NISTIR 5936

Electronics and Electrical Engineering Laboratory

J. M. Rohrbaugh
Compiler

Technical Progress Bulletin

96-3

Covering Laboratory Programs,
July to September 1996,
with 1997-1998 EEEL Events Calendar

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

NIST

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Semiconductor Electronics Division
Gaithersburg, MD 20899

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U.S. DEPARTMENT OF COMMERCE
Michael Kantor, Secretary
TECHNOLOGY ADMINISTRATION
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ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY
TECHNICAL PROGRESS BULLETIN, DECEMBER 1996 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 third 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 Unpublished papers appear under the subheading "Released for Publication."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 newly formed Optoelectronics Division in Boulder, Colo. The Office of Law Enforcement Standards conducts research and provides technical services to the U.S. Department of Justice and State and local governments, and other agencies in support of law enforcement activities. In addition, the Office of Microelectronics Programs (OMP) coordinates the growing number of semiconductor-related research activities at NIST. Reports of work funded through the OMP are included under the heading "Semiconductor Microelectronics."

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

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

Note on Publication Lists: Publication lists covering the work of each division are guides to earlier as well as recent work. These lists are revised and reissued on an approximately annual basis and are available from the originating division. The current set is identified in the Additional Information section, page 32.

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

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

TO LEARN MORE ABOUT THE LABORATORY...

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

EEEL 1995 Technical Accomplishments, Advancing Metrology for Electrotechnology to Support the U.S. Economy, NISTIR 5818 (December 1995).

The Electronics and Electrical Engineering Laboratory, working in concert with other NIST Laboratories, is providing measurement and other generic technology critical to the competitiveness of the U.S. electronics industry and the U.S. electricity-equipment industry. This report summarizes selected technical accomplishments and describes activities conducted by the Laboratory in FY 1995 in the field of semiconductors, magnetics, superconductors, low-frequency microwaves, lasers, optical fiber communications and sensors, video, power, electromagnetic compatibility, electronic data exchange, and national electrical standards. Also included is a profile of EEEL's organization, its customers, and the Laboratory's long-term goals.

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

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

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

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

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

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Released for Publication

Benz, S.P., and Burroughs, C.J., **Constant-Voltage Steps in Arrays of Nb-PdAu-Nb Josephson Junctions**.

Design and fabrication of Nb-PdAu-Nb trilayer Josephson junctions are described. The microwave response of an array of 1000 of these junctions was measured, and constant-voltage step amplitudes were characterized as a function of the microwave amplitude and frequency. Experimental results fit well to point-junction simulations at the 3 GHz design frequency of the microwave distribution network. The observed step amplitude of 3.8 mA shows that the array and microwave distribution are sufficiently uniform for application in programmable Josephson-voltage standards.
[Contact: Samuel P. Benz, (303) 497-5258]

Benz, S.P., Burroughs, C.J., and Hamilton, C.A., **Operating Margins for a Pulse-Driven Programmable Voltage Standard**.

We have designed and fabricated a Josephson voltage standard where the voltage can be rapidly and continuously programmed by changing the repetition frequency of a pulse drive. Simulations are made to optimize the operating margins of the circuit for different pulse waveforms. The response of a 1000-junction array of Nb-PdAu-Nb junctions is measured, and constant-voltage step heights are characterized as a function of the pulse amplitude, pulse width, and frequency. A dc bias range of 0.8 mA is demonstrated over a continuous voltage-tunable range from -4.4 mV to 4.4 mV.
[Contact: Samuel P. Benz, (303) 497-5258]

Hamilton, C.A., Benz, S.P., Burroughs, C.J., and Harvey, T.E., **SNS Programmable Voltage Standard**.

Superconductor-Normal Superconductor (SNS) junctions have been used in the design and fabrication of a 1 V rapidly programmable voltage standard. The superconducting circuit is a series array of 32,768 Nb-PdAu-Nb junctions with taps that divide the array into a binary sequence of smaller array segments with a minimum segment size of 128 junctions. The 16 GHz drive frequency is set by the characteristic frequency of the junctions. A computer-controlled 8-channel bias system controls the current in each segment and allows the rapid selection of any one of 513 discrete voltage levels. The system is designed for fast dc measurements and the synthesis of precise ac waveforms.
[Contact: Clark A. Hamilton, (303) 497-3740]

Hamilton, C.A., and Burroughs, C.J., **Josephson Voltage Standard - A Review**.

The unique ability of a Josephson junction to convert a microwave frequency f into a voltage $Nhf/2e$ with high accuracy and the adoption of this phenomenon as the basis for the SI Volt Realization have created a market for Josephson voltage standards that is unassailable from any other technology. This paper reviews the development of Josephson-voltage standards including the junction and array design, the microwave circuit, and the system integration. With the dc Josephson standard largely transferred to the commercial sector, NIST is developing a new class of devices in which the output voltage can be rapidly programmed either by digitally selecting the quantum number N or by driving the Josephson array with a variable frequency pulse train. These new devices will make possible fast, high-accuracy characterizations of A/D and D/A converters and the synthesis of ac waveforms.
[Contact: Clark A. Hamilton, (303) 497-3740]

Zimmerman, N.M., **Capacitors with Very Low Loss: Cryogenic Vacuum-Gap Capacitors**.

We report on measurements of capacitors with about 1 pF of capacitance, which have unmeasurably small leakage at very low frequencies, placing a lower bound of about 10^{19} Ω on the parallel resistance at an effective frequency of 1 mHz. These measurements are made possible by two themes: the use of vacuum-gap capacitors (i.e., no dielectric material, operated in vacuum), and detection of leakage using single electron tunneling electrometers, which have a very high input impedance. We also report on good achieved results in time stability and lack of frequency and voltage dependence.
[Contact: Neil M. Zimmerman, (301) 975-5887]

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Recently Published

Avramov-Zamurovic, S., Zimmerman, N.M., Clark, A.F., and Jeffery, A., **Proposed Tests to Evaluate the Frequency-Dependent Capacitor Ratio for Single Electron Tunneling Experiment**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 265-266.

A precise measurement of the ratio of two cryogenic capacitors is needed for a capacitor-charging experiment using Single Electron Tunneling phenomena. To support the capacitor-charging metrology, a frequency characterization of the capacitors is required. To cover the frequency range from 1 Hz to 1 kHz, resistive and inductive voltage divider bridges are proposed. Preliminary tests suggest that the uncertainty with which the capacitor ratio can be evaluated is less than one part per 10^6.
[Contact: Svetlana Avramov-Zamurovic, (301) 975-2414]

Elmquist, R.E., and Dziuba, R.F., **Loading Effects in Resistance Scaling**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 334-335.

[See DC and Low-Frequency Metrology.]

Fujii, K., Williams, E.R., Steiner, R.L., and Newell, D.B., **A New Refractometer by Combining a Variable Length Vacuum Cell and a Double-Pass Michelson Interferometer**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 128-129.

A new refractometer with a variable length vacuum cell has been developed, where the refractive index of air is determined between the air of interest and a vacuum as a function of the changes in the cell length. An uncertainty of 4×10^{-9} in the index has been achieved.
[Contact: Edwin R. Williams, (301) 975-4206]

Gillespie, A.D., Fujii, K., Newell, D., Olsen, P.T., Picard, A., Steiner, R., Stenbakken, G., and Williams, E., **Measurement and Reduction of Alignment Errors of the NIST Watt Experiment**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 614-615.

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

Jeffrey, R.A., Elmquist, R.E., Lee, L.H., Shields, J.Q., and Dziuba, R.F., **NIST Comparison of the Quantized Hall Resistance and the Realization of the SI Ohm through the Calculable Capacitor**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 358-359.

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

Jeffery, A.M., Shields, J.Q., and Lee, L.H., **Conversion of a 2-Terminal-Pair Bridge to a 4-Terminal-Pair Bridge for Increased Range and Precision in Impedance Measurements**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 358-359.

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

Kautz, R.L., **Noise, Chaos, and the Josephson Voltage Standard**, Reports on Progress in

Physics, Vol. 59, pp. 935-992 (1996).

The design of zero-bias Josephson voltage standards is presented as a case study in nonlinear dynamics. Based on superconducting tunnel junctions, such standards rely on nonlinearity to create a phase lock between an internal junction variable and an applied rf bias. In the terminology of nonlinear dynamics, phase lock corresponds to motion on a periodic attractor. Not all attractors of the rf-biased junction are periodic, however, and both quasiperiodic and chaotic attractors must be avoided in voltage standards. Surprisingly, the optimum operating point for zero-bias standards is near a region of chaos. Thus, the Josephson coupling energy E_J, a measure of the junction's nonlinearity, must be chosen much larger than the thermal energy k_BT to avoid disruption by intrinsic noise, but not so large that chaos is evoked. The optimum E_J maximizes the activation energy E_A required for thermally-induced escape from the phase-locked attractor. For nonequilibrium systems like the rf-biased junction, E_A is a difference in quasipotential that can be calculated by finding the most probable path for escape from a basin of attraction in the limit of low temperature.
[Contact: Richard L. Kautz, (303) 497-3391]

Steinbach, A., Martinis, J.M., and Devoret, M.H., **Observation of Hot-Electron Shot Noise in a Metallic Resistor**, Physical Review Letters, Vol. 76, No. 20, pp. 3806-3809 (13 May 1996).

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

Steiner, R.L., Gillespie, A.D., Fujii, K., Williams, E.R., Newell, D.B., Picard, A., Stenbakken, G.N., and Olsen, P.T., **The NIST Watt Balance: Progress toward Monitoring the Kilogram**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 6-7.

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

Zimmerman, N.M., Clark, A.F., and Williams, E.R., **Results of Capacitance Ratio Measurements for the Single Electron Pump-Capacitor Charging Experiment**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 505-506.

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

SEMICONDUCTOR MICROELECTRONICS

Silicon Materials

Recently Published

Bagchi, S., Lee, J.D., Krause, S.J., and Roitman, P., **Mechanism of Defect Formation in Low-Dose Oxygen Implanted Silicon-On-Insulator Material**, Journal of Electronic Materials, Vol. 25, No. 1, pp. 7-12 (1996).

The defects and microstructure of low-dose (<0.7 x

10^{18} cm^{-2}), oxygen-implanted silicon-on-insulator (SIMOX) material were investigated as a function of implant dose and annealing temperature by plan-view and cross-sectional transmission electron microscopy. The threading-dislocations in low-dose (0.2 to 0.3 x 10^{18} cm^{-2}), annealed SIMOX originate from unfaulting of long ($\sim$10 μm), shallow (0.3 μm), extrinsic stacking faults generated during the ramping stage of annealing. As dose increases, the defect density is reduced, and the structure of the buried oxide layer evolves dramatically. It was found that there is a dose window which gives a lower defect density and a continuous buried oxide with a reduced density of Si islands in the buried oxide.
[Contact: Peter Roitman, (301) 975-2077]

Compound Materials

Released for Publication

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

[See Device Physics and Modeling.]

Huang, X.R., Cheung, S.K., Cartwright, A.N., Smirl, A.L., and Tseng, W.F., **An interdigitated Stacked p-i-n Multiple-Quantum-Well Modulator**, IEEE Photonics Technology Letters, Vol. 8, No. 9, pp. 1172-1174 (September 1996).

We demonstrate low-voltage operation of a strained InGaAs-GaAs interdigitated hetero n-i-p-i modulator (or stacked SEED) that is grown and fabricated using a shadow-mask growth technique for making the metal contacts to the n- and p-layers separately. An absorption change of 6 x 10^{3} cm^{-1} with an applied bias as low as $\sim$1 V is observed in an unoptimized structure. Optical switching of the unbiased structure is also demonstrated.
[Contact: Wen F. Tseng, (301) 975-5291]

Kim, J.S., Seiler, D.G., Lancaster, R.A., and Reine, M.B., **Electrical Characterization of Very-Narrow-Gap Bulk HgCdTe Single Crystals by Variable Magnetic Field Hall Measurements**, Journal of Electronic Materials, Vol. 25, No. 8, pp. 1215-1220 (1996).

[See Photodetectors.]

Richter, C.A., Seiler, D.G., and Pellegrino, J.G., **Quantum Conductance Fluctuations in the Large-Size-Scale Regime**, Physical Review B, Vol. 53, No. 19, pp. 13 086—13 090 (15 May 1996).

We report the results of experimental studies of "universal" conductance fluctuations in a variety of millimeter-sized GaAs/$Al_xGa_{1-x}As$ heterostructures. The ability to observe these mesoscopic fluctuations in traditionally macroscopic semiconductor devices is due to the enhanced sensitivity of our magnetic-field modulation measurement technique, which allows a coherent interference effect to be observed and studied in the large-size-scale regime where both the sample length and width are much greater than the quantum scattering lengths.
[Contact: Curt A. Richter, (301) 975-2082]

Analysis and Characterization Techniques

Released for Publication

Marchiando, J.F., Lowney, J.R., and Kopanski, J.J., **Models for Interpreting Measurements from a Scanning Capacitance Microscope**.

To correlate the scanning capacitance microscope measurements with dopant concentrations, model capacitance curves have been calculated for silicon. For cases having two dimensions, the finite-element method is used to solve Poisson's equation in the semiconductor region and Laplace's equation in the oxide and the ambient regions. For cases having three dimensions, the collocation method is used in the semiconductor region, and the finite-element method is used outside. For a given oxide thickness, probe shape, probe-tip size, and the capacitance are calculated for cases of uniform doping, and example solutions are found for a graded-doping profile.
[Contact: Jay F. Marchiando, (301) 975-2088]

Analysis and Characterization Techniques

Recently Published

Amirtharaj, P.M., Chandler-Horowitz, D., and Bour,

D.P., **Double Modulation and Selective Excitation Photoreflectance for Characterizing Highly Luminescent Semiconductor Structures and Samples with Poor Surface Morphology**, Proceedings of the Materials Research Society, Boston, Massachusetts, November 25-29, 1995, Vol. 406, pp. 229-240 (1996).

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

Device Physics and Modeling

Released for Publication

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

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

Marchiando, J.F., Lowney, J.R., and Kopanski, J.J., **Models for Interpreting Measurements from a Scanning Capacitance Microscope**.

[See Analysis and Characterization Techniques.]

Dimensional Metrology

Released for Publication

Allen, R.A., and Marshall, J.C., **Critical Dimension Metrology for MEMS Processes Using Electrical Techniques**, to be published in the 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, Texas, October 14-15, 1996.

[See Microfabrication Technology.]

Dimensional Metrology

Recently Published

Lowney, J.R., Vladar, A.E., and Postek, M.T., **High-Accuracy Critical-Dimension Metrology Using a Scanning Microscope**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Metrology, Inspection, and Process Control for Microlithography X, Vol. 2725, pp. 515-526 (1996).

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

Integrated-Circuit Test Structures

Released for Publication

Cresswell, M.W., Sniegowski, J.J., Ghoshtagore, R.N., Allen, R.A., Guthrie, W.F., Gurnell, A.W., Linholm, L.W., and Teague, E.C., **Recent Developments in Electrical Linewidth and Overlay Metrology for Integrated Circuit Fabricaton Processes**.

Electrical linewidth measurements have been extracted from test structures replicated in planar films of monocrystalline silicon that were electrically insulated from the bulk-silicon substrate by a layer of silicon dioxide formed by separation by the implantation of oxygen processing. Appropriate selection of the surface orientation of the starting material, the design and orientation of the structure features, and patterning by a lattice-plane selective etch provide features with planar, atomically smooth sidewalls and rectangular cross sections. The primary motivation for this approach is to attempt to overcome the serious challenge posed by methods divergence to the certification of linewidth reference-materials for critical-dimension (CD) instrument calibration and related tasks. To enhance the physical robustness of reference features with deep submicrometer linewidths, the new test structure embodies short reference-segment lengths and arbitariy wide-voltage taps. Facilities for reconciliation of measurements extracted from the same feature by all normally practiced techniques are also implemented. In overlay metrology, electrical inspection of two types of hybrid overlay targets allows pixel calibration of, and shift extraction from, the overlay instruments. The overall strategic focus of this research is to resolve methods-divergence issues and possibly to develop universal deep-submicrometer linewidth reference materials for CD instruments and techniques for instrument- and process-specific shift extraction for optical overlay metrology.
[Contact: Michael W. Cresswell, (301) 975-2072]

Integrated-Circuit Test Structures

Recently Published

Cresswell, M.W., Sniegowski, J.J., Ghoshtagore, R.N., Allen, R.A., Linholm, L.W., and Villarrubia, J.S., **Electrical Test Structures Replicated in Silicon-on-Insulator Material**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Metrology, Inspection, and Process Control for Microlithography X, Vol. 2725, pp. 659-676 (1996).

Measurements of the linewidths of submicrometer features made by different metrology techniques have frequently been characterized by differences of up to 90 nm. The purpose of the work reported here is to address the special difficulties that this

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

Microfabrication Technology

Released for Publication

Allen, R.A., and Marshall, J.C., **Critical Dimension Metrology for MEMS Processes Using Electrical Techniques**, to be published in the Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Microlithography and Metrology in Micromachining II, Austin, Texas, October 14-15, 1996.

Electrical critical dimension (ECD) test structures have been adapted for use in a surface micromachining environment and fabricated along side 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]

Marshall, J.C., Read, D.T., and Gaitan, M.G., **Analysis of Fixed-Fixed Beam Test Structures**, to be published in the 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, Austin, Texas, October 14-15, 1996.

This paper presents recent NIST MicroElectroMechanical Systems (MEMS) 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]

Microfabrication Technology

Recently Published

Huang, X.R., Cheung, S.K., Cartwright, A.N., Smirl, A.L., and Tseng, W.F., **An Interdigitated Stacked p-i-n Multiple-Quantum-Well Modulator**, IEEE Photonics Technology Letters, Vol. 8, No. 9, pp. 1172-1174 (September 1996).

[See Compound Materials.]

Plasma Processing

Released for Publication

Christophorou, L.G., Olthoff, J.K., and Rao, M.V.V.S., **Electron Interactions with CHF_3**.

In this paper, we assess and synthesize the available information on the cross sections and the rate coefficients for collisional interactions of trifluoromethane (CHF_3) with electrons in an effort to build up a database on electronic and ionic collision processes that will aid the understanding of the behavior of CHF_3 in its use in manufacturing semiconductor devices and other applications. The limited data on the total and partial electron impact

ionization and dissociation cross sections, total and partial cross sections for electron impact dissociation of CHF_3 into neutral species, electron-impact-induced line and continuous light emission from CHF_3, negative ion states of CHF_3, and the energetics of ionization, dissociation, and attachment are summarized and discussed. To our knowledge, no measurements are available of the cross sections of any of the electron scattering processes (elastic, momentum, vibrational, inelastic, etc.) or the electron transport, attachment, and ionization coefficients. While the available information is meager, the synthesis of the existing knowledge and the background information provided in the paper can be helpful for modeling plasma reactors. Clearly, more measurements and calculations are needed of the cross sections for virtually all fundamental electron impact processes for this plasma processing gas. Measurements of the transport, attachment, and ionization coefficients over wide ranges of the density-reduced electric field are also needed.
[Contact: Loucas Christophorou, (301) 975-2432]

Wang, Y., and Van Brunt, R.J., **Calculations of Electron Transport in Ar/N_2 and He/Kr Gas Mixtures-Implications for Validity of the Blanc's Law Method**.

The electron drift velocities and corresponding mean energies have been calculated numerically using an approximate two-term solution of the Boltzmann transport equation for Ar/N_2 gas mixtures at electric field-to-gas density ratios (E/N) below 2.0 x 10^{-20} Vm^2 (20 Td) and for He/Kr mixtures at E/N below 5.0 x 10^{-21} Vm^2 (5.0 Td). The results are compared with predictions obtained from a method proposed by Chiflikian based on an "analog of Blanc's law." Large differences are found between the results derived from the Blanc's law method and those found here from solutions of the transport equation that indicate serious errors and limitations associated with use of the Blanc's law method to compute drift velocities in gas mixtures.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Plasma Processing

Recently Published

Foest, R., Olthoff, J.K., Van Brunt, R.J., Benck, E., and Roberts, J.R., **Optical and Mass Spectrometric Investigations of Ions and Neutrals in SF_6 Radio-Frequency Discharges**, Physical Review E, Vol. 54, No. 2, pp. 1876-1887 (August 1996).

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

discharge were found to dramatically affect the ion-energy distributions, LIF, and electrical characteristics.
[Contact: James K. Olthoff, (301) 975-2431]

Photodetectors

Recently Published

Kim, J.S., Seiler, D.G., Lancaster, R.A., and Reine, M.B., **Electrical Characterization of Very-Narrow-Gap Bulk HgCdTe Single Crystals by Variable Magnetic Field Hall Measurements**, Journal of Electronic Materials, Vol. 25, No. 8, pp. 1215-1220 (1996).

Variable-magnetic-field Hall measurements (0 to 1.5 T) are performed on very-narrow-gap bulk-grown $Hg_{1-x}Cd_xTe$ single crystals ($0.165 \leq x \leq 0.2$) at various temperatures (10 to 300 K). The electron densities and mobilities are obtained within the one-carrier (electrons) approximation of the reduced-conductivity-tensor scheme. The present data together with the selected data set reported by other workers exhibit a pronounced peak when the electron mobility is plotted against the alloy composition x-value which has been predicted to be due to the effective-mass minimum at the bandgap-crossing ($E_g \approx 0$). The observed position ($x \approx 0.165$), height ($\approx 4 \times 10^2$ m^2/Vs), and width (≈ 0.01 in x) of the mobility-peak can be explained by a simple simulation involving only ionized-impurity scattering. A lower bound of the effective mass is introduced as a fitting parameter to be consistent with the finiteness of the observed electron mobility and is found to be of the order of 10^{-4} of the mass of a free electron.
[Contact: Jin S. Kim, (301) 975-2238]

Reliability

Released for Publication

Lipkin, L.A., Palmour, J.W., and Suehle, J.S., **P-Type SiC MOS Reliability with Improved Oxidation Procedures and Aluminum or Boron P-Type Dopants**, to be published in the Proceedings of the Third International Conference on High Temperature Electronics, Albuquerque, New Mexico, June 9-14, 1996.

Thermal oxides grown on p-type SiC are shown to improve with a combination of low-oxidation temperature (1050 °C) followed by a 950 °C re-oxidation anneal. Measured oxide quality parameters include oxide charge, interface state densities, 22 °C and 350 °C breakdown field, and MOSFET surface channel mobility to date on p-type SiC MOSFETs: 72 cm^2/V-s. In addition, oxide quality on both aluminum- and boron-doped wafers across a wide doping range is reported. No significant difference is found between oxides grown on Al- or B-doped samples, in the 1×10^{16} or 1×10^{17} cm^{-3} doping ranges. Time-dependent dielectric breakdown results indicate thermal oxides grown on SiC have lifetimes as high as 700 years at 2 MV/cm and 350 °C. Samples fabricated on the more heavily-doped material demonstrate a reduced high-temperature lifetime. Although the MOSFETs have additional issues with the source/drain overlap region, time-dependent dielectric breakdown measurements indicate that there are no fundamental problems with oxide reliability that would prohibit a high-temperature MOS technology on SiC.
[Contact: John S. Suehle, (301) 975-2247]

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]

Other Semiconductor Metrology Topics

Recently Published

St. Pierre, J.A., Brady, K.G., and Stewart, S.L.,

Conformance Testing and Specification Management, NISTIR 5879 (September 1996).

[See Product Data Systems.]

SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

DC and Low-Frequency Metrology

Released for Publication

Oldham, N.M., and Parker, M.E., **NIST Multifunction Calibration System**, to be published as a NIST Technical Note.

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

Stenbakken, G.N., and Dolev, A., **NIST High Accuracy Sampling Wattmeter**.

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 measurement uncertainty of less than ±50 μW/W of full scale over these frequencies. 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]

DC and Low-Frequency Metrology

Recently Published

Dziuba, R.F., **Resistors**, Encyclopedia of Applied Physics, Vol. 16, VCH Publishers, Inc., (New York, New York, 1996), pp. 423-435.

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

intended use and inherent performance, is described. This classification includes standard resistors, resistors in electronic circuits, integrated-circuit resistors, high current resistors, and high-voltage resistors.
[Contact: Ronald F. Dziuba, (301) 975-4239]

Elmquist, R.E., and Dziuba, R.F., **Loading Effects in Resistance Scaling**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 334-335.

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

Jarrett, D.G., **Automated Guarded Bridge for Calibration of Multimegohm Standard Resistors**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 336-337.

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

Jarrett, D.G., **Resistance Measurements from 10 MΩ to 1 TΩ at NIST**, Proceedings of the 1996 National Conference of Standards Laboratories Workshop Symposium, Monterey, California, August 25-29, 1996, pp. 291-298.

Described are the measurement systems and methods used for calibrating standard resistors from 10 MΩ to 1 TΩ at the National Institute of Standards and Technology. Presently, four systems are used for the calibration of standard resistors at and above 10 MΩ. An automated guarded multimegohm bridge has recently been developed to augment a manual guarded-Wheatstone bridge and a semi-automated teraohmmeter system. An automated resistance ratio bridge is used during the scaling process. Scaling from one decade to the next is done by using guarded Hamon boxes and the high-resistance bridges.
[Contact: Dean G. Jarrett, (301) 975-4240]

Jeffrey, R.A., Elmquist, R.E., Lee, L.H., Shields, J.Q., and Dziuba, R.F., **NIST Comparison of the Quantized Hall Resistance and the Realization of the SI Ohm through the Calculable Capacitor**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 358-359.

[See Fundamental Electrical Measurements.]

Kinard, J.R., Lipe, T.E., Childers, C.B., Novotny, D.B., and Huang, D.-X., **High-Current Thin Film Multijunction Thermal Converters and Multi-Converter Modules**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 594-595.

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

Kinard, J.R., Novotny, D.B., Lipe, T.E., and Huang, D.-X., **Development of Thin-Film Multijunction Thermal Converters at NIST**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 493-494.

This paper gives an overview of the development of thin-film multijunction thermal converters (FMJTCs) at the National Institute of Standards and Technology (NIST). An historical perspective of film thermal converters is presented, followed by descriptions of the motivation, fabrication processes, physical characteristics, and the electrical properties of the FMJTCs produced at NIST. Integrated micropotentiometers which incorporate FMJTCs and

thermal converters, produced by an alternative fabrication technology using a CMOS foundry, are also described. The paper concludes with a report on the current status of the FMJTCs project and future directions.
[Contact: Joseph R. Kinard, (301) 975-4250]

Marshall, J.A., Marshall, T.A., Jarrett, D.G., and Dziuba, R.F., **A Low Thermal Guarded Scanner for High Resistance Measurement Systems**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 20-21.

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

Oldham, N.M., **Overview of Bioelectrical Impedance Analyzers**, The American Journal of Clinical Nutrition, Vol. 64, No. 3, pp. 405S-412S (1996).

Six commercial bioelectrical impedance analyzers were evaluated to determine their accuracy as impedance meters, their sensitivity to contact impedance, and other operating parameters such as maximum current amplitude and test waveform. Over a range of impedances that simulate human body impedance, analyzer errors varied from <1% to nearly 20%. Larger errors were observed when the contact impedance was at the limits of the operating range of the analyzer. Body models, sources of error, and several simple tests that the user can perform are also discussed.
[Contact: Nile M. Oldham, (301) 975-2408]

Oldham, N.M., Parker, M.E., Bell, B.A., and Avramov-Zamurovic, S., **Exploring the Low Frequency Performance of Thermal Converters Using Circuit Models and a Digitally Synthesized Source**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 495-496.

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

Oldham, N.M., Parker, M., Waltrip, B., and Avramov-Zamurovic, S., **Low Voltage Standards in the 10 Hz to 1 MHz Range**, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 570-571.

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

Waltrip, B.C., and Oldham, N.M., **DC-1 MHz Wattmeter Based on RMS Voltage Measurements**, Proceedings of the IEEE Instrumentation and Measurement Technology Conference, and IMEKO Technical Committee 7, Brussels, Belgium, June 4-6, 1996, Vol. 1, pp. 214-215.

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

Waveform Metrology

Recently Published

Oldham, N.M., **Overview of Bioelectrical Impedance Analyzers**, The American Journal of Clinical Nutrition, Vol. 64, No. 3, pp. 405S-412S (1996).

[See DC and Low-Frequency Metrology.]

Cryoelectronic Metrology

Released for Publication

Benz, S.P., and Burroughs, C.J., **Constant-Voltage Steps in Arrays of Nb-PdAu-Nb Josephson Junctions**.

[See Fundamental Electrical Measurements.]

Benz, S.P., Burroughs, C.J., and Hamilton, C.A., **Operating Margins for a Pulse-Driven Programmable Voltage Standard**.

[See Fundamental Electrical Measurements.]

Grossman, E.N., Reintsema, C.D., Koch, J.A., Berkowitz, S.J., Hirahara, A., and Char, K., **Far-Infrared Radiometers Based upon High-T_c and Low-T_c Superconducting Transition-Edge Thermometers**, to be published in the Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), International Symposium on Optical Science, Engineering, and Instrumentation, Denver, Colorado, August 4-9, 1996.

We describe two projects aimed at applying the great temperature sensitivity of superconducting thin films when biased at their critical temperature tc high sensitivity radiometry in the 10 to 50 μm wavelength region. The first is a standards-grade system for installation in the NIST Low-Background Infrared Calibration Facility. It employs thin-film Nb thermometers, and has an operating temperature of 9 K. This system's absorber is a large aperture Cu cone with a blackened interior to which a thermometer chip is thermally grounded. The absorber and a thermal isolation platform are each thermally stabilized with separate active feedback loops that sense the resistance of their respective thermometers. Temperature control at the level of 1.4 nK (Allan variance over 350 s) has been achieved with this system. The power sensitivity is presently limited by 1/f noise to approximately 10 pW (Allan variance), approximately a factor of 4 better than the current system based on Ge thermistors. The second system is intended for high-sensitivity imaging arrays, and employs YBCO films on free-standing zirconia membranes. The operating temperature is 89 K for pure YBCO devices and in the range of 70 to 85 K for Co-doped YBCO devices, depending on doping level. The best measured performance on these devices is an optical noise-equivalent power of 1.1 pW/Hz$^{1/2}$, with an associated 3 dB rolloff frequency of 130 Hz for the pure YBCO devices and 0.6 pW/Hz$^{1/2}$ and 31 Hz for the Co-doped devices. These values represent the best performance, by approximately a factor of 2 in NEP and an order of magnitude in speed, reported for superconducting infrared bolometers operating at liquid-nitrogen temperature.
[Contact: Erich N. Grossman, (303) 497-5102]

Hamilton, C.A., Benz, S.P., Burroughs, C.J., and Harvey, T.E., **SNS Programmable Voltage Standard**.

[See Fundamental Electrical Measurements.]

Hamilton, C.A., and Burroughs, C.J., **Josephson Voltage Standard - A Review**.

[See Fundamental Electrical Measurements.]

Huber, M.E., Cromar, M.W., and Ono, R.H., **Excess Low-Frequency Flux Noise in dc SQUIDS**.

We have fabricated dc superconducting quantum interference devices (SQUIDs) incorporating niobium/aluminum oxide/niobium Josephson junctions in both stripline and washer geometries. Low-frequency noise in excess of that predicted by the resistively-shunted junction model is present in both geometries and is demonstrated to be flux noise. This flux noise is not environmental. Improvements in fabrication processing over the past four years have reduced the level of this flux noise. SQUIDs are now fabricated with palladium-gold resistors, niobium wiring layers, and silicon dioxide passivation. Our best results to date are energy sensitivity at the level of 50 x 10^{-31} J·s for high frequencies with a 1/f knee below 1 Hz. We believe further reduction in the flux noise might be obtained with the use of on-chip flux shielding and/or trapping structures.
[Contact: Ronald H. Ono, (303) 497-3762]

Li, H.Q., Ono, R.H., Vale, L.R., Rudman, D.A., Liou, S.H., and Mallison, W.H., **An Improved Multi-Layer Fabrication Process for $YBa_2Cu_3O_{7-x}$ Based Circuits**.

Improved via connections in structures of $YBa_2Cu_3O_{7-x}/SrTiO_3/YBa_2Cu_3O_{7-x}$ (YBCO/STO/-

YBCO) multilayers have been made using a combined HF wet-etching and ion-milling process. The critical current density J_c of the via is as high as 2×10^6 A/cm^2 at 76 K and is dominated by edge contacts to ab-plane. YBCO and Sr_2AlNbO_6 (SAN) multilayer test circuits were also made with this process. The crossovers in a SAN test chip with 4° edge angles had a critical temperature T_c of 88 K and J_c of 1.5×10^6 A/cm^2 at 81 K, very close to those of the planar film, showing no evidence of weak links where the YBCO crosses low angle SAN steps.
[Contact: Ronald H. Ono, (303) 497-3762]

MacDonald, M.E., and Grossman, E.N., **Far-Infrared Bandpass Grid Filters**, to be published in the Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), International Symposium on Optical Science, Engineering, and Instrumentation, Denver, Colorado, August 4-9, 1996.

The spectral performance of bandpass grid filters centered at terahertz frequencies is presented. The filters are composed of a periodic array of cross-shaped apertures in an evaporated metal film on a thin dielectric backing. A commercial Fourier-transform spectrometer is used to measure spectral transmittance. Results are presented for filters using metals of different conductivity and thickness. The peak transmittance is correlated with the dc surface resistance R_s of the film, which is probed using an *in-situ* test structure on the fabricated filters. This is found to be true even though the metal films all have a thickness several times the classical skin depth at the resonant frequency. Measurements of R_s and peak transmittance at 77 K show an equivalent correlation, indicating that some of the loss is due to the finite conductivity of the metal film. Other loss mechanisms are discussed. Additional results are given for the effect of the dielectric backing, which causes a downward shift in the center frequency of the filter proportional to the dielectric constant and thickness of the backing. The center frequency shifts rapidly with increasing dielectric thickness and reaches an asymptotic value reduced from the freestanding case by the square root of the mean dielectric constant. Measurements are compared to a finite-difference time domain model, which accurately predicts the center frequency, but does not account for losses. The performance of these filters, along with their simple fabrication, makes them useful frequency-selective elements at far-infrared wavelengths.
[Contact: Erich N. Grossman, (303) 497-5102]

Cryoelectronic Metrology

Recently Published

Kautz, R.L., **Noise, Chaos, and the Josephson Voltage Standard**, Reports on Progress in Physics, Vol. 59, pp. 935-992 (1996).

[See Fundamental Electrical Measurements.]

Kunkel, G., and Ono, R.H., **Mutual Phase-Locking of Ten $YBa_2Cu_3O_7$ Step-Edge Josephson Junctions Up to 45 K**, Applied Physics Letters, Vol. 69, No. 13, pp. 1960-1962 (23 September 1996).

We have developed a microwave circuit using ten parallel-biased high-temperature superconductor Josephson junctions to demonstrate phase-locking for applications such as oscillators, mixers, and detectors. The basic cell consists of two Josephson junctions enclosed in a microstrip resonator, which provides voltage-locking and low-dynamic resistance in the current-voltage characteristic. Partial synchronization of the ten junctions was observed up to 45 K and up to 1 THz. The implications of this design for power and radiation linewidth are discussed.
[Contact: Ronald H. Ono, (303) 497-4762]

Antenna Metrology

Released for Publication

MacDonald, M.E., and Grossman, E.N., **Pattern and Polarization Measurements of Integrated-Circuit Spiral Antennas at 10 μm Wavelength**, to be published in the Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), International Symposium on Optical Science, Engineering, and Instrumentation, Denver, Colorado, August 4-9, 1996.

Radiation patterns are presented for planar equiangular spiral antennas at wavelengths of approximately 10 μm. These antennas are fabricated using integrated-circuit processes on silicon substrates and are coupled through dielectric lenses. Patterns are presented over a full two-dimensional (altitude and azimuth) scan for orthogonal linear polarizations, and for left- and right-circular polarizations. The antennas are found to respond preferentially to left-circular polarized radiation, as expected for the left-handed sense of the spiral arms. Cross-polarization ratios as large as 10 dB in circular polarization are obtained, corresponding to an axial ratio of 1.2. No difference in response between horizontally and vertically polarized radiation is observed, as expected for circularly polarized antennas. Directivities as large as 14 dB in left-circular polarization have been obtained. The cross-polarized directivity is considerably lower than the co-polarized directivity. Measured directivities in linear polarization are approximately 8.2 dB for both polarizations. All patterns are approximately circularly symmetric about the θ=0 axis. The cross-polarization ratio and pattern symmetry are strongly dependent on the alignment of the antenna and detector layers during fabrication. These results definitively demonstrate that the detector response is antenna coupled, even at radiation wavelengths ($\lambda_0 \approx 10$ μm, $\lambda_{substrate} \approx 3$ μm) of the same order of magnitude as the resolution limit of the optical lithography used to define the antenna geometry.
[Contact: Erich N. Grossman, (303) 497-5102]

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 Antenna Measurements Techniques Association, Seattle, Washington, September 30—October 4, 1996.

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**, to be published in the Proceedings of the Antenna Measurements Techniques Association Symposium, Seattle, Washington, September 30—October 4, 1996.

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]

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**, to be published in the Proceedings of the Antenna Measurements Techniques Association Symposium, Seattle, Washington, September 30—October 4, 1996.

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 reflector antenna.
[Contact: Carl F. Stubenrauch, (303) 497-3927]

Will, J.E., Norgard, J.D., Sega, R.M., Seifert, M., Pesta, A., Cleary, J., Stubenrauch, C.F., and MacReynolds, K., **Determining Antenna Near Field Phase Data from Infrared Thermograms Using Fourier Iterative Plane-to-Plane Techniques**, to be published in the Proceedings of the Antenna Measurements Techniques Association Symposium, Seattle, Washington, September 30—October 4, 1996.

This paper describes the application of the plane-to-plane (PTP) iterative Fourier processing technique to infrared (IR) thermographic images of microwave fields for the purpose of determining the near-field and far-field patterns of radiating antennas. The PTB technique allows recovery of the phase by combining magnitude-only measurements made on two planes, both in the radiating near field of the antenna under test (a companion paper in this proceedings describes the process of determining the field-magnitude data from IR thermograms). We describe the PTP technique and show comparisons made between the predicted results and results from measured IR thermograms of the field of a 36-element patch array antenna operating at 4 GHz, using the University of Colorado, Colorado Springs (UCCS) Thermal Camera.
[Contact: Carl F. Stubenrauch, (303) 497-3927]

Will, J.E., Norgard, J.D., Sega, R.M., Seifert, M., Pesta, A., Cleary, J., Stubenrauch, C.F., and MacReynolds, K., **Infrared Imaging Techniques for the Measurement of Complex Near-Field Antenna Patterns**, to be published in the Proceedings of the 1996 Quantitative Infrared Thermography, Stuttgart, Germany, September 2-5, 1996.

This paper describes the application of the "plane-to-plane" (PTP) iterative Fourier processing technique to infrared thermographic images of microwave fields to calculate the near-field and far-field patterns of radiating antennas. The PTP technique allows recovery of the phase by combining intensity (magnitude) measurements made on two planes, both in the radiating near field of the antenna under test. Starting with an estimate of the phase and the measured magnitudes, Fourier processing techniques are used to iteratively "propagate" between the planes to determine the correct phase distribution at each plane. We describe the technique and show comparisons made between predicted and measured results.
[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**, to be published in the Proceedings of the Antenna Measurements Techniques Association Symposium, Seattle, Washington, September 30—October 4, 1996.

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**, to be published in the Proceedings of the Antenna Measurements Techniques Association, Seattle, Washington, September 30—October 4, 1996.

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]

Noise Metrology

Released for Publication

McDonald, D.G., Phelan, R.J. Jr., Vale, L.R., Ono, R.H., Rice, J.P., Borcherdt, L., Rudman, D.A., Cosgrove, J., and Rosenthal, P., **Noise from YBCO Films: Size and Substrate Dependence**.

Electrical noise measurements at 10 Hz are reported for YBCO films at the resistive edge. Results are given for films with widths of 0.1, 1, and 5 mm that were deposited simultaneously on the same substrate, for three different substrate materials. The NET improves by approximately a factor of 10 as the thermometer area is increased by a factor of 2500, with fixed bias current. At temperatures giving maximum dR/dT and with nominally 19 mA bias currents, the 5 mm samples have very low noise equivalent temperatures of 3.1, 3.5, and 4.4 nK/$\sqrt{Hz}$ for $LaAlO_3$, Al_2O_3, and Si substrates, respectively. These are the lowest values reported up to the present time. Surprisingly, noise from the sample on Si is consistent with pure Johnson noise even with bias current as large as 5 mA (0.28×10^4 A/cm^2). For YBCO thicknesses no greater than 50 nm, excellent thermometers can be made on any of these substrates in spite of the mechanical strains produced in the films by the substrate.
[Contact: Ronald H. Rice, (303) 497-3762]

Noise Metrology

Recently Published

Williams, D.F., **Thermal Noise in Lossy Waveguides**, IEEE Transactions on Microwave Theory and Techniques, Vol. 44, No. 7, pp. 1067-1073 (July 1996).

[See Microwave and Millimeter-Wave Metrology.]

Microwave and Millimeter-Wave Metrology

Guerrieri, J.R., MacReynolds, K., Canales, S., and Tamura, D.T., **Mismatch Errors in Insertion-Loss Measurements Using Harmonic Mixers**, to be published in the Proceedings of the Antenna Measurements Techniques Association, Seattle, Washington, September 30—October 4, 1996.

In this paper, we discuss proper rf system design for performing insertion-loss measurements using a microwave receiver and harmonic mixers. Specifically, we will deal with problems caused by changing reflection coefficients of the devices which feed the mixer. When employing broadband mixers and coaxial isolators, problems may be encountered 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 measurements and suggest a procedure to properly minimize its effects.
[Contact: Jeffrey R. Guerrieri, (303) 497-3863]

Hill, D.A., and Kanda, M., **Electric Field Strength**.

Electric field strength measurements are reviewed. Field mills determine electrostatic field strength by measuring modulated, capacitively induced charges or currents on electrodes. Field strength meters for ac electric fields include some type of antenna and a detector. Specific antenna types are discussed for frequencies up to 40 GHz.
[Contact: David A. Hill, (303) 497-3472]

Walker, D.K., and Williams, D.F., **Compensation for Geometrical Variations in Coplanar Waveguide Probe-Tip Calibration**.

We show how coplanar-waveguide probe-tip scattering parameter calibrations performed in one coplanar waveguide conductor geometry may be adjusted for measurement in another. The method models the difference between the two probe-tip-to-coplanar-waveguide transitions as a change in shunt capacitance, and applies previously-developed techniques for its determination and compensation. Compensation to accurate multiline Thru-Reflect-Line calibrations verifies the accuracy of the method. Differences in both conductor geometry and substrate permittivity are considered in the comparison.
[Contact: David K. Walker, (303) 497-5490]

Williams, D.F., Marks, R.B., and Hayden, L.A., **A Complete Multimode Equivalent-Circuit Theory for Electrical Design**, to be published in Journal of Research of the National Institute of Standards and Technology.

This work presents an equivalent-circle theory for lossy multimode transmission lines. Its voltages and currents, which we call the conductor voltages and currents, are based on general linear combinations of standards normalized modal voltages and currents. We present new expressions for transmission line impedance matrices, symmetry and lossless conditions, source representations, and the thermal noise of passive multiports, completing the theory.
[Contact: Dylan F. Williams, (303) 497-3138]

Microwave and Millimeter-Wave Metrology

Recently Published

Williams, D.F., **Thermal Noise in Lossy Waveguides**, IEEE Transactions on Microwave Theory and Techniques, Vol. 44, No. 7, pp. 1067-1073 (July 1996).

This work rigorously treats thermal electromagnetic noise in lossy waveguides and develops explicit modal equivalent-circuit representations for the noise generated by arbitrary passive networks embedded in them. The results show that the formulations in common use are limited to lossless transmission media.
[Contact: Dylan F. Williams, (303) 497-3138]

Electromagnetic Properties

Released for Publication

Geyer, R.G., and Krupka, J., **Complex Permeability Measurements of Microwave Ferrites**, to be published in the Proceedings of Materials Research Society Meeting, San Francisco, California, April 7-12, 1996.

A rigorous and accurate method for the experimental determination of the complex permeability of demagnetized ferrites at microwave frequencies is presented. The measurement technique utilizes 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 were measured in the demagnetized state. Generally, at any frequency greater than gyromagnetic resonance, the real part of the complex permeability increases as saturation magnetization increases. For the same frequency magnetic losses increase 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]

Geyer, R.G., Krupka, J., Sengupta, L., and Sengupta, S., **Microwave Properties of Composite Ceramic Phase Shifter Materials**, to be published in the Proceedings of the 1996 IEEE International Symposium for Applications of Ferroelectrics, New Brunswick, New Jersey, August 19-21, 1996.

The microwave properties of bulk ceramic barium strontium titanate and nonferroelectric oxide composites are measured at X-band with a cylindrical modefiltered resonant cavity. A helical wire-wound wave-guide makes up the cavity's cylindrical wall, which permits the use of high purity TE_{01n} resonant modes for high accuracy permittivity measurements. Measurement results at 300 K show that microwave dielectric losses increase as the non-stoichiometric percentage of barium increases. The real relative permittivity increases with decreasing weight percent of added nonferroelectric low-loss oxide.
[Contact: Richard G. Geyer, (303) 497-5852]

Jones, C.A., Kantor, Y., and Grosvenor, J.H., **Permittivity Measurements of Low-Loss Dielectric Materials at 60 GHz**, to be published in the Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), International Symposium on Optical Science, Engineering, and Instrumentation, Denver,

Colorado, August 4-9, 1996.

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

Krupka, J., Geyer, R.G., Baker-Jarvis, J., and Ceremuga, J., **Measurements of the Complex Permittivity of Microwave Circuit Board Substrates Using Split Dielectric Resonator and Reentrant Cavity Techniques**, to be published in the Proceedings of the 7th International Conference on Dielectric Materials Measurements and Applications, Bath, England, September 23-26, 1996.

A dielectric resonator method for nondestructive testing of the complex permittivity of microwave dielectric substrates was developed. With this technique, the dielectric properties in the plane of the substrate under test are determined. The dielectric properties of uniaxially anisotropic substrates may be resolved by combining measurements performed with the dielectric resonator method with those from a reentrant cavity.
[Contact: Richard G. Geyer, (303) 497-5852]

Lewis, R.L., **Relative Permittivity Measurement of Square Copper-Laminated Substrates Using the Full Sheet Resonance Technique**, to be published as NISTIR 5053.

The full sheet resonance (FSR) technique has been available a number of years for measuring the relative permittivity of microwave circuit board substrates. A measurement program has been undertaken at NIST to evaluate this technique, and consistent values for the relative permittivity have been obtained. Here, we present an analysis of the theory underlying the FSR technique, along with a theoretical formulation described in the literature for related measurements which, when implemented with the FSR technique, should improve the technique's absolute measurement accuracy. A theoretical uncertainty analysis is presented both for the FSR technique assuming these improvements have been implemented and for the standard FSR technique. Numerical uncertainty estimates are presented for the standard FSR technique. Our measured results are compared against re-entrant cavity measurements of the substrate material, and it is shown that both the FSR and re-entrant cavity measurements agree within expected uncertainty limits. We also present FSR measurement results for a circular disk, fed at the center of the disk, which tend to be substantiated by the re-entrant cavity measurements.
[Contact: Richard L. Lewis, (303) 497-5916]

Electromagnetic Properties

Recently Published

Jargon, J.A., and Janezic, M.D., **Measuring Complex Permittivity and Permeability Using Time Domain Network Analysis**, Digest of the 1996 International Microwave Symposium, San Francisco, California, June 17-21, 1996, Vol. 3, pp. 1407-1410.

We use a time domain network analyzer along with a recent improvement to the transmission/reflection method to determine the complex permittivity and permeability of a sample in a coaxial line. Our data show that accurate measurements can be made without a conventional frequency domain network analyzer.
[Contact: Jeffrey A. Jargon, (301) 975-3596]

Complex System Testing

Recently Published

Deyst, J.P., Souders, T.M., and Blair, J.J., **Uncertainties of Frequency Response Estimates Derived from Responses to Uncertain Step-Like Inputs**, Proceedings of the 1996 IEEE Instrumentation and Measurement Technology Conference, Brussels, Belgium, June 4-6, 1996, pp. 151-154.

The frequency response of a linear time-invariant system can be estimated from the measurement of its response to an ideal step input. However, an ideal step is unrealizable, and various other error

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

Koffman, A.D., Souders, T.M., Stenbakken, G.N., Lipe, T.E., and Kinard, J.R., **Empirical Linear Prediction Applied to a NIST Calibration Service**, Proceedings of the 1996 National Conference of Standards Laboratories Workshop and Symposium, Monterey, California, August 25-29, 1996, pp. 207-212.

Empirical linear prediction, developed at NIST, has recently been applied to the NIST calibration of a commercial multi-range ac-dc thermal transfer standard. This approach reduced the number of required test points by 62%, resulting in significant cost savings. The calibration model was developed using extensive test data obtained from the instrument manufacturer. Calibration measurements for the instrument under test were made at the reduced set of test points, enabling subsequent predictions of the response at all unmeasured points using the model. Uncertainties for the unmeasured points were developed by testing the goodness of fit of the calibration measurements to the model. These uncertainty intervals depend on the quality of the model, as well as on the number of points actually measured. The ability of the model to characterize the instrument under test is key to achieving low uncertainties. A brief mathematical description of the modeling and prediction process is presented along with measurement results.
[Contact: Andrew D. Koffman, (301) 975-4518]

Other Signal Topics

Recently Published

Richter, C.A., Seiler, D.G., and Pellegrino, J.G., **Quantum Conductance Fluctuations in the Large-Size-Scale Regime**, Physical Review B, Vol. 53, No. 19, pp. 13 086—13 090 (15 May 1996).

[See Compound Materials.]

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: J. Andrew Aust, (303) 497-3942]

Day, G.W., **Optoelectronics at NIST**, to be published as NISTIR 5054.

This document is a product of efforts by the ad hoc NIST Optoelectronics Committee to encourage more coordination and collaboration among NIST researchers in the field and more efficient use of NIST resources. The primary audience is NIST scientists, engineers, and managers, but the document is also being made available externally to enable others in the optoelectronics community to identify work at NIST that could be of interest to them.

Fifty distinguishable projects are described. The smallest involves less than one full-time equivalent

staff member; the largest, eighteen. Altogether, approximately 170 FTE staff work in the field. Each project description was prepared by the project leader and contains information about the size of the project, its objectives, constituency, and major current tasks. Additional background information provides some perspective.
[Contact: Gordon W. Day, (303) 497-5204]

Day, G.W., Franzen, D.L., and Williams, P.A., **Technical Digest, Ninth Symposium on Optical Fiber Measurements, 1996**, to be published at NIST Special Publication 907.

Measurements of polarization mode dispersion (PMD) 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]

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

We have used multilayer mirror optimization methods to enhance the coupling of pump light into vertical-cavity surface-emitting lasers (VCSEL). With previously reported devices, pump light was coupled into VCSEL cavities through interference notches in the mirror-reflectance spectrum. This approach is sensitive to temperature-dependent reflectance spectrum shifts. We have created devices with a wide pump band window of low reflectance. We report the simulation, growth, and optically pumped lasing of such optimized low-ripple VCSELs. Further, broadband pump windows open the possibility of spectrally-broad optical pumps and they eliminate need for costly tunable pump lasers.
[Contact: David H. Christensen, (303) 496-3354]

MacDonald, M.E., and Grossman, E.N., **Far-Infrared Bandpass Grid Filters**, to be published in the Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), International Symposium on Optical Science, Engineering, and Instrumentation, Denver, Colorado, August 4-9, 1996.

[See Cryoelectronic Metrology.]

Masterson, K.D., Novotny, D.R., and Koepke, G.H., **The Electromagnetic Shielding Characteristics of Optical-Fiber Connectors**.

[See Radiated - EMI.]

Mechels, S.E., Schlager, J.B., and Franzen, D.L., **Accurate Measurements of the Zero-Dispersion Wavelength in Optical Fibers**, to be published in Journal of Research of the National Institute of Standards and Technology.

This paper reports the development of a Standard Reference Material (SRM) which characterizes the zero-dispersion wavelength (λ_0) and the dispersion slope (S_0) at λ_0 of single-mode optical fibers. We have documented a system which measures the dispersion of both dispersion-unshifted (λ_0 near 1.3 μm) and dispersion-shifted fibers (λ_0 near 1.55 μm). While the principal system uses the frequency-domain phase shift technique, a differential phase shift technique and four-wave mixing technique have also been investigated. The fiber SRMs have their λ_0 value measured with an accuracy of $\pm$0.08 nm. Dispersion slope was also studied, but with a more limited scope. The slope S_0 is determined to $\pm$0.0005 ps/nm^2 •km.
[Contact: Steven E. Mechels, (303) 497-5409]

Rose, A.H., **Devitrificaiton in Annealed Optical Fiber**.

The decrease in transmittance of annealed optical fiber has been measured versus temperature and time. The annealing loss is due to the devitrification of the glass and OH absorption in the 1200 nm to 1500 nm wavelength region. Both loss mechanisms propagate primarily from the surface into the core. However, to increase the OH absorption significantly, annealing times greater than 10 h are required. Fibers heated from 1000 °C to 1300 °C in an air atmosphere quickly devitrify and their transmittance approaches zero. Also, the current sensitivity of annealed fiber current sensors versus annealing time at 850 °C has been measured. A decrease in the current sensitivity is attributed to

devitrification in the fiber.
[Contact: Allen H. Rose, (303) 497-5599]

Schaafsma, D.T., and Christensen, D.H., **Cavity Effects and Metrology of Vertical-Cavity Semiconductor Lasers**, to be published as NISTIR 5047.

The growing sophistication of vertical-cavity surface-emitting lasers, or VCSELs, has fostered questions which have previously lacked a certain relevance. In particular, the gain medium in the laser can now be confined to a very small region of space and moved about within the cavity, and the mode volume of the cavity itself can be reduced to a scale where coupling between the source medium and the emitted radiation and even the quantum nature of light can become significant. This work explores two types of coupling in planar cavities: emitter coupling, a light-matter interaction; and mode coupling, a light-only interaction. Technological applications of coupling effect are discussed, along with novel metrology designed for devices such as VCSELs. A novel experimental technique for probing the side-emission from VCSELs is also described and is used to probe for coupling effects and to serve as a metrological tool. Experiments designed to probe for emitter coupling in VCSELS are described, and their results show that the effect of the cavity on the emitter can indeed be seen in side emission studies. The results of this experiment show side emission to be a versatile tool not only for examining cavity effects but also for basic metrology and modeling of optical responses. The general effects of mode coupling are illustrated in a simplified experiment designed to show the strong redistribution of energy from a dipole inside an etalon, which is much more pronounced than the normal etalon redistribution effects for light originating outside the cavity. These tests also show that redistribution of intensity patterns does not indicate feedback to an emitter from its own radiation. This type of coupling to cavity modes is then examined in VCSEL structures and shown to be potent enough for device applications.
[Contact: David T. Schaafsma, (303) 497-7281]

Svalgaard, M., and Gilbert, S.L., **Frequency Stability of Short Single-Mode Erbium-Doped Fiber Lasers**, to be published in the Proceedings of the 1997 Optical Fiber Communications Conference, Dallas, Texas, February 16-21, 1997.

We have measured the frequency noise of short erbium-doped Bragg-grating fiber lasers. We find that single-mode lasers have very low frequency jitter; the integrated noise from 50 Hz to 63 kHz was 36 kHz rms.
[Contact: Sarah L. Gilbert, (303) 497-3120]

Williams, P.A., Rose, A.H., and Wang, C.M., **Automated Polarimeter for Quarter-Wave Retardance Measurement at ±0.10° Accuracy**.

An automated polarimeter for the measurement of linear retardance independent of laser power and detector gain is described. Retardance is found from a curve fit to a unique normalization of the intensity response through the polarimeter over a range of input polarizer orientations. Performance of this polarimeter is demonstrated by measurements on stable Fresnel double rhombs of nominal quarter-wave retardance yielding combined standard uncertainties of less than 0.10°. Accuracy has also been verified by blind comparisons with interferometric and modified manual null retardance measurement techniques.
[Contact: Paul A. Williams, (303) 497-3805]

OPTOELECTRONICS

Recently Published

Huang, X.R., Cheung, S.K., Cartwright, A.N., Smirl, A.L., and Tseng, W.F., **An interdigitated Stacked p-i-n Multiple-Quantum-Well Modulator**, IEEE Photonics Technology Letters, Vol. 8, No. 9, pp. 1172-1174 (September 1996).

[See Compound Materials.]

Obarski, G.E., Larson, D.R., and Phelan, R.J., **Multi-Gigahertz Relative intensity Noise of an InGaAsP Laser at Cryogenic Temperature**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), High-Speed Semiconductor Laser Sources, Vol. 2684, pp. 84-91 (1996).

Using a well-characterized measurement system having 22 GHz bandwidth, we show that the relative

intensity noise (RIN) of a commercial InGaAsP laser (multi-longitudinal mode) operating at 77 K is significantly reduced below room-temperature values over a broad-frequency range. For laser operation with equal-drive currents at both temperature, a RIN reduction of as high as ≈24 dB/Hz is observed in the frequency region of relaxation oscillations, while for operation with equal power outputs, the maximum reduction observed is ≈14 dB/Hz.
[Contact: Gregory E. Obarski, (303) 497-5747]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Grossman, E.N., Reintsema, C.D., Koch, J.A., Berkowitz, S.J., Hirahara, A., and Char, K., **Far-Infrared Radiometers Based upon High-T_c and Low-T_c Superconducting Transition-Edge Thermometers**, to be published in the Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), International Symposium on Optical Science, Engineering and Instrumentation, Denver, Colorado, August 4-9, 1996.

[See Cryoelectronic Metrology.]

Stenbakken, G.N., and Dolev, A., **NIST High Accuracy Sampling Wattmeter**.

[See DC and Low-Frequency Metrology.]

Van Brunt, R.J., von Glahn, P., and Las, T., **Anomalous Stochastic Behavior of Partial Discharge on Aluminum Oxide Surfaces**.

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

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

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

Power Systems Metrology

Recently Published

Petersons, O., Simmon, E., and FitzPatrick, G.J., **An Active High Voltage Divider with 20 ppm**

Uncertainty, Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996, pp. 486-487.

A voltage divider has been designed which consists of a group of solid-dielectric capacitors maintained in a temperature-controlled environment, an external compressed-gas capacitor, and special electronic circuitry. The prototype divider has been constructed and preliminary results obtained to validate the operating principle and accuracy target. The principal innovative part is a feedback amplifier, complemented with an "open-loop" voltage source controlled from the high voltage. This enables achievement of a voltage ratio that is equal to the reciprocal of the capacitance ratio well within one ppm without encountering dynamic instability problems.
[Contact: Eric Simmon, (301) 975-3956]

Magnetic Materials and Measurements

Released for Publication

Rogers, C.T., Kirschenbaum, L.S., Beale, P.D., Russek, S.E., and Sanders, S.C., **Observation of a Fluctuation Enhanced Magnetoresistance in $Ni_{81}Fe_{19}$/Ag Multilayers at High Current Density**.

We report on the correlation between low frequency resistance noise and magnetoresistance for $Ni_{81}Fe_{19}$/Ag giant magnetoresistance systems with dc bias current density above 106 A/cm^2. Current densities at this level cause internal magnetic fields sufficient to magnetically saturate the $Ni_{81}Fe_{19}$ layers. Addition of an external magnetic field allows the local field at any given magnetic layer to be tuned to approximately zero strength. Under these conditions, we measure the resistance noise associated with magnetic orientational fluctuations within the multilayer. This magnetic noise has a 1/f-like spectrum and an amplitude that is strongly correlated with previously observed magnetoresistance peaks. These results suggest that the magnetoresistance peaks arise from a fluctuation-induced enhancement in antiferromagnetic order within the multilayer.
[Contact: Steven Russek, (303) 497-5097]

Magnetic Materials and Measurements

Recently Published

Kirschenbaum, L.S., Rogers, C.T., Beale, P.D., Russek, S.E., and Sanders, S.C., **Bias Current Dependent Resistance Peaks in NiFe/Ag Giant Magnetoresistance Multilayers**, Applied Physics Letters, Vol. 68, No. 22, pp. 3099-3101 (27 May 1996).

We show that thin film $Ni_{82}Fe_{18}$ multilayer structures display multiple peaks in their magnetoresistance curves when biased at current densities above 10^6 A/cm^2. These peaks appear for annealed and unannealed structures, and their number is correlated with the number of NiFe layers. At high-bias currents, the peak positions shift linearly with the internal magnetic field created by the bias current. The peak positions extrapolate to non-zero fields at zero bias currents, providing an upper bound on the magnetic layer-layer coupling strength of $J_0 \approx 10^{-20}$ J(= K_B x 700 K). The peak positions do not shift with temperature over the range 200 to 375 K: their widths narrow with increasing temperature. The single-domain magnetic moment μ is estimated as 10^{-17} J/T (10^6 μ_B) from the peak widths of ~0.8 kA/m.
[Contact: Stephen E. Russek, (303) 497-5097]

Oti, J.O., Cross, R.W., Russek, S.E. and Kim, Y.K., **Simulated Magnetoresistive Behavior of Geometrically Asymmetric Spin Valves**, IEEE Transactions on Magnetics, Vol. 32, No. 5, pp. 4606-4608 (September 1996).

A semi-analytical micromagnetic model is used to study how the magnetoresistive (MR) response is affected by uneven geometries in NiFe/Cu/NiFe spin-valve devices. Devices with unequal stripe heights and thicknesses of the magnetic layers are studied. The calculated devices are 4 μm long, pinned by a transverse field of 16 kA/m and have nonmagnetic spacer thicknesses of 4 nm. Stripe heights are varied from 0.5 μm to 2 μm and magnetic-layer thicknesses from 3 nm to 6 nm. Device responses are analyzed and used to indicate how optimal device geometries may be selected.
[Contact: John Oti, (303) 497-5557]

Superconductors

Released for Publication

Goodrich, L.F., Medina, L.T., and Stauffer, T.C., **Repeatability of Critical-Current Measurements on Nb_3Sn and Nb-Ti Wires**.

A varying degree of repeatability has been observed in critical-current (I_c) measurements as a function of the number of thermal cycles from room temperature to 4 K. These data indicate that, if the I_c changes beyond the error limits, it increases fairly monotonically with thermal cycling until it eventually saturates. The increase between the first and second thermal cycle can be 1 to 2% at 12 T for Nb_3Sn wires. This was observed on a Nb_3Sn wire by all four laboratories that participated in a recent interlaboratory comparison conducted in the International Thermonuclear Experimental Reactor (ITER) project. In contrast, the I_c of a Nb-Ti wire is very repeatable with thermal cycling. This suggests that the effect on the Nb_3Sn wire is due to its strain sensitivity. Most of these data were taken with the sample on a Ti-6Al-4V measurement mandrel. This study also investigated the repeatability of I_c measurements using other mandrel materials. The lack of repeatability in I_c measurements on Nb_3Sn wires is a limitation in precise interlaboratory comparisons and could have a positive effect on some applications.
[Contact: Loren F. Goodrich, (303) 497-3143]

Li, H.Q., Ono, R.H., Vale, L.R., Rudman, D.A., Liou, S.H., and Mallison, W.H., **An Improved Multi-Layer Fabrication Process for $YBa_2Cu_3O_{7-x}$-Based Circuits**.

[See Cryoelectronic Metrology.]

McDonald, D.G., Phelan, R.J. Jr., Vale, L.R., Ono, R.H., Rice, J.P., Borcherdt, L., Rudman, D.A., Cosgrove, J., and Rosenthal, P., **Noise from YBCO Films: Size and Substrate Dependence**.

[See Noise Metrology.]

Other Electrical Systems Topics

Released for Publication

Stricklett, K.L., and Vangel, M., **Electric Motor Efficiency Testing under the New Part 431 of Chapter II of Title 10, Code of Federal Regulations**, to be published as a NIST Technical Note.

The provisions for electric motor efficiency testing under the proposed new Part 431 of Chapter II of Title 10, Code of Federal Regulations, as published for public comment in the Federal Register, are discussed. The criteria for demonstration of compliance or noncompliance with the energy efficiency requirements established by Energy Policy and Conservation Act of 1975, as amended, and for substantiation of an alternative efficiency determination method are presented. The operational characteristics of the Sampling Plan for Enforcement Testing recommended by the new Part 431 are evaluated by model calculations. Results are presented that include ranges of motor efficiency variability, mean efficiency, and number of units tested.
[Contact: Kenneth L. Stricklett, (301) 975-3955]

ELECTROMAGNETIC INTERFERENCE

Conducted EMI

Released for Publication

Baird, R.C., and Kanda, M., **Measurement Related Issues, Problems and Requirements Associated with Electromagnetic Compatibility: Results of a Limited Survey**, to be published as NISTIR 5049.

[See Radiated EMI.]

Radiated EMI

Released for Publication

Baird, R.C., and Kanda, M., **Measurement Related Issues, Problems and Requirements Associated with Electromagnetic Compatibility: Results of a Limited Survey**, to be published as NISTIR 5049.

The purpose of this report is to give first-hand, up-to-date information on the measurement-related needs and problems associated with electromagnetic compatibility that are identified by U.S. industry. To achieve this goal, we interviewed

representatives of 23 major U.S. industries, 5 industrial associates, 1 university, and 8 government agencies concerned with electromagnetic interference/compatibility issues related to product performance and compliance, equipment use and manufacture, safety, and health. Although this report does not give specific recommendations for an expanded electromagnetic compatibility technology program in the Electromagnetic Fields Division at NIST, it does contain a wealth of information that should be considered in the Division's planning exercises. The anticipated result is a NIST program in electromagnetic interference/compatibility measurement technology that will provide optimum support to U.S. industry.
[Contact: Motohisa Kanda, (303) 497-5320]

Hill, D.A., and Kanda, M., **Electric Field Strength**.

[See Microwave and Millimeter-Wave Metrology.]

Masterson, K.D., Novotny, D.R., and Koepke, G.H., **The Electromagnetic Shielding Characteristics of Optical-Fiber Connectors**.

A number of commercially available fiber optic connector styles (ST, SC, and FC) were tested to determine the extent to which their use in bulkhead adapter feedthroughs would compromise the shielding of electromagnetic interference for electronic enclosures. Metal, ceramic, and polymer components were included in the test matrix. Tests were carried out using a nested reverberation cell technique and cover a frequency range from 1 GHz to 16 GHz. The shielding effectiveness varied widely, from a low of about 20 dB to a high for an all-metal FC connector system that was nearly equal to the 90 dB obtained for a blank reference plate. In some cases, the feedthrough coupled more energy into the enclosure than was coupled through the empty hole required to mount the adapter barrel. Comparison between the experimental results and the theory for coupling electromagnetic energy through a circular aperture enables us to more accurately determine the *Q* of the nested cell and to calculate transmission cross sections for the feedthroughs. The calculated transmission cross sections are not dependent on the specific experimental parameters and can be used to estimate the degradation in shielding effectiveness for enclosures other than our reference cell. The inaccuracies in the reported transmission cross sections are calculated to be ± 3 dB and are small compared to the differences between the measured cross sections.
[Contact: Keith D. Masterson, (303) 497-3756]

Radiated EMI

Recently Published

Camell, D., Koepke, G., Smith, R., and Rakoski, B., **A Standard Source Method for Reducing Antenna Factor Errors in Shielded Room Measurements**, NIST Technical Note 1385 (March 1996).

In this report, we examined the use of a well-characterized standard source of electromagnetic radiation as a means to calibrate the effects of the shielded room on a receiving antenna used for MIL-STD 461/462 RE102 emissions measurement. The goal was to compensate for the shielded room environment such that radiated emissions measurements can be more accurately compared from one room to another. This was accomplished by using a characterized spherical dipole source to calibrate an antenna's response in the location that it was used. An interlaboratory comparison was made of the detected emissions from a simulated equipment under test at three sites to see how this in-situ calibration of the receive antenna helped the shielded room test repeatability.
[Contact: Dennis G. Camell, (303) 497-3214]

Crawford, M.L., Loughry, T.A., Hatfield, M.O., and Freyer, G.J., **Band-Limited, White Gaussian Noise Excitation for Reverberation Chambers and Applications to Radiated Susceptibility Testing**, NIST Technical Note 1375 (January 1996).

This report gives the results of demonstration tests conducted to evaluate the electromagnetic environment (EME) produced by band-limited, white gaussian noise (BLWGN) excitation of a reverberation chamber and to verify its applications to susceptibility and shielding effectiveness testing. Data were collected to compare the EME produced in a reverberation chamber by CW and swept frequency excitation using both mechanical stirring and BLWGN to excite the cavity mode structure.

The feasibility of using the BLWGN technique for radiated susceptibility testing was evaluated by comparison with mechanical stirring in a reverberation chamber and with anechoic chamber results. Within normal measurement uncertainties, the response of both types of systems were the same for mechanical stirring and for BLWGN excitation and were consistent with the results obtained in the anechoic chamber.
[Contact: Myron L. Crawford, (301) 975-5497]

Ladbury, J.M., Johnk, R.T., and Ondrejka, A.R., **Rapid Evaluation of Mode-Stirred Chambers Using Impulsive Waveforms**, NIST Technical Note 1381 (June 1996).

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

PRODUCT DATA SYSTEMS

Released for Publication

Gale, R., and Parks, C.H., **A National Standard Keeps Pace**.

When it comes to comparisons, one point in favor of national versus international standards is that U.S. standards are capable of adapting to rapidly evolving technologies. To wit: a unique American National Standard CAD/CAM data exchange format, the Initial Graphics Exchange Specification (IGES), has kept pace with its technology over a span of 16 years. The authors attribute the IGES uniqueness to its process for managing changes. This paper traces the source of the IGES change management process, which is founded on the industry product configuration management disciplines, where each technical change is developed to consensus separately. Through this model, IGES has been able to take advantage of modern data technologies to release each technical change as it is approved. Although this standard, like many others, publishes successive versions, each version published incorporates only those technical changes which have been approved since the prior version. Many benefit from the practices described, including those people implementing the standard, those who rely on the implementations to exchange their CAD data, and the organization supporting IGES.
[Contact: Curtis H. Parks, (301) 975-3517]

PRODUCT DATA SYSTEMS

Recently Published

St. Pierre, J.A., Brady, K.G., and Stewart, S.L., **Conformance Testing and Specification Management**, NISTIR 5879 (September 1996).

This is the final report for the second year of a joint project between the National Institute of Standards and Technology and SEMATECH under a Cooperative Research and Development Agreement between the two organizations. A year ago, we submitted our first report: *Roadmap for the Computer Integrated Manufacturing Application Framework*. We are pleased to note that a number of our recommendations from that report have already been acted upon, and in some cases, going beyond what we expected. The *Computer Integrated Manufacturing (CIM) Application Framework Specification 1.3* has been made public in electronic form, it has been converted to a more accessible word processing format, and it has been divided into more manageable subdocuments for rapid evolution. SEMATECH has, to its credit, gone beyond our recommendations by adopting a networked-based document management system (Lotus Notes) that will support a much larger and distributed group of people participating in the further development of the CIM Framework.
[Contact: James A. St. Pierre, (301) 975-4124]

VIDEO TECHNOLOGY

Released for Publication

Boynton, P.A., and Kelley, E.F., **Measuring**

Contrast Ratio of Displays: It's Not As Trivial As You Think.

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 show possible methods for correcting for it.
[Contact: Paul A. Boynton, (301) 975-3014]

VIDEO TECHNOLOGY

Recently Published

Boynton, P., Jones, G., and Kelley, E., **Flat Panel Display Lab at NIST**, Proceedings of the Third Annual Military Display Workshop, Ft. Monmouth, New Jersey, July 11-13, 1995, Appendix G-1 (1996).

The United States is a very large market for high-performance, reasonable-cost, flat-panel displays for use in a wide variety of products: computer systems, transportation systems (air, water, and ground), as well as entertainment systems. As different display technologies become available, there will be a greater need to specify performance parameters in a well-characterized manner. In order to qualify a display's suitability for a given task, both the manufacturer and the user need a common specification language regarding display performance characteristics. Since the National Institute of Standards and Technology (NIST), is the nation's leading measurement and standards laboratory, and is neutral regarding manufacturer preference, it is in an ideal position to provide assistance to the development on standards and measurement practices which do not favor any single display technology.

Display quality issues are not simply a matter of light measurement, power efficiency, automation, quality control, display environment, or signal quality. Rather, many of these factors act in concert to affect display quality, with an important addition - the complexities of human visual perception. The Flat Panel Display Laboratory at NIST provides a flexible environment capable of addressing a large variety of display-quality measurements. It is not limited to emissive flat-panel displays, but also includes analysis of non-emissive displays, and projection systems, and CRTs. Research also includes the visual perception of the eye using a video supercomputer to provide parametric real-time modification of video images.
[Contact: Paul A. Boynton, (301) 975-3014]

Boynton, P.A., Ohno, Y., and Kelley, E.F., **Interference-Filter Characterization of Spectraradiometers and Colorimeters**, Digest of Technical Papers, Society for Information Display International Symposium, San Diego, California, May 12-17, 1996, pp. 207-210.

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

Jones, G.R., Kelley, E.F., and Germer, T.A., **Specular and Diffuse Reflection Measurements of Electronic Displays**, Digest of Technical Papers, Society for Information Display International Symposium, San Diego, California, May 12-17, 1996, pp. 203-206.

Display standards describe measurements of the diffuse and specular reflection coefficients. The adequacy of such procedures is compared with the bi-directional reflection distribution function (BRDF) measurements. Alternative methods are examined and their estimates of the specular and diffuse reflection coefficients are compared to the results of the BRDF measurement.
[Contact: George R. Jones, (301) 975-4225]

Kelley, E.F., Jones, G.R., Boynton, P.A., Grote, M.D., and Bechis, D.J., **A Survey of the Components of Display-Measurement Standards**, Journal of the Society for Information Display, Vol. 3, No. 4, pp. 219-222 (December 1995). [Also published in Society for Information Display, International Symposium, Digest of Technical Papers, Orlando, Florida, May 23-25,

1995, pp. 637-640.]

Several display standards are reviewed, and distinctive elements are compared. With flat-panel displays becoming more common and the CRT displays being so well established, the associated standards activities can be somewhat bewildering, even overwhelming. This paper attempts to identify complementary and inconsistent elements of related display standards.
[Contact: Edward F. Kelley, (301) 975-3842]

ADDITIONAL INFORMATION

Announcements

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

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

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

Characterization Workshop Proceedings Published

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

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

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

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

Lists of Publications

Bradford, A.G., **Metrology for Electromagnetic Technology: A Bibliography of NIST Publications**, NISTIR 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., and Derr, L.S., **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, 1990-1995**. (March 1996).

This List of Publications includes all papers relevant to semiconductor technology published by NIST staff, including work of the National Semiconductor Metrology Program, and the Semiconductor Electronics Division, and other parts of NIST having independent interests in semiconductor metrology. Bibliographic information is provided for publications from 1990 through 1995. Indices by topic area and by author are provided. Earlier reports of work performed by the Semiconductor Electronics Division (and its predecessor divisions) during the period from 1962 through December 1989 are provided in NIST List of Publications 72.
[Contact: E. Jane Walters, (301) 975-2050]

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]

March 23-27, 1998 (Gaithersburg, Maryland)

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

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NIST SILICON RESISTIVITY SRMs

The Semiconductor Electronics Division of NIST provides Standard Reference Materials (SRMs) for bulk silicon resistivity through the NIST Standard Reference Materials Program. The existing SRMs (on 50 mm wafers) shown in the table below will be augmented with an improved set (on 100 mm wafers) during CY 96-97. NIST efforts to produce the new SRMs have recently received increased emphasis. The earlier set will continue to be available until the supply is exhausted.

The new SRMs have similar values of nominal resistivity as the earlier set, but offer improved uniformity and substantially reduced uncertainty of certified values due both to material and procedural improvements. While it is expected that these wafers will offer considerable utility in calibrating contactless gauges, certification has been performed solely with four-point probe methods. Technical insights presented by the rigorous certification process will be presented in a NIST Special Publication. Individual data for each wafer will be supplied along with the SRM Certificate.

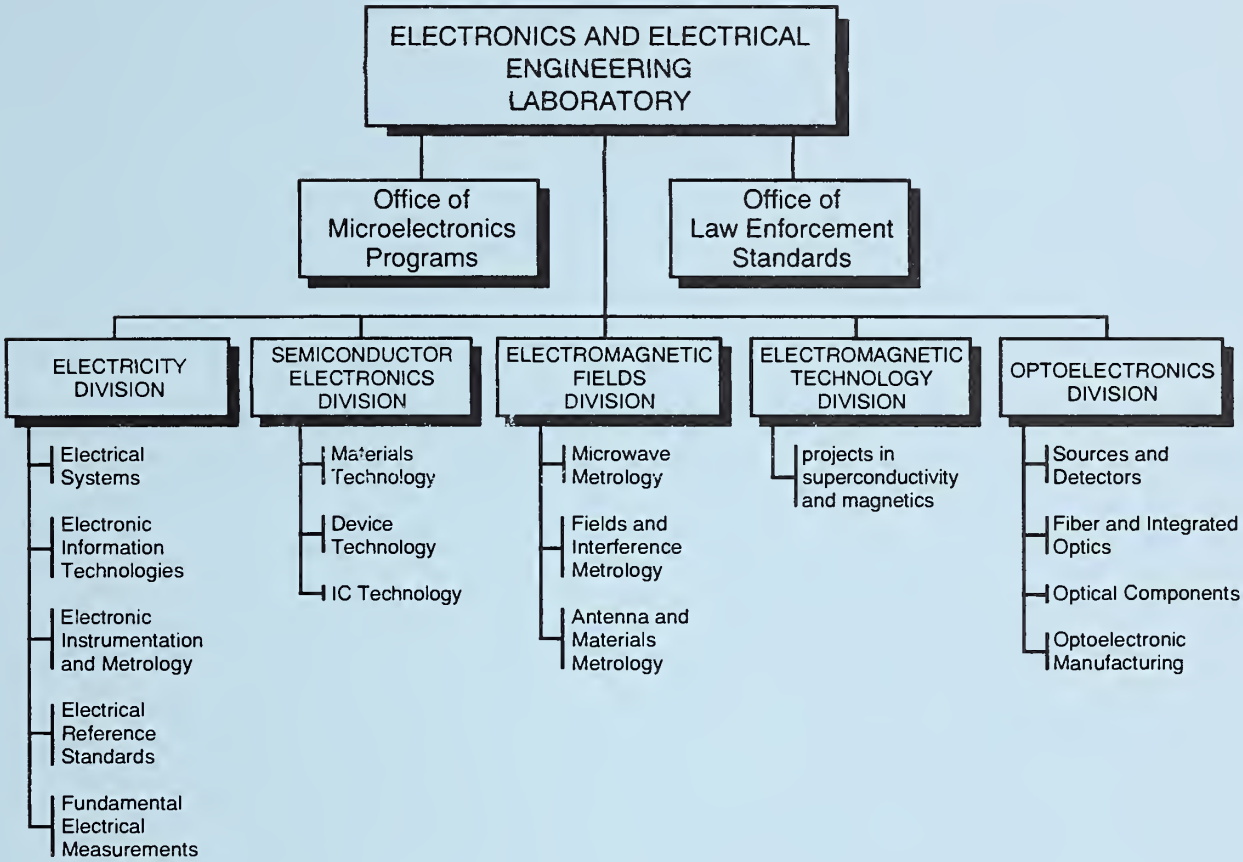
It is expected that the higher resistivity SRMs (2547, 2546) will be available first during CY 96 and be followed closely by SRM 2545. The low resistivity material (SRMs 2542, 2541) is expected to be available by year end. A limited number of SRM 2543 may also be available by year end, with the remainder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

NIST SILICON BULK RESISTIVITY STANDARD REFERENCE MATERIALS

DATE UPDATED: 23 JANUARY 1996

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

The above table will be updated in future issues to reflect changes in availability. Every effort will be made to provide accurate statements of availability; NIST sells SRMS on an as-available basis. For technical information, contact James R. Ehrstein, (301) 975-2060; for ordering information, call the Standard Reference Materials Program Domestic Sales Office: (301) 975-6776.



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