NISTIR 5895

Electronics and Electrical Engineering Laboratory

J. M. Rohrbaugh
Compiler

Technical Progress Bulletin

96-2

Covering Laboratory Programs,
April to June 1996,
with 1996-1998 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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ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY
TECHNICAL PROGRESS BULLETIN, OCTOBER 1996 ISSUE

INTRODUCTION

This is the fifty-fifth 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 second 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 Unpublished papers appear under the subheading "Released for Publication."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 1996 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 28.

Note on Publication Lists: Publication lists covering the work of each division are guides to earlier as well as recent work. These lists are revised and reissued on an approximately annual basis and are available from the originating division. The current set is identified in the Additional Information section, page 26.

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

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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

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**.

A new refractometer with a variable length vacuum-cell has been developed to eliminate errors caused by deformations in optical windows of the cell. The refractive index of air is determined by measuring the changes in the optical-path difference between the air of interest and a vacuum as a function of the changes in the cell length. An optical phase modulation technique and a dark-fringe detection method are used to get a high resolution in measuring the optical-path difference. A combined standard uncertainty of 5×10^{-9} in the measurement of the refractive index of air has been achieved.
[Contact: Ken-ichi Fujii, (301) 975-3979]

Gillespie, A.D., Fuji, K., Newell, D.B., Olsen, P.T., Picard, A., Steiner, R.L., Stenbakken, G.N., and Williams, E.R., **Alignment Uncertainties of the NIST Watt Experiment**.

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

Hamilton, C.A., Burroughs, C.J., Kupferman, S.L., Naujoks, G., and Vickery, A., **A Compact Transportable Josephson Voltage Standard**.

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

Jeffery, A.-M., Elmquist, R.E., Lee, L.H., Shields, J.Q., and Dziuba, R.F., **NIST Comparison of the Quantized Hall Resistance and the Realization of the SI Ohm through the Calculable Capacitor**.

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

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 Accuracy in Impedance**.

A new four-terminal-pair bridge, capable of achieving a relative standard uncertainty of 1×10^{-9}, has been constructed at NIST by converting a two-terminal-pair bridge. The conversion requires only the addition of components which are easily removed if two-pair measurements are to be made. The design and testing of this bridge is described. The new four-terminal-pair bridge requires fewer auxiliary balances than the present four-terminal-pair bridge used at NIST, which makes it much easier to use. This new design can be used to compare capacitance, resistance, and inductance standards.
[Contact: Ann-Marie Jeffery, (301) 975-4246]

Keller, M.W., Martinis, J.M., Steinbach, A.H., and Zimmerman, N.M., **A 7-Junction Electron Pump: Design, Fabrication, and Operation**.

We have developed a seven-junction electron pump for use in a new standard of capacitance based on measuring the voltage produced when a known charge is placed on a capacitor. This new pump is about 30 times more accurate than a five-junction pump made previously at NIST, with an error per pumped electron of 15 parts in 10^9. By careful

design of the pump geometry, we have reduced the effect of cross capacitance and simplified device operation. Our fabrication recipe produces small, stable tunnel junctions relatively quickly and reliably. We have developed a method of tuning the pump for highly accurate electron counting, which can be quickly repeated whenever fluctuations in the background charges degrade accuracy.
[Contact: John M. Martinis, (303) 497-3597]

Keller, M.W., Martinis, J.M., Zimmerman, N.M., and Steinbach, A.H., **Accuracy of Electron Counting Using a 7-Junction Electron Pump**.

We have operated a seven-junction electron pump with an error per pumped electron of 15 parts in 10^9 and an average hold time to 600 s. The pump counts electrons accurately enough to make a new capacitance standard feasible. We have measured the accuracy of the pump as a function of pumping speed and temperature. We compare our results with theoretical predictions based on a simple model of stray capacitance.
[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**.

Several improvements to the NIST watt balance have been made in the last year. These include the incorporation of three-laser interferometry, temperature control, coil-rotation damping, a refractometer, and a gravimeter. Systematic errors and scatter in long-term measurements have been reduced, but statistically significant deviations relative to within-run uncertainty still persist. The source of these deviations has not been identified.
[Contact: Richard L. Steiner, (301) 975-4226]

Zimmerman, N.M., **A Simple Fabrication Method for Nanometer-Scale Thin-Metal Stencils**.

[See Microfabrication Technology.]

Zimmerman, N.M., Cobb, J.L., and Clark, A.F., **Recent Results and Future Challenges for the NIST Charged-Capacitor Experiment**.

This paper reports on recent results of some of the work towards developing a new capacitance standard using single electron tunneling (SET) devices. In particular, we plan on using a SET pump to charge a cryogenic standard capacitor and measuring the voltage that develops. In this paper, we first briefly summarize recent results on 1) measurements of the ratio of two capacitors in a bridge configuration, using a SET transistor as the null detector, and 2) stability and leakage measurements on the cryogenic capacitors. We then discuss in some detail several of the as-yet unanswered challenges in this project, including the effects of stray capacitance and line impedance, and resulting requirements on the sensitivity of the SET null detector.
[Contact: Neil M. Zimmerman, (301) 497-5887]

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Recently Published

Benz, S.P., and Hamilton, C.A., **A Pulse-Driven Programmable Josephson Voltage Standard**, Applied Physics Letters, Vol. 68, No. 22, pp. 3171-3173 (27 May 1996).

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

Booi, P.A.A., and Benz, S.P., **High Power Generation with Distributed Josephson-Junction Arrays**, Applied Physics Letters, Vol. 68, No. 24, pp. 3799-3801 (24 June 1996).

We have experimentally coupled emission from a distributed series array of 1968 wide Josephson junctions to an on-chip 10.8 Ω load and detected 0.16 mW at 240 GHz. This result is achieved by reducing the parasitic inductance associated with shunt resistors so that junctions with critical currents of 23 mA are effectively shunted at the operating frequency. This power is less than the 1.3 mW expected from theory due to the presence of a large

impedance mismatch. Optimization of the load design will allow the detection of mW power.
[Contact: Peter A. A. Booi, (303) 497-5910]

Cage, M.E., **Evidence That Voltage Rather Than Resistance is Quantized in Breakdown of the Quantum Hall Effect**, Journal of Research of the National Institute of Standards and Technology, Vol. 101, No. 2, pp. 175-180 (March—April 1996).

Quantized longitudinal voltage drops are observed along a length of a GaAs/AlGaAs heterostructure quantum Hall effect device at applied currents large enough for the device to be in the breakdown regime. The range of currents is extensive enough to demonstrate that it is the longitudinal voltage that is quantized, rather than the longitudinal resistance. A black-box and a quasi-elastic inter-Landau level scattering model are then employed to calculate the fraction of electrons making transitions into higher Landau levels, the transition rates, and the maximum electric field across the device.
[Contact: Marvin E. Cage, (301) 975-4224]

Gillespie, A.D., **The NIST Watt Experiment: Monitoring the Kilogram**, Bulletin of the American Physical Society, Program of the 1996 March Meeting, St. Louis, Missouri, March 18-22, 1996, Vol. 41, No. 1, p. 405.

An apparatus has been constructed which measures both the force on a current-loop in a magnetic field and the voltage induced around that loop when it moves at some velocity through that same magnetic field. By comparing the force times the velocity to the current times the voltage, mechanical power is compared to electrical power, and a value for the watt which is consistent in both electrical and mechanical units can be derived. For this measurement, the reference values for the volt, ohm, meter, and second are all defined through quantum mechanical effects in terms of fundamental constants of nature. The kilogram is defined in terms of a physical artifact, and intercomparisons among various kilogram masses suggest that the kilogram mass standard changes over time. Present research on the watt experiment aims to improve the precision of the measurement so that a defined value of the watt can be used to monitor the drift of the kilogram mass standard in terms of fundamental natural constants.
[Contact: Aaron D. Gillespie, (301) 975-4056]

Stenbakken, G.N., Steiner, R., Olsen, P.T., and Williams, E., **Methods for Aligning the NIST Watt-Balance**, IEEE Transactions on Instrumentation and Measurement, Vol. 45, No. 2, pp. 373-377 (April 1996).

The NIST watt-balance has been developed to explore the possibility of monitoring the stability of the mass standard by means of electrical quantum standards. The mass standard is the last basic standard that is kept as an artifact. The watt-balance uses a movable coil in a radial magnetic field to compare the mechanical energy required to lift a kilogram mass in earth's gravity with the electrical energy required to move the coil the same distance in a magnetic field. The electrical energy is monitored in terms of quantized Hall resistance and Josephson junction voltage standards. The accuracy of this experiment depends on a large number of factors. Among them is the ability to align the apparatus so that the movable coil and magnet are coaxial and aligned to the local vertical. Misalignments of the coil and magnet result in forces and torques on the coil. The coil is suspended like a pendulum and responds easily to these torques and horizontal forces. This paper describes a computer program that was written to calculate the shape of the magnetic field and the torques and forces on the movable coil that result from any misalignments. This information is being used to develop an alignment procedure that minimizes misalignments and the errors they cause. This program has enhanced our understanding of the cause of torques about the vertical axis on the coil and the dependence of this torque on the magnetic field gradient.
[Contact; Gerard N. Stenbakken, (301) 975-2440]

SEMICONDUCTOR MICROELECTRONICS

Silicon Materials

Released for Publication

Kim, J.S., Seiler, D.G., and Ehrstein, J.R., **Determination of Densities and Mobilities of Heavy and Light Holes in P-Type Si Using Reduced-Conductivity-Tensor Analyses of Magnetic-Field Dependent Hall and Resistivity**

Measurements.

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

Compound Materials

Released for Publication

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**.

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 by 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 ~1 V is observed in an unoptimized structure. Optical switching of the unbiased structure is also demonstrated.
[Contact: Wen F. Tseng, (301) 975-5291]

Smirl, A.L., Bolger, J.A., Paul, A.E., and Pellegrino, J.G., **Time-Resolved Measurements of the Polarization State of Coherent Four-Wave-Mixing Signals from GaAs Multiple Quantum Wells**, to be published in the Proceedings of the 1996 Conference on Lasers and Electro-Optics/Quantum Electronics and Laser Science Conference, Anaheim, California, June 2-7, 1996.

The degree of ellipticity and the orientation of the polarization ellipse associated with the degenerate four-wave mixing signal are both observed to vary dramatically in time and to be too strongly dependent on the orientation of the input polarizations. These results are consistent with time-integrated measurements of the polarization state and are qualitatively consistent with the inclusion of both many-body interactions and biexcitonic effects.
[Contact: Joseph G. Pellegrino, (301) 975-2123]

Talwar, D.N., Roughani, B., Pellegrino, J.G., Amirtharaj, P.M., and Qadri, S.B., **Study of Phonons in Semiconductor Superlattices by Raman Scattering Spectroscopy and Microscopic Model Calculation**.

Raman spectroscopy is used to study phonons in a series of thin (AlAs)m/(GaAs)n superlattices (SLs) grown by molecular beam epitaxy (MBE). The influence of buffer layer type and thickness on the interface roughness of heterostructures is carefully evaluated. The accuracy of optical phonons and the degree of peak sharpness of GaAs-like confined modes are examined via off-resonance Raman spectroscopy. Theoretical calculations of phonons in thin (AlAs)m/()GaAs)n superlattices (i.e., samples with m, n ^{2}12) are reported for various directions of propagation by using a rigid-ion model. Optical phonons acquire significant dispersive character when the wavevector **q** forming an angle Θ with the growth axis of the superlattice is changed from Θ = 0 to $\pi/2$ (i.e., from [001] to [100]). The frequency gaps in the angular dispersions due to mode anti-crossing behavior observed recently by Zunke et al. using micro-Raman spectroscopy are found to be in reasonably good agreement with our model calculations.
[Contact: Joseph G. Pellegrino, (301) 975-2123]

Tseng, W.F., Chandler-Horowitz, D., Papanicolaou, N.A., and Boos, J.B., **Interdigitated Hetero InGaAs/GaAs n-i-p-i Modulators**.

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

Compound Materials

Recently Published

Paul, A.E., Bolger, J.A., Smirl, A.L., and Pellegrino, J.G., **Time-Resolved Measurements of the Polarization State of Four-Wave Mixing Signals from GaAs Multiple Quantum Wells**, Optical Society of America B., Vol. 13, No. 5, pp. 1016-1025 (May 1996).

The complete polarization state of the degenerate four-wave mixing signal from a GaAs/$Al_xGa_{1-x}As$ multiple quantum well is determined by time resolution of all four of its Stokes parameters as a function of the relative angle between the two linear input polarizations. The degree of ellipticity and the orientation of the polarization ellipse are both observed to vary dramatically in time, and the temporal evolution is found to depend strongly on the orientation of the input polarizations. These time-resolved results are show to be consistent with previous measurements of the time-integrated Stokes parameters and to provide new constraints for physical models. The results are shown to be qualitatively consistent with a phenomenological model requiring the inclusion of both many-body interactions and biexcitonic effects.
[Contact: Joseph G. Pellegrino, (301) 975-2123]

Analysis and Characterization Techniques

Released for Publication

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**.

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 by 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 ~1 V is observed in an unoptimized structure. Optical switching of the unbiased structure is also demonstrated.
[Contact: Wen F. Tseng, (301) 975-5291]

Kopanski, J.J., Marchiando, J.F., and Lowney, J.R., **Scanning Capacitance Microscopy Applied to 2D Dopant Profiling of Semiconductors**.

The scanning capacitance microscope (SCM) can image a semiconductor with contrast that is sensitive to variations in dopant density and spatial resolution on the order of the tip diameter, approximately 10 nm. SCMs can be operated in a direct-capacitance, a constant-voltage-difference (open loop), or a constant-capacitance-difference (closed loop) mode. A fast and accurate formalism to convert SCM images to quantitative two-dimensional dopant profiles, using either a one-dimensional model extended to two-dimensional (quasi-two-dimensional model) or a full two-dimensional, finite element, numerical solution of Poisson's equation, has been developed. Measurements on silicon junctions are used to illustrate the effect of the SCM operating conditions on the quality of the image. Dopant variations in a GaAs pn junction test structure have been imaged.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Device Physics and Modeling

Released for Publication

Lowney, J.R., **Application of Monte Carlo Simulations to Critical Dimension Metrology in a SEM**.

The state of the art in Monte Carlo simulations of SEM signals is reviewed, and specific work by the author is presented. Two Monte Carlo computer codes were 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 locations 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. Approaches are also discussed for efficient use of the Monte Carlo codes.

[Contact: Jeremiah R. Lowney, (301) 975-2048]

Device Physics and Modeling

Recently Published

Marchiando, J.F., **Application of the Collocation Method in Three Dimensions to a Model Semiconductor Problem**, International Journal for Numerical Methods in Engineering, Vol. 39, pp. 1029-1040 (1996).

A research code has been written to solve an elliptic system of coupled non-linear partial differential equations of conservation form on a rectangularly shaped three-dimensional domain. The code uses the method of collocation of Gauss points with tricubic Hermite piecewise continuous polynomial basis functions. The system of equations is solved by iteration. The system of non-linear equations is linearized, and the system of linear equations is solved by iterative methods. When the matrix of the collocation equations is duly modified by using a scaled block-limited partial pivoting procedure of Gauss elimination, it is found that the rate of convergence of the iterative method is significantly improved and that a solution become possible. The code is used to solve Poisson's equation for a model semiconductor problem. The electric potential distribution is calculated in a metal-oxide-semiconductor structure that is important to the fabrication of electron devices.
[Contact: Jay F. Marchiando, (301) 975-2088]

Zhang, Z.M., Livigni, D.J., Jones, R.D., and Scott, T.R., **Thermal Modeling and Analysis of Laser Calorimeters**, Journal of Thermophysics and Heat Transfer, Vol. 10, No. 2, pp. 350-356 (April–June 1996).

We performed detailed thermal analysis and modeling of the C-series laser calorimeters at the National Institute of Standards and Technology for calibrating laser power or energy meters. A finite element method was employed to simulate the space and time dependence of temperature at the calorimeter receiver. The inequivalence in the temperature response caused by different spatial distributions of the heating power was determined. The inequivalence between electrical power applied to the front and rear portions of the receiver is $\approx$1.7%, and the inequivalence between the electrical and laser heating is estimated to be <0.05%. The computational results are in good agreement with experiments at the 1% level. The effects of the deposited energy, power duration, and relaxation time on the calibration factor and cooling constant were investigated. This article provides information for future design improvement on the laser calorimeters.
[Contact: David Lavigni, (303) 497-5898]

Dimensional Metrology

Released for Publication

Lowney, J.R., **Application of Monte Carlo Simulations to Critical Dimension Metrology in a SEM**.

[See Device Physics and Modeling.]

Microfabrication Technology

Released for Publication

DeGroot, D.C., Rudman, D.A., Zhang, K., Ma, Q.Y., Kato, H., and Jaeger, N.A.F., **Planar Microwave Devices Fabricated by Ion-Implantation Patterning of High-Temperature Superconductors**.

[See Microwave and Millimeter-Wave Metrology.]

Li, H.Q., Ono, R.H., Vale, L.R., Rudman, D.A., and Liou, S.H., **A Novel Multilayer Circuit Process Using $YBa_2Cu_3O_x$/Sr TiO_3 Thin Films Patterned by Wet Etching and Ion-Milling**.

[See Cryoelectronic Metrology.]

Milanović, V., Gaitan, M., Bowen, E.D., and Zaghloul, M.E., **Micromachined Coplanar Waveguides in CMOS Technology**.

Coplanar waveguides were fabricated in standard complementary metal oxide semiconductor with post-processing micromachining. Integrated circuits were designed with commercial computer-aided design tools, fabricated through the MOSIS service, and subsequently suspended by top-side etching. Absence of the lossy silicon substrate after etching

results in significantly improved insertion loss characteristics, dispersion characteristics, and phase velocity. Measurements were performed at frequencies from 1 GHz to 40 GHz, before and after micromachining. These show improvement in loss characteristics of orders of magnitude. For the micromachined line, loss does not exceed 4 dB/cm. Before etching, loss as high as 38 dB/cm is measured. Phase velocity $v_p \approx 0.7$ °C is achieved for the micromachined line.
[Contact: Michael Gaitan, (301) 975-2070]

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

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

Milanović, V., Gaitan, M., and Zaghloul, M.E., **Micromachined Thermocouple Microwave Detector by Commercial CMOS Fabrication**.

[See Microwave and Millimeter-Wave Metrology.]

Zimmerman, N.M., **A Simple Fabrication Method for Nanometer-Scale Thin-Metal Stencils**.

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

Plasma Processing

Released for Publication

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

[See Power Systems Metrology.]

Christophorou, L.G., Olthoff, J.K., and Rao, M.V.V.S., **Electron Interactions with CF_4**.

Carbon tetrafluoride (CF_4) is one of the most widely used components of feed gas mixtures employed for a variety of plasma-assisted material-processing applications. It has no stable excited states and, in a plasma environment, is an ideal source of reactive species, especially F atoms. To assess the behavior of CF_4 in its use in manufacturing semiconductor devices and other applications, it is necessary to have accurate information about its fundamental properties and reactions, particularly its electronic and ionic interactions and its electron collision processes at low energies (<100 eV).

In this paper, we assess and synthesize the available information on the cross sections and/or the rate coefficients for collisional interactions of CF_4 with electrons. Assessed information is presented on: (i) cross sections for electron scattering (total, momentum, elastic, differential, inelastic), electron impact ionization (total, partial, multiple, dissociative), electron impact dissociation (total, and for dissociative excitation), and electron attachment (total, and for specific anions); (ii)

coefficients for electron transport (electron drift velocity, transverse and longitudinal electron diffusion coefficients), electron attachment, and electron impact ionization; and (iii) cross section sets derived from analyses of electron transport data. The limited ionization data on CF_4 radicals are also presented, and references are given to measurements of electron transport properties of CF_4 gas mixtures. Based upon the assessed published experimental measurements, values for various cross sections and coefficients are generated which are given in graphical and tabular form.
[Contact: Loucas Christophorou, (301) 975-2432]

Power Devices

Released for Publication

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

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

Photodetectors

Released for Publication

Berkowitz, S.J., Hirahara, A.S., Char, K., and Grossman, E.N., **Low Noise High-Temperature Superconducting Bolometers for Infrared Imaging**.

High-temperature superconducting bolometric infrared detectors offer the promise of matching the sensitivity of HgCdTe detectors, but with an extended detection range to longer wavelengths (λ15 μm). High-temperature superconducting bolometers have been fabricated by a novel all-epitaxial micromachining technology using a $YBa_2Cu_30_x$ thin film on a yttria-stabilized zirconia free-standing membrane supported on a $LaAlO_3$ substrate. This structure has simultaneously a low-thermal conductance and a low-heat capacity. Using this technology, we have made array-compatible pixels for infrared camera arrays with noise equivalent powers as low as 6.3×10^{-13} W/λHz at 32 Hz. Over more than 1 octave of frequency range, these bolometers are limited by fundamental (chiefly phonon) noise sources rather than excess film noise.
[Contact: Eric N. Grossman, (303) 497-5102]

Reliability

Recently Published

Chaparala, P., Suehle, J.S., Messick, C., and Roush, M., **Electric Field Dependent Dielectric Breakdown of Intrinsic SiO_2 Films**, Proceedings of the 1996 IEEE International Reliability Physics Conference, Dallas, Texas, April 30—May 2, 1996, pp. 61-66.

Time-dependent-dielectric-breakdown (TDDB) characteristics are reported for 6.5 nm, 9 nm, 15 nm, and 22 nm intrinsic silicon dioxide films stressed under dc and bipolar pulsed bias conditions for a wide range of electric fields and temperatures. Our results show that the increased lifetime observed under bipolar pulsed stress conditions diminishes as the stress electric field and oxide thickness are reduced. Similar electric field and temperature dependencies of TDDB are observed under both static and dynamic stress conditions. It is observed that lifetime enhancement only occurs for electric fields and thicknesses where charge trapping is significant. Contradictory to the conventional notion, TDDB tests on intrinsic thin

oxides indicate that static stress testing cannot be considered as a conservative test of bipolar stressing for estimating oxide reliability. These results also confirm the existence of two separate failure mechanisms for TDDB that are functions of electric field and oxide thickness.
[Contact: John S. Suehle, (301) 975-2241]

Martin, A., Suehle, J.S., Chaparala, P., O'Sullivan, P., and Mathewson, A., **A New Oxide Degradation Mechanism for Stresses in the Fowler-Nordheim Tunneling Regime**, Proceedings of the 1996 IEEE International Reliability Physics Conference, Dallas, Texas, April 30—May 2, 1996, pp. 67-76.

In this study, voltage- and current-stress measurements in the Fowler-Nordheim regime, performed on gate oxides (9 nm to 28 nm), indicated that a ramped pre-stress prior to a constant stress can increase the time-to-breakdown in some cases. In the literature, oxide breakdown is said to be related to a fixed amount of trapped oxide charge or to a fixed amount of generated traps in the oxide. However, these models cannot explain our experimental observations. Currently, time, current-charge, voltage-time characteristics and results of high-frequency pre-stresses have been extensively studied in order to gain information about the charge trapping properties of the virgin and pre-stressed oxides. It is concluded from experimental results that the rate of initial positive charge build-up in the oxide during the constant stress is a key factor for oxide degradation and breakdown.
[Contact: John S. Suehle, (301) 975-2241]

Schlund, B., Suehle, J.S., Messick, C., and Chaparala, P., **A New Physics-Based Model for Time-Dependent-Dielectric-Breakdown**, Proceedings of the 34th Annual 1996 IEEE International Reliability Physics Meeting, Dallas, Texas, April 30—May 2, 1996, pp. 84-92.

A new, physics-based model for time-dependent dielectric-breakdown has been developed, and is presented along with test data obtained by NIST on oxides provided by National Semiconductor. Testing included fields from 5.4 MV/cm to 12.7 MV/cm, and temperatures ranging from 60 °C to 400 °C. The physics, mathematical model, and test data all confirm a linear, rather than an inverse-field dependence. The primary influence on oxide breakdown was determined to be due to the dipole interaction energy of the field with the orientation of the molecular dipoles in the dielectric. The resultant failure mechanism is shown to be the formation and coalescence of vacancy defects, similar to that proposed by Dumin et al.
[Contact: John S. Suehle, (301) 975-2247]

Other Semiconductor Metrology Topics

Released for Publication

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

[See Announcements.]

SIGNAL ACQUISITION, PROCESSING AND TRANSMISSION

DC and Low-Frequency Metrology

Released for Publication

Jarrett, D.G., **Automated Guarded Bridge for Calibration of Multimegohm Standard Resistors from 10 MΩ to 1 TΩ**.

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

[Contact: Dean G. Jarrett, (301) 975-4240]

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

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]

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 Accuracy in Impedance**.

[See Fundamental Electrical Measurements.]

Kinard, J.R., Novotny, D.B., Lipe, T.E., and Huang, D.-X., **Development of Thin-Film Multijunction Thermal Converters at NIST**, to be published in the IEEE Transactions on Instrumentation and Measurement. [Also, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Branuschweig, Germany, June 17-20, 1996.]

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]

Oldham, N.M., Parker, M.E., Bell, B.A., and Zamurovic-Avramov, S., **Exploring the Low-Frequency Performance of Thermal Converters Using Circuit Models and a Digitally Synthesized Source**, to be published in the IEEE Transactions on Instrumentation and Measurement Special Issue on Selected Papers CPEM 96. [Also, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.]

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

DC and Low-Frequency Metrology

Recently Published

Boggs, S.A., FitzPatrick, G.J., and Kuang, J., **Transient Errors in a Precision Resistive Divider**, Proceedings of the 1996 IEEE International Symposium on Electrical Insulation, Piscataway, New Jersey, June 15-19, 1996, pp. 482-495.

Resistive dividers have the advantages of dc response and stability. However, unlike capacitive dividers, they inevitably involve power dissipation and also generally involve an appreciable inductance. These aspects of a resistive divider result in transient errors, i.e., errors which are a function of the applied waveform. This paper discusses transient measurement errors of precision high-voltage resistive dividers such as the one recently developed by NIST.
[Contact: Gerald J. FitzPatrick, (301) 975-2737]

Laug, O.B., **A 100 Ampere, 100 kHz Transconductor Amplifier**, IEEE Transactions on Instrumentation and Measurement, Vol. 45, No. 3, pp. 440-444 (June 1996). [Also published in the

Proceedings of the 1995 IEEE Instrumentation and Measurement Technology Conference, Waltham, Massachusetts, April 23-26, 1995, pp. 506-511.]

A high-current, wide-band transconductance amplifier is described that provides an unprecedented level of output current at high frequencies with exceptional stability. It is capable of converting a signal voltage applied to its input into a ground-referenced output current up to 100 A rms over a frequency range from dc to 100 kHz with a usable frequency extending to 1 MHz. The amplifier has a 1000 W output capability, ±10 V of compliance, and can deliver up to 400 A peak-to-peak of pulsed current. The amplifier design is based on the principle of paralleling a number of precision bipolar voltage-to-current converters. The design incorporates a unique ranging system controlled by opto-isolated switches, which permit a full-scale range from 5 A to 100 A. The design considerations for maintaining wide bandwidth, high-output impedance, and unconditional stability for all loads are discussed.
[Contact: Owen B. Laug, (301) 975-2412]

Cryoelectronic Metrology

Released for Publication

Berkowitz, S.J., Hirahara, A.S., Char, K., and Grossman, E.N., **Low Noise High-Temperature Superconducting Bolometers for Infrared Imaging**.

[See Photodetectors.]

Carelli, P., Castellano, M.G., Chiarello, F., Cirillo, M., Cosmeli, C., Costantini, A., Rotoli, G., Torrioli, G., and Kautz, R.L., **Thermally Activated Escape from the Zero-Voltage State in Long Josephson Junctions**.

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

Irwin, K.D., Hilton, G.C., Wollman, D.A., and Martinis, J.M., **X-Ray Detection Using a Superconducting Transition-Edge Sensor Microcalorimeter with Electrothermal Feedback**.

We are developing a new type of X-ray detector consisting of a normal metal absorber and a superconducting transition-edge thermometer operated near 100 mK. Energy from X-rays absorbed in the normal metal film is removed by a reduction of the Joule heating in the superconducting film due to electrothermal feedback, which is measured using a superconducting quantum interference device. A detector connected to a scanning electron microscope has measured the titanium K_α (4.5 keV) line with an energy resolution of less than 14 eV full width at half maximum. The energy resolution for Joule heat pulses is 2.6 eV at 1 keV, and 0.2 eV at 4 eV, the best energy resolution that has been reported for any calorimetric technology.
[Contact: John M. Martinis, (303) 497-3597]

Keller, M.W., Martinis, J.M., Steinbach, A.H., and Zimmerman, N.M., **A 7-Junction Electron Pump: Design, Fabrication, and Operation**.

[See Fundamental Electrical Measurements.]

Lee, A.T., Richard, P.L., Nam, S.W., Cabrera, B., and Irwin, K.D., **A Superconducting Bolometer with Strong Electrothermal Feedback**.

We present a theoretical analysis and experimental evaluation of a novel transition-edge superconducting bolometer for detecting infrared and millimeter waves. The superconducting film is voltage-biased and the current is read by a superconducting quantum interference device ammeter. Strong electrothermal feedback maintains the sensor temperature within the transition, gives

a current responsivity that is simply the inverse of the bias voltage, suppresses Johnson and sensor 1/f noise, and reduces the response time by several orders of magnitude below the intrinsic time constant C/G. A voltage-biased bolometer was evaluated that operates on the T_c ~95 mK transition of a tungsten film with a thermal conductance of G ~1.2 x 10^{-9} W/K. As expected, the electrical noise equivalent power of 3.3 x 10^{-17} W/$\sqrt{Hz}$ is close to the thermal fluctuation noise limit and is lower than that of other technologies for these values of G and temperature. The measured time constant of 10 μs is ~100 times faster than the intrinsic time constant.
[Contact: Kent D. Irwin, (303) 497-5911]

Li, H.Q., Ono, R.H., Vale, L.R., Rudman, D.A., and Liou, S.H., **A Novel Multilayer Circuit Process Using $YBa_2Cu_3O_x$/Sr TiO_3 Thin Films Patterned by Wet Etching and Ion-Milling**.

A process combining hydrofluoric acid (HF) and Ar^+ ion-milling has been used to make $YBa_3Cu_3O_x/SrTiO_3/YBa_2Cu_3O_x$ (YBCO/STO/YBCO) multilayer test circuits. Low-angle steps can be readily etched in STO and YBCO films with this process. YBCO lines crossing 5° steps have about the same critical temperature T_c (89 K to 90 K) and critical current density J_c (1 x 10^6 A/cm^2 at 86 K) as lines on planar surfaces. Via connections have the same T_c as other circuit components and adequate critical currents for most circuit designs.
[Contact: Ronald H. Ono, (301) 975-3762]

Wollman, D.A., Hilton, G.C., Irwin, K.D., and Martinis, J.M., **Energy Dispersive Spectroscopy X-Ray Microcalorimeters with 13 eV Energy Resolution**.

Although Si- and Ge-based Energy Dispersive Spectroscopy detectors are by far the most commonly used X-ray spectrometers for microanalysis, they are limited by energy resolutions on the order of 100 eV. This low-energy resolution is insufficient to clearly resolve many peak overlaps between K_α X-ray lines of different elements. In addition, many L and M lines of heavier elements fall in the 100 eV to 2 keV energy range, making it difficult in complicated spectra to identify and quantify the presence of technologically important lighter elements. Higher energy resolution and good count rates are necessary to provide improved limits of detectability.
[Contact: David A. Wollman, (303) 497-7457]

Cryoelectronic Metrology

Recently Published

Benz, S.P., and Hamilton, C.A., **A Pulse-Driven Programmable Josephson Voltage Standard**, Applied Physics Letters, Vol. 68, No. 22, pp. 3171-3173 (27 May 1996).

[See Fundamental Electrical Measurements.]

Booi, P.A.A., and Benz, S.P., **High Power Generation with Distributed Josephson-Junction Arrays**, Applied Physics Letters, Vol. 68, No. 24, pp. 3799-3801 (24 June 1996).

[See Fundamental Electrical Measurements.]

Irwin, K.D., Hilton, G.C., Martinis, J.M., and Cabrera, B., **A Hot-Electron Microcalorimeter for X-Ray Detection Using a Superconducting Transition Edge Sensor with Electrothermal Feedback**, Nuclear Instruments and Methods in Physics Research A, Vol. 370, pp. 177-179 (1996).

We investigate a hot-electron microcalorimenter for X-ray detection. The X-ray absorber consists of a normal metal film in thermal and electrical contact with a superconducting transition-edge sensor. The sensor is formed by a proximity-effect bilayer of aluminum and silver, with a sharp superconducting transition near 100 mK. Energy from X-rays absorbed in the normal film is removed by a reduction of the Joule heating in the proximity bilayer due to electrothermal feedback and measured using a superconducting quantum interference device. The feedback mode of operation allows the measurement of incident energy with no free parameters and should lead to improvement in detector resolution over existing hot-electron microcalorimeters.
[Contact: John M. Martinis, (303) 497-3597]

Martinis, J.M., **Hot-Electron-Microcalorimeters with 0.25 mm^2 Area**, Nuclear Instruments and Methods in Physics Research A, Vol. 370, pp.

171-172 (1996).

I present measurements on hot-electron microcalorimeter with a normal-insulator superconductor tunnel-junction thermometer that is used for the detection of X-rays. With an absorber area of 0.5 mm, pulses of 20 μs in duration were observed that gave a 30 eV FWHM resolution for 6 keV X-rays and an 18 eV resolution for heat pulses. This detector has sufficient resolution, detector area, and speed to warrant application in materials analysis.
[Contact: John M. Martinis, (303) 497-3597]

Antenna Metrology

Released for Publication

Will, J., Norgard, J., Sega, R., Seifert, M., Pesta, A., Cleary, J., Stubenrauch, C., and MacReynolds, K., **Near-Field to Far-Field Antenna Pattern Measurements Using Infrared Imaging and Fourier Iterative Plane-to-Plane Techniques**.

This paper describes the application of the "plane-to-plane" (PTP) iterative Fourier processing technique to infrared thermographic images of microwave fields to calculate the near-field and far-field patterns of radiating antennas. A resistive sheet is positioned in a radiating field, and a thermal "picture" is then taken of the heat pattern. Each pixel of this thermal image represents a measurement of the intensity (magnitude) of the field at the pixel location on the resistive sheet. The PTP technique allows recovery of the phase by combining measurements made on two planes, both in the radiating near field of the antenna under test. Starting with an estimate of the phase and the measured magnitudes, Fourier processing techniques are used to iteratively "propagate" between the planes to determine the correct phase distribution at each plane. We describe the technique and show comparisons made between the predicted results and results from measured IR thermograms of the field of a 36 element patch array antenna operating at 4 GHz using the University of Colorado, Colorado Springs (UCCS) Thermal Camera. [Contact: Carl F. Stubenrauch, (303) 497-3827]

Noise Metrology

Released for Publication

Wait, D.F., and Randa, J.P., **Amplifier Noise Measurements at NIST**.

We have recently measured the noise characteristics of two low-noise commercial amplifiers in the 2.0 GHz to 4.0 GHz frequency range. The tests were part of a program to develop and validate measurement methods for a noise-figure measurement service. Measured noise figures were about 0.5 dB $\pm$ dB. We present the results and the accompanying uncertainties. We also describe the measurement method and summarize the many checks which were used to validate the method.
[Contact: David F. Wait, (303) 497-3610]

Microwave and Millimeter-Wave Metrology

Released for Publication

DeGroot, D.C., Rudman, D.A., Zhang, K., Ma, Q.Y., Kato, H., and Jaeger, N.A.F., **Planar Microwave Devices Fabricated by Ion-Implantation Patterning of High-Temperature Superconductors**.

We have applied ion-implantation inhibit patterning as a new method of fabricating low-loss microwave transmission lines in high-temperature superconductor thin films. To determine the effectiveness of this technique, we fabricated coplanar waveguide transmission lines in $YBa_2Cu_3O_7$-δ thin films that had been deposited on $LaAlO_3$ substrates using pulsed laser deposition. Microwave characterizations of these lines are compared to a reference line fabricated with conventional ion-milling. At 76 K and 12 GHz, the attenuation constants of the ion-implanted transmission lines are approximately 0.02 dB/mm, and the overall loss response is indistinguishable from that of the ion-milled device.
[Contact: Donald C. DeGroot, (301) 975-7212]

DeGroot, D.C., Walker, D.K., and Marks, R.B., **Impedance Mismatch Effects on Propagation Constant Measurements**, to be published in the Proceedings of the 5th Topical Meeting on Electrical Performance of Electronic Packaging, Napa, California, October 28-30, 1996.

By measuring propagation constants of coplanar waveguide transmission lines, we show the significant systematic errors of common measurement techniques when the characteristic impedance of the lines does not match the reference impedance of the instrument.
[Contact: David K. Walker, (303) 497-5490]

Ginley, R.A., **Line-Reflect-March Calibration Technique for the Dual Six-Port ANA**.

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

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

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

Milanović, V., Gaitan, M., Bowen, E.D., and Zaghloul, M.E., **Micromachined Coplanar Waveguides in CMOS Technology**.

[See Microfabrication Technology.]

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

[See Microfabrication Technology.]

Milanović, V., Gaitan, M., and Zaghloul, M.E., **Micromachined Thermocouple Microwave Detector by Commercial CMOS Fabrication**.

This paper reports the design and testing of a thermocouple microwave detector fabricated through a commercial *n*-well CMOS foundry with an additional maskless etching procedure. The detector measures true rms power of signals in the frequency range from 50 MHz to 10 GHz, and input power ranging from -30 dBm to 10 dBm. The device has a good linearity of $<\pm 0.4\%$ for output vs. input power over the 40 dB dynamic range. Measurements of the return loss, obtained using an automatic network analyzer and de-embedding analysis, show an acceptable input return loss of ≤ 20 dB over the entire frequency range. The sensitivity of the detector was measured to be 1.328 ± 0.0035 mV/mW.
[Contact: Michael Gaitan, (301) 975-2070]

Williams, D.F., and Olyslager, F., **Modal Energy Distribution in Quasi-TEM Transmission Lines**.

This paper examines the distribution of energy between the modes of electromagnetic transmission lines. It shows that significant energy may be shared between nearly degenerate modes and that this occurs in quasi-TEM multiconductor transmission lines typical of modern electronic circuits at moderate- and low-microwave frequencies. The paper develops simple expressions to estimate the level of this energy sharing from the "power-normalized" conductor impedance and admittance matrices of the lines.
[Contact: Dylan F. Williams, (303) 497-3138]

Microwave and Millimeter-Wave Metrology

Recently Published

Krupka, J., and Geyer, R.G., **Complex Permeability of Demagnetized Microwave Ferrites Near and Above Gyromagnetic Resonance**, IEEE Transactions on Magnetics, Vol. 32, No. 3, pp. 1924-1933 (May 1996).

A wide variety of microwave ferrite phase-shifting materials have been measured in the demagnetized state. The relative magnetic permeability and loss factor were determined near and above natural gyromagnetic resonance using H_{011} cylindrical dielectric ring resonators. These low-loss dielectric

sleeves were dimensioned for accurate magnetic property measurements of single ferrite rod samples at logarithmically sampled resonant frequencies from 2 GHz to 25 GHz. Permeability and magnetic loss factor are computed from the measured resonant frequencies and Q factors of these resonators, with and without the ferrite sample, using exact eigenvalue equations. Generally, the real part of the complex magnetic permeability increases with decreasing saturation magnetization, while the magnetic loss factor increases nonlinearly with increasing saturation. Schloemann's theoretical model for the real part of initial permeability of a cylindrically symmetric domain configuration in the completely demagnetized state shows excellent agreement with measured data when $2\pi\gamma M_s/\omega < 0.75$. The data allow design optimization of circulators and dual-mode and polarization-insensitive phasers, which are widely used in antenna array systems.
[Contact: Richard G. Geyer, (303) 497-5852]

Electromagnetic Properties

Released for Publication

Jones, C.A., **A Comparison of Permittivity and Permeability Measurements Using Stripline Resonator Cavities**.

The permittivity and permeability of five materials were measured during a comparison of stripline resonator cavities. The National Institute of Standards and Technology organized this comparison in which a total of seven organizations participated. Each participant measured two dielectric materials and three magnetic materials. Results for this comparison suggest that dielectric property measurements are not as accurate as magnetic property measurements provided a correction for demagnetization is made. The results are compared to 7 mm coaxial transmission line measurements which have an uncertainty of less than ten percent for the relative permittivity, ϵ_r <15.
[Contact: Chriss A. Jones, (303) 497-5958]

Complex System Testing

Released for Publication

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**, to be published in the Proceedings of the 1996 National Conference of Standards Laboratories Workshop and Symposium, Monterey, California, August 25-29, 1996.

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]

Complex System Testing

Recently Published

Deyst, J.P., and Souders, T.M., **Bounds on Frequency Response Estimates Derived from Uncertain Step Response Data**, IEEE Transactions on Instrumentation and Measurement, Vol. 45, No. 2, pp. 378-383 (2 April 1996).

The frequency response of a system can be estimated from measurements of its step response; however, many error sources affect the accuracy of such estimates. This paper investigates the effects of uncertainty in the knowledge of the step response. Methods for establishing uncertainty bounds for the frequency response estimates are developed, based on the corresponding time-domain uncertainties associated with the measured-

step response. Two methods are described. One method produces bounds that are often very conservative. The other method produces bounds that are more realistic. End effects that influence the bounds are also considered. A simulation example and an application of the bounds are presented.
[Contact: John P. Deyst, (301) 975-2437]

Stenbakken, G.N., **Effects of Nonmodel Errors on Model-Based Testing**, IEEE Transactions on Instrumentation and Measurement, Vol. 45, No. 2, pp. 384-388 (April 1996). [Also published in the Proceedings of the 1995 IEEE Instrumentation and Measurement Technology Conference, Waltham, Massachusetts, April 24-26, 1996, pp. 384-388.

In previous work, methods have been developed for efficient testing of components and instruments that allow for their full behavior to be predicted from a small set of test measurements. While such methods can significantly reduce the testing cost of such units, these methods are valid only if the model accurately represents the behavior of the units. Previous papers on this subject described many methods for developing accurate models and using them to develop efficient test methods. However, they gave little consideration to the problem of testing units which change their behavior after the model has been developed, for example, as a result of changes in the manufacturing process. Such changed behavior is referred to as nonmodel behavior or nonmodel error. When units with this new behavior are tested with these more efficient methods, their predicted behavior can show significant deviations from their true behavior. This paper describes how to analyze the data taken at model predictions, even when the device has significant nonmodel error. Results of simulation are used to verify the accuracy of the estimates and to show the expected variation in the results for many modeling variables.
[Contact: Gerard N. Stenbakken, (301) 975-2440]

OPTOELECTRONICS

Released for Publication

Leonhardt, R.W., **Low-Level Pulsed 1064 nm Laser Radiometer Transfer Standard**, to be published in the Proceedings of SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Optical Radiation Measurements III, Symposium on Optical Science, Engineering and Instrumentation, Denver, Colorado, August 4-9, 1996.

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

Park, R., and Hale, P.D., **Frequency Response Measurement of Digital Communications Analyzer Plug-In Modules**.

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

Rochford, K.B., and Rose, A.H., **A Magneto-Optic Rotation Sensor Using a Laser Diode as Both Source and Detector**, to be published in the

Proceedings of the Eleventh International Conference on Optical Fiber Sensors, Sapporo, Japan, May 21-24, 1996.

We show that a laser diode can serve as both the emitter and detector in a diffraction-based magneto-optic rotation sensor. Self-detection devices have sufficient linearity and stability for applications with discrete measurands. Signal-to-noise ratios greater than 50 dB (1 Hz bandwidth) are possible for binary measurands, and a fiber-optic rotation sensor with a signal-to-noise ratio of 18 dB in a 1.25 kHz bandwidth is demonstrated.
[Contact: Kent B. Rochford, (303) 497-5170]

Rose, A.H., Ren, Z.B., and Day, G.W., **Twisting and Annealing Optical Fiber for Current Sensors**.

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

Schaafsma, D.T., and Christensen, D.H., **Mode Splitting in Side Emission from Vertical-Cavity Surface-Emitting Lasers**.

We present side emission (luminescence) data from vertical-cavity surface-emitting laser (VCSELs) that show cavity-induced effects on the emission spectrum. In particular, the heavy-hole luminescence spectrum contains two peaks when pumped in such a way as to excite electron-hole pairs well inside the cavity region, where coupling to free space modes in minimized, and only one peak when pumped near the edge of the cavity (near a cleaved facet), where coupling to free space modes is maximized. This splitting can be distinguished as a cavity-induced effect with little ambiguity from other factors present in semiconductor quantum well radiation, such as the light- and heavy-hole splitting. A fit to the data using Lorentzian lineshapes gives a vacuum-field Rabi splitting of roughly 34 meV, which is consistent with theoretical calculations and with other reports on this phenomenon. We, therefore, conclude that the two peaks in the spectrum are due to Rabi oscillation in the cavity, and that they represent an actual change in the energy configuration of the quantum well.
[Contact: David T. Schaafsma, (303) 497-7281]

Schaafsma, D.T., and Christensen, D.H., **Mode Splitting in Vertical-Cavity Microlasers from Side-Emission Measurements**, to be published in the Proceedings of the IEEE 1997 Lasers and Electro-Optics Society Meeting (LEOS'97), Baltimore, Maryland, May 18-23, 1997.

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

Schaafsma, D.T., Hill, J.R., and Christensen, D.H., **Gain Localization for Coupled Semiconductor Microcavities**, to be published in the Proceedings of the 1997 IEEE Lasers and Electro-Optics Society Meeting (LEOS'97), Baltimore, Maryland, May 18-23, 1997.

We examine a variant of a coupled-cavity design which would allow the proposed device to be operated under electrical injection rather than optical stimulation.
[Contact: David T. Schaafsma, (303) 497-7281]

Schaafsma, D.T., Hill, J.R., and Christensen, D.H., **Quantum Wells in Coupled Semiconductor Microcavity Structures**.

Vertical-cavity semiconductor laser devices with two cavity regions have recently been proposed as a means to study a three-oscillator system which has application to a number of optoelectronic problems. In this work, we examine a variant of that design which would allow the proposed device to be operated under electrical injection rather than optical stimulation. Specifically, this design puts the quantum well active region in the intermediate

mirror between the two cavities. The question of how well such a placement affects the coupling into the modes of the cavities is addressed experimentally, and we find, from the luminescent behavior of simple test structures, that such a design is at least feasible.
[Contact: David T. Schaafsma, (303) 497-7281]

Schlager, J.B., Mechels, S.E., and Franzen, D.L., **Determination of Zero-Dispersion Wavelength in Optical Fiber Using Four-Wave Mixing**, to be published in the Symposium on Optical Fiber Measurements, Boulder, Colorado, October 1-3, 1996.

Wavelengths of measured maximum four-wave mixing efficiency in optical fiber are compared to zero-dispersion wavelengths measured with a highly accurate frequency-domain phase shift technique. The average absolute discrepancy between the two wavelengths determined on 15 fibers is 0.19 nm; for an average pump-probe spacing of 5.9 nm, the average spectral width of the four-wave mixing efficiency curve is 0.45 nm.
[Contact: John B. Schlager, (303) 497-3542]

Schlager, J.B., Mechels, S.E., and Franzen, D.L., **Zero-Dispersion Wavelength Variations and Four-Wave Mixing in Optical Fiber**, to be published in the Proceedings of the IEEE Laser and Electro-Optics Society Meeting (LEOS'96), Boston, Massachusetts, November 18-21, 1996.

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

Smirl, A.L., Bolger, J.A., Paul, A.E., and Pellegrino, J.G., **Time-Resolved Measurements of the Polarization State of Coherent Four-Wave-Mixing Signals from GaAs Multiple Quantum Wells**, to be published in the Proceedings of the 1996 Conference on Lasers and Electro-Optics/Quantum Electronics and Laser Science Conference, Anaheim, California, June 2-7, 1996.

Tseng, W.F., Chandler-Horowitz, D., Papanicolaou, N.A., and Boos, J.B., **Interdigitated Hetero InGaAs/GaAs n-i-p-i Modulators**.

[See Compound Materials.]

Vayshenker, I., Li, X., Keenan, D., and Scott, T.R., **Effect of Connectors on Optical Fiber Power Meter Calibrations**, to be published in the Symposium on Optical Fiber Measurements, Boulder, Colorado, October 1-3, 1996.

We discuss errors in optical fiber power meter calibrations when using various types of connectors from different vendors; calibrations are performed for a limited number of power meter types at three telecommunication wavelengths. We speculate that the error is due to the reflecting surfaces of the connector and the detector window. An error (~10%) occurs while interchanging various types of connectors of the same vendor and while substituting a fiber connector from one vendor by the connector of the same type made by another vendor for some power meter types.
[Contact: Igor Vayshenker, (303) 497-3394]

Vayshenker, I., Yang, S., Li, X., and Scott, T.R., **Measurement of Nonlinearity of Optical Fiber Power Meters at NIST**, to be published in the Symposium on Optical Fiber Measurements, Boulder, Colorado, October 1-3, 1996.

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

Williams, P.A., **Accuracy in Polarization Mode Dispersion Measurements**, to be published in the Proceedings of the 1996 IEEE Lasers and Electro-Optics Society Meeting (LEOS'96), Boston, Massachusetts, November 18-21, 1996.

A description is given of ongoing work toward accuracy statements for polarization mode

dispersion measurements. The work described here includes theoretical comparisons of methods, experimental and simulated accuracies, and round-robin comparison results.
[Contact: Paul A. Williams, (303) 497-3805]

Williams, P.A., **Accuracy Issues in Comparisons of Time and Frequency Domain Polarization Mode Dispersion Measurements**, to be published in the Symposium on Optical Fiber Measurements, Boulder, Colorado, October 1-3, 1996.

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

OPTOELECTRONICS

Recently Published

Day, G.W., **Optoelectronics at NIST**, Proceedings of the 8th Annual 1995 IEEE Lasers and Electro-Optics Society Annual Meeting, San Francisco, California, October 30—November 2, 1995, Vol. 2, pp. 73-74 (1996).

Research in optoelectronics has a long history at the National Institute of Standards and Technology (NIST) (formerly NBS). The Optics Division, one of the first divisions formed after the National Bureau of Standards was established in 1901, was initially charged with work on radiometry, spectroscopy, and polarimetry. Over the next five or six decades, optics remained a significant topic of research, though the Optics Division eventually disappeared, and the work became more scattered. Within a year of Maiman's first demonstration of the ruby laser in 1960, a similar laser was constructed at the NBS-Boulder Laboratories. Demands for assistance in measuring the power or energy produced by such lasers led to the establishment of laser-calibration services beginning in 1967. Another early program was aimed at developing techniques for laser-frequency stabilization and absolute frequency and wavelength measurements. That effort culminated in 1972 with the determination of a much improved value for the speed-of-light, which led ultimately to a redefinition of the meter.

Today, approximately 140 NIST staff, scattered through six of the eight NIST Laboratories work in optoelectronics. Providing the optoelectronics industry with advanced measurement technology continues to be a major thrust, but optoelectronics is also an important tool in other areas of metrology. A brief introduction to some of the NIST optoelectronics programs follows. Additional information, including contacts in various areas of research can be found at the NIST World Wide Web Site (http://www.nist.gov).
[Contact: Gordon W. Day, (303) 497-5204]

Day, G.W., Rochford, K.B., and Rose, A.H., **Fundamentals and Problems of Fiber Current Sensors**, Proceedings of the Eleventh International Conference on Optical Fiber Sensors, Sapporo, Hokkaido, Japan, May 21-24, 1996, pp. 124-129.

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

Mechels, S.E., and Franzen, D.L., **Accurate Zero-Dispersion WaveLength Measurements in Single-Mode Fibers: Two Frequency-Domain Methods**, Proceedings of the 1995 IEEE Lasers and Electro-Optics Society Meeting (LEOS'95), San Francisco, California, October 30—November 2, 1995, pp. 75-76.

Accurate determination of the zero dispersion wavelength (λ_0) is crucial for high-bandwidth performance in single-mode fiber systems. We examine two dispersion measurement systems, based on the frequency-domain phase shift and differential phase shift techniques. Both systems are capable of measuring λ_0 with repeatabilities (precisions) of $\pm$ 0.1 nm; however, their ultimate accuracies have yet to be determined. By comparing the two systems, we get an estimate of

potential systematic errors. The systems will be used to determine λ_0 in standard reference fibers. [Contact: Steven E. Mechels, (303) 497-5409]

Paul, A.E., Bolger, J.A., Smirl, A.L., and Pellegrino, J.G., **Time-Resolved Measurements of the Polarization State of Four-Wave Mixing Signals from GaAs Multiple Quantum Wells**, Optical Society of America B., Vol. 13, No. 5, pp. 1016-1025 (May 1996).

[See Compound Materials.]

Rochford, K.B., Rose, A.H., Williams, P.A., Clarke, I., Hale, P.D., and Day, G.W., **Optical Retardance Standard: A Progress Report**, Proceedings of the 1995 Infrared and Millimeter Wave Polarimetry Workshop, Huntsville, Alabama, December 5-7, 1995, pp. 517-524 (April 1996).

The National Institute of Standards and Technology is developing a quarterwave linear retarder for operation at 1.3 μm, which is expected to be stable to within $\pm 0.1°$ over a variety of operational and environmental conditions. Our design consists of a double rhomb total internal reflection retarder constructed from a low-stress optic glass. Several measurement methods that are used in our evaluations are reviewed, and data showing retardance stability to $\pm 0.1°$ are presented. [Contact: Kent B. Rochford, (303) 497-5170]

Stephens, E.F., Patrick, H., and Gilbert, S.L., **Electronically Tunable Fiber Laser for Optical Pumping of ^{3}He and ^{4}He**, Rev. Sci. Instrum., Vol. 67, No. 3, pp. 843-844 (March 1996).

We present in this paper a low threshold, highly stable, integrated fiber laser cavity that uses an electronically tunable internal Bragg grating. The fiber laser produced over 5 mW with a spectral width of about 5 GHz at 1083 nm. The laser was used to achieve 30% polarization of the 2^3S_1 metastable states of ^{4}He in a weak rf discharge cell. [Contact: Heather Patrick, (303) 497-6353]

Williams, P.A., and Hernday, P.R., **Anomalous Relation between Time and Frequency Domain PMD Measurements**, Proceedings of the 3rd Optical Fibre Measurement Conference, Liège, Belgium, September 25-26, 1995, Section I-2.

We report nearly simultaneous measurements of polarization mode dispersion (PMD) in various samples of highly mode-coupled single-mode fiber using the measurement methods of Jones matrix eigenanalysis (JME) and Fourier-transformed wavelength scanning. The ratio of the PMD values resulting from these two methods differs by approximately 10% from current theoretical predictions. The measurements are verified by demonstrating the theoretical agreement between the JME and wavelength scanning extremum counting results. [Contact: Paul A. Williams, (303) 497-3805]

Zhang, Z.M., Livigni, D.J., Jones, R.D., and Scott, T.R., **Thermal Modeling and Analysis of Laser Calorimeters**, Journal of Thermophysics and Heat Transfer, Vol. 10, No. 2, pp. 350-356 (April—June 1996).

We performed detailed thermal analysis and modeling of the C-series laser calorimeters at the National Institute of Standards and Technology for calibrating laser power or energy meters. A finite element method was employed to simulate the space and time dependence of temperature at the calorimeter receiver. The inequivalence in the temperature response caused by different spatial distributions of the heating power was determined. The inequivalence between electrical power applied to the front and rear portions of the receiver is $\approx 1.7\%$, and the inequivalence between the electrical and laser heating is estimated to be <0.05%. The computational results are in good agreement with experiments at the 1% level. The effects of the deposited energy, power duration, and relaxation time on the calibration factor and cooling constant were investigated. This article provides information for future design improvement on the laser calorimeters. [Contact: David Lavigni, (303) 497-5898]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Bretagne, J., Gousset, G., Šimko, T., Rao, M.V.V.S., Van Brunt, R.J., Wang, Y., Olthoff, J.K., Peko, B.L., and Champion, R.L., **Distributions of**

H^+, H_2, and H_3^+ Ions in Townsend Discharge and Determination of Their Collision Cross Sections, to be published in the Proceedings of the XIIIth European Sectional Conference on Atomic and Molecular Physics of Ionized Gases, Poprad, Slovakia Republic, August 27-30, 1996.

The translational kinetic-energy distributions of the ions H^+, H_2^+, and H_3^+ at high-electric field-to-gas density ratio (E/N) have been measured in diffuse Townsend discharges in hydrogen gas using an ion energy analyzer-mass spectrometer system. The results are compared with ion-energy distributions predicted at the same (E/N) values using a Convective Scheme model that employs H_3^+/H_2 collision cross sections that were measured with an ion-beam apparatus. At (E/N) values below 5 x 10^{-18} Vm^2, there are discrepancies that need to be resolved.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Mansoor, A., Nastasi, D., and Martzloff, F.D., **Applying Reality Checks to Standards on the Surge Environment**, to be published in the Proceedings of the 23rd International Conference on Lightning Protection, Florence, Italy, September 23-27, 1996.

In this paper, we present four "reality checks" drawing on field experience or laboratory data. These reality checks can serve as a moderating influence to the quest for what could be overly conservative requirements for surge immunity or surge mitigation. Before proposing this moderation, the first check is actually a caution that some field recordings of surges may be misleadingly low in today's surge environment. The checks for moderation include: 1) the case history of a proposed high-stress 100/1300 μs surge test; 2) failure levels of clock motors or light bulbs from which useful inferences can be drawn on the infrequent occurrence of high-amplitude surges, and 3) measurements, validated by parametric modeling, showing that large currents cannot propagate into long cables without causing a flashover of the wiring devices at the beginning of the cable, effectively limiting the energy-delivery capability of a surge at the end of the cable.
[Contact: Françis D. Martzloff, (301) 975-2409]

Martzloff, F.D., **Surge Recordings That Make Sense: Shifting Focus from Voltage to Current Measurements**, to be published in the Proceedings of the 1996 Symposium on Electromagnetic Compatibility, Rome, Italy, September 17-20, 1996.

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

Martzloff, F.D., Key, T., and Mansoor, A., **No Joules for Surges: Relevant and Realistic Assessment of Surge Threats**, to be published in the Proceedings of the 1996 IEEE International Conference on Harmonics and Power Quality, Las Vegas, Nevada, October 19, 1996.

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

comprehensive set of parameters in conducting future surveys.
[Contact: François D. Martzloff, (301) 975-2409]

Martzloff, F.D., Mansoor, A., and Phipps, K.O., **Gapped Arresters Revisited: A Solution to Cascade Coordination**, to be published in the Proceedings of the 23rd International Conference on Lightning Protection, Florence, Italy, September 23-27, 1996.

This paper provides a brief perspective on how the coordination of cascaded surge-protection devices (SPDs) has become an issue. We propose an approach where the "ancient" technology of gapped arresters may well be the answer to the dilemma of the incompatibility of a service-entrance SPD having relatively high-limiting voltage with the proliferation of built-in or plug-in SPDs having relatively low-limiting voltage inside the buildings. The solution involves providing a gapped arrester at the service entrance and gapless SPDs inside the building. An example is given of such a combination, with experimental verification of the proposed solution and computer modeling that allows a parametric evaluation of the significant factors in any candidate combination of SPDs.
[Contact: François D. Martzloff, (301) 975-2409]

Misakian, M., and Fenimore, C., **Distributions of Measurement Errors for Single-Axis Magnetic Field Meters During Measurements Near Appliances**.

[See Magnetic Materials and Measurements.]

Petersons, O., Simmon, E., and FitzPatrick, G.J., **An Active High Voltage Divider with 20 ppm Uncertainty**, to be published in the Digest of the 1996 Conference on Precision Electromagnetic Measurements, Braunschweig, Germany, June 17-20, 1996.

A voltage divider consisting of a group of solid-dielectric capacitors maintained in a temperature-controlled environment, an external compressed-gas capacitor and special electronic circuitry have been designed, a prototype 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, enabling achievement of a voltage ratio that is equal to the reciprocal of the capacitance ratio well within one part per million without encountering dynamic instability problems.
[Contact: Eric Simmon, (301) 975-3956]

Power Systems Metrology

Recently Published

Boggs, S.A., FitzPatrick, G.J., and Kuang, J., **Transient Errors in a Precision Resistive Divider**, Proceedings of the 1996 IEEE International Symposium on Electrical Insulation, Piscataway, New Jersey, June 15-19, 1996, pp. 482-495.

[See DC and Low-Frequency Metrology.]

Magnetic Materials and Measurements

Released for Publication

Misakian, M., and Fenimore, C., **Distributions of Measurement Errors for Single-Axis Magnetic Field Meters During Measurements Near Appliances**.

Comparisons are made between the maximum average magnetic flux density as would be measured with a single axis coil probe and the flux density at the center of the probe. Probability distributions of the differences between the two quantities are calculated assuming a dipole magnetic field are found to be asymmetric. The distributions are used to estimate the uncertainty for maximum magnetic field measurements made near some electrical appliances and other electrical equipment.
[Contact: Martin Misakian, (301) 975-2426]

Liou, S.H., Malhotra, S.S., Moreland, J., and Hopkins, P.F., **Thin Film Recording Heads by Superparamagnetic Magnetic Force Microscopy Tips**.

We have shown a method using superparamagnetic force microscopy (MFM) tips to obtain MFM images

of recording heads with high-spatial resolution. Profiles of magnetic field gradient of the thin-film recording head under different current bias to the head and various tip-head distance conditions were measured. At a low-scan height, the gap width and the gap location, as well as the gap-field structure, can be well resolved by MFM images. Superparamagnetic tips show promise for magnetic imaging of recording heads with gap size well below 200 nm.
[Contact: John Moreland, (303) 497-3641]

Oti, J.O., Cross, R.W., Russek, S.E., and Kim, Y.K., **Simulated Magnetoresistive Behavior of Geometrically Non-Symmetric Spin Valves**.

A semi-analytical micromagnetic model is used to study how the magnetoresistive 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]

Magnetic Materials and Measurements

Recently Published

Hopkins, P.F., Moreland, J., Malhotra, S.S., and Liou, S.H., **Superparamagnetic Magnetic Force Microscopy Tips**, Journal of Applied Physics, Vol. 79, No. 8, pp. 6448-6450 (8 April 1996).

We report on magnetic force microscopy (MFM) images of a thin-film magnetic recording head taken using batch micromachined silicon tips coated with nanocomposite $Fe_{60}(SiO_2)_{40}$ and $Fe_{70}(SiO_2)_{30}$ films. The small Fe grain size (<10 nm) and dilute Fe volume fraction (0.29 to 0.4) of these granular films produce tip coatings of low remanence and essentially zero coercivity, reduced by the superparamagnetic properties of these films. We have used these tips to obtain MFM images of the write field of the head with high spatial and magnetic-field resolution. In comparison to images taken using commercial $Co_{85}Cr_{15}$-coated tips, these MFM images show reduced tip memory effects and clearly delineate the gap field from the pole pieces.
[Contact: John Moreland, (303) 497-3641]

Oti, J.O., and Kim, Y.K., **Modeling Effects of Temperature Annealing on Giant Magnetoresistive Response in Discontinuous Multilayer NiFe/Ag Films**, Journal of Applied Physics, Vol. 79, No. 8, pp. 5596-5598 (15 April 1996).

The giant magnetoresistive (GMR) behaviors of discontinuous double-layer giant magnetoresistive films, with different microstructure arising from different annealing conditions, are calculated using a numerical micromagnetic model. The effect of magnetic grain growths in the perpendicular and lateral directions in the magnetic layers, and the formation and growth of grain clusters were studied. The GMR responses of the films are analyzed in terms of magnetostatic interactions between the magnetic layers and the microstructural geometric effects on the transport properties of the samples.
[Contact: John O. Oti, (303) 497-5557]

Superconductors

Released for Publication

DeGroot, D.C., Rudman, D.A., Zhang, K., Ma, Q.Y., Kato, H., and Jaeger, N.A.F., **Planar Microwave Devices Fabricated by Ion-Implantation Patterning of High-Temperature Superconductors**.

[See Microwave and Millimeter-Wave Metrology.]

Superconductors

Recently Published

Yuan, C.W., Zheng, Z., de Lozanne, A.L., Tortonese, M., Rudman, D.A., and Eckstein, J.N., **Vortex Images in Thin Films of $YBa_2Cu_3O_{7-x}$ and $Bi_2Sr_2Ca_1Cu_2O_{8+x}$ Obtained by Low-Temperature Magnetic Force Microscopy**, Journal of Vacuum Science Technology, Vol. 14, No. 2, pp. 1210-1213 (March/April 1996).

We have imaged vortices in superconducting thin

films with a low-temperature magnetic force microscope that utilizes microfabricated piezoresistive with built-in tips. The films of $YBa_2Cu_3O_{7-x}$ and $Bi_2Sr_2Ca_1Cu_2O_{8+x}$, are made by laser ablation and molecular beam epitaxy, respectively. The vortices usually appear as round features in the noncontract image with a diameter of about 1 μm or slightly less. In some cases, the position of the vortices is correlated to defects observed in the topographic image of the same area. The vortices move sometimes, especially after taking a topographic (contact mode) scan.
[Contact: David A. Rudman, (303) 497-5081]

LAW ENFORCEMENT STANDARDS

Released for Publication

Field, B.F., Kelley, E.F., and McCabe, R.M., **Specification for Interoperability between Ballistic Imaging System**, to be published as NISTIR 5855.

To facilitate interoperability between existing ballistic imaging systems, the Office of National Drug Control Policy, the Federal Bureau of Investigation, and the Bureau of Alcohol, Tobacco, and Firearms executed a Memorandum of Understanding that recognized, in part, that it is imperative that the Drugfire and IBIS Ballistic Imaging Systems are interoperable. Further, the National Institute of Standards and Technology was asked to provide technical assistance in this effort. This document is the first of a series of planned documents that will specify the hardware and software requirements to permit interoperability between the Drugfire and IBIS systems as specified in the MOU. This specific document provides a complete specification of hardware requirements for capture of cartridge image and ancillary data for each system, and the data exchange formats required for transmitting and processing information requests.
[Contact: Bruce F. Field, (301) 975-4230]

VIDEO TECHNOLOGY

Released for Publication

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

Display standards describe measurements of the diffuse and specular reflection coefficients. The adequacy of such procedures is compared with the bidirectional 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]

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 5040 (September 1995).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NIST during the period from January 1970 through publication of this report. A few earlier references that are directly related to the present work of the Division are also included. This edition of the bibliography is the first since the Electromagnetic Technology Division split into two Divisions, and it includes publications from the areas of cryoelectronic metrology and superconductor and magnetic measurements. The optical electronic metrology section found in earlier editions is now being produced separately by the new Optoelectronics Division of NIST. That companion bibliography to this publication is NISTIR 4041.
[Contact: Ann G. Bradford, (303) 497-3678]

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

This bibliography lists the publications by the staff of the National Institute of Standards and Technology's Electromagnetic Fields Division for the period January 1970 through July 1995. It supersedes NISTIR 5028 which listed the publications of the Electromagnetic Fields Division from January 1970 through July 1994. Selected earlier publications from the Division's predecessor organizations are included.
[Contact: Ruth Marie Lyons, (303) 497-3132]

Schmeit, R.A., **Electrical and Electronic Metrology: A Bibliography of NIST Electricity Division's Publications, NIST List of Publication 94** (July 1995).

This bibliography covers publications of the Electricity Division (and predecessor organizational units), Electronics and Electrical Engineering Laboratory, National Institute of Standards and Technology, for the period of January 1968 through December 1994. A brief description of the

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

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

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

Walters, E.J., **NIST List of Publications 103, National Semiconductor Metrology Program, and the Semiconductor Electronics Division, 1990-1995**. (March 1996).

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

1996-1998 Calendar of Events

October 1-3, 1996 (Boulder, Colorado)

Symposium on Optical Fiber Measurements. This Symposium, held at NIST in Boulder, provides a forum for reporting the results of recent measurement research in the area of lightwave communications, including optical fibers. Aspects of optical fiber metrology will be discussed, including attenuation, dispersion, geometry, reflectometry, and connectors; integrated optic devices; laser diode sources and detectors; and system measurements.
[Contact: Douglas L. Franzen, (303) 497-3346]

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.

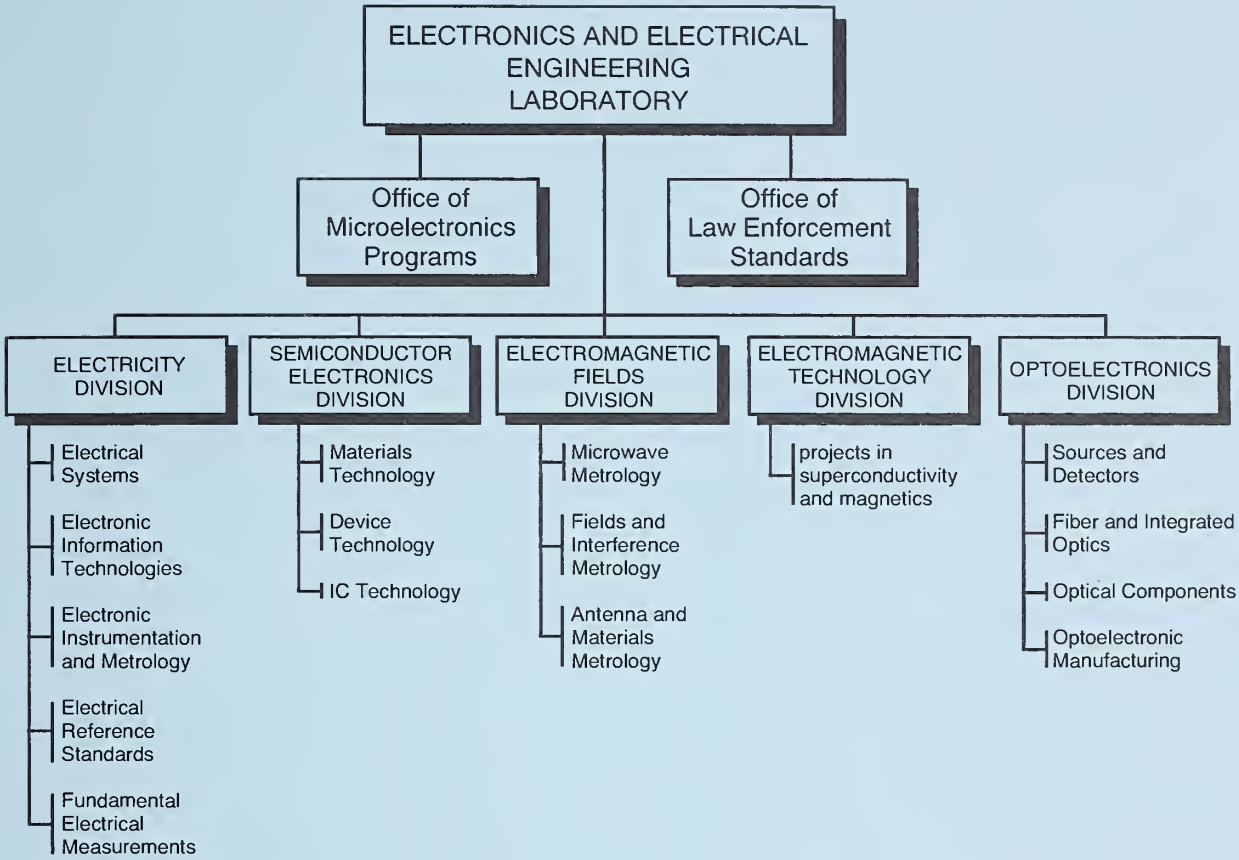
It is expected that the higher resistivity SRMs (2547, 2546) will be available first during CY 96 and be followed closely by SRM 2545. The low resistivity material (SRMs 2542, 2541) is expected to be available by year end. A limited number of SRM 2543 may also be available by year end, with the remainder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