_3O_{7-\delta}$ thin films deposited on $LaAlO_3$ substrates. We have used both resonant and broadband measurements in order to characterize the performance of the resulting transmission line structures. For the broadband measurements, on-wafer calibrations were used to obtain accurate S-parameters and transmission line propagation constants up to 25 GHz. The propagation constants of the ion-implanted transmission lines do not differ significantly from those of lines patterned using conventional ion milling over the frequency range studied, with a value for the attenuation constant of approximately 0.03 to 0.04 dB/cm at 50 K and 10 GHz. The relatively low losses of the ion-implanted devices demonstrate the effectiveness of this method of patterning for HTS microwave device

fabrication.
[Contact: James C. Booth, (303) 497-7900]

Juroshek, J.R., Wang, C.M., McCabe, G.P., **Statistical Analysis of Network Measurements**.

For the past five years, the Automatic radio frequency and Techniques Group has conducted a measurement comparison program for vector network analyzers. Five traveling verification kits have been in circulation for measurement by participating laboratories. The accuracy of those measurements varies substantially, and classical statistical measures such as the mean and standard deviation are significantly distorted by a few participants whose measurements differ significantly from the others. This report describes some robust statistical techniques for analyzing those measurements. The techniques described are based on calculating the deviation from the median, and they are not unduly influenced by outliers or bad data. The performance of each participant is summarized by three numbers: the mean deviation, and the 10th, and 90th percentile deviations.
[Contact: John R. Juroshek, (303) 497-5362]

Marks, R.B., Jargon, J.A., and Juroshek, J.R., **A Vector Network Analyzer Calibration Comparison Method**, to be published in the Proceedings of the 48th Automatic Radio Frequency Techniques Group, Clearwater, Florida, December 5-6, 1996.

In this paper, 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**, to be published in the Proceedings of the 48th Automatic Radio Frequency Techniques Group, Clearwater, Florida, December 5-6, 1996.

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., **Characterization of Embedded Multiconductor Transmission Lines**, to be published in the Proceedings of the 1997 IEEE International Microwave Symposium, Denver, Colorado, June 8-13, 1997.

This paper presents a measurement method that characterizes lossy printed multiconductor transmission lines embedded in transitions, connectors, or packages with significant electrical parasitics. We test the method on a pair of lossy coupled asymmetric microstrip lines and compare to previous results.
[Contact: Dylan F. Williams, (303) 497-3138]

Williams, D.F., **The Measurement and Characterization of Lossy Printed Multiconductor Transmission Lines**.

This paper presents a method that completely characterizes lossy printed multiconductor transmission lines from measurement. It determines not only the matrices of impedances and admittances per unit length describing the transmission line in the conductor representation, but the propagation constants, characteristic impedances, and cross powers for each mode supported in the line. We apply the method to a pair of lossy coupled asymmetric microstrip lines.
[Contact: Dylan F. Williams, (303) 497-3138]

Microwave and Millimeter-Wave Metrology

Recently Published

Guerrieri, J.R., MacReynolds, K., Canales, N., and Tamura, D.T., **Mismatch Errors in Insertion-Loss Measurements Using Harmonic Mixers**, Proceedings of the Eighteenth Annual Meeting and Symposium of the Antenna Measurement Techniques Association, Seattle, Washington, September 30—October 3, 1996, pp. 377-382.

In this paper, we discuss proper rf system design for performing insertion-loss measurements using a microwave receiver and harmonic mixers. Specifically, we deal with problems caused by changing reflection coefficients of the devices which feed the mixer. When broadband mixers and coaxial isolators are used, problems may be caused by the changing load seen by the local oscillator. This is due to local oscillator leakage through the mixer and isolator. We elaborate on this problem, noting its impact on the measurement and suggest a procedure to properly minimize its effect.
[Contact: Jeffrey R. Guerrieri, (303) 497-3863]

Milanović, V., Gaitan, M., Bowen, E.D., and Zaghloul, M.E., **Micromachined Coplanar Waveguides in CMOS Technology**, IEEE Microwave and Guided Wave Letters, Vol. 6, No. 10, pp. 380-382 (October 1996).

[See Microfabrication Technology.]

Milanović, V., Gaitan, M., Marshall, J.C., and Zaghloul, M.E., **CMOS Foundry Implementation of Schottky Diodes for RF Detection**, IEEE Transactions on Electron Devices, Vol. 43, No. 12, pp. 2210-2214 (December 1996).

[See Microfabrication Technology.]

Electromagnetic Properties

Released for Publication

Krupka, J., Derzakowski, K., Abramowicz, A., Ceremuga, J., and Geyer, R.G., **Application of Mode-Matching Technique for Modeling Cylindrical Dielectric Resonators Containing Multilateral Superconducting, Metal, and Dielectric Media**, to be published in the Proceedings of the 2nd European Conference on Numerical Methods in Electromagnetism, Lyon, France, March 19-21, 1997.

Applications of the radial mode-matching technique for computations of resonant frequencies and unloaded Q-factors of dielectric resonators containing multilateral superconducting, metal, and dielectric media are described. This technique permits highly accurate computations of the resonant frequencies and Q-factors of these structures at low computational cost.
[Contact: Robert G. Geyer, (303) 497-5852]

Krupka, J., Derzakowski, K., Abramowicz, A., Tobar, M., and Geyer, R., **Use of Whispering Gallery Modes for Complex Permittivity Determinations of Ultra-Low Loss Dielectric Materials**.

Whispering gallery modes are used for very accurate permittivity, dielectric loss, and temperature coefficient of permittivity measurements of both isotropic and uniaxially anisotropic dielectric materials. The relationship between resonant frequency, dimensions of the resonant structure, and permittivity of the sample under test is calculated with mode-matching techniques. The relative accuracy of these computations is better than 10^{-4}. The influence of conductor losses on dielectric loss tangent determination is treated for both whispering gallery mode and $TE_{01\delta}$ mode dielectric resonator techniques. Two permittivity tensor components of sapphire and their temperature dependence were measured at temperatures from 4.2 K to 300 K. The total uncertainty in permittivity when use is made of whispering gallery modes is estimated to be less than 0.05%. This uncertainty is limited principally by uncertainty in sample dimensions. Experimental and calculated resonant frequencies of several whispering gallery modes differ by no more than 0.01%. The dielectric loss tangent of sapphire parallel and perpendicular to its anisotropy axis was measured to be less than 10^{-9} at 4.2 K. The permittivity and dielectric loss tangent of a commercially available low loss, high permittivity ceramic material has also been measured at S- and C-band frequencies using a large number of whispering gallery modes.
[Contact: Robert G. Geyer, (303) 497-5852]

Lewis, R.L., **Relative Permittivity Measurement of Rectangular Copper-Laminated Substrates Using the Full-Sheet Resonance Technique**.

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]

Electromagnetic Properties

Recently Published

Baker-Jarvis, J.R., and Riddle, B.F., **Dielectric Measurements Using a Reentrant Cavity: Mode-Matching Analysis**, NIST Technical Note 1384 (November 1996).

The coaxial reentrant cavity dielectric measurement technique is examined. A full-mode model for the cavity is developed and solved numerically. Analytical expressions for wall losses are presented. The filing factor due to a partially-filled cavity is discussed. Dielectric results are presented and compare very closely to previous round-robin results.
[Contact: James R. Baker-Jarvis, (303) 497-5621]

Geyer, R.G., and Krupka, J., **Complex Permeability Measurements of Microwave Ferrites**, Proceedings of Materials Research Society Symposium, San Francisco, California, April 7-12, 1996, pp. 257-262.

A rigorous and accurate method for the experimental determination of the complex permeability of demagnetized ferrites at microwave frequencies is presented. The measurement uses low-loss dielectric ring resonators, is nondestructive, and allows complex permeability characterization of a *single* ferrite sample to be performed at frequencies from 2 GHz to 25 GHz. A wide variety of ceramic microwave ferrites having various compositions and differing saturation magnetizations was measured in the demagnetized state. Generally, at any frequency greater than gyromagnetic resonance, the real part of the complex permeability increase as saturation magnetization increases. For the same frequency, magnetic losses increases as saturation magnetization increases. The real permeability results are compared with magnetostatic theoretical predictions. Measurement data show excellent agreement with theoretical predictions, but only when $2\pi\gamma\tau M_s/\omega < 0.75$, where γ is the gyromagnetic ratio, M_s is saturation magnetization, and ω is the radian rf frequency.
[Contact: Richard G. Geyer, (303) 497-5862]

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 (unpaged).

Dielectric properties of microwave circuit-board materials are usually measured with stripline or microstripline resonator techniques. These techniques have two disadvantages. Firstly, 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. Secondly, 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]

OPTOELECTRONICS

Released for Publication

Amin, J., Aust, J.A., and Sanford, N.A., **Z-Propagating Waveguide Lasers in Rare-Earth-Doped Ti:LiNbO$_3$**.

We demonstrate, through judicious choice of waveguide orientation, a means of reproducibly fabricating table cw lasers in rare-earth-doped Ti:LiNbO$_3$. Z-propagating waveguides have been fabricated, for the first time, in Nd- and Er-diffused Ti:LiNbO$_3$, and room-temperature laser operation with greatly reduced photorefractive instability has been obtained. The reduced photorefractive damage susceptibility in this waveguide configuration has led to the realization, for the first time, of a 980 nm-pumped laser in Er:Ti:LiNbO$_3$, with a threshold of 10.5 mW of absorbed pump power and a slope efficiency of 8.5%.
[Contact: Andrew J. Aust, (303) 497-3942]

Amin, J., Veasey, D.L., Sanford, N.A., and Hayden, J.S., **Waveguide Lasers at 1.5 μm in Silicate Glass**.

Waveguide lasers in Er and Er/Yb co-doped silicate glass have been fabricated by silver ion-exchange and their characteristics analyzed. Direct comparisons are made in the lasing properties of these devices. We show that through proper choice of host glass, it is possible to make low-threshold lasers both in singly- and co-doped devices.
[Contact: David L. Veasey, (303) 497-5952]

Aust, J.A., Steiner, B., Sanford, N.A., Fogarty, G., Yang, B., Roshko, A., Amin, J., and Evans, C., **Examination of Domain-Reversed Layers in Z-Cut LiNbO Using Maker Fringe Analysis, Atomic Force Microscopy, and High-Resolution X-Ray Diffraction Imaging**, to be published in the Proceedings of the 1997 Conference on Lasers and Electro-Optics, Baltimore, Maryland, May 18-23, 1997.

Domain-inverted regions on z-cut LiNbO plates were examined using Maker fringe analysis, atomic force microscopy, high-resolution X-ray topography, and optical interferometry. Domain-inverted layers native to the +z faces of the samples were examined in addition to electric-field-poled sections.
[Contact: Andrew J. Aust, (303) 497-3942]

Knopp, K.J., Christensen, D.H., and Hill, J.R., **Vertical-Cavity Surface-Emitting Lasers with Low-Ripple Optical Pumping Windows**.

A general technique for numerically optimizing the optical admittances in vertical-cavity structures is used to suppress the interference ripple in the typical reflectance/transmittance spectra. This technique is applicable to any vertical-cavity device whose photonic properties at various wavelengths require engineering for specific applications. In this paper, we report the use of this optimization method to enhance the coupling of pump light into 850 nm vertical-cavity surface-emitting lasers (VCSELs). We have designed and fabricated novel lasers which contain a wideband window of low reflectance amidst the typical interference fringe spectrum. The 750 nm to 800 nm region for the low-ripple design has an average reflectance of 5%; the peak-to-peak amplitude of the ripple is 0.25%. The sensitivity of these devices to temperature variations and layer-thickness manufacturing variations is also studied. The low-ripple pump window shifts at a rate of 0.036 nm/°C, the peak-to-peak ripple of the reflectance varies less than 2%, and the pump bandwidth remains constant, over temperatures ranging from 0 °C to 100 °C. The low-ripple devices substantially improves the variation of reflectance, and thus, pump-field overlap, with temperature. We present here the design, simulation, growth, characterization, and manufacturing and temperature sensitivity of such optimized non-periodic low-ripple VCSELs.
[Contact: David H. Christensen, (303) 497-3354]

Knopp, K.J., Hill, J.R., Bertness, K.A., Mirin, R.P., and Christensen, D.H., **Optoelectronic Band Engineering of Vertical-Cavity Surface-Emitting Lasers**, to be published in the Proceedings of the 1997 Conference on Lasers and Electro-Optics, Baltimore, Maryland, May 18-23, 1997.

A general method for numerically matching the optical admittances in vertical-cavity surface-emitting lasers (VCSELs) is used to suppress the interference ripple in the typical reflectance/transmittance spectrum. This tailoring of the cavity electric field results in modification of both the one-dimensional photonic band structure and the electric field overlap with the electronic-band absorption of the quantum well active region. We report the design, simulation, growth, characterization, and manufacturing and temperature sensitivity of these non-periodic low-ripple VCSELs. Devices with pump windows on the short wavelength side of the high reflector, as well as devices with transmission windows on the long wavelength side, are considered.
[Contact: James R. Hill, (303) 497-3370]

Knopp, K.J., Ketterl, J.R., Christensen, D.H., Pearsall, T.P., and Hill, J.R., **Simultaneous Monitoring of Wafer- and Environment-States during Molecular Beam Epitaxy**, to be published in the Proceedings of the Materials Research Society Symposium, Boston, Massachusetts, December 5-8, 1996.

We report the simultaneous monitoring of the environment-state and wafer-state during epitaxial crystal growth using a single real-time measurement. Atomic absorption spectroscopy (AAS) is used to monitor the incident molecular beam flux, while UV-reflectance (UVR) at 396 nm with an incident angle of 78° is used to monitor growth on the wafer. We have studied the utility of AAS/UVR monitoring of $Al_xGa_{1-x}As$ deposition, AlAs growing on GaAs, GaAs on AlAs, and superlattice growth. Additionally, optical multichannel spectroscopy (OMS) data were acquired throughout the growth of a distributed Bragg reflector. The relationship of the structure of the real-time OMS data to absorption, optical path length variation and differential layer thickness variations is also discussed. Numerical simulations of the real-time wafer-state monitors using pseudodielectric constants, appropriate at a growth temperature of 852 K, show good agreement with measured spectra.
[Contact: David H. Christensen, (303) 497-3354]

Lehman, J.H., and Aust, J.A., **A Bi-Cell Pyroelectric Detector Made from a Single $LiNbO_3$ Domain-Reversed Electret**.

Using electric-field poling at room temperature, we have selectively reversed the direction of the spontaneous polarization in z-cut $LiNbO_3$ to produce a bi-cell pyroelectric detector. The detector required only a single set of electrodes, one electrode on the front surface and one on the back surface. Microphonic noise that is typical of monocell pyroelectric detectors is reduced in the present device. Our data indicate that the spatial uniformity of one half of the bi-cell pyroelectric detector compared to a reference mono-cell pyroelectric detector was better than -36 dB from 10 Hz to 50 Hz and -118 dB at 35 Hz.
[Contact: John H. Lehman, (303) 497-3654]

Masterson, K.D., Novotny, D.R., and Cavcey, K.H., **Standard Antennas Designed with Electrooptic Modulators and Optical-Fiber Linkage**, to be published in the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), 1996 Symposium on Intense Microwave Pulses IV, Denver, Colorado, August 4-9, 1996.

[See Antenna Metrology.]

Munroe, M., Knopp, K.J., and Christensen, D.H., **Ultrafast Optical Excitation of Vertical-Cavity Surface-Emitting Lasers**, to be published in the Proceedings of the 1997 Conference on Lasers and Electro-Optics, Baltimore, Maryland, May 18-23, 1997.

We introduce a novel design for a vertical-cavity surface-emitting laser (VCSEL), which eliminates the ripple in the transmission over a very broad bandwidth (50 nm), thus allowing direct excitation of the quantum well by ultrashort (sub-100 fs) pulses. Examples of this design are presented, including simulations of the ultrafast temporal response of the VCSEL cavity.
[Contact: Michael Munroe, (303) 497-7948]

Obarski, G.E., and Jones, R.D., **Relative Intensity Noise Correlates with Beam Profile in an LP_{11} Mode Vertical-Cavity Surface Emitting Laser**, to be published in the Proceedings of the 1997 Conference on Lasers and Electro-Optics, Baltimore, Maryland, May 18-23, 1997.

We show how correlations between relative intensity noise and beam profile geometry of a vertical-cavity surface-emitting laser, in single-transverse LP_{11} mode, support a mode partition of the noise based on spatial overlap of orthogonal polarization components and polarization degeneracies.
[Contact: Richard D. Jones, (303) 497-3439]

Rochford, K.B., Rose, A.H., Williams, P.A., Wang, C.M., Clarke, I.G., Hale, P.D., and Day, G.W., **Design and Performance of a Stable Linear Retarder**.

NIST has developed a nominally quarterwave retarder for wavelengths near 1.3 μm that is stable to within ±0.1° retardance over a range of wavelength, input angle, temperature, and environmental variations. The device consists of two concatenated Fresnel rhombs made from a low-stress optic coefficient glass that minimizes the residual birefringence from machining and packaging. Device machining, assembly, and antireflection coating tolerances are discussed, and the theoretical performance is compared to measurements. Humidity on the total-internal-reflection surfaces can modify retardance. We discuss packaging that mitigates this effect and provide an estimated 10-year lifetime for the device. Several measurement methods were intercompared to ensure that the device retardance can be measured with an uncertainty less than 0.1°. Similar retarders will be certified by NIST and made available as Standard Reference Materials.
[Contact: Kenneth B. Rochford, (303) 497-5170]

Rochford, K.B., and Wang, C.M., **Accurate Interferometric Retardance Measurements**.

An interferometric system using a low-retardance beamsplitter and digital-signal processing has been used to measure the retardance of optical devices. Error analysis of the improved optical system and data processing shows that the measurement has an uncertainty of 0.039° for measurements of nominally 90° retarders. Retardance variations arising from coherent reflections in the retarder used for intercomparison add an uncertainty of 0.005° to 0.03°, increasing the combined measurement uncertainty to as much as 0.049°.
[Contact: Kenneth B. Rochford, (303) 497-5170]

Svalgaard, M., and Gilbert, S.L., **Stability of Short Single-Mode Erbium-Doped Fiber Lasers**.

We have conducted a detailed study of the stability of short erbium-doped fiber lasers fabricated using two UV-induced Bragg gratings written into the doped fiber. We find that the relative intensity noise of single longitudinal-mode fiber grating lasers is about three orders of magnitude lower than that of a single-frequency 1.523 μm helium-neon laser. The frequency noise spectrum contains very few resonances, none of which exceeds 0.6 kHz/Hz$^{1/2}$ rms; the integrated rms frequency noise from 50 Hz to 63 kHz is 36 kHz. We also demonstrate a simple method for monitoring of the laser power and number of oscillating modes during the laser fabrication process.
[Contact: Sarah L. Gilbert, (303) 497-3120]

OPTOELECTRONICS

Recently Published

Day, G.W., Franzen, D.L., and Williams, P.A., Eds., **Technical Digest, Symposium on Optical Fiber Measurements, 1996**, NIST Special Publication 905, Technical Digest—Symposium on Optical Fiber Measurements, Boulder, Colorado, October 1-3, 1996 (October 1996).

Measurements of polarization mode dispersion and nonlinear processes in optical fiber are two of the major topics in this Digest of Papers presented at the Ninth Symposium on Optical Fiber Measurements, held October 1-3, 1996, at the laboratories of the National Institute of Standards and Technology in Boulder, Colorado. Summaries of all of the papers presented at the Symposium–10 invited and 39 contributed–are included.
[Contact: Gordon W. Day, (303) 497-5204]

Deeter, M.N., and Bon, S., **Molecular Field Theory Analysis of Magneto-Optic Sensitivity of Gallium-Substituted Yttrium Iron Garnets**, Applied Physics Letters, Vol. 69, No. 5, pp. 702-704 (29 July 1996).

The temperature dependence of the magneto-optic sensitivity of gallium-substituted yttrium iron garnets was measured at 1.3 μm and compared with a model based on molecular field theory. The model

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

Hale, P.D., Wang, C.M., Park, R., and Lau, W.I., **A Transfer Standard for Measuring Photoreceiver Frequency Response**, Journal of Lightwave Technology, Vol. 14, No. 11, pp. 2457-2466 (November 1996).

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

Leonhardt, R.W., **Low-Level Pulsed 1064 nm Laser Radiometer Transfer Standard**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Optical Radiation Measurements III, Vol. 2815, pp. 154-159 (1996).

The National Institute of Standards and Technology (NIST) has developed a low-level peak power and pulse energy radiometer (APD 900) transfer standard for collimated laser light at a wavelength of 1064 nm. The peak power irradiance measurement range is from 500 pW/cm^2 to 50 μW/cm^2 for laser pulse widths of 10 ns to 250 ns. The pulse energy measurement range is from 0.05 fJ/cm^2 to 50 pJ/cm^2. The instrument combines the functions of peak-power and pulse energy measurement into one unit, and improves the responsivity by two orders of magnitude greater than previous NIST designs calibrated at 1064 nm. The radiometer is based on an infrared-enhanced silicon avalanche photodiode with 100 mm diameter full aperture collecting optics. Selectable aperture sizes and a neutral density filter extend the measurement range of the instrument to higher levels, especially with large diameter beams. The output is a voltage waveform that can be measured with an oscilloscope. Calibration uncertainty for the APD 900 radiometer is typically less than $\pm$8%. Improvements in the NIST calibration system will potentially lower the uncertainty to approximately $\pm$5%.
[Contact: Rodney W. Leonhardt, (303) 497-5162]

Park, R., and Hale, P.D., **Frequency Response Measurement of Digital Communications Analyzer Plug-In Modules**, Hewlett-Packard Journal, Vol. 47, No. 6, pp. 37-40 (December 1996).

It has been extremely difficult to characterize the SONET/SDH standard receiver with tolerances of $\pm$0.3 dB. This paper describes a method for calibrating photoreceiver frequency response with the low inherent uncertainty of the U.S. National Institute of Standards and Technology Nd:YAG heterodyne system and transferring this calibration to a production test system while maintaining a low uncertainty.
[Contact: Paul D. Hale, (303) 497-5367]

Rochford, K.B., and Rose, A.H., **Simultaneous Laser Diode Emission and Detection for Optical Fiber Sensors**, Optics and Photonics News, Vol. 7, No. 12, pp. 35-36 (December 1996).

A summary is given of highlights of research published in 1996 in the area of laser diode emission and detection.
[Contact: Kenneth B. Rochford, (303) 497-5170]

Rochford, K.B., Rose, A.H., and Day, G.W.,

Magneto-Optic Sensors Based on Iron Garnets, IEEE Transactions on Magnetics, Vol. 32, No. 5, pp. 4113-4117 (September 1996).

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

Rochford, K.B., and Wang, C.M., **Uncertainty in Null Polarimeter Measurements**, NISTIR 5055 (October 1996).

This internal report details the error analysis of a nulling polarimeter used for retardance measurements. We determined that the uncertainty arising from random effects is between 0.07° and 0.10° for measurements of several retarders with nominally 90° retardance. This instrument and two other methods were used to determine the retardance of a stable rhomb device proposed as a standard retarder. The measurement results were used to support certification of our retarder as a NIST Standard Reference Material.
[Contact: Kenneth B. Rochford, (303) 497-5170]

Rose, A.H., Ren, Z.B., and Day, G.W., **Twisting and Annealing Optical Fiber for Current Sensors**, Journal of Lightwave Technology, Vol. 14, No. 11, pp. 2492-2498 (November 1996).

We demonstrate that twisting a fiber a few turns per meter before it is annealed largely eliminates the residual linear birefringence. This dramatically improves the yield of annealed coils used for current sensing and makes it possible to use fibers that previously had large residual linear birefringence. Twisting the fiber is effective because the residual birefringence, associated with core ellipticity, is reduced to near zero by twisting. A theoretical model of the twisted and annealed fiber current sensor is compared to experimental data. We also show good temperature stability for a sensor made with this new technique.
[Contact: Allen H. Rose, (303) 497-5599]

Schlager, J.B., Mechels, S.E., and Franzen, D.L., **Determination of Zero-Dispersion Wavelength in Optical Fiber Using Four-Wave Mixing**, NIST Special Publication 905, Technical Digest-Symposium on Optical Fiber Measurements, Boulder, Colorado, October 1-3, 1996, pp. 121-124.

Wavelengths of measured maximum four-wave mixing efficiency in optical fiber are compared to zero-dispersion wavelengths measured with a highly accurate frequency-domain phase shift technique. The average absolute discrepancy between the two wavelengths determined on fifteen fibers is 0.19 nm; for an average pump-probe spacing of 5.9 nm, the average spectral width of the four-wave mixing efficiency curve is 0.45 nm.
[Contact: John B. Schlager, (303) 497-3542]

Vayshenker, I., Li, X., Keenan, D., and Scott, T.R., **Errors Due to Connectors in Optical Fiber Power Meters**, NIST Special Publication 905, Technical Digest—Symposium on Optical Fiber Measurements, Boulder, Colorado, October 1-3, 1996, pp. 101-104.

We discuss results of a major potential error source in the use of optical fiber power meters; outputs can vary dramatically when using various types of connectors or even connectors of the same type, but from different vendors. We investigate the magnitude of this connector-induced variation by calibrating several types of optical fiber power meters at three telecommunications wavelengths of 850, 1310, and 1550 nm. In these measurements, we vary the connector type and connector vendor, and observe the resulting offsets in calibration results. Observed variations of as much as 10% were found, due, presumably, to the different reflection properties of the detectors, windows, and connectors involved. A test meter user, therefore, can expect an error as large as 10% if the optical fiber power meter is used with a different connector (or vendor) than that used for calibration.
[Contact: Igor Vayshenker, (303) 497-3394]

Vayshenker, I., Yang, S., and Scott, T.R., **Nonlinearity of Optical Fiber Power Meters**, NIST Special Publication 905, Technical

Digest—Symposium on Optical Fiber Measurements, Boulder, Colorado, October 1-3, 1996, pp. 101-104.

We have developed a system for measuring the nonlinearity of optical power meters over a dynamic range of more than 60 dB at three telecommunications wavelengths. This system uses optical fiber components and is designed to accommodate common optical powers; it is based on the triplet superposition method. This measurement system provides accurate determination of optical power meter nonlinearity through the use of correction factors.
[Contact: Igor Vayshenker, (303) 497-3394]

Williams, P.A., **Accuracy Issues in Comparisons of Time- and Frequency-Domain Polarization Mode Dispersion Measurements**, NIST Special Publication 905, Technical Digest—Symposium on Optical Fiber Measurements, Boulder, Colorado, October 1-3, 1996, pp. 125-130.

Systematic errors in Fourier transformed wavelength scanning and interferometric measurements limit comparisons between time and frequency domain polarization mode dispersion measurements. Several sources of systematic error in time domain measurements are discussed. Correction algorithms are described and applied to experimental comparison data.
[Contact: Paul A. Williams, (303) 497-3805]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

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**, to be published in the Proceedings of the Thirteenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium - SEMITHERM XIII, Austin, Texas, January 28-30, 1997.

[See Device Physics and Modeling.]

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

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 do not occur, therefore, surges above the failure threshold must be infrequent.
[Contact: François Martzloff, (301) 975-2409]

Cookson, A.H., **Role of Electrical Insulation in the Design and Operation of High Voltage Equipment**, to be published in the Proceedings of the 5th International Conference on Properties and Applications of Dielectric Materials, Seoul, Korea, May 26-30, 1997.

Electrical insulation is key for all high-voltage equipment. The insulation design factors are summarized for major high-voltage equipment for generation and transmission systems, including generators, capacitors, transformers, underground transmission cables, and gas-insulated equipment. Recent developments of new insulation systems have resulted in significantly improved systems, including enhanced performance, improved manufacturability, reduced size and cost, and extended operational life. The impact of these developments and the future directions of new insulation systems are discussed for each system. It is emphasized that to appreciate the full technical and economic impact of changing the insulation, one needs to consider not just the component, but the complete, installed and operational system.
[Contact: Alan H. Cookson, (301) 975-2220]

Paulter, N.G., **A Real-Time Optically-Isolated Technique for Measuring the RMS Values of High-Voltages**.

A real-time electro-optic-based technique for measuring the root-mean-square (rms) value of high-voltage power lines is proposed. The procedure for extracting an rms voltage in the presence of harmonic distortion is presented, and an analysis of the approximations necessary to obtain an rms is provided. This analysis shows that for rms measurement uncertainties of up to 0.1%, 3% total harmonic distortion is acceptable.
[Contact: Nicholas G. Paulter, (301) 975-2405]

Petersons, O., FitzPatrick, G.J., and Simmon, E., **An Active High Voltage Divider with 20-μV/V Uncertainty**.

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

Stenbakken, G.N., and Dolev, A., **NIST High Accuracy Sampling Wattmeter**, NIST Technical Note 1420 (August 1996).

[See DC and Low-Frequency Metrology.]

von Glahn, P., Stricklett, R.L., Van Brunt, R.L., and Chelm, L.A.V., **Simultaneous Recording of Electrical and Acoustical Partial-Discharge in Transformer Oil**.

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

Pulse Power Metrology

Recently Published

FitzPatrick, G.J., and Kelley, E.F., **Comparative High Voltage Impulse Measurement**, Journal of Research of the National Institute of Standards and Technology, Vol. 101, No. 5, pp. 639-658 (September—October 1996).

A facility has been developed for the determination of the ratio of pulse high voltage dividers over the range from 10 kV to 300 kV using comparative techniques with Kerr electro-optic voltage measurement systems and reference resistive voltage dividers. Pulse voltage ratios of test dividers can be determined with relative expanded uncertainties of 0.4% (coverage factor k = 2 and thus a two standard deviation estimate) or less using the complementary resistive divider/Kerr cell reference systems. This paper describes the facility and specialized procedures used at NIST for the determination of test voltage divider ratios through comparative techniques. The error sources and special considerations in the construction and use of reference voltage dividers to minimize errors are discussed, and estimates of the uncertainties are presented.
[Contact: Gerald J. FitzPatrick, (301) 975-2737]

Magnetic Materials and Measurements

Released for Publication

Rice, P., and Hoinville, J., **Direct Comparison of Magnetic Force Microscopy Images and Recording Head Output**.

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]

Shafi, K., Goldfarb, R.B., Felner, I., and Gedanken, A., **Sonochemical Preparation of Nanosized Amorphous Fe-Ni Alloys**.

Nanosized amorphous alloy powders of $Fe_{20}Ni_{80}$, $Fe_{40}Ni_{60}$, and $Fe_{60}Ni_{40}$ were prepared by sonochemical decomposition of solutions of volatile organic precursors, $Fe(CO)_5$ and $Ni(CO)_4$ in decahydronapthalene, under an argon pressure of 100 kPa to 150 kPa at 273 K. The Mössbauer spectrum of crystallized $Fe_{20}Ni_{80}$ shows a clear sextet pattern with a hyperfine-field value of 25.04 T. Differential scanning calorimetry indicates two endothermic transitions. Thermogravimetric magnetic measurements give Curie temperatures of 322 °C and 550 °C for amorphous and crystallized samples, respectively. Mass magnetization of $Fe_{40}Ni_{60}$ and $Fe_{60}Ni_{40}$, as a function of increasing temperature after zero-field cooling and field cooling in a field of 1 mT, exhibit blocking temperatures of 35 K. Magnetic irreversibility occurs below 200 K to 250 K for both compositions.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Superconductors

Released for Publication

Booth, J.C., Beall, J.A., DeGroot, D.C., Rudman, D.A., Ono, R.H., Zhang, K., Hong, S., and Ma, Q.Y., **Microwave Characterization of Coplanar Waveguide Transmission Lines Fabricated by Ion Implantation Patterning of $YBa_2CuO_{7-\delta}$**.

[See Microwave and Millimeter-Wave Metrology.]

Bray, S.L., Ekin, J.W., and Sesselmann, R., **Tensile Measurements of the Modulus of Elasticity of Nb_3Sn at Room Temperature and 4 K**.

The critical current of Nb_3Sn superconductors is highly sensitive to strain. Consequently, accurate mechanical modeling of these conductors is necessary to interpret experimental data and to predict conductor performance in applications such as large magnet systems. A key parameter in these models is the modulus of elasticity (E. Young's modulus); however, there are large discrepancies in the available data, and there are no published tensile-test data on E for Nb_3Sn. Tensile test specimens were prepared from a starting material of Nbtape with 1.4 wt% ZrO_2 precipitates. Tensile measurements of unreacted Nb and partially reacted Nb-Nb_3Sn tapes were made at room temperature (293 K) and at 4 K. A modulus of elasticity of 65 ± 15 GPa was extrapolated from these measurements for polycrystalline Nb_3Sn at 4 K, and 150 ± 15 GPa at room temperature.
[Contact: Steven L. Bray, (303) 497-5631]

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

A conductance peak at zero-bias voltage is consistently observed in the tunneling characteristics of a series of oxide-superconductor/noble-metal systems in which the oxide superconductors ($YBa_2Cu_3O_{7-\delta}$ and $Tl_2Ba_2CaCu_2O$) show d-wave pairing behavior, but

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

Roshko, A., Stork, F.J.B., Rudman, D.A., Aldrich, D.J., and Morris-Hotsenpiller, P.A., **Comparison of Heteroepitaxial $YBa_2Cu_3O_{7-\delta}$ and TiO_2 Thin Film Growth**.

[See Cryoelectronic Metrology.]

Stork, F.J.B., Beall, J.A., Roshko, A., DeGroot, D.C., Rudman, D.A., Ono, R.H., and Krupka, J., **Surface Resistance and Morphology of YBCO Films as a Function of Thickness**.

We have examined the thickness dependence of the growth morphology and surface resistance, R_s, of laser ablated $YBa_2Cu_3O_{7-x}$ films with transition temperatures over 89 K and critical current densities greater than 10^6 A/cm^2 at 76 K. The thickness was varied from 50 nm to 1600 nm while maintaining all other deposition conditions constant. The microstructure has been characterized by scanning electron microscopy and scanning tunneling microscopy. The films exhibit two-dimensional island growth at all thicknesses, and the island density continuously decreased with film thickness as a power law with an exponent of -0.5. The surface resistance was measured at 76 K with a dielectric rod resonator. For films less than 300 nm thick, the fields penetrated the superconducting films, causing a rapid increase in the apparent R_s with decreasing film thickness. Films thicker than 800 nm showed microcracks and the R_s increased sharply, and no resonance was observed above 1000 nm.
[Contact: James A. Beall, (303) 497-5989]

ELECTROMAGNETIC INTERFERENCE

Conducted EMI

Released for Publication

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

[See Power Systems Metrology.]

Radiated EMI

Recently Published

DeLyser, R.R., Holloway, C.L., Johnk, R.T., Ondrejka, A.R., and Kanda, M., **Figure of Merit for Low Frequency Anechoic Chambers Based on Absorber Reflection Coefficients**, IEEE Transactions on Electromagnetic Compatibility, Vol. 38, No. 4, pp. 576-584 (November 1996).

Return loss as a function of frequency and angle of incidence is studied to determine the effectiveness of the absorbing material used in an anechoic chamber. This alone is not enough to determine a figure of merit for an anechoic chamber or to compare the figure of merit for one anechoic chamber to that of another. While the information gained from return-loss calculations and measurements as a function of angle of incidence is valuable, an overall measure of anechoic chamber effectiveness is necessary in order to compare different designs. In this paper, a new chamber figure of merit which is based on the decay time of the chamber is introduced. This decay time is, in turn, based on the average power absorbed by the chamber walls. The resulting model is simple and does not require intensive numerical computation. Calculations of the figure of merit for anechoic chambers which contain different types of absorbing materials are shown, and calculated and measured values of decay time for a primary standards calibrations facility are

compared.
[Contact: Robert T. Johnk, (303) 497-3737]

Johnk, R., and Randa, J., **Low-Frequency Representation of Radio-Frequency Absorbers**, Proceedings of the 1996 IEEE International Symposium on Electromagnetic Compatibility, Santa Clara, California, August 19-23, 1996, pp. 174-179.

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

Tofani, S., Ossola, P., d'Amore, G., Anglesio, L., Kanda, M., and Novotny, D.R., **A Three-Loop Antenna System for Performing Near-Field Measurements of Electric and Magnetic Fields from Video Display Terminals**, IEEE Transactions on Electromagnetic Compatabilty, Vol. 38, No. 3, pp. 341-347 (August 1996).

This paper discusses the use of a three-loop antenna system (TLAS) for near-field measurement of electric and magnetic fields from video display terminals (VDTs). We calculated the electric and magnetic dipole moments to derive the electric and magnetic field patterns in the near field region. Electric and magnetic fields, emitted by several different models of VDTs, were evaluated with the TLAS and were compared with those measured by conventional electric and magnetic field probes at different distances and directions from VDTs. A good correlation (±1.6 dB) between the two measurement techniques was found. This agreement is within the accuracy (±2 dB) of the conventional field probe measurements.
[Contact: Motohisa Kanda, (303) 497-5320]

VIDEO TECHNOLOGY

Recently Published

Boynton, P.A., and Kelley, E.F., **Measuring Contrast Ratio of Displays**, Information Display, Vol. 12, No. 11, pp. 24-27 (November 1996).

Conventional methods of measuring the contrast ratio of displays usually involve measuring the luminance of a black and white pattern on a screen using some type of light-measuring device. However, different methods can produce widely varying results which can be attributed to veiling glare. We showed possible methods for correcting for it.
[Contact: Paul A. Boynton, (301) 975-3014]

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.
[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** (February 1996).

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 1995. 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

January 28-30, 1997 (Austin, Texas)

Thirteenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM) 1997. Co-sponsored by NIST and IEEE, the Symposium will present papers on current thermal management 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, and thermal design and testing for reliability.
[Contact: David L. Blackburn, (301) 975-2068]

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]

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 Sinagore, 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 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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