NISTIR 5471

Electronics and Electrical Engineering Laboratory

Technical Publication Announcements

J. M. Rohrbaugh
Compiler

August 1994

Covering Laboratory Programs,
January to March 1994
with 1994/1995 EEEL Events Calendar

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

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U.S. DEPARTMENT OF COMMERCE
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INTRODUCTION TO THE EEEL TECHNICAL PUBLICATION ANNOUNCEMENTS

This is the fortieth issue of a quarterly 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 first quarter of calendar year 1994.

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 1994/1995 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 four technical research Divisions: the Semiconductor Electronics and the Electricity Divisions in Gaithersburg, Md., and the Electromagnetic Fields and Electromagnetic Technology Divisions in Boulder, Colo. In 1991, the Office of Law Enforcement Standards, formerly the Law Enforcement Standards Laboratory, was transferred to EEEL. This Office conducts research and provides technical services to the U.S. Department of Justice, State and local governments, and other agencies in support of law enforcement activities. In addition, the Office of Microelectronics Programs (OMP) was established in EEEL to coordinate 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 24.

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 19.

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GENERAL INFORMATION

Surette, J.M., **Electronics and Electrical Engineering Laboratory: 1993 Technical Accomplishments Supporting, Technology for U.S. Competitiveness**, NISTIR 5355 (December 1993).

The Electronics and Electrical Engineering Laboratory (EEEL), 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. electrical-equipment industry. This report summarizes selected technical accomplishments and describes activities conducted by the Laboratory in FY 1993. Also included is a profile of EEEL's organization, its customers, and the Laboratory's long-term goals.
[Contact: JoAnne M. Surette, (301) 975-5267]

Surette, J.M., **Electronics and Electrical Engineering Laboratory 1994 Program Plan--Supporting Technology for U.S. Competitiveness in Electronics**, NISTIR 5337 (December 1993).

The Electronics and Electrical Engineering Laboratory (EEEL), 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. electrical-equipment industry. This 1994 Program Plan describes the projected metrological support that EEEL intends to provide to U.S. industry.
[Contact: JoAnne M. Surette, (301) 975-5267]

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Eiles, T.M., Devoret, M.H., and Martinis, J.M., **Coulomb Blockade of Andreev Reflection in the NSN Single-Electron Transistor**, Elsevier Surface Science, pp. 1-5 (June 1993).

We have measured at low temperatures the current through a submicrometer superconducting island connected to normal-metal leads by ultrasmall tunnel junctions. At low bias voltages, the current changes from being *e*-periodic in the applied gate charge to 2*e*-periodic. We interpret this 2*e*-periodic current as a manifestation of a sequence of Andreev reflection events which transports two electrons at a time across the island. This behavior is clear evidence that there is a difference in total energy between ground states of a even or odd number of electrons.
[Contact: Travis M. Eiles, (303) 497-3969]

Martinis, J.M., and Nahum, M., **Effect of Environmental Noise on the Accuracy of Coulomb-Blockade Devices**, Physical Review B, Vol. 48, No. 24, pp. 18 316-18 319 (December 15, 1993).

We calculate how noise generated by a finite environment impedance limits the ultimate performance of Coulomb-blockade devices and possible current or charge standards. We have expressed the environmental theory of the Coulomb blockade in terms of the spectral density of the voltage noise arising from the environment, and have calculated the resulting single-junction tunneling and two-junction co-tunneling rates. These rates are used to predict the tunneling rate of electrons through a five-junction pump and may explain the anomalously large rates that are observed experimentally.
[Contact: John M. Martinis, (303) 497-3597]

Martinis, J., Nahum, M., and Jensen, H.D., **Metrological Accuracy of the Electron Pump**, Physical Review Letters, Vol. 72, No. 6, pp. 904-907 (February 7, 1994).

We have operated a five-junction electron pump with an error for transferring electrons of approximately 0.5 ppm. The predicted error from previous theoretical considerations is expected to be several orders of magnitude smaller, thus implying that our present understanding of Coulomb blockade is incomplete. We conjecture that the errors arise from photon-assisted tunneling, where the photon energy is supplied by noise from the environment.
[Contact: John M. Martinis, (303) 497-3597]

SEMICONDUCTOR MICROELECTRONICS

Silicon Materials

Albers, J., **An Exact Solution for the Steady-State Surface Temperature of a General Multilayer Structure**, Proceedings of the Tenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium, San Jose, California, February 1-3, 1994, pp. 129-137.

A recursion relation technique has been used in the past to determine the surface potential from the multilayer electrical Laplace equation. This has provided for a vastly simplified evaluation of the electrical spreading resistance and four-probe resistance. The isomorphism of the multilayer Laplace equation and the multilayer steady-state heat flow equation suggests the possibility of developing a recursion relation applicable to the multilayer thermal problem. This recursive technique is developed and is shown to provide the surface temperature of the multilayer steady-state heat flow equation. For the three-layer case, the thermal recursion relation readily yields the surface results which are identical with those presented by Kokkas and the TXYZ thermal code. This recursive technique can be used with any number of layers while incurring only a small increase in computation time for each added layer. For the case of complete, uniform top surface coverage by a heat source, the technique gives rise to the generalized one-dimensional thermal resistance result. An example of the use of the new recursive method is provided by the preliminary calculations of the surface temperature of a buried oxide (SOI, SIMOX) structure containing several thicknesses of the surface silicon layers. This new technique should prove useful in the investigation and understanding of the steady-state thermal response of modern multilayer microelectronic structures.
[Contact: John Albers, (301) 975-2075]

Analysis and Characterization Techniques

Bertness, K.A., Kramer, C., Olson, J.M., and Moreland, J., **In Situ Observation of Surface Morphology of InP Grown on Singular and Vicinal (001) Substrates**, Journal of Electronic Materials, Vol. 23, No. 2, pp. 195-200 (1994).

Surface morphology of InP layers is monitored during organometallic vapor phase epitaxy using an in-situ diffuse laser light-scattering technique. Changes in the diffuse scatter signal are noted for several substrate orientations near the (001) plane and at various growth temperatures. The diffuse scatter signal is shown to be a semi-quantitative indicator of surface roughness through postgrowth examination of the samples with phase contrast optical microscopy and atomic force microscopy. Singular substrates consistently have almost featureless surfaces and very little diffuse scattering during growth. Vicinal substrates display a more complicated morphological evolution which cannot be deduced from the diffuse scattering alone, but which does produce characteristic changes in diffuse scattering.
[Contact: John Moreland, (303) 497-3641]

Integrated-Circuit Test Structures

Recently Published

Allen, R.A., Cresswell, M.W., Linholm, L.W., Owen, J.C., III, Ellenwood, C.H., Hill, T.A., Benecke, J.D., Volk, S.R., and Stewart, H.D., **Application of the Modified Voltage-Dividing Potentiometer to Overlay Metrology in a CMOS/Bulk Process**, Proceedings of the 1994 IEEE International Conference on Microelectronic Test Structures, San Diego, California, March 22-24, 1994, pp. 51-56.

The measurement of layer-to-layer feature overlay will, in the foreseeable future, continue to be a critical metrological requirement for the semiconductor industry. Meeting the image placement metrology demands of accuracy, precision, and measurement speed favors the use of electrical test structures. In this paper, a two-dimensional, modified voltage-dividing potentiometer is applied to a short-loop VLSI process to measure image placement. The contributions of feature placement on the reticle and registration on the wafer to the overall measurement are analyzed and separated. Additional sources of uncertainty are identified, and methods developed to monitor and reduce them are described.
[Contact: Richard A. Allen, (301) 975-5026]

Cresswell, M.W., Penzes, W.B., Allen, R.A., Linholm, L.W., Ellenwood, C.H., and Teague, E.C., **Electrical Test Structure for Overlay Metrology Referenced to Absolute Length Standards**, Proceedings of SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Integrated Circuit Metrology, Inspection, and Process Control, Vol. 2196, pp. 512-520 (March 1994).

This test structure is based on the voltage-dividing potentiometer principle and was originally replicated in a single lithography cycle to evaluate feature placement by a primary pattern generator. A new test structure has now been developed from the single-cycle version and has been used for measuring the overlay of features defined by two different exposures with a stepping projection aligner. The as-measured overlay values are processed by an algorithm which minimizes the effects of nominal random pattern imperfections. The algorithm further partitions measurements of overlay into contributions which derive, respectively, from misregistration of the image fields projected by the two masks and from the drawn misplacement of features on the masks. The numerical estimates of these contributions so obtained from the electrical measurements were compared with those extracted from the same features by the NIST Line Scale Interferometer, providing traceability to absolute length standards. The two sets of measurements were found to agree to within the several-nanometer uncertainty cited for the line scale interferometer's readings alone. The motivation for this work was to compare the nanometer-level distortions, produced by alternative chucking arrangements, of proximity X-ray masks having various support-ring architectures. However, the technique may also be used to evaluate optical aligner tools and to determine image placement quality on optical reticles with traceability to the ISO Standard for the definition of the meter.
[Contact: Michael W. Cresswell, (301) 975-2072]

Marshall, J.C., and Zaghloul, M., **Color Supplement to NIST Special Publication 400-93: CMOS and Lateral Bipolar-On-SOI Test Structures**, NISTIR 5324 (March 1994).

This report is the supplement to the NIST Special Publication entitled, "*Semiconductor Measurement Technology:*" Design and Testing Guides for the CMOS and Lateral Bipolar-on-SOI Test Library." This supplement contains the complete set of figures from the above mentioned document with the test structures provided in color for easier interpretation.
[Contact: Janet C. Marshall, (301) 975-2049]

Marshall, J.C., and Zaghloul, M.E., **Semiconductor Measurement Technology: Design and Testing Guides for the CMOS and Lateral Bipolar-On-SOI Test Library**, NIST Special Publication 400-93 (March 1994).

Design and testing guides have been developed for the test library from which test chip NIST8 and test wafer NIST9 were derived. They were designed for use in process monitoring and device parameter extraction to evaluate and compare CMOS (Complementary Metal-Oxide-Semiconductor) test structures, including devices and circuits, fabricated on both bulk silicon and SOI (Silicon-on-Insulator), specifically SIMOX (Separation by the IMplantation of OXygen), wafers. The test library consists of both CMOS-on-SOI and lateral bipolar-on-SOI modules. From it, 20 modules were assembled to create CMOS test chip NIST8 that was fabricated using a standard bulk CMOS foundry through the MOSIS service. SOI/SIMOX test wafer NIST9 contains approximately 1000 modules and was also assembled from modules in this test library. Fourteen processing masks are used to fabricate depletion-mode MOSFETs, lateral bipolar devices, and CMOS MOSFETs with source-to-channel ties. The SOI/SIMOX technology file used with the Magic VLSI layout editor was modified to include the layers necessary to generate these 14 processing masks. This modification is discussed, and unique test structure designs are presented.
[Contact: Janet C. Marshall, (301) 975-2049]

Microfabrication Technology

Gaitan, M., Parameswaran, M., Zaghloul, M.E., Marshall, J.C., Novotny, D.B., and Suehle, J.S., **Design Methodology for Micromechanical Systems at Commercial CMOS Foundries through MOSIS**, Proceedings of the 35th Midwest Symposium on Circuits and Systems, Washington, D.C., August 9-12, 1992, pp. 1357-1360 (1993).

A methodology is presented for the design and fabrication of micromechanical structures through MOSIS. Using this methodology, a new class of devices can be fabricated at commercial foundries that are based on electrothermal-mechanical properties with associated circuits for communication and control. The technique is a method of making microdynamical devices and systems using existing VLSI design capabilities with minimal additional equipment cost. Examples of devices

and applications produced by this technique are presented with trade-offs of this technique compared to the traditional custom fabrication techniques.
[Contact: Michael Gaitan, (301) 975-2070]

Tseng, W.F., Dagata, J.A., Silver, R.M., Fu, J., and Lowney, J.R., **Junction Locations by Scanning Tunneling Microscopy: In-Air-Ambient Investigation of Passivated GaAs *pn* Junctions**, Journal of Vacuum Science Technology B, Vol. 12, No. 1, pp. 373-377 (January/February 1994).

Scanning tunneling microscopy (STM) and atomic force microscopy operating in air have been used to investigate locations of molecular-beam epitaxially grown GaAs multiple *pn* junctions cleaved and passivated with P_2S_5. Symmetrically and asymmetrically doped junctions were prepared within topographically delineated AlAa/GaAs marker regions for this in-air study of electronic junction contrast. Our results indicate that the STM-delineated junction locations do not coincide with the electrical junction locations, but rather shift into the *p*-type regions.
[Contact: Wen F. Tseng, (301) 975-5291]

Plasma Processing

Roberts, J.R., Olthoff, J.K., Whetstone, J.R., Van Brunt, R.J., and Sobolewski, M.A., **The Gaseous Electronics Conference Radio-Frequency Reference Cell: A Defined Parallel-Plate Radio-Frequency System for Experimental and Theoretical Studies of Plasma-Processing Discharges**, Review of Scientific Instruments, Vol. 65, No. 1, pp. 140-154 (January 1994).

A "reference cell" for generating radio-frequency (rf) glow discharges in gases at a frequency of 13.56 MHz is described. The reference cell provides an experimental platform for comparing plasma measurements carried out in a common reactor geometry by different experimental groups, thereby enhancing the transfer of knowledge and insight gained in rf discharge studies. The results of performing ostensibly identical measurements on six of these cells in five different laboratories are analyzed and discussed. Measurements were made of plasma voltage and current characteristics for discharges in pure argon at specified values of applied voltages, gas pressures, and gas flow rates. Data are presented on relevant electrical quantities derived from Fourier analysis of the voltage and current wave forms. Amplitudes, phase shifts, self-bias voltages, and power dissipation were measured. Each of the cells was characterized in terms of its measured internal reactive components. Comparing results from different cells provides an indication of the degree of precision needed to define the electrical configuration and operating parameters in order to achieve identical performance at various laboratories. The results show, for example, that the external circuit, including the reactive components of the rf power source, can significantly influence the discharge. Results obtained in reference cells with identical rf power sources demonstrate that considerable progress has been made in developing a phenomenological understanding of the conditions needed to obtain reproducible discharge conditions in independent reference cells.
[Contact: James R. Roberts, (301) 975-3225]

Power Devices

Hefner, A.R., and Blackburn, D.L., **Simulating the Dynamic Electrothermal Behavior of Power Electronic Circuits and Systems**, IEEE Transactions on Power Electronics, Vol. 8, No. 4, pp. 376-385 (October 1993).

A methodology is presented for simulating the dynamic electrothermal behavior of power electronic circuits and systems. In the approach described, the simulator solves for the temperature distribution within the semiconductor devices, packages, and heatsinks (thermal network), as well as the currents and voltages within the electrical network. The thermal network is coupled to the electrical network through the electrothermal models for the semiconductor devices. The electrothermal semiconductor device models calculate the electrical characteristics based upon the instantaneous value of the device silicon chip surface temperature and calculate the instantaneous power dissipated as heat within the device. The thermal network describes the flow of heat from the chip surface through the package and heatsink and, thus, determines the evolution of the chip surface temperature used by the semiconductor device models. The thermal component models for the device silicon chip, packages, and heatsinks

are developed by discretizing the nonlinear heat diffusion equation and are represented in component form so that the thermal component models for various packages and heatsinks can be readily connected to one another to form the thermal network.
[Contact: Allen R. Hefner, (301) 975-2071]

Photodetectors

Phelan, R.J., Jr., Lehman, J.H., and Larson, D.R., **Electrically Calibrated Pyroelectric Detector-Refinements for Improved Optical Power Measurements**, Proceedings of SPIE (The International Society for Optical Engineering, P.O. Box 10, Bellingham, Washington 98227-0010), Photodetectors and Power Meters, Vol. 2022, pp. 160-164 (1993).

This paper describes the present efforts at NIST to improve the accuracy of the electrically calibrated pyroelectric detector for measuring optical power by an order of magnitude. The principal limitation, the uniformity of the responsivity over the receiving aperture, has been significantly improved.
[Contact: Robert J. Phelan, Jr., (303) 497-3696]

Reliability

Suehle, J.S., **Reproducibility of JEDEC Standard Current and Voltage Ramp Test Procedures for Thin-Dielectric Breakdown Characterization**, Proceedings of the 1993 IEEE International Integrated Reliability Workshop Final Report, Lake Tahoe, California, October 24-27, 1993, pp. 22-34.

Six laboratories and a reference laboratory participated in an interlaboratory experiment that was conducted to determine the reproducibility of breakdown electric field, E_{BR}, and breakdown charge density, q_{bd}, measurements using the JEDEC standard voltage and current ramp dielectric test procedures. The results indicate that the measurement of E_{BR} is much more reproducible than q_{bd}. Much of the variability in the q_{bd} measurements was found to be due to an allowed range of values that could be chosen for a parameter in the current ramp procedure. When this source of variability is accounted for, the results indicate that the standard test procedures can be implemented to obtain critical dielectric integrity parameters with good reproducibility for a wide variety of test equipment.
[Contact: John S. Suehle, (301) 975-2247]

Suehle, J.S., Chaparala, P., Messick, C., Miller, W.M., and Boydo, K.C., **Experimental Investigation of the Validity of TDDB Voltage Acceleration Models**, Final Report of the 1993 IEEE International Integrated Reliability Workshop, Lake Tahoe, California, October 24-27, 1993, pp. 59-67.

Time-Dependent Dielectric Breakdown (TDDB) data are presented for 15- and 22.5-nm oxides collected over a wide range of electric fields and temperatures. The results indicate that it is necessary to obtain data over this range to distinguish between the two field acceleration models and to quantify the electric field and temperature dependencies of the thermal activation energy and the field acceleration factor, respectively. We also demonstrate the use of temperatures as high as 400 °C to accelerate time-dependent dielectric breakdown.
[Contact: John S. Suehle, (301) 975-2247]

Suehle, J.S., Chaparala, P., Messick, C., Miller, W.M., and Boyko, K.C., **Field and Temperature Acceleration of Time-Dependent Dielectric Breakdown in Instrinsic Thin SiO_2**, Proceedings of the 1994 IEEE International Reliability Physics Workshop, San Jose, California, April 12-14, 1994, pp. 120-125.

Time-Dependent Dielectric Breakdown (TDDB) data are presented for 15- and 22.5-nm oxides collected over a wide range of electric fields and temperatures. The results indicate that it is necessary to obtain data over this range to distinguish between the two field acceleration models and to quantify the electric field and temperature dependencies of the thermal activation energy and the field acceleration factor, respectively. We also report on the TDDB characteristics of thin SiO_2 films at temperatures as high as 400 °C and demonstrate the use of these temperatures to accelerate TDDB.
[Contact: John S. Suehle, (301) 975-2247]

SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Cryoelectronic Metrology

Benz, S.P., Burroughs, D.J., and Hamilton, C.A., **Experimental Results on Single Flux Quantum Logic**, IEEE Transactions on Applied Superconductivity, Vol. 3, No. 1, pp. 2582-2585 (March 1993).

We have optimized the design and calculated the margins for a number of single flux quantum (SFQ) logic elements including AND, OR, XOR, Splitter, DC-to-SFQ converter, and SFQ-to-DC converter. These are the fundamental building blocks necessary to construct more complex logic functions such as the half adder, and full adder. Experimental tests of the *primary* gates, the AND, OR, XOR, and splitter, were made by imbedding each test gate between DC-to-SFQ converters at the inputs and SFQ-to-DC converters at the outputs. Automated testing of each circuit was used to determine functionality, optimum bias levels, and margins. The experimental bias current margins for each gate are consistent with the simulations. This is the first experimental functional confirmation of these SFQ logic gates.
[Contact: Samuel P. Benz, (303) 497-5258]

Booi, P.A.A., Benz, S.P., Doderer, T., Hoffmann, D., Schmidt, J., Leachenmann, S., and Huebener, R.P., **Frequency Dependence of the Emission from 2D Array Josephson Oscillators**, IEEE Transactions on Applied Superconductivity, Vol. 3, No. 1, pp. 2493-2495 (March 1993).

Coherent emission from two-dimensional arrays of Josephson junctions, coupled to a detector junction through a dc blocking stripline capacitor, was detected over a frequency range from 50- to 210-GHz. A power of 0.26 μW which is larger than the 0.1 μW expected from the resistively shunted junction model was detected in a range from 140- to 150-GHz. Frequencies where no emission was detected correspond to standing waves in the capacitor when multiples of the half-wavelength match the capacitor length. Low temperature scanning electron microscopy confirmed the presence of standing waves at other frequencies, indicating an impedance mismatch and a possible extension of the standing waves into the array.
[Contact: Peter A. A. Booi, (303) 497-5910]

Burroughs, C.J., and Hamilton, C.A., **Automated Josephson Integrated Circuit Test System**, IEEE Transactions of Applied Superconductivity, Vol. 3, pp. 2687-2689 (March 1993).

We have developed an automated test system for complex superconductive integrated circuits. Its low speed capability consists of 96 identical I/O channels which are controlled by a PC-486 computer. Each channel is capable of driving currents and reading voltages at frequencies up to 40 kHz. Integrating this low speed I/O capability with high-speed test equipment controlled over the IEEE 488 bus allows measurements at frequencies up to the limits of the test equipment. The system can automatically set biases, display I-V curves, measure parameter margins, plot threshold curves, extract experimental circuit values, and collect statistical data on parameter spreads and error rates. Issues of noise suppression, ground loop handling, and auto-calibration are discussed.
[Contact: Charles J. Burroughs, (303) 497-3906]

Doderer, T., Hoffmann, D., Huebener, R.P., Kirchmann, N., Krulle, C.A., Lachenmann, S., Quenter, D., Schmidt, J., Stehle, S., Niemeyer, J., Pöpel, Benz, S.P., and Booi, P.A.A., **Susan (Superconducting Systems Analysis) Low Temperature Scanning Electron Microscopy (LTSEM)**, IEEE Transactions on Applied Superconductivity, Vol. 3, No. I, pp. 2724-2727 (March 1993).

We used the technique of Low Temperature Scanning Electron Microscopy for spatially resolved investigations of both Josephson junctions and superconducting integrated circuits during their operation with a spatial resolution of about 1 μm. Two examples of our studies are presented: With single Josephson tunnel junctions of various geometries, we studied different dynamic states such as fluxon oscillations or unidirectional flux flow. With an integrated circuit consisting of a two-dimensional array of tunnel junctions and an rf detection circuit, we investigated the rf properties of the coupling circuit and confirmed the existence of an impedance mismatch and a geometrical standing wave in the blocking capacitor.
[Contact: Samuel P. Benz, (303) 497-5258]

Grossman, E.N., Sauvageau, J.E., and McDonald, D.G., **Optical Performance of Photoinductive**

Mixers at Terahertz Frequencies, Proceedings of the Fourth International Symposium on Space Terahertz Technology, Los Angeles, California, March 30—April 2, 1993, pp. 588-604.

We have investigated the electrical and optical properties of detectors based on the change in kinetic inductance of a superconducting film with incident terahertz-frequency radiation. Two different geometric configurations, stripline and slotline, of these photoinductive detectors have been explored. Both include a loop of thin niobium coupled to the incident radiation through a lithographic antenna; the loop inductance is read out via an integrated dc SQUID. The slotlline geometry is substantially simpler to fabricate, but electrically, the two geometries have very similar properties. The loop inductance varies with temperature in good agreement with the two-fluid model, while the critical current varies with temperature in agreement with Ginzburg-Landau theory. The maximum voltage-flux transfer characteristic of the SQUID varies with temperature according to the empirical relation $dV/d\Phi(\max) = R/L$, where R is the resistance of the junction shunt resistors and L the loop inductance. The thermal conductance is less accurately determined experimentally, but the approximate value of 5×10^{-7} W/K implies a peak electrical responsivity of 2200 V/W. No excess audio frequency noise has been observed down to our amplifier's noise floor of 190 $\mathrm{pV/Hz^{1/2}}$. This yields an electrical noise-equivalent-power of 8×10^{-14} $\mathrm{W/Hz^{1/2}}$, a factor of 2.5 from the expected phonon-noise limit. The response to 992-GHz laser radiation varies with reduced temperature as expected for a purely bolometric response in the limited range over which it was examined, $0.78 < t < 0.95$. The optical power level at which the response saturates indicates that in a heterodyne mixing application, the optimum local oscillator power level would be approximately 2 nW.
[Contact: Erich N. Grossman, (303) 497-5102]

Rice, J.P., Grossman, E.N., Missert, N., Rosenthal, P.A., Cromar, M.W., and Rudman, D.A., **Kinetic-Inductance Infrared Detector Based on an Antenna-Coupled High-T_c SQUID**, Proceedings of the 4th International Superconductive Electronics Conference, Boulder, Colorado, August 11-14, 1993, pp. 382-383.

Noise Metrology

Pucic, S.P., **Derivation of the System Equation for Null-Balanced Total-Power Radiometer System NCS1**, NIST Journal of Research, Vol. 99, No. 1, pp. 55-63 (January—February 1994).

A system equation of a recently developed null-balanced, total-power radiometer system is rigorously derived. Delivered noise power and temperature is related to available power (temperature) through an extension of the mismatch factor to broadband systems. The available power ratio α_g, the available gain G_g, and the delivered power ratio (efficiency) η_1 are defined. Properties of idealized, but in principle realizable components such as an infinitely directive isolator and a lossless matched waveguide-below-cutoff attenuator are used. A cascading technique is repeatedly applied to the fundamental noise equation. Mathematically modeling the experimental procedure of sequentially attaching the two noise standards and the unknown source to the system input, we obtain the system of three equations that can be solved for the noise temperature of the unknown noise source.
[Contact: Sunchana P. Pucic, (303) 497-3546]

Pucic, S.P., **Evaluation of Uncertainties of the Null-Balanced Total-Power Radiometer System NCS1**, NIST Journal of Research, Vol. 99, No. 1, pp. 65-75 (January—February 1994).

Standard uncertainties are evaluated for the null-balanced, total-power, heterodyned radiometer system with a switched input that was recently developed at NIST to calibrate thermal noise sources. Eight significant sources of uncertainty due to systematic effects are identified, two attributable to the two noise standards, and one each to connectors, the input mismatch, the input switch asymmetry, the isolator, the broadband mismatch, and the attenuator. The combined standard uncertainty of a typical coaxial noise source calibration at a representative frequency of 2 GHz is about 1%. A strategy for reducing uncertainties is discussed.
[Contact: Sunchana P. Pucic, (303) 497-3546]

Pucic, S.P., **A Null-Balanced Total-Power Radiometer System NCS1**, NIST Journal of Research, Vol. 99, No. 1, pp. 45-53 (January—February I994).

A recently developed radiometer system NCS1 is used to calibrate thermal noise temperature at any frequency between 1.0 GHz and 12.0 GHz. Any cryogenic noise source can be measured; the upper limit of noise temperatures measured without a loss of accuracy is estimated to be about 10^5 K. For a typical hot noise source with the noise temperature of 8400 K and a reflection coefficient magnitude of 0.1, the expanded uncertainty is $\approx 1.8\%$, and the system sensitivity ≈ 2 K. Implemented in Type N connector, it can be easily modified to calibrate noise sources with other coaxial connectors or waveguide flanges.
[Contact: Sunchana P. Pucic, (303) 497-3546]

Microwave and Millimeter-Wave Metrology

Clague, F.R., **Microcalorimeter for 7 mm Coaxial Transmission Line**, NIST Technical Note 1358 (August 1993).

Design, evaluation, and construction details are given for the coaxial microcalorimeter used by NIST as part of the microwave power standard in a 7-mm coaxial transmission line. Two versions are described: one with a Type N connector and one with an APC-7 connector. The operating frequency range is 0.01- to 18-GHz with either connector. The microcalorimeter is used to measure the effective efficiency of a reference standard, which is then used to calibrate other microwave power sensors. These reference standards are thermistor mounts designed by NIST to be compatible with the microcalorimeter. Detailed microcalorimeter drawings and assembly instructions are included.
[Contact: Fred R. Clague, (303) 497-5778]

Clague, F.R., **NIST Model PM2 Power Measurement System for 1 mW at 1 GHz**, NISTIR 5016 (December 1993).

The design and operation of an automated measurement system designed to measure power accurately at the level of 1 mW and at the frequency of 1 GHz are described. The system consists of commercial IEEE Std-488 bus-controlled instruments, a computer controller, and software. The results of a series of measurements are output to the computer display and, optionally, to a printer. The results are the mean of the measurement series and an estimate of the Type A (here random) and Type B (here systematic) uncertainty. The estimated total expanded uncertainty for the average of six consecutive measurements of a nominal 1 mW, 1 GHz source is typically less than 1%. The system can measure any power from 0.1- to 10-mW at any microwave frequency by making appropriate changes to the software and, possibly, the hardware.
[Contact: Fred R. Clague, (303) 497-5778]

Clague, F.R., and Voris, P.G., **Coaxial Reference Standard for Microwave Power**, NIST Technical Note 1357 (April 1993).

Design and construction details are given for the bolometer (thermistor) mounds used by NIST as working reference standards for microwave power calibrations in coaxial transmission line. The effective efficiency of these reference standards can be measured directly in the NIST coaxial microcalorimeters. The standards are then used to calibrate other microwave power sensors. Two versions are described: one with a Type N connector and one with an APC-7 connector. The operating frequency range is 0.05 to 18 GHz with either connector. Detailed drawings and performance measurements are included.
[Contact: Fred R. Clague, (303) 497-5778]

Marks, R.B., **Comments on "Protecting EFIE-Based Scattering Computations from Effects of Interior Resonances,"** IEEE Transactions on Antennas and Propagation, Vol. 41, No. 3, pp. 387-389 (March 1993).

An approach to the problem of interior resonances is presented which plague the integral equations governing many scattering problems. It aims to determine the smallest singular value, which vanishes at the resonance, and orthogonalize the solution to the corresponding singular vector if resonance is detected. The computation of the smallest singular value makes use of the inverse power method.
[Contact: Roger B. Marks, (303) 497-3037]

Marks, R.B., and Williams, D.F., **Verification of Commercial Probe-Tip Calibrations**, Conference Digest of the 42nd Automatic Radio Frequency

Techniques Group, San Jose, California, December 2-3, 1993, pp. 37-41.

We present results of a verification procedure useful in evaluating the accuracy of probe-tip scattering parameter measurements. The procedure was applied to calibrations and measurements performed in industrial laboratories. Actual measurement discrepancies, due primarily to calibration errors, are directly compared to bounds determined by the comparison method. The results demonstrate the utility of the verification technique as well as serious flaws, particularly at high frequencies, in some conventional calibrations.
[Contact: Roger B. Marks, (303) 497-3037]

Williams, D.F., and Marks, R.B., **Accurate Transmission Line Characterization**, IEEE Microwave and Guided Wave Letters, Vol. 3, No. 8, pp. 247-249 (August 1993).

This letter introduces a new method for the characterization of transmission lines fabricated on lossy or dispersive dielectrics. The method, which is more accurate than conventional techniques, is used to examine the resistance, inductance, capacitance, and conductance per unit length of coplanar waveguide transmission lines fabricated on lossy silicon substrates.
[Contact: Dylan F. Williams, (303) 497-3138]

Williams, D.F., and Marks, R.B., **LRM Probe-Tip Calibrations with Imperfect Resistors and Lossy Lines**, Conference Digest of the 42nd Automatic Radio Frequency Techniques Group, San Jose, California, December 2-3, 1993, pp. 32-36.

The line-reflect-match calibration is extended, without significant loss of measurement accuracy, to accommodate imperfect match standards and lossy lines typical of monolithic microwave integrated circuits. We characterize the match and line standards using an additional line standard of moderate length. The new method provides a practical means of obtaining accurate, wideband calibrations with compact standard sets.
[Contact: Dylan F. Williams, (303) 497-3138]

Electromagnetic Properties

Grosvenor, J.H., **NIST Measurement Service for Electromagnetic Characterization of Materials**, NISTIR 5006 (August 1993).

This paper presents an overview of the special test/measurement services currently available at the National Institute of Standards and Technology for characterizing the dielectric and magnetic properties of materials at the rf and microwave frequencies. Many important applications of materials used throughout the electronics, microwave, aerospace, and communications industries have created a significant and increased need for reliable data on the electromagnetic properties of such materials. This paper emphasizes recent improvements in metrology capabilities developed at NIST. These include the broadband (0.1-MHz to 18-GHz) transmission-line techniques and low-frequency parallel-plate capacitor methods. The paper also briefly addresses other facets of the NIST program, including the provision of dielectric and magnetic reference materials to customers and the organization of national round-robin intercomparisons.
[Contact: John H. Grosvenor, (303) 497-5533]

Hill, D.A., **Gradiometer Antennas for Tunnel Detection**, Proceedings of the Fourth Tunnel Detection Symposium on Subsurface Exploration Technology, Golden, Colorado, April 26-29, 1993, pp. 479-496.

The use of gradiometer antennas for detection of long conductors and detection of empty tunnels is analyzed. For reception in vertical boreholes, the gradiometer consists of two vertical electric or magnetic dipoles with a vertical separation. Both sum and difference responses are useful, but the difference response has the potential advantage of suppressing the primary field and making the scattered field easier to detect. The difference response is most effective in suppressing the primary field for a parallel scan where the transmitting antenna and receiving gradiometers are always at the same height. Gradiometers are most advantageous at low frequencies where the scattered field is small compared to the primary field.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., **Gradiometer Antennas for Detection of Long Subsurface Conductors**, Journal of

Electromagnetic Waves and Applications, Vol. 8, No. 2, pp. 237-248 (1994).

The use of gradiometer antennas for detection of long conductors in tunnels is analyzed. For reception in vertical boreholes, the gradiometer consists of two vertical magnetic dipoles with a vertical separation. The source is a vertical magnetic dipole located in an adjacent vertical borehole. Both sum and difference responses are useful, but the difference response has the potential advantage of suppressing the primary field and making the scattered field easier to detect. The difference response is most effective in suppressing the primary field for a parallel scan where the transmitting antenna and receiving gradiometer are always at the same height.
[Contact: David A. Hill, (303) 497-3472]

Pucic, S.P., **Diffusion of Copper into Gold Plating**, Conference Record of the IEEE Instrumentation and Measurement Technology Conference, Irvine, Orange County, California, May 18-20, 1993, pp. 114-117.

The value of the room-temperature copper-gold interdiffusion coefficient derived by extrapolating from high-temperature measurements is an underestimate by several orders of magnitude. Once the full thickness of the gold film is penetrated, copper accumulates on the surface, and a layer of high concentration of copper exists immediately below the gold/air interface.

Electrical resistivity of an alloy is much higher than the resistivity of either component. This high resistivity layer may be localized within the skin depth of propagating electromagnetic waves; in cases where copper has reached the surface, it is permanently within the skin depth at any frequency.

A nickel 'diffusion barrier,' commonly applied between copper and gold, is unsuitable in many microwave and millimeter-wave applications because of ferromagnetism of nickel at room temperature. The compound that forms on the surface of untreated copper at room temperature in a reasonably clean atmosphere is cuprous oxide. Its properties make it a better alternative to gold in microwave and millimeter-wave engineering.
[Contact: Sunchana P. Pucic, (303) 497-3546]

Vanzura, E.J., Geyer, R.G., and Janezic, M.D., **The NIST 60-Millimeter Diameter Cylindrical Cavity Resonator: Performance Evaluation for Permittivity Measurements**, NIST Technical Note 1353 (August 1993).

Uncertainty estimates are developed for dielectric permittivity calculations made using the NIST 60-mm diameter cylindrical resonator. A mode-filtering helical waveguide makes up the cavity's cylindrical wall, which permits the generation of high-purity TE_{01p} resonant modes for high-accuracy permittivity measurements. The cavity's length can be varied from 408 to 433 mm. Fixed-length and fixed-frequency measurements in the X-band frequency range are evaluated with particular emphasis on 10 GHz. Resonator theory and design, measurement tolerances, and software are included.
[Contact: Eric J. Vanzura, (301) 497-5752]

Laser Metrology

Jones, R.D., and Scott, T.R., **Error Propagation in Laser Beam Spatial Parameters**, Optical and Quantum Electronics, Vol. 26, No. 1994, pp. 25-34 (January 1994).

We have performed a propagation-of-errors analysis on two methods used to determine the spatial parameters of a laser beam. We measured diameters of a diode laser beam focused by a 993-mm focal length lens. Measurement uncertainties of less than 1% can result in uncertainties greater than 200% in locating the beam waist of the laser. We compare the inherent uncertainties in the spatial parameters as obtained by the two methods. Longer focal length lenses and lens position can reduce the magnification of uncertainty, but would require large propagation distances.
[Contact: Richard D. Jones, (303) 497-3439]

Optical Fiber Metrology

Danielson, B.L., **Low-Coherence Interferometric Measurement of Group Transit Times in Precision Optical Fiber Delay Lines**, Proceedings of the 2nd Optical Fibre Measurement Conference, Torino, Italy, September 21-22, 1993, pp. 159-162.

We describe a low-coherence interferometric

method for measuring the transit time in optical fiber delay lines as long as 1.5 km. Group delays in 100 m standard reference fibers can be determined, with an expanded uncertainty of about 4 ps (1 mm) and a resolution of 0.15 ps (0.03 mm). The principal limitations of this approach is identified and discussed.
[Contact: Bruce L. Danielson, (303) 497-5620]

Franzen, D.L., **Lightwave Standards Development at NIST**, Proceedings of the 4th Biennial Department of Defense Fiber Optics and Photonics Conference, McLean, Virginia, March 21-24, 1994, pp. 443-445.

Standards being developed at the National Institute of Standards and Technology support the following parameters of interest to lightwave communications: optical fiber geometry, optical fiber chromatic dispersion, absolute optical power, high-speed detector frequency response, and wavelength.
[Contact: Douglas L. Franzen, (303) 497-3346]

Gallawa, R.L., Goyal, I.C., and Ghatak, A.K., **Calculated Fiber Attenuation: A General Method Yielding Stationary Values**, Journal of Lightwave Technology, Vol. 11, No. 12, pp. 1900-1904 (December 1993).

A method of calculating the attenuation constant of an optical fiber under very general, but weakly guiding, conditions is derived. The method, based on Galerkin's formalism, allows a nonuniform and complex refractive-index profile. The real and imaginary parts of the refractive index are allowed to vary independently and arbitrarily as a function of radius. The result is the predicted complex propagation constant. The results are inherently stationary.
[Contact: Robert L. Gallawa, (303) 497-3761]

Gallawa, R.L., Kumar, A., and Weisshaar, A., **Fibre Splice Loss: A Simple Method of Calculation**, Optical and Quantum Electronics, Vol. 26, pp. S165-S172 (1994).

We evaluate the loss encountered when splicing between two circular single-mode fibres with unmatched parameters. Our method represents a significant improvement in simplicity over other methods, with only an insignificant degradation of accuracy. We use Galerkin's method, but expand the field of both fibres in terms of the same set of basis functions, leading to considerable simplicity: the overlap integral is simply the inner (dot) product of the eigenvectors. Integration is thus avoided. We assume that weakly guiding conditions prevail.
[Contact: Robert L. Gallawa, (303) 497-3761]

Optical Fiber/Waveguide Sensors

Craig, R.M., Tang, D., and Day, G.W., **Interlaboratory Comparison of Polarization-Holding Parameter Measurements on High Birefringence Optical Fiber**, Proceedings of the 2nd Optical Fibre Conference, Torino, Italy, September 21-22, 1993, pp. 177-180.

We report the results of a preliminary interlaboratory comparison of polarization-holding parameter (h-parameter) measurements, in which seven participants' measured three coils of fiber using the participants' normal procedures. The variations in results (one standard deviation) among the three coils ranged from 13% to 50%.
[Contact: Rex M. Craig, (303) 497-3359]

Gallawa, R.L., Kumar, A., and Weisshaar, A., **Mode Coupling and Loss on Tapered Optical Waveguides**, Proceedings of the Integrated Photonics Research Meeting, San Francisco, California, February 17-19, 1994, pp. ThD6-1/57—ThD6-3/59.

Tapered dielectric waveguides have been analyzed using a variety of methods including the coupled-mode theory, a step-tapered configuration, a method that uses a ray-optics model, and the beam propagation method. We also use a step-taper approach, approximating the smooth taper with a series of discrete steps. Our method accounts for the interaction between modes and is capable of tracking the propagation through the taper by using an expansion of the field on each side of the step; we use basis functions that are known to approximate the field very accurately. Integration is avoided in evaluating the coupling efficiency across the step.
[Contact: Robert L. Gallawa, (303) 497-3761]

Simmon, E.D., Rose, A.H., and FitzPatrick, G.J., **An Optical Current Transducer for Calibration**

Studies, Proceedings of the 8th International Symposium on High Voltage Engineering, Yokohama, Japan, August 23-27, 1993, pp. 399-402.

Optical current transducers (OCTs) are well-suited for current measurements in high-voltage applications because they offer advantages over conventional oil-filled current transformers such as greater immunity from electromagnetic interference, intrinsic safety, and wide dynamic range. This paper describes an OCT designed and built at the National Institute of Standards and Technology for the development of calibration methods for OCTs for power system applications. The design and operating characteristics of the NIST OCT are described, and the results of tests for sensitivity, linearity, and dynamic range are reported. Some of the sources of measurement error are discussed.
[Contact: Eric D. Simmon, (301) 975-3956]

Whitesel, H.K., Day, G.W., Rose, A.H., and Miller, C.A., **Self-Calibrating Fiber Optic Sensors: Potential Design Methods**, Naval Surface Warfare Center Technical Report, CARDIVNSWC-TR-80-92/15, pp. 1-A8 (May 1993).

Potential applications of optical fiber sensors in the Navy and elsewhere involve networks of hundreds or thousands of sensors. Routine maintenance and calibration of these sensor networks, if undertaken manually, would involve unacceptable commitments of ship personnel and time. This has led to the present investigation into methods that can be used to produce sensor systems that can be self-testing and/or self-calibrating. A self-testing sensor is one in which one or more internal tests are used to verify the performance of the sensor. Self-calibration extends the self-testing concept to the point where, when defects are identified, calibration corrections can be made automatically. Three design concepts can be considered for optical fiber sensors: substitution, redundancy, and internal diagnostics. Substitution involves applying a measurand of known value to the sensor in a manner similar to most laboratory calibrations. Redundancy involves using multiple sensors in such a way that the failure of a single sensor can be detected; correct values are then attributed to sensors giving consistent results. Internal diagnostics can take many forms, but involves the use of various optical tests to insure the proper performance of the sensor. These tests may include changing the amplitude, wavelength (frequency), phase, or polarization of the light propagating through the sensor. Examples of how diagnostics of these types can be used to test and recalibrate various types of sensors are described in this report; a more detailed study of potential designs for a self-calibration polarimetric temperature sensor is also included.
[Contact: Gordon W. Day, (303) 497-5204]

Integrated Optics — [formerly Electro-Optic Metrology]

Gallawa, R.L., Kumar, A., and Weisshaar, A., **Symbolic Programming with Series Expansions: Applications to Optical Waveguides**, Proceedings of the 10th Annual Review of Progress in Applied Computational Electromagnetics, Monterey, California, March 21-26, 1994, pp. 475-481.

We discuss the utility of symbolic computer languages in the context of optical fiber analysis. The symbolic *Map* command, for example, is useful whenever a series expansion approach is used in eigenvalue problems if the basis functions are integrable in closed form. We show how this command allows a simple but accurate evaluation of single-mode fiber parameters in most cases of practical interest. The *ReplaceAll* command is also demonstrated in tracking the variation of fiber operational parameters as a function of the V-parameter. The savings in CPU time is evaluated.
[Contact: Robert L. Gallawa, (303) 497-3761

Hickernell, R.K., Christensen, D.H., Pellegrino, J.G., Wang, J., and Leburton, J.P., **Determination of the Complex Refractive Index of Individual Quantum Wells from Distributed Reflectance**, Journal of Applied Physics, Vol. 75, No. 6, pp. 3056-3059 (March 15, 1994).

We investigate the measurement of the complex refractive index of individual quantum wells by reflectance spectroscopy. Placing the wells at half-wavelength spacing to cause resonant feedback produces an order-of-magnitude increase in measurement sensitivity over that of nonresonant structures. Quantum well dispersive and absorptive

effects on reflectance can be differentiated in certain spectral regions. Experimental data confirm a theoretical model of refractive index and absorption for quantum wells of GaAs in $Al_{0.2}Ga_{0.8}As$ in the region of the well bandgap.
[Contact: Robert K. Hickernell, (303) 497-3455]

Other Signal Topics

Marks, R.B., **Comments on "Protecting EFIE-Based Scattering Computations from Effects of Interior Resonances,"** IEEE Transactions on Antennas and Propagation, Vol. 41, No. 3, pp. 387-389 (March 1993).

[See Microwave and Millimeter Wave-Metrology.]

ELECTRICAL SYSTEMS

Power Systems Metrology

FitzPatrick, G.J., and McComb, T.R., **Investigation of the Effects of Aging on the Calibration of a Kerr-Cell Measuring System for High Voltage Impulses**, Proceedings of the 8th International Symposium on High Voltage Engineering, Yokohama, Japan, August 23-27, 1993, pp. 387-390.

Kerr-cell measuring systems can be used for high-voltage measurements from direct voltage up to impulses with a few nanoseconds risetime. In principle, this allows a measuring system for impulses to be calibrated at high voltage using direct or alternating voltage which can be measured with a smaller uncertainty than is needed for impulse measurements. Unfortunately, the liquid normally used in such systems, nitrobenzene, degrades with time. This paper reports on an investigation into methods of calibrating an aged Kerr-cell so that a measuring system based on a Kerr-cell could be used as a Reference Measuring System. The methods investigated include direct voltage calibration and impulse calibration with direct voltage calibration and impulse calibration with direct voltage bias. The repeatability of measurements using a fixed geometry to determine the voltage scale factor was also investigated. Results from both approaches are presented and recommendations are given for reference measuring systems.
[Contact: Gerald J. FitzPatrick, (301) 975-2737]

McComb, T.R., and FitzPatrick, G.J., **Comparative Measurements of High-Voltage Impulses Using a Kerr Cell and a Resistor**, Proceedings of the 8th International Symposium on High Voltage Engineering, Yokohama, Japan, August 23-27, 1993, pp. 383-386.

Recent proposals in committee drafts of IEC TC42 have placed greater emphasis on the use of comparative measurements as a method of qualifying impulse measuring systems. This paper describes some further investigations of comparative measurements where a Kerr-cell system is compared against a system based on a resistor divider. This paper describes the experimental techniques used to make comparative measurements, and the results of tests on the linearity of the systems are presented. Finally, recommendations are made for the use of comparative measurements in qualifying impulse measuring systems.
[Contact: Gerald J. FitzPatrick, (301) 975-2737]

Pulse Power Metrology

McComb, T.R., Cherbaucich, C., Goffeen, L., Deschamps, M.F., FitzPatrick, G.J., Hanique, E., Lehmann, K., McBride, J., Ribot, J.-J., Rizzi, G., Vaessen, P., and Zaengl, W., **An Approach to Setting Performance Requirements for Automated Evaluation of the Parameters of High-Voltage Impulses**, Proceedings of the 8th International Symposium on High Voltage Engineering, Yokohama, Japan, August 23-27, 1993, pp. 309-312.

This paper reports the present status of an ongoing study of digital signal processing applied to various impulse waveforms. In a round-robin study, twelve laboratories are using their own software to evaluate the parameters of impulse waveforms in a database of 31 waveforms with the objective of establishing minimum performance requirements. This paper presents the results obtained for smooth full impulses and some examples of results on more complex waveforms.
[Contact: Gerald J. FitzPatrick, (301) 975-2737]

Magnetic Materials and Measurements

Goldfarb, R.B., and Itoh, K., **Reduction of Interfilament Contact Loss in Nb_3Sn Superconductor Wires**, Journal of Applied Physics, Vol. 75, No. 4, pp. 2115-2118 (February 15, 1994).

Interfilament contact in Nb_3Sn wires made by the internal-tin-diffusion process causes excess hysteresis loss beyond the intrinsic magnetic hysteresis loss of the filaments. In analogy with eddy-current and proximity-effect coupling losses, the excess contact loss can be reduced by decreasing the twist-pitch length of the filaments in the wire. One consequence of interfilament contact is that volume magnetization measurements are strongly dependent on sample length below about one twist pitch. We define a characteristic length whose reciprocal is equal to the sum of the reciprocals of the sample length and the twist pitch. Hysteresis loss is a universal function of characteristic length for different sample lengths and twist pitches. We discuss several experimental parameters for the magnetic determination of hysteresis loss.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Oti, J.O., **Numerical Micromagnetic Techniques and Their Applications to Magnetic Force Microscopy Calculations**, IEEE Transactions on Magnetics, Vol. 29, No. 6, pp. 2359-2364 (November 1993).

Numerical micromagnetics is a flexible and powerful means of designing and characterizing magnetic devices. This paper presents an overview of numerical methods of solution of micromagnetics problems. The modeling of exchange, anisotropy and magnetostatic interaction fields in magnetic films, and micromagnetic modeling of magnetic force microscopy are discussed.
[Contact: John O. Oti, (303) 497-5557]

Wadas, A., Moreland, J., Rice, P., and Katti, R.R., **Magnetic Force Microscopy Images of Magnetic Garnet with Thin-Film Magnetic Tip**, Applied Physics Letters, Vol. 64, No. 9, pp. 1156-1158 (February 28, 1994).

We present magnetic force microscopy images of YGdTmGa/YSmTmGa magnetic garnet, using a thin magnetic film deposited on Si_3N_5 atomic force microscopy tips. We have found correlations between the topography and the magnetic domain structure. We show that by using either magnetized Fe-Ni bilayer tips versus unmagnetized single-layer Fe tips that the image contrast shows domains versus domain walls, respectively.
[Contact: John M. Moreland, (303) 497-3641]

Superconductors

Cutro, J.A., Rudman, D.A., Orlando, T.P., van Dover, R.B., Schneemeyer, L.F., White, A.E., Gyorgy, E.M., Waszczak, J.V., and Felder, R.J., **Increased Pinning Energies and Critical Current Densities in Heavy-Ion-Irradiated $Bi_2Sr_2CaCu_2O_8$ Single Crystals**, Applied Physics Letters, Vol. 62, No. 7, pp. 759-761 (15 February 1993).

We report a significant increase in the pinning energy of vortices in single-crystal $Bi_2Sr_2CaCu_2O_8$ when irradiated with heavy ions such as Ar^+. This is in contrast with the results of light ion (H^+, He^+) irradiations which give pinning energies comparable with those of unirradiated crystals. The stronger pinning is attributed to defects larger than point defects, e.g., clusters or amorphized regions. As a result of higher pinning energies, critical currents persist at markedly higher temperatures and fields.
[Contact: David A. Rudman, (303) 497-5081]

Ekin, J.W., Bray, S.L., Lutgen, C.L., and Bahn, W.L., **Electromechanical Properties of Superconductors for DOE Fusion Applications**, NISTIR 5013 (January 1994).

The electrical performance of many superconducting materials is strongly dependent on mechanical load. This report presents electromechanical data on a broad range of high-magnetic-field superconductors. The conductors that were studied fall into three general categories: candidate conductors, experimental conductors, and reference conductors. Research on candidate conductors for fusion applications provides screening data for superconductor selection as well as engineering data for magnet design and performance analysis. The effect of axial tensile strain on critical-current density was measured for several Nb_3Sn candidate conductors including the United States Demonstration Poloidal Coil (US-DAC) cable strand and an International Thermonu-

clear Experimental Reactor (ITER) candidate conductor. Also, data are presented on promising experimental superconductors that have strong potential for fusion applications. Axial strain measurements were made on a V_3Ga tape conductor that has good performance at magnetic fields up to 20 T. Axial strain data are also presented for three experimental Nb_3Sn conductors that contain dispersion-hardened copper reinforcement for increased tensile strength. Finally, electromechanical characteristics were measured for three different Nb_3Sn reference conductors from the first and second VAMAS (Versailles Project on Advanced Materials and Standards) international Nb_3Sn critical-current round-robins. Published papers containing key results, including the first measurement of the transverse stress effect in Nb_3Sn, the effect of stress concentration at cable-strand crossovers, and electromechanical characteristics of Nb_3Al, are included throughout the report.
[Contact: John W. Ekin, (303) 497-5448]

Goodrich, L.F., Srivastava, A.N., and Stauffer, T.C., **Standard Reference Devices for High Temperature Superconductor Critical Current Measurements**, Cryogenics, Vol. 33, No. 12, pp. 1142-1148 (1993).

Obtaining repeatable critical-current measurements for a high-temperature superconductor (HTS) is a challenging task, since HTSs are highly susceptible to degradation due to mechanical stress, moisture, thermal cycling, and aging. This paper discusses the development of a high-temperature superconducting standard reference device (SRD) to address these measurement concerns and gives preliminary data on its characteristics. An SRD is an HTS specimen that has had its critical current I_c nondestructively evaluated. Because HTSs are sensitive to mechanical alterations, minor changes in sample preparation or mounting procedure could yield large changes in the measured critical current. Preliminary data on SRDs made using Bi-based oxide tapes (2212) with an Ag substrate are presented. Differences between two consecutive measurements of I_c can typically change by 40%; these deviations have been reduced to $\approx$4%.
[Contact: Loren F. Goodrich, (303) 497-3143]

Guha, S., Peebles, D., Browning, V., Wieting, T., Chandler-Horowitz, D., and Norton, M., **Optical Conductivity of Single Crystals of $Ba_{1-x}M_xBiO_3$ (M = K, Rb, x = 0.04, 0.37)**, Journal of Superconductivity, Vol. 6, No. 5, pp. 339-349 (1993).

Reflectance data (0.001 to 4.0 eV) from several large (a typical surface area 3 x 3 mm^2) single crystals of $Ba_{1-x}K_xBiO_3$ (x = 0.04. 0.37) (BKBO) and $Ba_{1-x}Rb_xBiO_3$ (x = 0.37) (BRBO) were obtained by Fourier transform infrared (FTIR) and ellipsometric methods. Normal-state optical conductivities (σ_1) of these samples were obtained from infrared and ellipsometric measurements using a Kramers-Kronig transform. A broad mid-IR band was observed that peaked at 0.3 eV for BKBO and at 0.16 eV for BRBO at room temperature. Each band was fitted with two Lorentz oscillators. The optical mass of the charge carriers was obtained from a Drude fit, and was found to be large (m^* = 28 to 33 m_c). These overdamped charge carriers can be viewed as polarons with a large effective mass. An optic phonon mode at 325 cm^{-1} was also observed in the metallic phase. This mode was identified as a disorder-induced lattice mode, and was strongly enhanced at 8 K, favoring a strong coupling between this phonon and itinerant electronic states. Low-frequency spectra between 10 and 400 cm^{-1} observed below the superconducting temperature indicated an energy gap that agreed with the BCS-type mechanism. Interpretations of low-temperature measurement on BKBO and BRBO were complicated due to the change of color of the sample from bluish-green to bronze-red. Upon warming, samples revert to their original bluish-green color.
[Contact: Deane Chandler-Horowitz (301) 975-2084]

Hyun, O.B, **Experimental Aspects of Flux Expulsion in Type-II Superconductors**, Physical Review B, Vol. 48, No. 2, pp. 1244-1248 (July 1, 1993).

Experimental aspects of flux expulsion in Nb_3Sn and $YBa_2Cu_3O_7$ type-II superconductors are presented. There is a clear distinction in magnetization between field-cooled-measured-upon-cooling (FCC) and field-cooled-measured-upon-warming (FCW) results. This thermal hysteresis, predicted in the temperature-dependent critical-state theory at low fields by Clem and Hao, was observed for measuring fields up to about 0.5 T. The model explains the observation of increases in diamag-

netism after field cooling (FC) and thermal cycling. The thermal hysteresis, together with weak links, accounts for the occurrence of a negative peak in FCW magnetization. The FCC-FCW bifurcation observed for 0.l-mT field down to 5 K might imply that flux lines are not completely frozen below T_{c1}, the temperature at which the lower critical field is equal to the measuring field, but are expelled from the sample even in the Meissner state.
[Contact: Ok-Bae B. Hyun, (303) 497-3725]

Rosenthal, P.A., Grossman, E.N., Ono, R.H., and Vale, L.R., **High Temperature Superconductor-Normal Metal-Superconductor Josephson Junctions with High Characteristic Voltages**, Applied Physics Letters, Vol. 63, No. 14, pp. 1984-1986 (October 4, 1993).

We have fabricated step edge superconductor-normal metal-superconductor microbridges using $YBa_2Cu_3O_{7-x}$ (YBCO) and noble metals with critical current-normal resistance (I_cR_N) products as high as 10 mV and normal resistances up to 38 **Ω**. Our fabrication process achieves high values of the I_cR_N product by exploiting the anisotropy in the properties of epitaxial YBCO films, allowing contact only between normal metal and superconductor through the crystalline axes which support the largest Josephson coupling. This results in a dramatic increase in the normal resistance of a junction without decreasing its critical current. We discuss the role of the superconductor-normal metal boundary resistance on the junction electrical properties. We have coupled submillimeter wave rf currents quasi-optically into junctions integrated at the feeds of noble metal planar log periodic antennas and have induced up to seven Shapiro steps in the current-voltage characteristics with a 760-GHz beam from a far infrared laser.
[Contact: Peter A. Rosenthal, (303) 497-5844]

ELECTROMAGNETIC INTERFERENCE

Radiated EMI

Adams, J.W., **Electric-Field Strengths Measured near Personal Transceivers**, Symposium Record of the 1993 IEEE International Symposium on Electromagnetic Compatibility, Dallas, Texas, August 9-13, 1993, pp. 42-45.

Electric-field strengths were measured at a number of points near 5-W personal transceivers. The points were located on cylinders of revolution with radii of 7 and 12 cm around the antenna. The transceivers operated on four authorized frequencies of 40.27, 162.475, 464, and 823 MHz, and radiated powers of 5, 5, 5, and 3 W, respectively. In some cases, these measured values exceeded the exposure limits suggested in ANSI Standard C95.1-1982.
[Contact: John W. Adams, (303) 497-3328]

Allen, O.E., Hill, D.A., and Ondrejka, A.R., **Time-Domain Antenna Characterizations**, IEEE Transactions on Electromagnetic Compatibility, Vol. 35, No. 3, pp. 339-346 (August 1993).

A set of time-domain characterizations that can efficiently describe wide-band antennas is proposed in this paper. The experimentally measured responses of transverse electromagnetic horn antennas are used to evaluate the utility of these characterizations. Comparisons are made between the antennas' frequency-domain response and their time-domain characterizations. The comparisons show that the time-domain characterizations can provide significant insight into an antenna's behavior, as well as providing a means to accurately compare two or more different antennas.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., Cavcey, K.H., and Johnk, R., **Crosstalk Between Microstrip Transmission Lines**, NISTIR 5015 (December 1993).

Methods for prediction of crosstalk between microstrip transmission lines are reviewed and simplified for the weak coupling case. Classical coupled transmission line theory is used for uniform lines, and potential and induced electromagnetic field methods are used for crosstalk between nonuniform lines. It is shown that the potential method is equivalent to classical coupled transmission line theory for the case of uniform lines. An experiment was performed for uniform coupled microstrip lines for frequencies from 40 MHz to 5 GHz, and good agreement between theory and measurement was obtained for both near-end and far-end crosstalk.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., Crawford, M.L., and Motohisa, K., **Aperature Coupling to Shielded Transmission Lines: Theory and Experiment**, Proceedings of the Electromagnetic Compatibility 1993 10th International Zurich Symposium, Zurich, Switzerland, March 9-11, 1993, pp. 569-571. [Also published as NISTIR 3988 (April 1992).]

Coupling through circular apertures in the shields of a coaxial air line and a TEM cell is studied theoretically and experimentally. Polarizability theory is used to compute the effective dipole moments that excite the transmission lines in the internal region. Measurements of shielding effectiveness of both structures were made in a reverberation chamber over wide frequency ranges. Agreement between theory and measurements is generally within ±10 dB. Recommendations for improvements in the measurements and theory are made for achieving closer agreement that would be desirable for an artifact standard for shielding effectiveness measurements.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., Ma, M.T., Ondrejka, A.R., Riddle, B.F., Crawford, M.L., and Johnk, R., **Aperture Excitation of Electrically Large, Lossy Cavities**, NIST Technical Note 1361 (September 1993).

We present a theory based on power balance for aperture excitation of electrically large, lossy cavities. The theory yields expressions for shielding effectiveness, cavity Q, and cavity time constant. In shielding effectiveness calculations, the incident field can be either a single plane wave or a uniformly random field to model reverberation chamber or random field illumination. The Q theory includes wall loss, absorption by lossy objects within the cavity, aperture leakage, and power received by antennas within the cavity. Extensive measurements of shielding effectiveness, cavity Q, and cavity time constant were made on a rectangular cavity, and good agreement with theory was obtained for frequencies from 1 to 18 GHz.
[Contact: David A. Hill, (303) 497-3472]

Kanda, M., **Standard Probes for Electromagnetic Field Measurements**, IEEE Transactions on Antennas and Propagation, Vol. 41, No. 10, pp. 1349-1364 (October 1993).

This tutorial paper discusses various standard antennas for measuring radio-frequency electric and magnetic fields. A theoretical analysis of each antenna's receiving characteristics is summarized and referenced. The standard probes described are an electrically short dipole, a resistively loaded dipole, a half-wave dipole, an electrically small loop, and a resistively loaded loop. A single-turn loop designed for simultaneous measurement of the electric and magnetic components of near-fields and other complex electromagnetic environments is also described. Each type of antenna demonstrates a different compromise between broadband frequency response and sensitivity.
[Contact: Motohisa Kanda, (303) 497-5320]

Johnk, R.T., Ondrejka, A., Tofani, S., and Kanda, M., **Time-Domain Measurements of the Electromagnetic Backscatter of Pyramidal Absorbers and Metallic Plates**, IEEE Transactions on Electromagnetic Compatibility, Vol. 35, No. 4, pp. 429-433 (November 1993).

A wideband time-domain measurement system has been developed for the evaluation of the backscatter performance of dissipative macrostructures. Backscatter measurements have been performed in an ordinary room environment on metal plates as well as on samples of pyramidal absorbing material. The backscattering performance of pyramidal absorbers is evaluated in the 50- to 1000-MHz frequency range with a varying incident field angle of incidence. In the case of rectangular metal plates, numerically generated results are compared with measured data in order to gauge the accuracy of the system.
[Contact: Robert T. Johnk, (303) 497-3737]

Koepke, G., and Randa, J., **Results of Screened-Room Measurements on NIST Standard Radiators**, NISTIR 5010 (October 1993).

We report the results of a study of measurements of radiated emissions from the NIST spherical-dipole standard radiator in several screened rooms. The measurements were performed in accordance with MIL-STD-462 (1967). Large differences occur in the field intensity measured at different laboratories and even on different days at the same laboratory. There is also a systematic difference at low frequencies between the screened-room results and

results obtained in a TEM cell, open-area test site, and anechoic chamber. Results obtained using a monopole radiator are also presented and discussed.
[Contact: Galen H. Koepke, (303) 497-5766]

Ma, M.T., and Adams, J.W., **Characteristics of Unknown Linear Systems Deduced from Measured CW Magnitude**, NIST Journal of Research, Vol. 98, No. 3, pp. 297-319 (May—June 1993).

A method is presented for predicting the total response, in both frequency and time, of an unknown linear system when only the measured continuous wave (cw) magnitude is available. The approach is based on approximating the square of the measured magnitude by a rational function, from which various system transfer functions in terms of complex frequency are deduced. These transfer functions may or may not be at minimum phase. The corresponding impulse response is then obtained by taking the inverse Laplace transform of the transfer function. The impulse response of the minimum-phase case rises faster initially to its first maximum than the nonminimum-phase counterparts. This result confirms that, for the same cw magnitude response, the accumulative energy contained in the impulse response is the greatest when the transfer function is at minimum phase. Physical meaning of the energy content is also discussed.
[Contact: Mark T. Ma, (303) 497-3800]

Ma, M.T., and Adams, J.W., **Characterization of Unknown Linear Systems Based on Measured CW Amplitude**, Symposium Record of the 1993 IEEE International Symposium on Electromagnetic Compatibility, Dallas, Texas, August 9-13, 1993, pp. 78-82.

An approximate squared-magnitude function is derived from a given measured cw amplitude response to characterize an unknown linear system. Various possible system transfer functions (both amplitude and phase) and the corresponding impulse responses are then deduced. These transfer functions may or may not be minimum phase. The first impulse maximum and accumulated energy content are the greatest when the transfer function is at minimum phase.
[Contact: Mark T. Ma, (303) 497-3800]

Novotny, D.R., Masterson, K.D., and Kanda, M., **An Optically Linked Three-Loop Antenna System for Determining the Radiation Characteristics of an Electrically Small Source**, Symposium Record of the 1993 IEEE International Symposium on Electromagnetic Compatibility, Dallas, Texas, August 9-13, 1993, pp. 300-304.

This paper presents the experimental results of an antenna system for determining the radiation characteristics of an electrically small source. Three orthogonal loop antennas, each terminated at diametrically opposite points with identical loads, encircle the source and characterize its equivalent electric and magnetic dipole moments. The total radiated power can be determined from this near-field measurement of the device under test. The test system operates from 3 kHz to over 100 MHz with up to 90 dB of dynamic range.
[Contact: David R. Novotny, (303) 497-3168]

Randa, J.P., Gilliland, D., Gjertson, W., Lauber, W., and McInerney, M., **Condensed Catalogue of Electromagnetic Environment**, Symposium Record of the 1993 IEEE International Symposium on Electromagnetic Compatibility, Dallas, Texas, August 9-13, 1993, pp. 126-131.

The IEEE Electromagnetic Compatibility Society's Technical Committee on Electromagnetic Environments (TC-3) has undertaken a long-term project to compile an inventory or catalogue of published measurements of electromagnetic environments. The frequency spectrum has been divided into tractable bands which will be considered one at a time. We have now completed the 30- to 300-Hz band. We present here an abridge-version of the resulting bibliography, along with a brief summary of what has been measured.
[Contact: James P. Randa, (303) 497-3225]

ADDITIONAL INFORMATION

Lists of Publications

Smith, A.J., **Metrology for Electromagnetic Technology: A Bibliography of NIST Publications**, NISTIR 5008 (September 1993).

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.
[Contact: Annie Smith, (303) 497-3678]

Lyons, R.M., and Gibson, K.A., **A Bibliography of the NIST Electromagnetic Fields Division Publications**, NISTIR 5009 (September 1993).

This bibliography lists publications by the staff of the National Institute of Standards and Technology's Electromagnetic Fields Division for the period from January 1970 through July 1993. Selected earlier publications from the Division's predecessor organizations are included.
[Contact: Kathryn A. Gibson, (303) 497-3132]

Meiselman, B., **Electrical and Electronic Metrology: A Bibliography of NIST Electricity Division's Publications, NIST List of Publications 94** (January 1994).

This bibliography covers publications of the Electricity Division, Electronics and Electrical Engineering, Laboratory, NIST, and of its predecessor sections for the period January 1968 to December 1993. A brief description of the Division's technical program is given in the introduction.
[Contact: Katherine H. Magruder, (301) 975-2401]

Walters, E.J., **Semiconductor Measurement Technology, 1990-1993, NIST List of Publications 103** (January 1994).

The bibliography provides information on technology transfer in the field of microelectronics at NIST for the calendar years 1990 through 1993. Publications from groups specializing in semiconductor electronics are included, along with NIST-wide research now coordinated by the NIST Office of Microelectronics Programs which was established in 1991. Indices by topic area and by author are provided. Earlier reports of work performed during the period from 1962 through December 1989 are provided in NIST List of Publications 72.
[Contact: E. Jane Walters, (301) 975-2050]

Availability of *Measurements for Competitiveness in Electronics* [First Edition], NISTIR 4583 (April 1993).

This document is the successor to NISTIR 90-4260, *Emerging Technologies in Electronics ...and their Measurement Needs* [Second Edition]. The new *Measurements for Competitiveness in Electronics* identifies 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 consensus on the principal measurement needs affecting U.S. competitiveness, as the basis for an *action plan* to meet those needs and to improve U.S. competitiveness.

Copies of this document are available as Order No. PB93-160588 from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, at (800) 553-6847 or (703) 487-4650.

Abstract -- Measurements are used to determine the values of hundreds of important quantities in the electronics industry. Representative quantities are the widths of the interconnections within semiconductor integrated circuits, the attenuation of lightwaves in optical fibers, and the signal power from microwave satellite antennas. Measurement capability is a fundamental tool used to build the nation's high-technology products. As such, it is part of the national infrastructure for the realization of these products.

Measurement capability is critical to research and development, manufacturing, marketplace entry, and after-sales support of products. Thus, measurement capability affects the performance, quality, reliability, and cost of products. The result of this pervasive impact is that the level of U.S. measurement capability places an upper limit on the competitiveness of U.S. products.

At present, U.S. industry is experiencing a major shortfall in the measurement capability needed for competitiveness in electronic products. This document identifies 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 measurement needs are reviewed for nine important fields of electronics, including semiconductors, magnetics, superconductors, microwaves, lasers, optical-fiber communications, optical-fiber sensors, video, and electromagnetic compatibility. These fields of electronics underlie more than $300 billion of electronic and electrical products manufactured in the U.S. each year.

This assessment provides the framework for an action plan to correct the shortfall in U.S. measurement capability in electronics and to advance U.S. competitiveness.

Guide -- The compiler of the document provided an introductory guide to its organization and content. Because EEEL believes that a number of *TPB* readers will be interested in the information presented in the various chapters, the contents of this guide are reproduced below (page numbers of chapter summaries are included to provide a measure of the extent of the treatment):

This document contains 12 chapters, divided into two groups. The first three chapters are introductory in nature and are relevant to all of the following chapters. The remaining nine chapters address individual fields of electronic technology. Each chapter begins with a two-page summary that provides ready access to the major points made in the chapter. These short summaries are found on the pages identified below. By selecting from these summaries, you can quickly access information on the subjects of most interest to you.

Introductory Information -- Chapter 1, Role of Measurements in Competitiveness (page 3); Chapter 2, NIST's Role in Measurements (page 21); Chapter 3, Overview of U.S. Electronics and Electrical-Equipment Industries (page 31).

These three chapters introduce the subject of measurements and provide an overview of the products of the U.S. electronics and electrical-equipment industries.

> Chapter 1, **Role of Measurements in Competitiveness**, shows why measurements are a fundamental part of the infrastructure of the nation. Chapter 1 also sets measurements in the context of the many other important factors that affect competitiveness.
>
> Chapter 2, **NIST's Role in Measurements**, indicates the circumstances under which Government assistance to industry in the development of measurement capability is appropriate in pursuit of a strengthened national economy.
>
> Chapter 3, **Overview of U.S. Electronics and Electrical-Equipment Industries**, introduces these industries through an overview of their major product lines. This chapter shows the various ways in which the products of these industries are commonly classified and how those classifications relate to the structure of this document.

Fields of Technology -- Chapter 4, Semiconductors (page 53); Chapter 5, Magnetics (page 95); Chapter 6, Superconductors (page 129); Chapter 7, Microwaves (page 147); Chapter 8, Lasers (page 183); Chapter 9, Optical-Fiber Communications (page 217); Chapter 10, Optical-Fiber Sensors (page 303); Chapter 11, Video (page 339); Chapter 12, Electromagnetic Compatibility (page 381).

Each of these chapters contains four basic types of information:

> *Technology Review*: The field of technology is reviewed to highlight and explain the special capabilities that make the technology important. This review introduces the technical concepts that are necessary for understanding the sections that follow.
>
> *World Markets and U.S. Competitiveness*: The economic significance of the field of technology is highlighted through use of national and international market data for major products that employ the technology. Available information on the U.S. competitiveness is described.
>
> *Goals of U.S. Industry for Competitiveness*: The goals that U.S. industry is pursuing to improve its competitiveness are discussed so that they can be related to requirements for new measurement capability supportive of the goals.

Measurement Needs: The new measurement capability that U.S. industry will need to enable it to achieve its goals is described. This discussion emphasizes measurement capability that is needed widely in U.S. industry, that will have high economic impact if provided, and that is beyond the resources of the broad range of individual U.S. companies to provide.

[While the assessment of measurement needs in this document is wide ranging, not every field of technology important to the electronic and electrical-equipment industries has been covered. NIST plans to expand this assessment in future editions to include additional fields.]

The order in which chapters appear is intentional: the technologies on which most other technologies depend are introduced first. Thus, the chapter on semiconductors appears first because most electronic technologies depend on semiconductor materials. In contrast, the chapter on video is located near the end because it depends on nearly every other technology discussed earlier.

Chapters 4, 5, and 6 of this document describe the measurement needs arising from three important materials technologies that underlie current and emerging electronic and electrical products. These chapters also describe the measurement needs of components and equipment based on these materials and not discussed separately in other chapters.

Chapter 4, **Semiconductors**, addresses both silicon and compound semiconductors and their use in components, including individual (discrete) electronic and optoelectronic devices and integrated circuits. Semiconductor components are central to all modern electronic products from consumer products to supercomputers.

Chapter 5, **Magnetics**, focuses on both magnetic materials and the components made from them. Magnetic materials are second in importance only to semiconductor materials for electronic products and play a central role in electrical products. This chapter also addresses the measurement needs of selected equipment critically dependent on magnetic materials, including magnetic information storage equipment, electrical power transformers, and others.

Chapter 6, **Superconductors**, examines superconductor materials and addresses both present and emerging applications of these materials in electronic and electrical products.

Chapters 7 through 11 describe the measurement needs associated with selected technologies of importance to U.S. competitiveness for current and emerging products.

Chapter 7, **Microwaves**, describes the highest-information-capacity radio technology. Microwave electronics provide the basis for modern and emerging wireless communications systems and radar systems. Included are new personal communications services with both local and worldwide access, intelligent vehicle-highway systems, and advanced audio and video broadcasting systems, among others.

Chapter 8, **Lasers**, addressed the single most important component for emerging lightwave systems used for manufacturing, medicine, communications, printing, environmental sensing, and many other applications.

Chapter 9, **Optical-Fiber Communications**, describes the highest-information-capacity cable technology. It provides the basis for national and international information highways of unprecedented performance and broad economic impact. Optical-fiber systems will be linked with microwave systems to interconnect mobile and portable users and to backup cable systems.

Chapter 10, **Optical-Fiber Sensors**, focuses on an emerging class of sensors that offers outstanding performance for a broad spectrum of applications in manufacturing, aerospace, medicine, electrical power, and other areas.

Chapter 11, **Video**, emphasizes advanced, high-performance systems, such as high-definition television, which offer, for the first time, simultaneous access to high-resolution, smooth motion, and great color depth. The chapter notes the potential of full-power implementations of video technology in interactive networked environments. The chapter contains a special focus on flat-panel displays.

Chapter 12, **Electromagnetic Compatibility**, describes the special challenges that the U.S. faces in maintaining electromagnetic compatibility among the many new products of electronic and electrical technologies. Such compatibility is essential if the full potential of all of the above technologies is to be realized without debilitating mutual interference.

Appendices -- The three appendices provide definitions of the U.S. electronics and electrical-equipment industries. These definitions were used in preparing much of the economic information in the report.

Appendix 1 describes the Standard Industrial Classification System that the U.S. Government uses for collecting data about U.S. industry. This appendix also lists publications in which the U.S. Government reports data on U.S. shipments.

Appendix 2 provides a definition of the U.S. electronics industry in terms of the Standard Industrial Classification System.

Appendix 3 provides a definition of the U.S. electrical-equipment industry in terms of the Standard Industrial Classification System.

1994/1995 Calendar of Events

June 8-10, 1994 (near Windsor, U.K.)

IEEE/CHMT Workshop on MCM and VLSI Packaging Techniques and Manufacturing Technologies. Sponsored by IEEE/CHMT Society and NIST, this Workshop will be held in cooperation with the European Communities DGXIII-A. The main topics of the Workshop will be the design and implementation of first-level electronic packaging and the technologies, materials, and equipment for the manufacture of multichip modules (MCM) and single-chip packages.
[Contact: George G. Harman, (301) 975-2097]

June 14-17, 1994 (Boulder, Colorado)

Computer Modeling of Optical Waveguides and Components: A Hands-On Workshop. The purpose of this Workshop, sponsored by NIST, is to disseminate computer modeling tools for fiber and integrated optics waveguides and to discuss and demonstrate methods of understanding engineering parameters of optical waveguides.
[Contact: Robert L. Gallawa, (303) 497-3761]

June 27-July 1, 1994 (Boulder, Colorado)

Conference on Precision Electromagnetic Measurements. In sponsorship with the IEEE Instrumentation and Measurement Society and Union Radio Scientifique Internationale, NIST will be holding the biennial meeting of CPEM in Boulder, Colorado. Topics to be discussed include: advanced instrumentation including new sensors and measurement methods; automated measurement methods; dielectric and antenna measurements; direct current and low-frequency measurements; fundamental constants and special standards; laser, optical fiber, and optical electronic measurements; RF, microwave, and millimeter-wave measurements; superconducting and other low-temperature measurements; and time and frequency measurements. CPEM '94 is extended to five days to provide for added special sessions on the fundamental constants.
[Contact: Gwen E. Bennett, (303) 497-3295]

July 28, 1994 (Gaithersburg, Maryland)

Ion Implant Users Group Meeting. Among the topics to be discussed at this NIST-sponsored meeting will be Retrofits and Upgrades II, an update since September 1991.
[Contact: John Albers, (301) 975-2075]

September 13-15, 1994 (Boulder, Colorado)

Symposium on Optical Fiber Measurements. Sponsored by the IEEE Lasers & Electro-Optics Society, the Optical Society of America, and NIST, the Symposium will provide a forum for reporting the results of recent measurement research in the area of lightwave communications, including optical fibers.
[Contact: Douglas L. Franzen, (303) 497-3346]

October 27, 1994 (Gaithersburg, Maryland)

Ion Implant Users Group Meeting. One of the topics to be discussed will be Atomic and Electrical Profiling of Ion Implanted Layers. Additional topics

will be announced at a later date.
[Contact: John Albers, (301) 975-2075]

January 30–February 2, 1995 (Gaithersburg, Maryland)

International Workshop on Semiconductor Materials Characterization: Present Status and Future Needs. Papers will be presented in all relevant fields of interest to materials characterization in semiconductor device manufacturing, growth, processing, diagnostics, in-situ, real-time control and monitoring, etc. All relevant semiconductor materials will be addressed: Group IV elements, Group III-V compounds, Group II-VI compounds, IV-VI compounds, and others. The Workshop is sponsored by the Advanced Research Projects Agency (ARPA), SEMATECH, and NIST. Other co-sponsors are expected.
[Contact: David G. Seiler, (301) 975-2074]

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Department of Transportation
  National Highway Traffic Safety Administration; Federal Aviation Administration
Tennessee Valley Authority
MIMIC Consortium
Nuclear Regulatory Commission
Various Federal Government Agencies

NIST Silicon Resistivity SRMs

In response to needs of the semiconductor industry, NIST's Semiconductor Electronics Division provides silicon bulk resistivity Standard Reference Materials (SRMs) through the NIST Standard Reference Materials Program. A new class of resistivity SRMs is being introduced to respond better to users' requirements.

The first NIST (then NBS) resistivity SRMs were fabricated from crystal 50 mm (2 in) in diameter. These wafers represented various combinations of crystal growth process, crystallographic orientation, and doping, each combination chosen to give the best expected wafer uniformity for a given resistivity level. Each wafer in every set was individually measured and certified. Some of these sets are still available until the supply is exhausted (see table).

The Division is now certifying single-wafer resistivity standards at approximately the same resistivity values as were available in the earlier sets. These new SRMs are fabricated from crystal 100 mm in diameter, intended to provide improved compatibility with newer end-use instrumentation. In response to user comments, the new SRMs will be more uniform in both thickness and resistivity, will have reduced uncertainty of certified value due to use of an improved certification procedure using a four-point probe, and will be measured and certified at additional measurement sites for better characterization of wafer uniformity at its core. The additional measurements needed to qualify the improved SRMs will make them more expensive on a per-wafer basis than the earlier sets.

NIST SILICON BULK RESISTIVITY STANDARD REFERENCE MATERIALS

DATE UPDATED: 4 FEBRUARY 1994

NOMINAL RESISTIVITY (ohm · cm)	OLD SRMs	AVAILABILITY	NEW SRMs	ANTICIPATED AVAILABILITY
0.01	1523 (one of set of two wafers)	limited supply	2541	to be announced
0.1	1521 (one of set of two wafers)	limited supply	2542	to be announced
1	1523 (one of set of two wafers)	limited supply	2543	to be announced
10	1521 (one of set of two wafers)	limited supply	2544	early in calendar year 1994
25	1522	set of three wafers no longer available	2545	to be announced
75	1522		2546 (100)	to be announced
180	1522		2547 (200)	early in calendar year 1994

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.

INTERNATIONAL WORKSHOP ON

Semiconductor Characterization: Present Status and Future Needs

January 30 - February 2, 1995
Gaithersburg, Maryland, U.S.A.

Sponsors

The Advanced Research Projects Agency, National Institute of Standards and Technology, and SEMATECH. Other expected co-sponsors: Air Force Office of Scientific Research, Department of Energy, Office of Naval Research, and the National Science Foundation.

Purpose and Goals of the Workshop

Semiconductors form the backbone of all modern-day microelectronic and optoelectronic devices. Semiconductor characterization has proven to be fundamental for the advancement of semiconductor technology. A comprehensive "world-class" workshop dedicated to giving critical reviews of the most important semiconductor characterization techniques that are useful to the semiconductor industry is envisioned. Because of the increasing importance of in-line and in-situ characterization methods, a strong emphasis will be placed on ascertaining their present status and future needs.

The purpose of this workshop is to bring together scientists and engineers interested in all aspects of characterization (research, development, manufacturing, diagnostics...): chemical and physical, electrical, optical, in-situ, and real-time control and monitoring.

The workshop goals are: (1) to provide a forum in which measurements of current and future interest to the semiconductor industry can be reviewed, discussed, critiqued, and summarized; (2) to demonstrate and review important applications for diagnostics, manufacturing, and in-situ monitoring and control in real-time environments; and (3) to act as an important stimulus for new progress in the field by providing new perspectives.

Scope of the Workshop

Papers are solicited in all relevant fields of interest to characterization in semiconductor device manufacturing, growth, processing, diagnostics, in-situ, real-time control and monitoring, etc. All relevant semiconductor materials will be addressed: Group IV elements (Si, etc.), Group III-V compounds (GaAs, InP, etc.), Group II-VI compounds (ZnSe, HgCdTe, etc.), IV-VI compounds (PbTe, etc.), and others. Heavy emphasis will be placed on invited papers that provide up-to-date critical reviews that discuss and evaluate the science and technology of the major techniques or areas. Recent developments of novel measurement methods will also be considered.

For technical information, contact: Dr. David G. Seiler, NIST, A305 Technology Bldg., Gaithersburg, MD 20899-0001, USA, Telephone: 301/975-2081, Fax: 301/948-4081, email: seiler@sed.eeel.nist.gov

The National Institute of Standards and Technology

NIST Standard Reference Materials (SRMs) are used by thousands of companies to calibrate their equipment

NIST photomask SRMs help reduce linewidth measurement errors by a factor of 10 and save manufacturers over $30 million annually

NIST research in electromigration is saving manufacturers over $26 million and has contributed to a new thrust in building-in reliability

NIST research improved production yield of high reliability devices by factors of 2 to 35

NIST developed a tester that characterizes the breakdown of semiconductor power devices without destroying them

NIST is developing test structures and test methods for nanometer overlay metrology

NIST is developing new optical measurement tools for advanced semiconductor manufacturing

NIST research works.

Find out how NIST can help you.
See us at SEMICON/West '94
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Hall 4, Booth 5722
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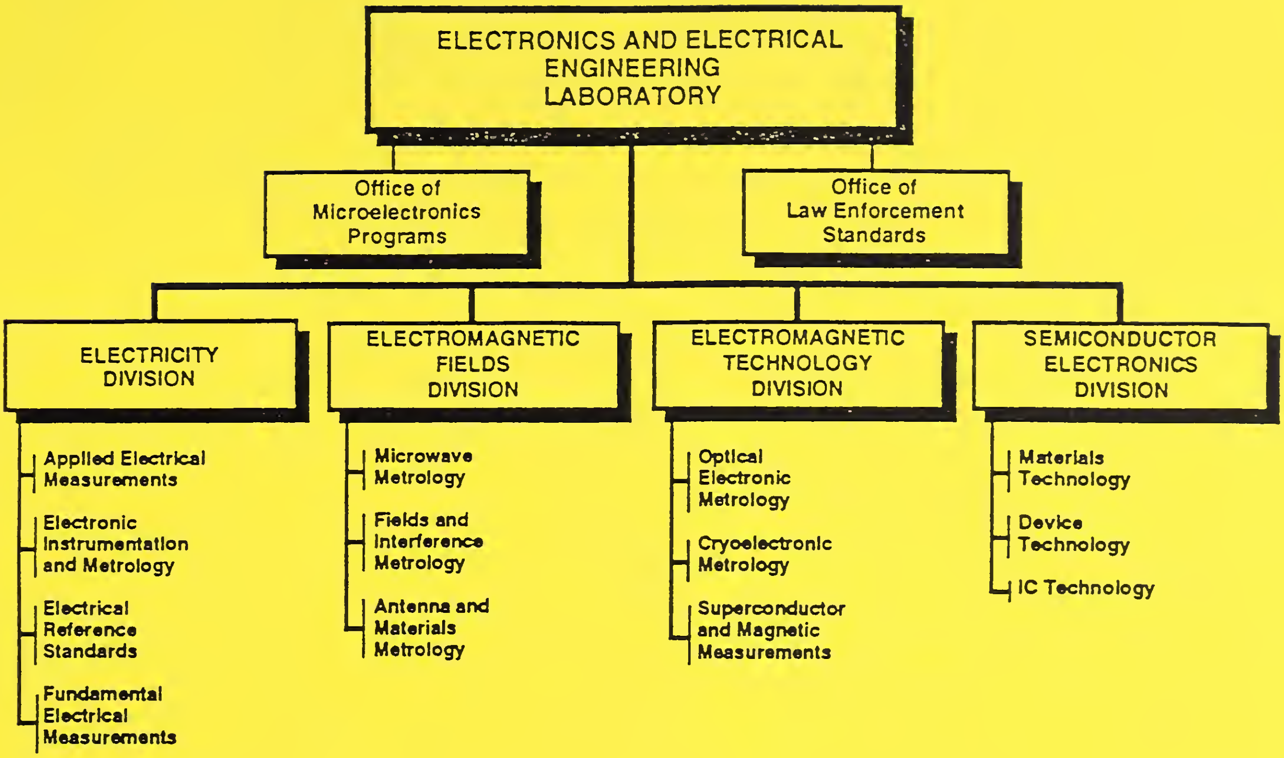

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Office of Law Enforcement Standards	Acting Director, Dr. Daniel E. Frank	(301) 975-2757
Electricity Division (811)	Acting Chief, Dr. Alan H. Cookson	(301) 975-2400
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