NISTIR 5937

# Electronics and Electrical Engineering Laboratory

J. M. Rohrbaugh
Compiler

# Technical Publication Announcements

## 49

Covering Laboratory Programs,
April to June 1996,
with 1997-1998 EEEL Events Calendar

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

NIST

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Electronics and Electrical
Engineering Laboratory
Semiconductor Electronics Division
Gaithersburg, MD 20899

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**49**

U.S. DEPARTMENT OF COMMERCE
Michael Kantor, Secretary
TECHNOLOGY ADMINISTRATION
Mary L. Good, Under Secretary for Technology
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Arati Prabhakar, Director

## INTRODUCTION TO THE EEEL TECHNICAL PUBLICATION ANNOUNCEMENTS

This is the forty-ninth 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 Publication Announcements covers the second quarter of calendar year 1996.

Organization of Bulletin: This issue contains citations and abstracts for Laboratory publications published in the quarter. Entries are arranged by technical topic as identified in the Table of Contents and alphabetically by first author within each topic. Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Laboratory conferences and workshops planned for calendar years 1997 and 1998 and a list of sponsors of the work.

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

The work of the Laboratory is conducted by five technical research Divisions: the Semiconductor Electronics and the Electricity Divisions in Gaithersburg, Md., and the Electromagnetic Fields, Electromagnetic Technology 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 given on the inside back cover; 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 12.

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 11.

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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

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

### Compound Materials

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]

### Device Physics and Modeling

Marchiando, J.F., **Application of the Collocation Method in Three Dimensions to a Model SemiconductorProblem**, 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]

Reliability

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]

## SIGNAL ACQUISITION, PROCESSING AND TRANSMISSION

DC and Low-Frequency Metrology

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

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 $\mu$s 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]

Microwave and Millimeter-Wave Metrology

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 $2\pi\gamma M_s/\varpi < 0.75$. 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]

Complex System Testing

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

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 ($\lambda_0$) 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 $\lambda_0$ with repeatabilities (precisions) of ± 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 $\lambda_0$ 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 $\mu$m, which is expected to be stable to within ±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 ±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

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

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

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 $\mu$m 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]

## ADDITIONAL INFORMATION

Announcements

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

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

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

**Characterization Workshop Proceedings Published**

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

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

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

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

Lists of Publications

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

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

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

This bibliography lists the publications by the staff of the National Institute of Standards and Technology's Electromagnetic Fields Division for the period January 1970 through July 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** (February 1996).

This bibliography covers publications of the Electricity Division (and predecessor organizational units), Electronics and Electrical Engineering Laboratory, National Institute of Standards and Technology, for the period of January 1968 through December 1995. A brief description of the Division's technical program is given in the introduction.
[Contact: Ruth A. Schmeit, (301) 975-2401]

Smith, A.J., and Derr, L.S., **A Bibliography of Publications of the NIST Optoelectronics Division**, NISTIR 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]

1997-1998 Calendar of Events

January 28-30, 1997 (Austin, Texas)

**Thirteenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM) 1997**. Co-sponsored by NIST and IEEE, the Symposium will present papers on current thermal management and measurement work on electronic components and systems in the following areas: thermal characterization - component through system; analytical and computational modeling and simulation; experimental methods and applications, and thermal design and testing for reliability.
[Contact: David L. Blackburn, (301) 975-2068]

March 23-27, 1998 (Gaithersburg, Maryland)

**Semiconductor Characterization: Present Status and Future Needs II**. This workshop is to bring together scientists and engineers interested in all aspects of the technology and characterization techniques for semiconductor device research, development, manufacturing, and diagnostics: chemical and physical, electrical, optical, in-situ, and real-time control and monitoring.

The Workshop provides a forum to present and discuss critical issues; problems and limits; evolving requirements and analysis needs; future directions; and key measurement principles, capabilities, applications, and limitations. It will be comprised of formal invited presentation sessions, poster sessions for contributed papers, and panel sessions. This Workshop is the second in a series. The first was held at NIST January 30 to February 2, 1995. Papers from that Workshop were published in *Semiconductor Characterization: Present Status and Future Needs* (AIP Press, New York, 1996), W. M. Bullis, D. G. Seiler, and A. C. Diebold, editors. This Workshop is sponsored by NIST, SEMATECH, Semiconductor Research Corporation, and American Vacuum Society - Manufacturing Science and Technology Group.
[Contact: David G. Seiler, (301) 975-2074]

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## NIST SILICON RESISTIVITY SRMs

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

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

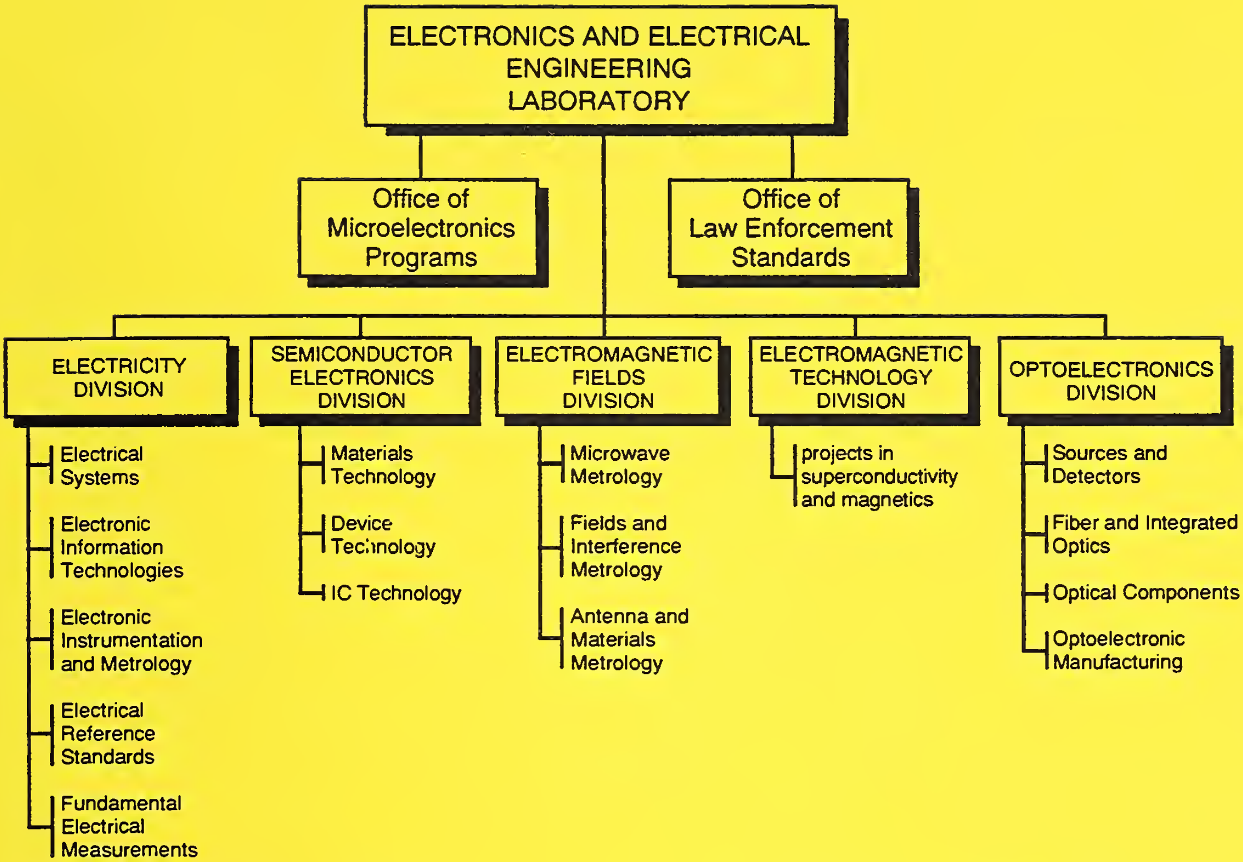
It is expected that the higher resistivity SRMs (2547, 2546) will be available first during CY 96 and be followed closely by SRM 2545. The low resistivity material (SRMs 2542, 2541) is expected to be available by year end. A limited number of SRM 2543 may also be available by year end, with the remainder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

***NIST SILICON BULK RESISTIVITY STANDARD REFERENCE MATERIALS***

**DATE UPDATED: 23 JANUARY 1996**

| NOMINAL RESISTIVITY (ohm · cm) | OLD SRMs | AVAILABILITY | NEW SRMs (ohm · cm) | ANTICIPATED AVAILABILITY |
|---|---|---|---|---|
| 0.01 | 1523 (one of set of two wafers) | limited supply | 2541 | CY 96 |
| 0.1 | 1521 (one of set of two wafers) | limited supply | 2542 | CY 96 |
| 1 | 1523 (one of set of two wafers) | limited supply | 2543 | CY 96-97 |
| 10 | 1521 (one of set of two wafers) | limited supply | 2541 | 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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