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Center for Electronics and Electrical Engineering

Technical Publication Announcements

Covering Center Programs,
April to June 1989,
with 1990 CEEE Events Calendar

21

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INTRODUCTION TO THE CEEE TECHNICAL PUBLICATION ANNOUNCEMENTS

This is the twenty-first issue of a quarterly publication providing information on the technical work of the National Institute of Standards and Technology (formerly the National Bureau of Standards) Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Publication Announcements covers the second quarter of calendar year 1989.

Organization of Bulletin: This issue contains citations and abstracts for Center 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 Center conferences and workshops planned for calendar year 1990 and a list of sponsors of the work.

Center for Electronics and Electrical Engineering: Center 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 Center is divided into two major programs: the Semiconductor Technology Program, carried out by the Semiconductor Electronics Division in Gaithersburg, MD, and the Signals and Systems Metrology Program carried out by the Electricity Division in Gaithersburg and the Electromagnetic Fields and Electromagnetic Technology Divisions in Boulder, CO. Key contacts in the Center are given on the back cover; readers are encouraged to contact any of these individuals for further information.

Center sponsors: The Center 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 17.

Note on Publication Lists: Guides to earlier as well as recent work are the publication lists covering the work of each division. 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 14.

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SEMICONDUCTOR TECHNOLOGY PROGRAM

Silicon Materials

Kopanski, J.J., Albers, J., and Carver, G.P., **Experimental Verification of the Relation Between Two-Probe and Four-Probe Resistances**, Extended Abstract, Electrochemical Society Meeting, Los Angeles, California, May 7-12, 1989, pp. 367-368.

Recent innovations in the measurement of two-probe (spreading resistance) and four-probe resistance using an array of lithographically fabricated, geometrically well-defined contacts have enabled the measurement of these quantities with high accuracy and reproducibility. This has permitted experimental verification of the relationship between the two-probe resistances and the four-probe resistance. Verification was also made of the predicted dependence of the four-probe resistance on the ratio of wafer thickness to probe spacing for in-line and square probe configurations.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Thurber, W.R., Lowney, J.R., Larrabee, R.D., Talwar, P., and Ehrstein, J.R., **An ac Impedance Method for High Resistivity Measurements of Silicon**, Extended Abstract, Electrochemical Society Meeting, Los Angeles, California, May 7-12, 1989, pp. 365-366.

An ac impedance method for measuring the average bulk resistivity of ingots and slices of high-resistivity silicon is described. Easily removable contacts, such as silver paste, are applied to the end faces of the sample and the impedance of the resulting capacitive sandwich is measured as a function of frequency. The resistivity can be calculated from the frequency of the negative peak in the imaginary part of the impedance and model consistency can be checked by comparison of values of resistance obtained from real and imaginary parts at this peak. Comparisons with van der Pauw and four-probe measurements are consistent with this impedance method.
[Contact: W. Robert Thurber, (301) 975-2057]

Dimensional Metrology

Nyyssonen, D., **Narrow-Angle Laser Scanning Microscope System for Linewidth Measurements on Wafers**, NISTIR 88-3808 (April 1989).

The integrated-circuit industry in its push to finer and finer line geometries approaching submicrometer dimensions has created a need for ever more accurate and precise feature-size measurements to establish tighter control of fabrication processes. In conjunction with the NBS Semiconductor Linewidth Metrology Program, a unique narrow-angle laser measurement system was developed. This report describes the theory, optical design, and operation of this system and includes computer software useful for characterizing the pertinent optical parameters and images for patterned thin layers. For thick layers, the physics is more complex, and only elements of the theory are included here. For more detail, the reader is referred to several related reports listed in the references.
[Contact: Beverly M. Wright, (301) 975-2166]

Postek, M.T., Keery, W.J., and Larrabee, R.D., **Specimen Biasing to Enhance or Suppress Secondary Electron Emission from Charging Specimens at Low Accelerating Voltages**, Journal of Scanning Microscopy, Vol. 11, pp. 111-121 (1989).

Specimen biasing is shown to produce improved images in the scanning electron microscope at low-beam energies (0.8 to 2.5 keV) when charging effects, topographic effects, or detector shadowing effects would otherwise be present. Examples of such improvement are given for gallium arsenide field-effect transistors (positive charging), Dimensional Metrology (cont'd.)

patterned photoresist layers on silicon wafers (negative charging and shadowing in contact holes), fractured lucite (negative charging), polyethylene wrapper material (positive charging), and polished diamond tools (positive charging). It is concluded that specimen biasing may be a simpler and more convenient way to achieve some of the advantages of the converted backscattered secondary electron technique for imaging, but without some of the fundamental disadvantages of that technique. Characterization of this backscattered electron-derived image bears further investigation for possible metrological applications.
[Contact: Beverly M. Wright, (301) 975-2166]

Postek, M.T., Larrabee, R.D., and Keery, W.J., **An Approach to Accurate X-Ray Mask Measurements in a Scanning Electron Microscope**, NISTIR 89-4047 (January 1989).

This paper presents the concept and some preliminary experimental data on a new method for measuring critical dimensions on masks used for x-ray lithography. The method uses a scanning electron microscope in a transmitted-scanning electron microscope imaging mode and can achieve nanometer precision. Use of this technique in conjunction with measurement algorithms derived from electron-beam interaction modeling may ultimately enable measurements of these masks to be made to nanometer accuracy.
[Contact: Beverly M. Wright, (301) 975-2166]

Young, M., **Spatial Filtering Microscope for Linewidth Measurements**, Applied Optics, Vol. 28, No. 8, pp. 1467-1473 (15 April 1989).

High-pass filtering has been relatively little used in microscopy, yet it may have application to linewidth measurement and visualization of phase objects. A spatial-filtering microscope has been designed and built, entirely of conventional microscope objectives. For linewidth measurement, the spatial filter has an optimum width that allows linewidths to be measured within a few percent. Phase lines can also be examined, but phase-contrast microscopy may be more suited to weak phase objects such as integrated optical waveguides.
[Contact: Matt Young, (303) 497-3223/-5342]

Analysis Techniques

Bouldin, C.E., Carter, A.C., Kirkland, J., and Neiser, R., **Silicon Photodiode Detectors for EXAFS**, Physica B, Vol. 158 (North-Holland, Amsterdam, 1989), pp. 339-341.

Results are shown of using a large-area silicon diode as a fluorescence detector for extended x-ray absorption fine-structure (EXAFS) measurements. A direct comparison of this diode detector relative to a gas ionization fluorescence detector is made. Advantages of the diode detector include: higher signal for a given photon flux (due to higher quantum efficiency), vacuum and cryogenic compatibility, freedom from microphonic noise, good linearity, extremely wide dynamic range, operation without high voltage or gas connections, very simple electronics, and low cost. Use of photodiodes for transmission EXAFS is discussed.
[Contact: Charles E. Bouldin, (301) 975-2046]

Power Devices

Blackburn, D.L., **Power MOSFET Failure Revisited**, PESC '88 Record, Proceedings of the 1988 IEEE Power Electronics Specialists Conference, Kyoto, Japan, April 11-14, 1988, pp. 681-688 (1988).

The failure of power MOSFETs during avalanche breakdown is discussed. A theory is presented that relates the failure to the temperature rise of the chip during avalanche breakdown and to a critical current for failure. It is

Power Devices (cont'd.)

shown that the energy that can be safely dissipated during avalanche breakdown decreases as the starting current increases or as the case temperature increases. Thus, if power MOSFETs are to be rated for their energy dissipation capability during avalanche breakdown, both the starting current and temperature must be specified, as it is these two parameters that determine the failure limits.
[Contact: David L. Blackburn, (301) 975-2068]

Hefner, A.R., Jr., **An Improved Understanding for the Transient Operation of the Power Insulated Gate Bipolar Transistor (IGBT)**, PESC '89 Record, Proceedings of the 1989 IEEE Power Electronics Specialists Conference, Milwaukee, Wisconsin, June 26-29, 1989, pp. 303-313.

It is shown that a non-quasi-static analysis must be used to describe the transient current and voltage waveforms of the IGBT. The non-quasi-static analysis is necessary because the transports of electrons and holes are coupled for low-gain, high-level injection conditions, and because the quasi-neutral base width changes faster than the base transit speed for typical load circuit conditions. To verify that both of these non-quasi-static effects must be included, the results of quasi-static and non-quasi-static models are compared with measured current and voltage switching waveforms. The comparisons are performed for different load circuit conditions and for different device base lifetimes.
[Contact: Allen R. Hefner, Jr., (301) 975-2071]

Integrated Circuit Test Structures

Khera, D., Zaghloul, M.E., Linholm, L.W., and Wilson, C.L., **A Neural Network Approach for Classifying Test Structure Data**, Proceedings of ICMTS 1989, International Conference on Microelectronic Test Structures, Edinburgh, Scotland, March 13-14, 1989, pp. 201-204.

This paper describes a new approach for identifying and classifying semiconductor manufacturing process variations using test structure data. The technique described in this paper employs a machine-learning algorithm based on neural networks to train computers to detect patterns associated with test structure results. The objective of this work is to develop more reliable machine-learning classification procedures using test structure data from a semiconductor manufacturing environment. An example based on characterizing the performance of a 1-μm lithography process is presented as well as a description of the test chip.
[Contact: Dheeraj Khera, (301) 975-2240]

Suehle, J.S., and Schafft, H.A., **The Electromigration Damage Response Time and Implications for dc and Pulsed Characterizations**, Proceedings of the 27th Annual International Reliability Physics Symposium, Phoenix, Arizona, April 10-13, 1989, pp. 229-233.

A new measurement interference for highly accelerated electromigration stress tests is identified. Measurements of the median-time-to-failure, t_{50}, for dc and for pulsed current stress as a function of frequency reveal that highly accelerated stress tests may overestimate metallization reliability if t_{50} is comparable with the response time of the vacancy concentration. Techniques necessary to make reliable wafer-level t_{50} measurements are described.
[Contact: John S. Suehle, (301) 975-2247]

Zaghloul, M.E., Khera, D., Linholm, L.W., and Reeve, C.P., **A Machine-Learning Classification Approach for IC Manufacturing Control Based on Test Structure Measurements**, IEEE Transac-

IC Test Structures (cont'd.)

tions on Semiconductor Manufacturing, Vol. 2, No. 2, pp. 47-53 (May 1989).

This paper describes the use of a machine-learning method for classifying electrical measurement results from a custom-designed test chip. These techniques are used for characterizing the performance of a 1-μm integrated circuit lithography process. The focus of the work is to develop a method for producing reliable classification rules from data bases containing large samples of measurement data. The paper describes a test chip, data-handling methods, rule generation techniques, and statistical data reduction and parameter extraction techniques. An analysis of error introduced by noise in the rule formation process is presented.
[Contact: Mona E. Zaghloul, (301) 975-2239]

Device Physics and Modeling

Lowney, J.R., and Bennett, H.S., **Effects of Doping-Density Gradients on Band-Gap Narrowing in Silicon and GaAs Devices,** Journal of Applied Physics, Vol. 65, No. 12, pp. 4823-4827 (June 15, 1989).

The limitations of the theory for band-gap narrowing, which is based on uniform material, are considered in devices that have steep doping gradients. Validity criteria are derived that place upper bounds on the dopant and carrier density gradients for the application of the results from uniform theory. The existence of wavefunction tailing beyond the potential barriers that occur in devices is studied. At room temperature the effects due to these tails are usually small, but at low temperatures they can become very significant.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

Insulators and Interfaces

Bouldin, C.E., **EXAFS Study of a Buried Germanium Layer in Silicon,** Physica B, Vol. 158 (North-Holland, Amsterdam, 1989) pp. 596-597.

EXAFS measurements are made of a 200 Å layer of Ge on a Si substrate. The Ge layer is covered by a 3000 Å layer of SiO_2. Sensitivity to the buried layer is enhanced through the use of grazing-incidence fluorescence detection. A two-channel photodiode detector is used to detect the fluorescence and to discriminate against Bragg peaks from the single-crystal Si substrate. Since the fluorescence signal is isotropic while the Bragg peaks are directional, one channel of the detector is always free of Bragg-peak interference. We determine the average number of Ge-Ge and Ge-Si neighbors in the buried Ge layer, the distances, and disorder in the first-shell. Prospects for studying the buried Ge-SiO_2 interface are discussed.
[Contact: Charles E. Bouldin, (301) 975-2046]

Dumin, D.J., Dabral, S., Freytag, M., Robertson, P.J., Carver, G.P., and Novotny, D.B., **High Mobility CMOS Transistors Fabricated on Very Thin SOS Films,** IEEE Transactions on Electron Devices, Vol. 36, No. 3, pp. 596-598 (March 1989).

The increased emphasis on submicron geometry CMOS/SOS devices has created a need for high-mobility CMOS transistors fabricated on high-quality films with thicknesses of the order of 0.1 to 0.2 μm. To date, the only demonstrated way of producing high-mobility transistors on very thin, high-quality SOS films in this thickness range has been to apply recrystallizations and regrowths to the films prior to transistor fabrication. It has been found that the mobility of CMOS transistors fabricated on very thin SOS films is a function of film growth rate. Transistors with mobilities nearly as high as those obtained on 1.0-

Insulators and Interfaces (cont'd.)

μm thick films have been fabricated on SOS films 0.2 μm thick that have been grown at growth rates above 4 μm/min.
[Contact: Donald B. Novotny, (301) 975-2699]

Other Semiconductor Metrology Topics

Bouldin, C.E., Bunker, G., McKeown, D.A., Ritter, J.J., and Forman, R.A., **Multiple Scattering in the XANES** (X-ray Absorption Near Edge Structure) **of Tetrahedral Germanium Gases,** Physica B, Vol. 158 (North-Holland, Amsterdam, 1989), pp. 362-364.

X-ray absorption fine-structure (XAFS or EXAFS (E = Extended)) measurements of $GeCl_4$, GeH_3Cl, and GeH_4 are reported. Since wide-angle multiple scattering (MS) involving H atoms is negligible, we experimentally isolate the single and MS terms in the XAFS of $GeCl_4$ by comparison of the spectra of the three compounds. We find that MS is nowhere dominant over single scattering (SS), although within 15 eV of the edge the two are comparable in size. However, the MS damps out very quickly with increasing energy above the absorption edge. Beyond 40 eV past the edge the MS/SS ratio is less than 0.06. Our calculations are found to be in qualitative agreement with experiment, but overestimate the size and energy range of the MS. Our results suggest that XAFS data in the range $1 < K < 3$ $Å^{-1}$ can be analyzed in an SS picture in many cases, as long as good standard compounds are used, and calculations are used to estimate possible errors due to neglect of MS. We also report the first evidence of single scattering observed from H atoms.
[Contact: Charles E. Bouldin, (301) 975-2046]

SIGNALS & SYSTEMS METROLOGY PROGRAM

FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Waveform Metrology

Oldham, N.M., Hetrick, P.S., and Xiangren, Z., **A Calculable, Transportable Audio-Frequency AC Frequency Standard,** IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 368-371 (April 1989). [Also published in the Conference Digest of CPEM '88, 1988 Conference on Precision Electromagnetic Measurements, Tsukuba Science City, Japan, June 7-10, 1988, pp. 46-47 (IEEE, New York, New York, June 1988).]

A transportable ac voltage source is described, in which sinusoidal signals are digitally synthesized in the audio-frequency range. The rms value of the output waveform may be calculated by measuring the dc level of the individual steps used to generate the waveform. The uncertainty of this calculation at the 7-V level is typically less than ±5 ppm from 60 Hz to 2 kHz and less than ±10 ppm from 30 Hz to 15 kHz.
[Contact: Nile M. Oldham, (301) 975-2408]

Oldham, N.M., Petersons, O., and Waltrip, B.C., **Audio-Frequency Current Comparator Power Bridge: Development and Design Considerations,** IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 390-394 (April 1989). [Also published in the Conference Digest of CPEM '88, 1988 Conference on Precision Electromagnetic Measurements, Tsukuba Science City, Japan, June 7-10, 1988, p. 48 (IEEE, New York, New York, June 1988)].

The development, design, construction, and partial evaluation of a system for performing active and reactive power measurement from 50 to 20 kHz is described. The technique is an extension of a power bridge based on a current comparator capacitance bridge that was originally restricted to power frequencies. The design features and component characteristics for wide-band operation are emphasized. A digitally synthesized, dual-channel signal source

Waveform Metrology (cont'd.)

provides the required voltage and current signals.
[Contact: Nile M. Oldham, (301) 975-2408]

Souders, M.T., and Hetrick, P.S., **Accurate RF Voltage Measurements Using a Sampling Voltage Tracker**, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 451-456 (April 1989). [Also published in the Conference Digest of CPEM '88, 1988 Conference on Precision Electromagnetic Measurements, Tsukuba Science City, Japan, June 7-10, 1988, pp. 270-271 (IEEE, New York, New York, June 1988).]

The radio-frequency (rf) voltage measurement capability of an equivalent time-sampling system is described. The frequency range investigated is 1 to 100 MHz. Over this range, the measured errors, determined by ac/dc thermal transfer, are within the stated uncertainties presently provided by NIST for thermal converter calibrations. The system offers several advantages over conventional thermal transfer techniques: ac/dc transfers are not required, loading and transmission line problems are reduced, and direct measurement of voltages from 2 V to as low as 10 mV are possible.
[Contact: T. Michael Souders, (301) 975-2406]

Cryoelectronic Metrology

Danchi, W.C., Sutton, E.C., Jaminet, P.A., and Ono, R.H., **Nb Edge Junction Process for Submillimeter Wave SIS Mixers**, IEEE Transactions on Magnetics, Vol. 25, No. 2, pp. 1064-1067 (March 1989). [A separate paper by the same authors, **A Superconducting Tunnel Junction Receiver for 345 GHz**, has been approved by NIST for publication.]

We describe a junction fabrication process that produces high-quality Nb edge junctions of areas less than 0.2 μm^2 on thin quartz (0.10-mm) substrates. This process utilizes a 10:1 projection wafer stepper for high resolution and high-accuracy layer-to-layer registration. We have fabricated large numbers of junctions reliably with high-quality I-V characteristics and with impedances suitable for use in SIS mixers for submillimeter astronomy. Junctions produced by this process can be stored on the shelf for more than two years with no special precautions taken, and with an impedance change of less than 10%. No failures have been observed after thermal cycling. Currently, these junctions are being used in an astronomical receiver that demonstrates state-of-the-art performance in the atmospheric window centered at 345 GHz. With some improvements to the process, it is possible to make junctions with areas sufficiently small so that the product of frequency, junction normal-state resistance, and junction capacitance is about 3 at 800 GHz.
[Contact: Ronald H. Ono, (303) 497-3762]

Moreland, J., Ono, R.H., Beall, J.A., Madden, M., and Nelson, A.J., **Evidence for the Superconducting Proximity Effect in Junctions Between the Surfaces of $YBa_2Cu_3O_x$ Thin Films** [original title: Superconducting Proximity Contacts Between the Surfaces of $YBa_2Cu_3O_x$ Thin Films], Appl. Phys. Lett., Vol. 54, No. 15, pp. 1477-1479 (10 April 1989).

We use the squeezable electron tunneling (SET) junction technique for testing the superconducting properties of the surfaces of $YBa_2Cu_3O_x$ (YBCO) thin-film electrodes. The I-V characteristics of the SET junctions indicate that superconductor/normal metal/superconductor contacts exist between the surfaces of the electrodes when they are allowed to touch each other. As deposited and annealed, the surfaces of the electrodes are not superconducting at 4 K. Several methods are used to improve the superconducting properties of the surfaces of the electrodes, including rapid thermal annealing, Cryoelectronic Metrology (cont'd.)

oxygen sputter etching, and thin-silver coating treatments. The greatest improvement occurs after deposition of a 5-nm Ag coating and subsequent rapid thermal anneal of the YBCO film. Under these conditions, it is possible to make a superconducting Josephson point contact between the surfaces of the electrodes. We believe that the Ag acts as a normal-metal proximity layer effectively bridging the degraded surfaces of the electrodes.
[Contact: John Moreland, (303) 497-3641]

Electro-Optic Metrology

Day, G.W., and Rose, A.H., **Faraday Effect Sensors: The State of the Art,** Proceedings of SPIE (The International Society for Optical Engineering, P.O. Box 20, Bellingham, WA 98227), Vol. 985, Fiber Optic & Laser Sensors VI, pp. 138-150 (1988).

The Faraday effect is becoming widely used as an optical method of measuring electric current or magnetic field. It is particularly advantageous where the measurements must be made at high voltage or in the presence of electromagnetic interference, and where speed or stability are considerations. In this paper we review the development of the technology over the last twenty years, with an emphasis on the basic principles, design considerations, and performance capabilities of sensors that represent the latest achievements. Faraday effect current sensors are now used routinely in the measurement of large current pulses, and are starting to become available for ac current measurements in the power industry. Recent developments include their extension to the measurement of currents in the milliampere range and substantial reductions in size. Similar devices, in slightly different configurations, can be used for magnetic field measurements. Further improvements, based on new fiber types and new materials, are projected.
[Contact: Gordon W. Day, (303) 497-5204]

Hickernell, R.K., Larson, D.R., Phelan, R.J., Jr., and Larson, L.E., **Waveguide Loss Measurement Using Photothermal Deflection**, Applied Optics, Vol. 27, No. 13, pp. 2636-2638 (July 1, 1988).

Photothermal deflection (PTD) is introduced as a technique for measuring propagation loss in optical channel waveguides. A probe laser beam is deflected by the thermally induced refractive-index gradient due to the absorption of guided pump light. The technique is noncontact and is applicable to a wide range of channel waveguide geometries and materials, including buried guides. Scattering centers and unguided background light affect the measurement only indirectly, since the PTD signal depends on the gradient of the local temperature and not the light intensity directly.

The pump beam from a HeNe laser of 633-nm wavelength was mechanically chopped and coupled into potassium, ion-exchanged, glass waveguides. The probe beam, also of 633-nm wavelength, was focused on the substrate surface, and its deflection was measured by a silicon bicell using lock-in detection. Our measurements of the PTD signal as a function of the probe spot position agree with similar measurements performed on bulk materials by other researchers. Scans of the PTD signal as a function of distance along the waveguide yielded propagation loss measurements with lower uncertainty than scans of the scattered light intensity. The PTD technique should be useful in the study of waveguide loss mechanisms.
[Contact: Robert K. Hickernell, (303) 497-3455]

DC and Low Frequency Metrology

Field, B.F., and McCaleb, M.R., **An Improved Transportable DC Voltage Standard**, IEEE Transactions on Instrumentation and Measurement, Vol.

DC and Low Frequency Metrology (cont'd.)

38, No. 2, pp. 324-329 (April 1989).

Zener-diode-based dc voltage standards can be excellent transport standards for the unit of dc voltage because of their resistance to physical shock and temperature changes. The problems of transporting a unit of voltage and the properties of available Zener standards were studied to develop a set of characteristics that we consider to be essential for an optimum transport standard. We report some of the results of this requirements study, explain the design of our improved transport standard, discuss our efforts to select Zener diodes for the standard, and present data obtained from prototype Zener reference modules to be used in the standard.
[Contact: Bruce F. Field, (301) 975-4230]

Steiner, R.L., and Field, B.F., **Josephson Array Voltage Calibration System Operational Use and Verification**, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 296-301 (April 1989).

A new Josephson array system now maintains the U.S. Legal Volt. This system is almost fully automated, operates with a typical precision of 0.009 μV, and readily allows U.S. Legal Volt measurements weekly, or more frequently if desired. This system was compared to the previous volt maintenance system, and agreement was achieved to within 0.03 ppm. This verification is limited by uncertainties in the resistive-divider instruments of the previous system.
[Contact: Richard L. Steiner, (301) 975-4226]

Fundamental Electrical Measurements

Belecki, N.B., Dziuba, R.F., Field, B.F., and Taylor, B.N., **Guidelines for Implementing the New Representations of the Volt and Ohm Effective January 1, 1990**, NIST Technical Note 1263 (June 1989).

This document provides general guidelines and detailed instructions on how to bring laboratory reference standards of voltage and resistance and related instrumentation into conformity with newly established and internationally adopted representations of the volt and ohm. Based on the Josephson and quantum Hall effects, respectively, the new representations are to come into effect worldwide starting on January 1, 1990. Their implementation in the United States will result in increases in the values of the national volt and ohm representations maintained at the National Institute of Standards and Technology of 9.264 parts per million (ppm) and 1.69 ppm, respectively. The resulting increase in the value of the U.S. representations of the ampere will be about 7.57 ppm and in the U.S. electrical representation of the watt, about 16.84 ppm. Also discussed are the effects on electrical standards of the January 1, 1990, replacement of the International Practical Temperature Scale of 1968 by the International Temperature Scale of 1990; and of the January 1, 1990, approximate 0.14-ppm decrease in the U.S. representation of the farad.
[Contact: Norman B. Belecki, (301) 975-4223]

Cage, M.E., Dziuba, R.F., Elmquist, R.E., Field, B.F., Jones, G.R., Jr., Olsen, P.T., Phillips, W.D., Shields, J.Q., Steiner, R.L., Taylor, B.N., and Williams, E.R., **NIST Determination of the Fine-Structure Constant, and of the Quantized Hall Resistance and Josephson Frequency to Voltage Quotient in SI Units**, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 284-289 (April 1989).

Results from NIST experiments to realize the ohm and the watt, to determine the proton gyromagnetic ratio and the time dependence of the NIST ohm using the quantum Hall effect, and to maintain the

Fundamental Electrical Meas. (cont'd.)

NIST volt using the Josephson effect are appropriately combined to obtain an accurate value of the fine-structure constant and of the quantized Hall resistance in SI units, and values in SI units of the Josephson frequency to voltage quotient, Planck constant, and elementary charge.
[Contact: Barry N. Taylor, (301) 975-4220]

Cage, M.E., Dziuba, R.F., Van Degrift, C.T., and Yu, D., **Determination of the Time-Dependence of Ω_{NBS} Using the Quantized Hall Resistance**, IEEE Transactions of Instrumentation and Measurement, Vol. 38, No. 2, pp. 263-269 (April 1989).

The quantum Hall effect is being used to monitor the U.S. legal representation of the ohm, or as-maintained ohm, Ω_{NBS}. Measurements have been made on a regular basis since August 1983. Individual transfers between the quantized Hall resistance R_H and the five 1-Ω resistors which comprise Ω_{NBS} can now be made with a total one standard deviation (1σ) uncertainty of ± 0.014 ppm. This uncertainty is the root-sum-square of 32 individual components. The time-dependent expression for R_H in terms of Ω_{NBS} is: $R_H = 25\ 812.8[1 + (1.842 \pm 0.012) \times 10^{-6} + (0.0529 \pm 0.0040)(t-0.7785) \times 10^{-6}/\text{year}]\Omega_{NBS}$, where t is measured in years from January 1, 1987. The value of Ω_{NBS} is, therefore, decreasing at the rate of (0.0529 ± 0.0040) ppm/year.
[Contact: Marvin E. Cage, (301) 975-4248]

Olsen, P.T., Elmquist, R.E., Phillips, W.D., Williams, E.R., Jones, G.R., Jr., and Bower, V.E., **A Measurement of the NBS Electrical Watt in SI Units**, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 238-244 (April 1989).

We have measured the NBS (now NIST) electrical watt in SI units to be: $W_{NIST}/W = K_W = 1 - (16.69 \pm 1.33)$ ppm. The uncertainty of 1.33 ppm has the significance of a standard deviation and includes our best estimate of random and known or suspected systematic uncertainties. The mean time of the measurement is 15 May 1988. Combined with the recent measurement of the NIST ohm in SI units: $\Omega_{NIST}/\Omega = K_\Omega = 1 - (1.593 \pm 0.022)$ ppm, this leads to a Josephson frequency/voltage quotient of $E_j = E_o [1 + (7.94 \pm 0.67)\ \text{ppm}]$ where $E_o = 483594$ GHz/V.
[Contact: P. Thomas Olsen, (301) 975-6553]

Shields, J.Q., Dziuba, R.F., and Layer, H.P., **New Realization of the Ohm and Farad Using the NBS Calculable Capacitor**, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 249-251 (April 1989).

Results of a new realization of the ohm and farad using the NBS calculable capacitor and associated apparatus are reported. The results show that both the NBS representation of the ohm and the NBS representation of the farad are changing with time, Ω_{NBS} at the rate of -0.054 ppm/year and F_{NBS} at the rate of 0.010 ppm/year. The realization of the ohm is of particular significance at this time because of its role in assigning an SI value to the quantized Hall resistance. The estimated uncertainty of the ohm realization is 0.022 ppm (1σ), while the estimated uncertainty of the farad realization is 0.014 ppm (1σ).
[Contact: John Q. Shields, (301) 975-4223]

Williams, E.R., Jones, G.R., Jr., Sheng, Y., Liu, R., Sasaki, H., Olsen, P.T., Phillips, W.D., and Layer, H.P., **A Low Field Determination of the Proton Gyromagnetic Ratio in Water**, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 233-237 (April 1989).

We measure the proton gyromagnetic ratio in H_2O by the low-field method, $\gamma_p'(\text{low})$.

Fundamental Electrical Meas. (cont'd.)

The result, $\gamma_p'(\text{low}) = 2.67513376\ 10^8\ s^{-1}\ T_{NIST}^{-1}$ (0.11 ppm), leads to a value of the fine structure constant of α^{-1} = 137.0359840 (0.037 ppm) and a value for the quantized Hall resistance in SI units of R_H = 25812.80460 Ω (0.037 ppm). To achieve this result, we measured the dimensions of a 2.1-m solenoid with an accuracy of 0.04 μm, and then measured the NMR frequency of a water sample in the field of the solenoid.
[Contact: Edwin R. Williams, (301) 975-6555]

ELECTRICAL SYSTEMS

Power Systems Metrology

Anderson, W.E., **Calibration of Voltage Transformers and High-Voltage Capacitors at NIST**, Journal of Research of the National Institute of Standards and Technology, Vol. 94, No. 3, pp. 179-195 (May-June 1989).

The National Institute of Standards and Technology (NIST) calibration service for voltage transformers and high-voltage capacitors is described. The service for voltage transformers provides measurements of ratio correction factors and phase angles at primary voltages up to 170 kV and secondary voltages as low as 10 V at 60 Hz. Calibrations at frequencies from 50 to 400 Hz are available over a more limited voltage range. The service for high-voltage capacitors provides measurements of capacitance and dissipation factor at applied voltages ranging from 100 V to 170 kV at 60 Hz depending on the nominal capacitance. Calibrations over a reduced voltage range at other frequencies are also available. As in the case with voltage transformers, these voltage constraints are determined by the facilities at NIST.
[Contact: William E. Anderson, (301) 975-2423]

McComb, T.R., Hughes, R.C., Lightfoot, H.A., Schon, K., Schulte, R., McKnight, R.H., and Zhang, Y.X., **International Comparison of HV Impulse Measuring Systems**, IEEE Transactions on Power Delivery, Vol. 4, No. 2, pp. 906-915 (April 1989).

Present standards for qualifying high voltage (HV) impulse measuring systems by unit-step-response parameters are complex and difficult to apply, and some systems, which have response parameters within the limits of the standards, have unacceptable errors. This paper takes the first step in providing a simplified method based on simultaneous measurements of an HV impulse by a reference system and the system under test. Comparative measurements have been made in four national laboratories, and the relative differences are reported. The results are discussed and the further work which is required is outlined.
[Contact: John Lagnese, (301) 975-2423]

Misakian, M., **Discussion of Paper 88 SM 560-5, "Performance of a Long-Term Unattended Station for Measuring DC Fields and Air Ions from an Operating HVDC Line," by V.L. Chartier, L.D. Dickson, L.Y. Lee, and R.D. Stearns**, IEEE Transactions on Power Delivery, Vol. 4, No. 2, p. 1328 (April 1989).

This discussion refers to a paper presented at the IEEE Power Engineering Society 1988 summer meeting in Portland, Oregon.
[Contact: Martin Misakian, (301) 975-2426]

Misakian, M., Anderson, W.E., and Laug, O.B., **Drift Tubes for Characterizing Atmospheric Ion Mobility Spectra Using AC, AC-Pulse, and Pulse Time-of-Flight Measurement Techniques**, Rev. Sci. Instrum., Vol. 60, No. 4, pp. 720-729 (April 1989).

Two drift tubes constructed of insulating cylinders with conductive guard rings on the inside walls were examined to determine their suitability for measuring ion mobility spectra at

Power Systems Metrology (cont'd.)

atmospheric pressure. One drift tube is of the pulse time-of-flight (TOF) type with adjustable drift distance, and the other is an ac-TOF drift tube similar in principle to a device reported by Van de Graaff. The latter tube was evaluated using sinusoidal and alternating-polarity pulse-voltage waveforms for gating the shutters.
[Contact: Martin Misakian, (301) 975-2426]

Moore, W.J.M., So, E., Oldham, N.M., Miljanic, P.N., and Bergeest, R., **An International Comparison of Power Meter Calibrations Conducted in 1987**, IEEE Transactions on Instrumentation and Measurement, Vol. 38, No. 2, pp. 395-401 (April 1989). [Also published in the Conference Digest of CPEM'88, 1988 Conference on Precision Electromagnetic Measurements, Tsukuba Science City, Japan, June 7-10, 1988, pp. 341-342 (IEEE, New York, New York, June 1988)].

The results of an intercomparison of power meter calibrations conducted during 1987 between the National Research Council, Ottawa, the National Bureau of Standards (now the National Institute of Standards and Technology), Gaithersburg, the Physikalisch-Technische Bundesanstalt, Braunschweig, and the Institut Mihailo Pupin, Belgrade, are described. The comparison was implemented by a transfer standard consisting of a time-division multiplier watt-converter developed at the Institut Mihailo Pupin. The measurements were made at 120 V, 5 A, 50 and 60 Hz, at power factors of 1.0, 0.5 lead and lag, and 0.0 lead and lag. An agreement between the laboratories of better than 20 ppm is indicated.
[Contact: Nile H. Oldham, (301) 975-2408]

Zhang, Y.X., McKnight, R.H., and Hebner, R.E., **Interactions Between Two Dividers Used in Simultaneous Comparison Measurements**, IEEE Transactions on Power Delivery, Vol. 4, No. 3, pp. 1586-1594 (July 1989).

A revised international standard for the measurement of lightning and front-chopped lightning impulses is presently under consideration. This standard states that the accuracy of the measuring systems used is to be determined by comparison to reference systems maintained by appropriate national laboratories. Investigations have been made of the interactions between two systems configured for simultaneous measurements and of methods for minimizing these interactions. Unit step responses were measured for different configurations, and a model developed to predict divider response. Simultaneous measurements were made of full and chopped lightning impulses using different divider systems to determine the effects of divider interactions on measurements.
[Contact: Robert E. Hebner, (301) 975-2403]

Superconductors

Moreland, J., Li, Y., Folsom, R., and Capobianco, T.E., **Cryogenic Bathysphere for Rapid Variable-Temperature Characterization of High-T_c Superconductors**, Rev. Sci. Instrum., Vol. 59, No. 12, pp. 2535-2538 (December 1988).

A bathysphere consisting of an inverted dewar flask for submersible operation in cryogenic fluids is used to measure the resistance of superconductors, including high-T_c superconducting copper oxides, as a function of temperature from 4 to 300 K. We describe the cryostat incorporating the bathysphere and present data on NbTi (44% Ti) and $YBa_2Cu_3O_{7-\delta}$ with respective superconducting transition temperatures of 9.5 and 91.5 K. There are several advantages of the bathysphere method. The cryostat is of simple, compact design easily adapted to high-field applications where magnet bore size is a limiting factor. The sample and thermometer are thermolyzed in the dry vapor trapped at the top of the

Superconductors (cont'd.)

bathysphere. Temperature can be varied rapidly from 300 to 4 K at a rate of 1 K per minute with less than a 0.1-K thermal lag between the sample and thermometer.
[Contact: John Moreland, (303) 497-3641]

Moreland, J., Li, Y., Folsom, R.M., and Capobianco, T.E., **Resistance Measurements of High T_c Superconductors Using a Novel "Bathysphere" Cryostat** [original title: Novel "Bathysphere" Cryostat for Resistance Versus Temperature Experiments on High-T_c Superconductors], IEEE Transactions on Magnetics, Vol. 25, No. 2, pp. 2560-2562 (2 March 1989).

We have developed a novel cryostat for variable temperature testing of high-temperature superconductors. The cryostat is a bathysphere consisting of an overturned stainless-steel Dewar flask suspended in liquid helium. A sample-heater-thermometer assembly is located at the top of the encapsulated (and thermally insulated) vapor space inside of the Dewar. The sample can be rapidly cycled from 300 K to 4 K at an average rate of 1 K/min with a thermal hysteresis of less than 0.1 K. Helium vapor flows through a plug in the bottom of the bathysphere so that pressure of the vapor is roughly ambient. This provides ample heat transfer to and from the sample to maintain thermal equilibrium in the vapor space. Results for resistance-versus-temperature of some high-temperature superconductors in a magnetic field are presented. Also, various definitions for thermodynamic and practical critical temperatures derived from transport resistivity measurements are suggested and discussed.
[Contact: John Moreland, (303) 497-3641]

Moreland, J., Ono, R.H., Beall, J.A., Madden, M., and Nelson, A.J., **Evidence for the Superconducting Proximity Effect in Junctions Between the Surfaces of $YBa_2Cu_3O_x$ Thin Films** [original title: Superconducting Proximity Contacts Between the Surfaces of $YBa_2Cu_3O_x$ Thin Films], Appl. Phys. Lett., Vol. 54, No. 15, pp. 1477-1479 (10 April 1989).

We use the squeezable electron tunneling (SET) junction technique for testing the superconducting properties of the surfaces of $YBa_2Cu_3O_x$ (YBCO) thin-film electrodes. The I-V characteristics of the SET junctions indicate that superconductor/normal metal/superconductor contacts exist between the surfaces of the electrodes when they are allowed to touch each other. As deposited and annealed, the surfaces of the electrodes are not superconducting at 4 K. Several methods are used to improve the superconducting properties of the surfaces of the electrodes, including rapid thermal annealing, oxygen sputter etching, and thin-silver coating treatments. The greatest improvement occurs after deposition of a 5-nm Ag coating and subsequent rapid thermal anneal of the YBCO film. Under these conditions, it is possible to make a superconducting Josephson point contact between the surfaces of the electrodes. We believe that the Ag acts as a normal-metal proximity layer effectively bridging the degraded surfaces of the electrodes.
[Contact: John Moreland, (303) 497-3641]

Nikolo, M., and Goldfarb, R.B., **Flux Creep and Activation Energies at the Grain Boundaries of Y-Ba-Cu-O Superconductors**, Physical Review B, Vol. 39, No. 10, pp. 6615-6618 (1 April 1989).

We measured the ac susceptibility of sintered $Y_1Ba_2Cu_3O_{7-\delta}$ pellets as a function of temperature, applied magnetic field, and frequency. The imaginary part of susceptibility exhibits a peak below the critical temperature that is attributed to hysteresis losses at the grain boun-

Superconductors (cont'd.)

daries. There is a small shift in this coupling peak towards higher temperature with frequency increasing from 10 to 1000 Hz. We explain the shift in the context of Anderson flux creep on a scale of milliseconds at the grain boundaries. The shift is dependent on the amplitude of the measuring field. The activation energy for flux creep ranges from 11.9 eV at 0.8 $A \cdot m^{-1}$ (0.01 Oe) to 1.2 eV at 800 $A \cdot m^{-1}$ (10 Oe). We extrapolate our data to find the value for an intergrain decoupling field of 1.1 $kA \cdot m^{-1}$ (14 Oe) above which the flux creep presumably becomes flux flow. We also measured a frequency shift of the intrinsic peak of the imaginary part of susceptibility, attributed to grains, for a measuring field of 4.8 $kA \cdot m^{-1}$ (60 Oe). For lower fields, there was no observed shift in the intrinsic peak as a function of frequency.
[Contact: Martin Nikolo, (303) 497-5869]

Other Electrical Systems Topics

Olthoff, J.K., and Hebner, R.E., **Assessment of Space Power Related Measurement Requirements of the Strategic Defense Initiative**, NIST Technical Note 1259 (April 1989).

A survey has been performed to determine the measurement requirements of space power systems for anticipated Strategic Defense Initiative (SDI) deployments. These requirements have been compared to present state-of-the-art metrology capabilities as represented by the calibration capabilities of the National Institute of Standards and Technology. Metrology areas where present state-of-the-art capabilities are inadequate to meet SDI requirements are discussed, and areas of metrology-related research which appear promising to meet these needs are examined. Particular attention is paid to the difficulties of long-term, unattended sensor calibrations and long-term reliability of measuring systems.
[Contact: James K. Olthoff, (301) 975-2431]

ELECTROMAGNETIC INTERFERENCE

Conducted Electromagnetic Interference

Martzloff, F.D., **Discussion by F.D. Martzloff of IEEE PES Paper 88 SM 541-5, T.L., "Steep-Front Short-Duration Voltage Surge Tests of Power Line Filters and Transient Voltage Suppressors," by P.R. Barnes and T.L. Hudson**, IEEE Transactions on Power Delivery, Vol. 4, No. 2, pp. 1029-1036 (April 1989).

The authors report interesting results of their tests on commercial filters (presumably consisting of linear elements), enhanced by two types of nonlinear surge-protective devices. While there is no problem with the reported performance per se, the wording of the report summary suggests an inconsistency in reporting otherwise accurate results.
[Contact: Francois D. Martzloff, (301) 975-2409]

ADDITIONAL INFORMATION

Lists of Publications

Reidy, A.M., and Gibson, K.A., **A Bibliography of the NIST Electromagnetic Fields Division Publications**, NISTIR 88-3900 (September 1988).

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 August 1988. Selected earlier publications from the Division's predecessor organizations are included.
[Contact: Kathryn A. Gibson, (303) 497-3132]

DeWeese, M.E., **Metrology for Electromagnetic Technology: A Bibliography of NBS Publications**, NBSIR 88-3097 (August 1988).

Additional Information (cont'd.)

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NIST in 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 included.
[Contact: Sarabeth Moynihan, (303) 497-3678]

Palla, J.C., and Meiselman, B.,

Electrical and Electronic Metrology: A Bibliography of NBS Electrosystems Division Publications, NBS List of Publications 94 (January 1989).
This bibliography covers publications of the Electrosystems Division, Center for Electronics and Electrical Engineering, NIST, and of its predecessor sections for the period January 1968 to December 1988. A brief description of the Division's technical program is given in the introduction.
[Contact: Jenny C. Palla, (301) 975-2220]

Walters, E.J., **Semiconductor Measurement Technology, NBS List of Publications 72** [a bibliography of NBS publications concerning semiconductor measurement technology for the years 1962-1988] (March 1989).

This bibliography contains reports of work performed at the National Institute of Standards and Technology in the field of Semiconductor Measurement Technology in the period from 1962 through December 1988. An index by topic area and a list of authors are provided.
[Contact: E. Jane Walters, (301) 975-2050]

NEW CALIBRATION SERVICES OFFERED

The explosive growth of optical fiber use in the communications industry has resulted in a demand for calibration services. NIST's Boulder, Colorado, laboratory now offers **measurements of optical laser power and energy at wavelengths and power levels of interest to fiber optic producers and users.** Measurements are based on a standard reference instrument called the C-series calorimeter. An electrically calibrated pyroelectric radiometer (ECPR) is calibrated against the calorimeter and is then used to calibrate optical power meters at wavelengths of 850, 1300, and 1550 nm. To improve calibration capabilities, NIST is preparing test measurement systems for detector linearity, detector uniformity, and detector spectral responsivity. These systems should be available in 6 months. For a paper outlining NIST's optical power measurement capabilities, contact Fred McGehan, Division 360, NIST, 325 Broadway, Boulder, Colorado 80303. For more information on calibration services, contact Thomas R. Scott, Div. 724, same address, or phone (303) 497-3651.

R&D 100 AWARD WINNER

Image-Preserving Optical Delay

Edward F. Kelley of the Electrosystems Division is the recipient of an R&D 100 Award in 1988 for generating a pioneering photographic "time machine" which, when used with a high-speed camera, permits photographing events which occurred before the camera's shutter is opened.

The system, called an image-preserving optical delay, differs from conventional photography which records an event only when the shutter is open.

This new device, an arrangement of optical components including mirrors and a crystal shutter, allows researchers to take detailed, high-speed photographs of random, that is, nontriggered, events.

It is now used for processes which last from 100 ns to 10 μs to study materials utilized by the electric power industry.

This system stores optical images of a

Additional Information (cont'd.)

random event long enough so the shutter of a high-speed camera can be opened and photographs taken of the processes leading to the random event. Kelley has filed a patent application on the system.

Functionally, the optical delay is equivalent to forcing the image to travel an additional 120 m before it gets to the camera. Using a series of concave and planar mirrors, this path length is folded into about 4 m.

The system is rugged enough to be used in a variety of settings. Normal vibration, air currents, and airborne dust have minimal effect on its operation.
[Contact: William E. Anderson, (301) 975-2423]

RECENTLY ISSUED
STANDARD REFERENCE MATERIALS

The Semiconductor Electronics Division announces the release of a new Standard Reference Material (SRM) for **ellipsometrically derived thickness and refractive index of a silicon dioxide film on silicon.** Available for sale to the public through the NIST Office of Standard Reference Materials [for orders, (301) 975-6776], SRM 2530 is separately available for three oxide thicknesses: 50 nm (2530-1), 100 nm (2530-2), and 200 nm (2530-3).

This SRM was developed to respond to industry needs to evaluate the accuracy of ellipsometers, but may also be used as aid in the calibration of various other optical and mechanical thickness monitoring instruments.

Each SRM consists of a 76-mm (3-in.) diameter silicon wafer on which a uniform silicon dioxide layer was grown, patterned, and partially covered with chromium. The certified values were determined from measurements made using the highly accurate ellipsometer developed in the Division and are the ellipsometric parameters delta, Δ, and psi, ψ, at a wavelength of $\lambda = 632.8$ nm. The SRMs are also certified for the derived values of thickness and refractive index of its silicon dioxide layer determined by using a two-layer model consisting of a silicon dioxide layer on a thin silicon-rich oxide interlayer.
[Contact: Deane Chandler-Horowitz, (301) 975-2084]

1990 CEEE CALENDAR

February 6-8, 1990 (Phoenix, AZ)

IEEE Semiconductor Thermal and Temperature Measurements Symposium. This sixth annual **SEMI-THERM** symposium is sponsored by the Components, Hybrids, and Manufacturing Technology Society of IEEE in cooperation with NIST and constitutes an international forum for the presentation of new developments relating to generation and removal of heat within semiconductor devices, measurement of device temperatures, and the simulation of device and system thermal behavior. Major SEMI-THERM topic areas include thermal measurements; thermal characterization; applications; and simulation, computation, and software.

The program includes keynote speakers, technical presentations, tutorial sessions, workshops, and an exhibit. In addition, the Semiconductor Equipment and Materials Institute (SEMI) and the Joint Electron Devices Engineering Council (JEDEC) have scheduled in conjunction with SEMI-THERM several Standards Committee Task Force meetings, to which attendees are invited.
[Contact: David L. Blackburn, (301) 975-2068]

September 10-12, 1990 (Boston, MA)

VLSI and GaAs Chip Packaging Workshop. The IEEE CHMT Society and the National Institute of Standards and Technology are co-sponsoring the Ninth VLSI packaging Workshop. Topics to be

CEEE Calendar (cont'd.)

discussed include VLSI package design; multichip module design; WSI packaging; package thermal design; package electrical design; GaAs IC packaging; VLSI package interconnection options; VLSI package materials and die-attach solutions; and failure mechanism and quality of VLSI packages. All attendees are expected to be specialists working in the field and to participate in discussions.
[Contact: George G. Harman, (301) 975-2097]

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11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

This is the twenty-first issue of a quarterly publication providing information on the technical work of the National Institute of Standards and Technology (formerly the National Bureau of Standards) Center for Electronics and Electrical Engineering. This issue of the Center for Electronics and Electrical Engineering Technical Publication Announcements covers the second quarter of calendar year 1989. Abstracts are provided by technical area for papers published this quarter.

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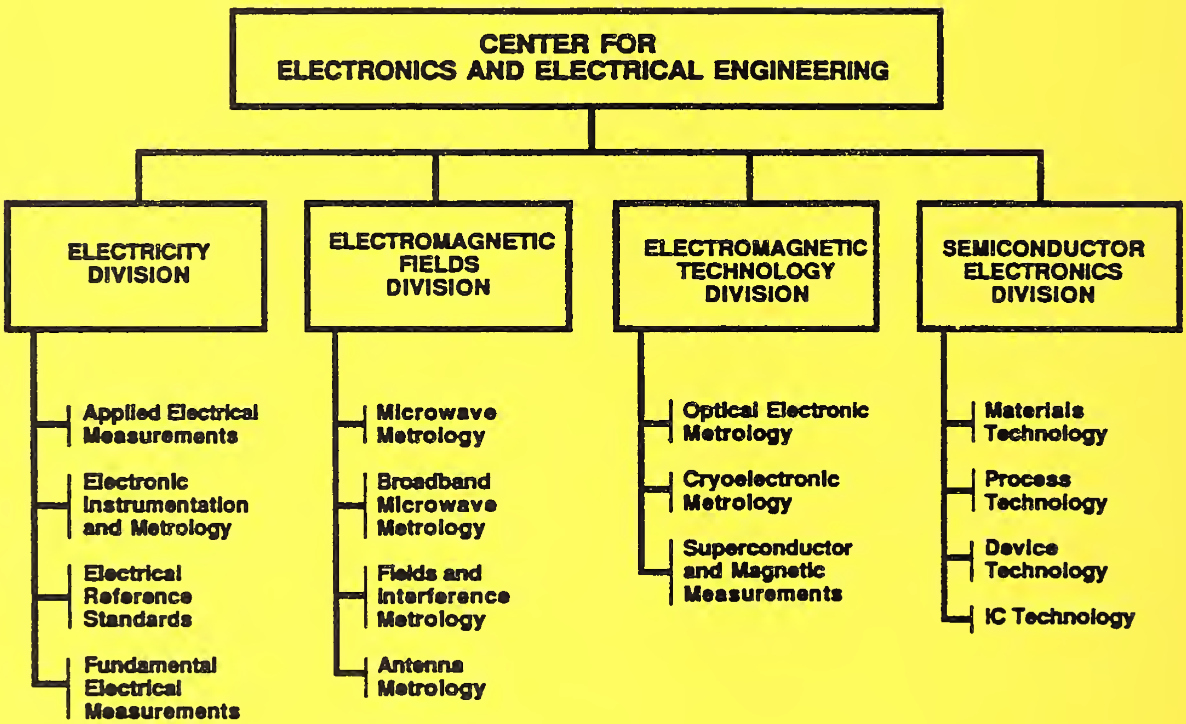

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