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# Center for Electronics and Electrical Engineering

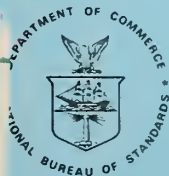


# Technical Progress Bulletin

Covering Center Programs,  
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## INTRODUCTION TO DECEMBER 1984 ISSUE OF THE CEEE TECHNICAL PROGRESS BULLETIN

This is the eighth issue of a quarterly abstract journal covering the work of the National Bureau of Standards Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Progress Bulletin covers the third quarter of calendar year 1984.

Organization of Bulletin: This issue contains abstracts for all Center papers released for publication by NBS in the quarter and citations and abstracts for Center papers published in the quarter. Entries are arranged by technical topic as identified in the table of contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication". Papers published in the quarter appear under the subheading "Recently Published". Following each abstract is the telephone number of the individual to contact for more information on the topic; unless otherwise noted, this person is the first author. This issue also includes a calendar of Center conferences and workshops now planned for calendar year 1985, an announcement of newly released standard reference materials, 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 Materials and Processes and Semiconductor Devices and Circuits Divisions in Gaithersburg, MD, and the Signals and Systems Metrology Program, carried out by the Electrosystems 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 Bureau of Standards and a number of other organizations, in both the Federal and private sectors; these are identified on page 21.

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 [publications from the Semiconductor Technology Program are covered in a single list, available from either Semiconductor Division].

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KEY CONTACTS IN CENTER, CENTER ORGANIZATION . . . . . back cover

**SEMICONDUCTOR TECHNOLOGY PROGRAM**Silicon Materials

Released for Publication

Ehrstein, J.R., **Preparation and Certification of SRMs for Calibration of Spreading Resistance Probes**, to be published as NBS Special Publication 290-93.

This technical note describes the material selection, characterization, data analysis, and measurement process control procedures for four types of Standard Reference Materials (SRMs), available from the National Bureau of Standards, for calibration of spreading resistance measurements on semiconductor silicon. Each of the four comprises a single combination of silicon conductivity-type and crystallographic orientation and contains 16 rectangular silicon chips which are certified for resistivity value based on four-probe resistivity measurements on the slices from which they were cut. The resistivity values of the chips in each set range from about  $0.001 \Omega \cdot \text{cm}$  to about  $100 \Omega \cdot \text{cm}$ . The uncertainty of the certified resistivity, as it applies to any individual chip, depends both on the uniformity of the starting slice and on the inherent measurement process uncertainty. The procedure for determining this uncertainty, which is specifically evaluated and tabulated on the certificate for each SRM set, is described.

[(301) 921-3625]

Recently Published

Larrabee, R.D., Ed., **Neutron Transmutation Doping of Semiconductor Materials**, Proc. 4th Neutron Transmutation Doping Conference, June 2-3, 1982, Plenum Press, NY (1984).

This volume contains the papers presented at the Fourth International Neutron Transmutation Doping Conference held at the National Bureau of Standards

in Gaithersburg, Maryland on June 1-3, 1982. The Fourth International Transmutation Doping Conference reported in this volume includes invited papers summarizing the present and anticipated future of NTD silicon, the processing and characterization of NTD silicon, and the use of NTD silicon in semiconductor power devices. In addition, four papers were presented on NTD of nonsilicon semiconductors, five papers on irradiation technology, three papers on practical utilization of NTD silicon, four papers on the characterization of NTD silicon, and five papers on neutron damage and annealing. These papers indicate that irradiation technology for NTD silicon and its use by the power-device industry are approaching maturity.

[(301) 921-3786]

Gallium Arsenide Materials

Erratum

The wrong abstract appeared in the April 84 (3) issue of the Technical Progress Bulletin [NBSIR 84-2857-4] for the following published paper. The correct abstract follows the citation.

Pande, K.P. and Seabaugh, A.C., **Low Temperature Plasma-Enhanced Epitaxy of GaAs**, J. Electrochem. Soc., 131, No. 6, pp. 1357-1359 (June 1984).

Low-temperature ( $<450^\circ\text{C}$ ) deposition of single crystal GaAs using a new plasma-enhanced MO-CVD technique is reported. In this technique, plasma is created by a dc potential and the substrate is not directly exposed to the plasma. Deposition of GaAs was achieved at extremely low plasma power ( $0.3$  to  $0.5\text{W}/\text{cm}^2$ ) using trimethylgallium (TMGa) and arsine (or trimethylarsenic) reactants. The resulting epitaxial films show excellent surface morphology and thickness uniformity over a large area substrate. A linear dependence of growth rate upon TMGa concentration was observed with a typical growth rate of  $0.1 \mu\text{m}$  per minute for a TMGa flow rate of  $15 \text{ mL}$  per

Gallium Arsenide Materials, cont'd.

minute. Undoped films were found to be n-type with a room temperature mobility in the range of  $5200 \text{ cm}^2 \text{ V}^{-1} \cdot \text{s}^{-1}$ . Measurements on Schottky barrier devices fabricated on n/n<sup>+</sup> layers show uniform impurity doping profiles. Temperature dependence of the diode capacitance indicates a density of deep trapping centers as low as  $6.2 \times 10^{13} \text{ cm}^{-3}$ . [Contact: Seabaugh (301) 921-3625]

Analysis Technique

Released for Publication

Forman, R.A. and Mayo, S., **In Situ Alignment for X-Ray Topography.**

A simple method for in situ alignment of samples in a double crystal x-ray topography system is described. This method permits a specific crystallographic axis to be made coincident with the sample rotation axis used to set the Bragg angle. Surface reflections from approximately orthogonal crystallographic planes are required, and tables of such planes suitable for alignment of cubic crystals are given. This procedure allows rapid setup for the other accessible surface reflection or transmission topographs. [(301) 921-3625]

Insulators and Interfaces

Released for Publication

Candela, G.A. and Chandler-Horowitz, D., **An Ellipsometry System for High Accuracy Metrology of Thin Films** [paper given at Soc. Photo-Optical & Instrum. Engrs., Arlington, VA, May 1-4, 1984].

A computer-controlled spectroscopic ellipsometer of high accuracy has been designed and constructed. A theta-two-theta goniometer unit and optical rail system allows various ellipsometric methods to be used to measure the parameters  $\Delta$  and  $\psi$ . Three important

methods under study for accuracy, precision, and speed of measurement are the conventional null method, the rotating analyzer method, and the principal angle method. All the goniometer angles, including the angle of incidence, can be measured to an accuracy of 0.001 deg. The present light sources are two lasers with fixed wavelengths, 632.8 nm and 441.6 nm, in addition to a monochromator that can be used to scan the wavelength range from 190 to 2600 nm. A unique sample alignment system which utilizes two quadrant detectors has been developed and a simple but very effective nulling scheme is used. This instrument is primarily used for the metrology of semiconductor materials and for the calibration of reference standards for thin film thickness and refractive index.

[(301) 921-3625]

Dimensional Metrology

Released for Publication

Nyyssonen, D., **Optical Linewidth Measurement on Patterned Metal Layers** [paper given at Soc. Photo-Optical & Instrum. Engrs., Arlington, VA. May 1-4, 1984].

In a previous paper [1], a waveguide model was developed for the imaging of micrometer-sized lines patterned in thick layers of dielectric materials (silicon dioxide) with application to linewidth measurement on integrated-circuit wafers. This paper describes the extension of this work to metals characterized by their complex index of refraction,  $n + iK$ , as well as the inclusion of a sublayer such as a silicon dioxide insulating layer. This extension allows the modeling of optical imaging and linewidth measurement on metal-on-silicon (MOS) structures. It is shown that the image structure for metals at and near focus is different from that for dielectrics. Thick and thin layer (less than 200 nm) imaging is compared. Experimental image profiles

Dimensional Metrology, cont'd.

of metal lines at and near focus are also shown. The experimental data were obtained from a bright-field microscope using a laser source (530 nm) and controlled spatial coherence.

[(301) 921-3786]

Integrated Circuit Test Structures

Released for Publication

Glendinning, W., Kwiatkowski, J., and Yen, D., **Electron-Beam Patterning Via Peripheral Writing.**

Resistor-type test structures were patterned in aluminum using a Gaussian-spot laboratory e-beam exposure system. For peripheral writing, a two-step process is used: (1) the line boundaries outlining the periphery of the test structures are written into positive resist (PMMA), developed, and etched; and (2) an optical aligner exposes background metal pattern areas coated with positive resist, followed by standard development and wet etching. For comparison, solid-fill e-beam patterning of identical test structures with negative resist was performed. Electrical measurements of linewidths using these test structures show that greater proximity distorted linewidths occur for solid-fill versus peripherally written devices. Computer simulation of the e-beam exposures employing a double Gaussian electron scattering model predicts that peripheral writing should result in smaller proximity distortions. Additionally, a direct-write speed advantage of 3 to 5 times is realized with peripheral writing.

[Contact: Yen (301) 921-3621]

Recently Published

Mazer, J.A. and Linholm, L.W., **Comments on "Determining Specific Contact Resistivity from Contact End Resistance Measurements"**, IEEE Electron Devices Letters, EDL-5, pp. 347-348 (September 1984).

Comments are rendered on the application of the transmission-line model (TLM) to the determination of specific contact resistance by Chern and Oldham in a recent letter appearing in this journal. Comments are also made on those authors' interpretation of related work by Proctor and Linholm. It is shown that Chern and Oldham have misinterpreted some of the results of Proctor and Linholm and have failed to recognize certain critical assumptions that underlie the TLM.

[(301) 921-3621]

Schafft, H.A., Younkings, C.D., Grant, T.C., Kao, C.-Y., and Saxena, A.N., **Effect of Passivation and Passivation Defects on Electromigration Failure in Aluminum Metallization**, 22nd Annual Proceedings, Reliability Physics 1984, Las Vegas, NV, pp. 250-255 (April 3-5, 1984).

Metal line structures with intentional defects in the passivation, to simulate cracks or pin holes, were used in electromigration studies. Results show that the stress changes in the metallization caused by these defects are not as important as the restraining action of the passivation in affecting a metallization's resistance to electromigration failure. Also, the observed effects of restorative forces acting on the metallization suggests that continuous monitoring for open-circuit failure may be necessary to obtain an accurate measure of the mean-time-to-failure.

[(301) 921-3621]

Process & Device Modeling

Released for Publication

Bennett, H.S., **Heavy Doping Effects on Bandgaps, Effective Intrinsic Carrier Concentrations, and Carrier Mobilities and Lifetimes.**

Conventional device physics in most computer models of transistors may not predict correctly the measured electrical performance for shallow,

Process & Device Modeling, cont'd.

heavily doped transistors. This paper presents improved concepts for numerical simulations of solid-state devices with donor densities up to  $3 \times 10^{20} \text{ cm}^{-3}$  and junction depths as small as  $1 \mu\text{m}$ . These improved concepts pertain to bandgap narrowing, effective intrinsic carrier concentrations, and carrier mobilities and lifetimes.

[(301) 921-3541]

Lowney, J.R., **Band-Gap Narrowing in the Space-Charge Region of Heavily Doped Silicon Diodes.**

The densities of states of the valence and conduction bands have been calculated in the space-charge region of a heavily doped linearly graded p-n junction silicon diode. Both the donor and acceptor densities were chosen to be equal to  $6.2 \times 10^{18} \text{ cm}^{-3}$ . The results showed the emergence of band tails which penetrated deeply into the energy gap and accounted for the band-gap narrowing observed in such a diode by analysis of capacitance vs. voltage measurements of the built-in voltage.

[(301) 921-3786]

Marchiando, J.F., Roitman, P., and Albers, J., **Verification of a Model for Boron Diffusion in Silicon.**

Understanding the effects of high- and low-temperature anneals of boron implanted in silicon is important in the calculation of shallow p-n junction profiles used as source and drain in p-channel MOSFETs. Here, a sample matrix of boron implanted into silicon over a range of fluences and annealing temperatures is considered. The matrix of samples was measured by SIMS (secondary ion mass spectrometry). The measured profiles were compared with simulations from an annealing/diffusion model. Calculations of the annealed profiles were found to be in agreement with the SIMS data at temperatures greater than  $1000^\circ\text{C}$ . At lower temperatures, the profiles exhibit

effects due to implantation damage which are not included in the diffusion model. [(301) 921-3621]

Wilson, C.L. and Blue, J.L., **Two-Dimensional Modeling of N-Channel MOSFETs Including Radiation-Induced Interface and Oxide Charge**, IEEE Trans. Nucl. Sci.

A model of the radiation-induced charges produced in n-channel MOSFETs is presented. The model is applicable for the unirradiated device and accurately predicts device characteristics for doses of up to 500 krad(Si). The model is verified by comparing the results obtained with the model to n-channel MOSFETs for doses of 0, 10, 50, 100, and 500 krad(Si). Detailed comparison of the model with a  $7.8\text{-}\mu\text{m}$  channel length transistor, to eliminate short-channel effects, shows excellent agreement between the model and measured current-voltage characteristics in the subthreshold region, the triode region, and the saturation region. Analysis of the model parameters shows that the oxide charge and interface trap density are linear with dose in these devices. The mobility decrease used in the model can best be accounted for by the combined effects of scattering from oxide and interface charge in the channel.

[(301) 921-3541]

Wilson, C.L., Roitman, P., and Blue, J.L., **High Accuracy Physical Modeling of Submicron MOSFETs.**

Using the data obtained from the measurements described in this work, it is possible to model the drain current for all of the transistors studied with no adjustable parameters. Transistors with  $0.81 \mu\text{m}$  channel length differ in model input from those with  $8.17 \mu\text{m}$  channel length only in the length of the polysilicon gate. The accuracy of the simulation is maintained over the subthreshold, triode, and saturation regions and is comparable for all channel lengths. [(301) 921-3541]

Radiation Effects

Released for Publication

Gaitan, M. and Russell, T.J.,  
**Measurement of Radiation-Induced  
 Interface Traps Using MOSFETs.**

The effect of gamma irradiation on the density of SiO<sub>2</sub>/Si interface traps was measured using n- and p-channel MOSFETs. The density of traps was measured by a charge pumping measurement method and by a technique based on the slope of the transistor ln(I<sub>d</sub>)-V<sub>g</sub> characteristics in weak inversion. An increase in the density of interface traps with dose is observed with a greater increase just above compared to just below the center of the silicon bandgap.

[(301) 921-3621]

Packaging

Recently Published

Moore, B.A. and Ruthberg, S., **RADC/NBS  
 Workshop - Moisture Measurement and  
 Control for Semiconductor Devices,  
 III, NBSIR 84-2852 (May 1984).**

The workshop, one of a series concerned with measurement problems in integrated circuit processing and assembly, served as a forum to examine the continuing progress that has been made in the measurement and control of moisture in hermetically packaged semiconductor devices. Thirty-four presentations are included which contain detailed information for securing hermetic packages with low moisture content. Agreement in measurement has been obtained with the mass spectrometer for cerdip and metal packages at the 5000 ppmv level of moisture through the use of suitable moisture generators, a 3-volume calibrator, calibrated dewpoint hygrometers, and appropriate operational procedures. An approach is given for a reproducible and reliable transfer package. However, the increased use of organic materials in new and rapidly expanding technologies such as

VLSI/VHSIC and hybrid packaging presents new and more complex challenges to accurate measurement of interior moisture.

[Contact: Ruthberg (301) 921-3625]

Other Semiconductor Metrology

Released for Publication

Hinkley, J.A., **Adsorption of  
 Polystyrene on Glassy SiO<sub>2</sub>.**

Ellipsometry was used to observe the adsorption of polystyrene from theta solvents onto thermally oxidized silicon wafers. Since no absorption is seen when a polar theta solvent is used, it is concluded that specific acid-base interactions are decisive in adsorption. At high surface coverages, with cyclohexane as solvent, the present results agree with those on various metal surfaces, and the root-mean-square extension of the polymer coils from the surface is almost twice the radius of gyration of a chain in solution. Calculated amounts of polymer in the adsorbed films are a factor of two higher than literature values determined using high-surface-area silica powders, however. Possible reasons for the discrepancy are discussed.

[Contact: G.P. Carver, (301) 921-3786]

Scace, R.I., **Standards and Test  
 Methods for VLSI Materials,** to be published in Proc. SEMI Technology Symposium, (paper to be given at Symposium, Tokyo, Japan, December 7-8, 1984).

Standard measurement methods and specifications for the semiconductor industry will be reviewed and discussed with emphasis on applications to VLSI processes. These standards are well accepted in the U.S. and in Europe, but are not so well known in Japan. The standards development process is an excellent way for material producers and users to develop good working relations and to solve their shared measurement problems; this process will be described



Other Semiconductor Metrology, cont'd.

in some detail. Because the semiconductor industry is an international one, serious efforts have been made for a number of years to rationalize the technical differences between test method standards in Europe and the U.S. with considerable success. The present state of such cooperative activity with Japan, which has a more recent origin, will also be reported.

[(301) 921-3357]

## Recently Published

Forman, R.A. and Kratz, H.D., **A Simple Vacuum Pump Exhaust Filter**, Rev. Sci. Instrum., 55, p. 1503 (Sept. 1984).

A simple high throughput, exhaust filter for oil-filled mechanical vacuum pumps is described. The design allows easy connection to external systems. Inexpensive filter elements, available anywhere, are a further feature of the system. [(301) 921-3625]

Hinkley, J.A., **Adsorption of Polystyrene on Thermally Oxidized Silicon**, Polymer Preprints, 25, pp. 178-179 (April 1984).

Ellipsometry was used to observe the adsorption, from theta solvents, of polystyrene on thermally oxidized silicon. Since no adsorption was seen with a polar solvent, it is concluded that specific acid-base interactions are decisive in adsorption. At high surface coverages, the present results agree with those on various metal surfaces, and the root-mean-square extension of polymer coils from the surface is almost twice the radius of gyration of a chain in solution.

[Contact: G.P. Carver, (301) 921-3786]

**FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION**Waveform Metrology

Released for Publication

Lawton, R.A., **An Efficient Antialiasing Filter**, to be published in Proc. of Conf. on Precision Electromagnetic Measurements [paper given at Conference, Delft, Netherlands, August 20-24, 1984].

The application of a solid state reference filter as an efficient antialiasing filter is described. The analytical basis for the efficiency of this filter is described and a specific example of measuring a 1024 point waveform with an RC filter and the solid state filter is given.

[(303) 497-3339]

Souders, T.M., Flach, D.R., and Schoenwetter, H.K., **Dynamic Characterization of Waveform Recorders Using a Precision Programmable Step Generator**.

An automated system is described for measuring the dynamic response of waveform recorders. Based on a precision step generator, the system is capable of characterizing a recorder's transfer function as well as its static and dynamic linearity, and transient thermal errors. Measurement accuracy is suitable for characterizing recorders having up to 10 bits of resolution, with bandwidths up to 100 MHz. Test procedures and typical test results are included.

[(301) 921-2727]

Cryoelectronic Metrology

Released for Publication

Hamilton, C.A., Lloyd, F.L., and Kautz, R.L., **High Speed Superconducting A/D Converter**, to be published in Proc. 1984 Government Microcircuit Applications Conference [paper given at Conference, Las Vegas, NV, Nov. 6-8, 1984].

Superconducting electronics has demonstrated impressive performance capabilities for small digital systems and analog signal processing

Cryoelectronic Metrology, cont'd.

applications. One of the areas where superconductivity offers a unique advantage is in ultra-high speed A/D conversion. This paper will describe the operation and current status of a 6-bit, 4 gigasample/s A/D converter which has been developed at NBS.

[(303) 497-3740]

Hamilton, C.A., Lloyd, F.L., and Kautz, R.L., **Superconducting A/D Converter Using Latching Comparators**, to be published in Proc. 1984 Applied Superconductivity Conf. [paper given at Conference, San Diego, CA, Sept. 10-13, 1984].

This paper describes the design and performance of a six-bit A/D converter using fast edge latching comparators. Simulations predicting conversion times of 100 ps and 100 MHz signal bandwidth are verified experimentally. The addition of a superconducting track/hold circuit in front of the A/D converter is expected to substantially improve the signal bandwidth.

[(303) 497-3740]

McDonald, D.G., **Amplification by the Phase-Locking Mechanism in a 4-Junction SQUID**.

It is shown that the phase-locking property of an array of Josephson junctions can be used as a basis for amplification. The particular device simulated is a SQUID (superconducting quantum interference device) with 4 junctions in the loop, rather than the usual 1 or 2. Novel consequences of this design are that it allows direct rather than inductive coupling to the SQUID and, because of its potentially compact form, it probably can have a bandwidth well into the gigahertz range, in agreement with the simulations.

[(303) 497-5113]

Muhlfelder, B., Beall, J.A., Cromar, M.W., Ono, R.H., and Johnson, W.W., **Well Coupled, Low**

**Noise, dc SQUIDS**, to be published in Proc. 1984 Applied Superconductivity Conference [paper given at Conference, San Diego, CA, Sept. 10-13, 1984].

We have designed, fabricated, and tested a Double Transformer (DT) coupled dc SQUID (Superconducting Quantum Interference Device) with low noise, an input inductance of one microhenry and a smooth input-output characteristic. A transmission line model is presented to explain a resonance in the input-output characteristic of early versions of this device. Guided by the results of numerical simulations a new version of this device has been built and tested. Experimental results are presented that show that the resonance can be moved to a higher voltage by reducing the area of the SQUID loop. The voltage-external flux characteristic of some of these new devices agrees to within 10% with computer simulations. The minimum detectable energy (MDE) referred to the SQUID loop is 10 h. Computer simulations indicate an MDE of 6 h.

[(303) 497-5988]

Ono, R.H., Beall, J.A., and Harris, R.E., **Fabrication of a Miniaturized DCL OR Gate**, to be published in Proc. 1984 Applied Superconductivity Conf. [paper given at Conference, San Diego, CA, Sept. 10-13, 1984].

Using niobium edge junctions and electron beam lithography (EBL) we have made direct-coupled-logic (DCL) OR gates with 1  $\mu\text{m}$  minimum line widths. The gate cell, containing an isolator and a buffer section, fits into an area of approximately 25 by 30  $\mu\text{m}^2$ .

Our computer simulations show that these gates can have switching times of less than 10 pcs. We have simulated the DCL circuit with several values of the most space-consuming element, an inductor. This paper describes the results of these simulations and presents a detailed description of the 7-level fabrication process. The mix of optical

Cryoelectronic Metrology, cont'd.

and electron-beam lithography used relies heavily on an inexpensive, yet powerful, circuit layout program. [(303) 497-3762]

Zimmerman, J.E., **Recent Developments in Low-Power Self-Contained Cryocoolers for SQUIDS**, to be published in Proc. International Cryogenic Engineering Conference - 10, [paper given at Conference, Helsinki, Finland, August 1-4, 1984].

The particular requirements of refrigeration for very low power cryoelectronic devices have been addressed only during the last few years. A number of laboratory prototypes are now near realization, and commercial systems may be available soon. These include Stirling and Gifford-McMahon machines and a four-stage Joule-Thomson machine, or a combination of one of the former with a final Joule-Thomson stage to achieve 4 K, and small liquid-helium cryostats with integral intermittent reliquefying capability. The most difficult technical problem outstanding is to design reliable, non-contaminating, miniature compressors for these machines. [(303) 497-3901]

Antenna Metrology

Released for Publication

Newell, A.C., Francis, M.H., and Kremer, D.P., **The Determination of Near-Field Correction Parameters for Circularly Polarized Probes**, Trans. on Antennas and Propagation, Proc. Antenna Measurement Techniques Assoc. [paper to be given at Conference, Atlanta, GA, October 2-4, 1984].

In order to accurately determine the far-field of an antenna from near-field measurements the receiving pattern of the probe must be known so that probe correction can be performed. When the antenna to be tested is circularly polarized, the measurements are more

accurate and efficient if circularly polarized probes are used. Further efficiency is obtained if one probe is dual polarized to allow for simultaneous measurements of both components. A procedure used by the National Bureau of Standards for determining the plane-wave receiving parameters of a dual-mode, circularly polarized probe is described herein. First, the on-axis gain of the probe is determined using the three antenna extrapolation technique. Second, the on-axis axial ratios and port-to-port comparison ratios are determined for both the probe and source antenna using a rotating linear horn. Far-field pattern measurements of both amplitude and phase are then made for both the main and cross components. In the computer processing of the data, the on-axis results are used to correct for the non-ideal source antenna polarization, scale the receiving coefficients, and correct for some measurement errors. The plane wave receiving parameters are determined at equally spaced intervals in k-space by interpolation of the corrected pattern data. [(303) 497-3743]

Stubenrauch, C.F. and Francis, M.H., **Comparison of Measured and Calculated Mutual Coupling in the Near Field Between Microwave Antennas**, also to be published in IEEE Trans. on Antennas and Propagation and in Proc. 1984 Antenna Applications Symposium [University of Illinois, September 19-21, 1984 (but without additional section on comparison of computer program ENVLP with empirical data, included in NBSIR 84-3010)].

Measurements of near-field mutual coupling were performed between two moderate sized microwave antennas and compared to coupling calculated using recently developed computer programs. Required input data for the programs are the complex far-field radiation patterns of the antennas and various geometrical factors describing the relative positions and orientations of the two antennas. Experimentally determined and

Antenna Metrology, cont'd.

calculated coupling as a function of both transverse displacement and separation agree closely except for a constant offset observed in some cases. In addition, coupling values computed using a program which approximates the far-field radiation patterns were compared to experiment and found to be satisfactory. [(303) 497-3927]

Noise Metrology

## Released for Publication

Daywitt, W.C., **Design and Error Analysis for the WR10 Thermal Noise Standard**, to be published in Proc. 1984 Antenna Applications Symposium (Symposium, Alberton Park, Monticello, Illinois, September 19-21, 1984). [This paper previously appeared as NBS Technical Note 1071 (December 1983). The appendices of Tech Note 1071 do not appear in this paper].

This paper describes the design and error analysis of a WR10 thermal noise power standard. The standard is designed to operate at the boiling point of liquid nitrogen with a noise temperature accurate to  $\pm 1$  K. [(303) 497-3720]

Daywitt, W.C., **A Preliminary Investigation into Using the Sun as a Source for G/T Measurements**, to be published as NBSIR 84-3015.

This report describes a preliminary investigation into determining the solar flux density, the atmospheric correction factor, and the star shape correction factor for use in G/T measurements above 5 GHz. An estimate of errors is also included. Preliminary results show: an improved algorithm for determining diffusive and refractive attenuation; a viable technique for estimating the solar flux density from daily AFGL flux density measurements and a centimeter/millimeter wave spectrum function; and the possibility of reducing star shape

correction factor errors by use of an effective solar rf diameter. [(303) 497-3720]

## Recently Published

Miller, C.K.S. and Daywitt, W.C., **The NBS Switching Radiometers**, NBSIR 84-3004.

An error analysis for the Dicke radiometers used by the National Bureau of Standards (NBS) in their WR90 and WR62 waveguide noise calibration services for sources with noise temperatures above 1000 kelvin is discussed. A list of measurement frequencies currently available in the WR90 and WR62 bands is presented. [(303) 497-3131]

Miller, C.K.S. and Daywitt, W.C., **The NBS WR62 and WR90 Reference Noise Standards**, NBSIR 84-3005.

The basis for the National Bureau of Standards (NBS) WR90 and WR62 Waveguide Reference Noise Standards and the corresponding error analyses are described. The standards are heated (1270 K) thermal noise generators, and a derivation of their output noise temperature equations is also presented. Results of comparisons of the NBS WR90 standard with those of Sweden, England, Australia, and Japan are included. The text is extracted from course notes presented at NBS in 1970, and hence does not include descriptions of standards constructed at NBS since that time. [(303) 497-3131]

Microwave and Millimeter-Wave Metrology

## Released for Publication

Hoer, C.A., **Multiport Network Analyzers**, to be published in McGraw-Hill Yearbook of Science and Technology.

This paper is a tutorial summary of the principles of multiport network analyzers, their use in microwave

Microwave and Millimeter-Wave, cont'd.

measurements of reflection coefficient and scattering parameters, and the significance of this development for the field of microwave measurements.

[(303) 497-3705]

## Recently Published

Judish, R.M. and Jones, R.N., **A Generalized Method for the Calibration of Four-Terminal-Pair Type Digital Impedance Meters**, NBSIR 84-3016 (August 1984).

Since the introduction of automated, four-terminal, pair-type impedance meters, there has been a continuing interest in the development of calibration techniques which would satisfactorily verify the accuracy capabilities of these instruments. Various attempts have been made and all have helped to provide a certain degree of confidence in instrument performance, but until now, a generalized approach with a good mathematical and statistical background has been lacking. This paper describes a calibration procedure having such a background and illustrates its use. The calibration is accomplished through the use of impedance standards which relate instrument readings to the values of the standards through a known functional relationship. The calibration procedure described estimates the parameters associated with the functional relationship and requires the use of a computer. Calibration is accomplished at the reference plane of the impedance standards and any adapter required to connect the standards to the instrument is assumed to be an integral part of the impedance meter.

[(303) 497-3380]

Laser Metrology

## Released for Publication

Johnson, E.G., **Using Optical Processing to Find the Beam Profile of a Laser Pulse (Theory)**, to be

published in Proc. SPIE - The International Society for Optical Engineering [paper given at Conference, San Diego, CA, August 19-24, 1984].

This paper looks at a particular form of optical processing, namely a form of cross-correlation, and demonstrates how the method measures certain beam profile features of a laser pulse. Beam profile is defined to mean a description of the electromagnetic field of a laser pulse in space and time. In this paper, I represent the laser pulse as a complete set of orthogonal modes and show that an appropriate spatial filter and a measurement system, can provide information about the beam profile of the laser in terms of the individual eigenfunctions of this representation. Here I trace what happens when a laser pulse is modified by the spatial filter. I then do a specific example which looks at the TEM00 laser beam pulse with beam tilt, beam curvature, beam width, and beam shift to show that these effects produce higher order Hermite modes in the measurement system. The spatial filter modifies the electric field distribution in the focal plane such that at known spatial locations, the magnitude of the intensity is proportional to the pulse power or energy in particular Hermite modes. Since the size of these locations is infinitesimal without getting errors from the electromagnetic fields from other modes, I demonstrate the effect and errors associated with using finite size detectors for measuring the magnitude of the intensity at these locations.

[(303) 497-3234]

Rasmussen, A.L. and Sanders, A.A., **Transfer Standards for Energy and Power of Low-level 1.064  $\mu\text{m}$  Laser Pulses and cw**, to be published in Proc. SPIE - The International Society for Optical Engineering [paper given at Conference San Diego, CA, August 19-24, 1984].

For the first time traceable transfer standards have been developed for

Laser Metrology, cont'd.

measuring 1.064  $\mu\text{m}$  laser pulses duration about 10 to 100 ns, peak power density of about  $10^{-8}$  to  $10^{-4}$   $\text{W}/\text{cm}^2$ , and energy density of about  $10^{-16}$  to  $10^{-11}$   $\text{J}/\text{cm}^2$ . These power and energy transfer standards use APD and PIN silicon photodiode detectors, respectively. They are stable and have total uncertainties of about 10 percent. The system for calibrating them and other devices consists of a cw Nd:YAG laser beam acousto-optically modulated to provide low-level laser pulses of known peak power and energy. With pulse height analyzer readout, this system can measure energy or average power. These pulsed and cw measurement techniques can be extended to the visible and other near-infrared wavelengths.  
[(303) 497-5367]

Simpson, P.A. and Johnson, Jr., E.G., **A Calorimeter for Measuring 1-15 kJ Laser Pulses**, to be published in Proc. International Society of Optical Engineering [paper given at Conference, San Diego, CA, August 19-24, 1984].

Two calorimeters for measuring high peak power laser pulses have been constructed by the NBS and delivered to the Newark Air Force Station, Newark, Ohio. These calorimeters are designed to measure pulses having intensities great enough to damage the volume absorbing material in normal calorimeters. In these new calorimeters the volume absorbing material is already fragmented and flowing dry  $\text{N}_2$  gas is used to extract the temperature rise information. Pulse energy can be in the range 1 to 15 kJ. Wavelength range is from the i.r. to u.v. by employing various volume absorbing materials.  
[(303) 497-3789]

Optical Fiber Metrology

Released for Publication

Day, W.G. and Franzen, D.L., **Technical Digest - Symposium on Optical Fiber**

**Measurements, 1984**, to be published as NBS Special Publication.

This volume contains summaries of 31 papers presented at the Symposium on Optical Fiber Measurements held October 2-3, 1984, at the National Bureau of Standards, Boulder, Colorado. Subjects include measurements on singlemode fiber, multimode fiber, fiber designed for sensing applications, instrumentation, field measurements, and standards.  
[(303) 497-5204]

Engelsrath, A., Larson, D.R., Phelan, R.J., and Franzen, D.L., **Attenuation of Multimode Fused Silica Optical Fibers Cooled to Liquid Helium Temperature**, to be published in Proc. of SPIE - The International Society for Optical Engineering, (paper given at Conference, San Diego, CA, August 19-24, 1984).

The feasibility of bringing an optical signal through an optical fiber to a detection and processing system at liquid helium temperature was examined. The attenuation of three commercially available multimode optical fibers, from two different manufacturers with different buffer coatings, was measured under different cooling conditions. It was found that the attenuation depends on the cooling condition and has hysteresis effects. Independent of the  $\lambda$  tested (0.4 - 1.65  $\mu\text{m}$ ) the attenuation stayed below 0.1 dB/m under controlled slow cooling and under 0.5 dB/m with very fast cooling. Therefore, optical fibers can be used to bring optical signals into a liquid-helium-cooled dewar for detection and processing.  
[Contact: Larson (303) 497-3440]

Franzen, D.L., **An Interlaboratory Measurement Comparison Among Fiber Manufacturers to Determine the Effective Cut-off Wavelength and Mode Field Diameter of Single Mode Fiber**, to be published in Technical Digest of Proc. Optical Fiber Communications Conference [paper to be given at

Optical Fiber Metrology, cont'd.

Conference, San Diego, February 11-13, 1985].

A National Bureau of Standards/Electronic Industries Association sponsored interlaboratory measurement comparison evaluated three transmission methods for determining cut-off wavelength and four methods (transverse offset, near-field, far-field, and variable aperture far-field) for determining mode field diameter. Interlaboratory agreement and systematic offsets between methods will be discussed. [(303) 497-3346]

Maisonneuve, J.M. and Gallawa, R.L., **The Use of Power Transfer Matrices in Predicting System Loss: Theory and Experiment**, to be published in Proc. SPIE - The International Society for Optical Engineering [paper given at Conference, San Diego, CA, August 19-24, 1984].

The phase space diagram for parabolic and step index fibers leads to a graphic representation of the bound, leaky, and refracted rays of ray theory. This concept is used to predict the attenuation of typical components of local area networks. The technique uses power transfer matrices to track the evolution of power distribution in ray packets. In particular, we predict and then measure the power transfer of two ray packets for a step index fiber. The comparison is encouraging.

[Contact: Gallawa (303) 497-3761]

Other Fast Signal Topics

Released for Publication

Belsher, D.R., McLaughlin, R.H., Repjar, A.G., and Bussey, H.E., **Detection of Lost Wells and Unknown Water-filled Voids in Coal Mines through Development of an Experimental Microwave System**, to be published as NBSIR 84-3017.

Work on contract H0272007 is summarized

for the period of January 1979 through March 1984. The development of improved antennas usable with both a pulse system or an FM-CW system is described. The development of a field prototype pulse sampling system is described. Initial theoretical work on the problem of dielectric loading of antennas as well as a study of potential system range is included.

[Contact: Repjar (303) 497-5703]

Phelan, R.J., Jr., Larson, D.R., Franzen, D.L., and Frederick, N.V., **Detectors for Picosecond Optical Power Measurements**, to be published in Proc. SPIE - The International Society for Optical Engineering [paper given at Conference, San Diego, CA, August 19-24, 1984].

There are many features in addition to time resolution that are desirable for a picosecond optical power measurement system. An interdigitated contact, Schottky barrier silicon photodiode coupled to an electro-optic sampler exhibits a rise time better than 22 picoseconds, a quantum efficiency greater than 30%, a uniform responsivity over its receiving aperture, and a usable spectral response to beyond 2 micrometers.

[(303) 497-3696]

Young, M., Katzir, Y., and Glaser, I., **Pattern Recognition Using Incoherent OTF Synthesis and Edge Enhancement**.

This paper describes a system for pattern recognition using an incoherent-optical correlator. The system uses OTF synthesis to perform correlations with an edge-enhanced image of the object or pattern being sought. The resulting correlations are free of bias and show good discrimination between objects. In addition, the difficult or time-consuming computations are performed before the operation of the system; this reduced the amount of post-processing by computer and should allow real-time operation at video rates.

[(303) 497-3223]

Other Fast Signal Topics, cont'd.

## Recently Published

Kamper, R.A. and Kline, K.E., **Metrology for Electromagnetic Technology: A Bibliography of NBS Publications**, NBSIR 84-3014 (July 1984).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NBS in the period from January 1970 through December 1983. A few earlier references that are directly related to the present work of the Division are included. [(303) 497-3535]

**ELECTRICAL SYSTEMS**Power Systems Metrology

## Released for Publication

FitzPatrick, G.J., Forster, E.O., Hebner, R.E., and Kelley, E.F., **Streamer Initiation in Liquid Hydrocarbons Under Divergent Field Conditions**, to be published in Proc. IEEE Conf. Electrical Insulation & Dielectric Phenomena [paper to be given at Conference, Wilmington, DE, October 21-25, 1984].

The initiation of streamers at the surface of a needle cathode in contact with cyclohexane has been investigated using an improved optical system, allowing for high magnification of the cathode, in conjunction with a high speed framing camera. To cover a broad range of conditions, the gap between the electrodes was varied from 0.2 to 0.5, 1.0 and 2.0 cm. Also, the rate of rise of the applied voltage at each gap setting ranged from 17 to 23, 29 and 35 KV/ $\mu$ s. The streamer initiation was found to occur at a voltage which was independent of both the gap and the rate of rise of the voltage. The shape of the cathode point was found to influence the scatter of the initiation voltage particularly at the lowest applied

voltages but it did not affect the average value. The significance of these observations will be discussed. The implications of these findings on the charge carrier injection process will be analyzed. [(301) 921-3121]

**Hebner, R.E., Electro-Optical Measurement Techniques.**

This paper reviews the use of the Faraday effect, the Pockels effect, and the Kerr effect to measure electric fields, magnetic fields, voltages, currents, and space charge density. Each of the three effects is introduced conceptually, the use of Jones or Mueller matrices to describe the optical system is presented, and some applications of these effects are described. [(301) 921-3121]

## Recently Published

Fulcomer, P.M., **Calibration Check of Bonneville Power Administration 60-Hz Electric Field Exposure Monitor and Measurement of Its Surface Field Enhancement for Various Uniform and Nonuniform Operating Configurations**, NBSIR 84-2885.

This report presents the results of tests requested by the Bonneville Power Administration (BPA) on a 60-Hz Electric Field Exposure Monitor (EFEM) developed by their Instrumentation and Standards Branch. The unit is designed to be worn on the body, such as in a shirt pocket or attached to the clothing. The calibration of two sample units is examined, information on surface field enhancement (which results from the EFEM sensors' elevated position relative to the surface of the body) is presented, the effect of material covering the sensor is specified, and the applicability of calibration and operational information obtained in uniform fields to nonuniform fields is investigated. [(301) 921-3121]



Power Systems Metrology, cont'd.

Hebner, R.E., **Development of Power System Measurements -- Quarterly Report January 1, 1984 to March 31, 1984**, NBSIR 84-2898.

This report documents the progress on three technical investigations sponsored by the Department of Energy and performed by the Electrosystems Division, the National Bureau of Standards. The work described covers the period from January 1, 1984 to March 31, 1984. The report emphasizes the performance of ion counters like those used to measure the ions near dc transmission lines, the production rates of oxyfluorides in SF<sub>6</sub> corona discharges, and the measurement of space charge associated with a pressboard interface in transformer oil.

[(301) 921-3121]

Magnetic Materials and Measurements

Released for Publication

Capobianco, T.E. and Fickett, F.R., **Precision Measurement of Eddy Current Coil Parameters**, to be published in Proc. Review of Progress in Quantitative NDE [paper given at Conference, University of California, San Diego, July 9-13, 1984].

Precision measurements of impedance, phase angle, and dissipation factor of both commercial eddy current coils and specially prepared test coils by various techniques are described. Special emphasis is placed on use of the digital storage oscilloscope and commercial LCZ meter. Detection of the effect on the coil parameters of shorted turns, deformation, and ferrite defects is described. [(303) 497-3641]

Clark, A.F., Cromar, M.W., and Fickett, F.R., **Design of the NBS Magnetic Monopole Detectors**, to be published in Proc. International Cryogenic Engineering Conference - 10 [paper given at Conference in Helsinki,

Finland, August 1-4, 1984].

Several different configurations of magnetic monopole detectors have been built and operated at the National Bureau of Standards. These have been designed based on the objectives of: (1) Study of the noise characteristics, (2) Simplicity and ease of changing configurations, (3) Operation in relatively large magnetic fields, and (4) Optimum detector area. Satisfying these objectives has resulted in several compromises, but also a flexible and useful apparatus for studying the behavior of the SQUID - detector loop combination with particular emphasis on noise sources that can simulate a monopole signal. Several sources of noise and techniques for their elimination will be discussed. Data from the spectral analysis of the noise signals will be presented.

[(303) 497-3253]

Cromar, M.W., Fickett, F.R., and Clark, A.F., **The NBS Magnetic Monopole Detector**, to be published in Proc. 1984 Applied Superconductivity Conference [paper given at Conference, San Diego, CA, Sept. 10-13, 1984].

We have built and operated several inductive type monopole detectors, the present one having three concentric, orthogonal loops operated in coincidence. The area of each loop is 200 cm<sup>2</sup> and the cross sectional area of the superconducting shield is 700 cm<sup>2</sup>. The detector loops are in a trapped magnetic field of approximately 3 milligauss. The system is mechanically stable and is relatively insensitive to external disturbances, both mechanical and electromagnetic. The detector is quiet, having a signal-to-noise ratio for monopole detection of approximately 20. We have also investigated several sources of noise and spurious signals which might mimic a monopole event.

[(303) 497-5375]

Fickett, F.R. and Capobianco, T.E., **Magnetic Field Mapping with a SQUID**

Magnetic Materials and Meas., cont'd.

(July 1984).

**Device**, to be published in Proc. Review of Progress in Quantitative NDE, [paper given at Conference, University of California, San Diego, July 9-13, 1984].

Results of tests applying a SQUID (superconducting quantum interference device) system to measurement of the magnetic near field of commercial eddy current coils is reported. The SQUID system offers some significant advantages over more conventional techniques in that very small coils can be used and the calibration of the system is tied to the quantum of flux. [(303) 497-3785]

Goldfarb, R.B., Reed, R.P., Ekin, J.W., and Arvidson, J.M., **Magnetic Susceptibility and Strain-Induced Martensite Formation at 4 K in Type 304 Stainless Steel**, to be published in Advances in Cryogenic Engineering, Vol. 30.

Changes in magnetic susceptibility,  $\chi$ , as a function of strain-induced structural transformations in AISI type 304 stainless steel at 4 K have been observed using a mutual inductance technique with simultaneous measurement of stress and strain. There is a small increase in  $\chi$  coincident with plastic strain and a large increase in  $\chi$  with the load drops that occur during serrated yielding. These are attributed to the formation of bcc martensite. The increases in  $\chi$  are irreversible upon unloading. The application of a moderate 3-MA/m (37-kOe) dc field had no effect on the martensite formation. [(303) 497-3650]

## Recently Published

Fickett, F.R., **The Effect of Mill Temper on the Mechanical and Magnetoresistive Properties of Oxygen-Free Copper in Liquid Helium**, Advances in Cryogenic Engineering--Materials, Vol. 30, pp. 453-460

Depending on the source of the ore and its subsequent processing, oxygen-free copper can show wide variations in low temperature mechanical and electrical properties. Further mechanical and thermal processing by the wire producer and final user will also affect the behavior of the copper as a stabilizer. Here we present data showing the effect of these processes on coppers from a variety of sources. [(303) 497-3785]

Superconductors

## Released for Publication

Clark, A.F. and Goodrich, L.F., **Characterization of a Standard Reference Superconductor for Critical Current and a Summary of Other Standard Research at NBS**, to be published in Proc. International Cryogenic Engineering - 10 [paper given at Conf., Helsinki, Finland, August 1-4, 1984].

A standard reference material can be useful for the calibration of measurement apparatus and interlaboratory comparison of research results. We have carefully characterized the first practical superconductor SRM for critical current and it is now available from NBS as "Standard Reference Material 1457 Superconducting Critical Current - NbTi Wire." The selection, characterization, and statistical analysis of this material will be described. The progress in other standards research will also be discussed for large conductor critical current, ac losses, stability, and critical field. [(303) 497-3253]

Ekin, J.W. and Yamashita, T., **Effect of Uniaxial Strain on the Critical Current and Critical Field of Chevrel Phase  $\text{PbMo}_6\text{S}_8$  Superconductors**, to be published in Proc. of 1984 Applied Superconductivity Conference [paper given at Conference, San Diego, CA, September 10-14, 1984].

Superconductors, cont'd.

The effect of uniaxial strain on the critical current of a Chevrel phase superconductor,  $\text{PbMo}_6\text{S}_8$ , has been measured at 4.2 K in magnetic fields from 2 T to 24 T. The data show there is a very significant effect of elastic strain on the critical current of  $\text{PbMo}_6\text{S}_8$ , comparable in magnitude to that of  $\text{Nb}_3\text{Sn}$ . This is the result of both the peak pinning force and upper critical field being very sensitive to elastic strain. A general correlation is made between the uniaxial strain effect and crystal phase.  
[(303) 497-5448]

Fickett, F.R., **Standards for Measurement of the Critical Fields of Superconductors**, to be published in NBS Journal of Research.

The origins, definitions, and measurement of the various critical magnetic fields associated with superconductors are reviewed. The potential need for an ASTM-type standard for the measurement of these fields is discussed. Measurement techniques as practiced both in industry and in the national laboratories are reviewed. Extrapolation techniques commonly used to determine the upper critical fields of the newer materials are evaluated as to their suitability for various applications. Sources of error in the experimental determination of critical fields are assessed for the various common techniques. A comprehensive bibliography of the modern literature on critical field measurement and interpretation is included.  
[(303) 497-3785]

Goldfarb, R.B. and Clark, A.F., **Magnetic Hysteresis and Complex Susceptibility as Measures of AC Losses in a Multifilamentary NbTi Superconductor**.

Magnetization and ac susceptibility of a standard NbTi superconductor were measured as a function of longitudinal

dc magnetic field. The field-amplitude and frequency dependence of the complex susceptibility is examined. The magnetization is related to the susceptibility by means of a theoretical derivation based on the field dependence of the critical current density. Hysteresis losses, obtained directly from dc hysteresis loops and derived theoretically from ac susceptibility and critical current density, were in reasonable agreement.  
[(303) 497-3650]

## Recently Published

Ekin, J.W., **Strain Effects in Superconducting Compounds**, Advances in Cryogenic Engineering--Materials, Vol. 30, pp. 823-836 (July 1984).

An overview of the effect of strain on the critical current, critical field, and critical temperature of Al5, B1, and C15 superconductors is presented. Reversible elastic strain effects in many Al5 superconductors have been measured, analyzed and compared in terms of simple strain scaling parameters. In addition, a new critical parameter -- critical strain  $\epsilon_c$  -- is described and used to characterize the strain sensitivity of these materials. The elastic strain effect is shown to be strongly dependent on crystal structure; it is nonexistent in all superconductors with the B1 and C15 crystal structure tested thus far. Possible mechanisms for explaining the elastic strain effect are briefly described. [(303) 497-5448]

Ekin, J.W., Pittman, E.S., Goldfarb, R.B., Superszynski, M.J., and Waltman, D.J., **Training Studies of Epoxy-Impregnated Superconductor Windings - Part III: Epoxies, Conductor Insulations and Copper Ratio**, Advances in Cryogenic Engineering--Materials, Vol. 30, pp. 977-984 (July 1984).

A systematic study of the materials and construction factors that affect training in epoxy-impregnated

Superconductors, cont'd.

superconductor windings are reported. Using relatively small test rings (18 cm diam), the training rate was measured for several epoxies currently used in magnet construction. These training data correlated well with the strain at fracture measured on these same epoxy materials at 4 K. Results are also reported on the dependence of the training rate on the fiberglass cloth configuration in the winding, the type of superconductor insulation, and the copper-to-superconductor ratio of the conductor. [(303) 497-5448]

Goodrich, L.F., Vecchia, D.F., Pittman, E.S., Ekin, J.W., and Clark, A.F., **Critical Current Measurements on an NbTi Superconducting Wire Standard Reference Material**, NBS Special Publication 260-91 (September 1984), and **Advances in Cryogenic Engineering--Materials**, Vol.30, pp. 953-960 (July 1984).

This report reviews the selection and certification by NBS of a Standard Reference Material (SRM) for the measurement of superconducting critical current. Procedures for preparing and measuring five candidate conductors are described. Evaluation criteria are discussed by which one of the five conductors is selected for the critical current SRM. The designated superconducting wire, SRM 1457, has been subdivided and wound onto 500 spools for distribution. Certified critical current measurements were made on a sample of these spools. Material variability, or inhomogeneity, along the whole wire is included in a statistical model based on the dependence of critical current on temperature and electric field. Critical currents for SRM 1457 are certified at magnetic fields of 2, 4, 6, and 8 T for temperatures from 3.90 to 4.24 K and electric field criteria from 0.05 to 0.2  $\mu\text{V}/\text{cm}$ . Statistical tolerance limits and estimated systematic errors are combined to give an overall uncertainty in the

certified values. The total uncertainty is no greater than 2.57 percent of the reported critical current at any of the four magnetic fields.

[(303) 497-3143]

Pasztor, G. and Ekin, J.W., **Development of Nb<sub>3</sub>Sn Cabled Conductor by External Diffusion Process and the Effect of Strain on the Critical Current**, *Advances in Cryogenic Engineering*, Vol. 30, pp. 787-795 (July 1984).

This paper describes detailed processing and procedures for producing stranded Nb<sub>3</sub>Sn conductors using the external diffusion technique developed by Brown, Boveri & Co., Inc. and is at present being pursued at the Swiss Institute for Nuclear Research for applications in a planned high-fields test facility (12 Tesla). The result of processing trials intended to optimize the critical current density and at the same time to minimize the formation of Kirkendall voids are described. The results are presented of measurements of critical current as a function of applied tensile strain for a previously developed main cable.

[Contact: Ekin (303) 497-5448]

Tinkham, M., Beasley, M.R., Larbalestier, D.C., Clark, A.F., and Finnemore, D.K., **Research Opportunities in Superconductivity**, *Cryogenics*, July 1984, pp. 378-388.

Opportunities for research in the field of superconductivity are identified in this report of a "Workshop on problems in superconductivity" held at Copper Mountain, Colorado, August 22-23, 1983. Key problems in superconductivity, high payoff areas of research, barriers to progress, and the need for new facilities are outlined in the three areas of basic physics, materials, and devices.

[Contact: Clark (303) 497-3253]

Other Electrical Systems Topics

Other Electrical Systems Topics, cont'd.

## Erratum

An incomplete title appeared for the following published paper.

Bell, R.S., Jones, C.K., and Fickett, F.R., **Copper-TFE Friction at Cryogenic Temperatures**, Cryogenics, pp. 31-35 (January 1984)

Interfaces between metals and polytetrafluorethylene (TFE) are common in cryogenic systems. In this paper we present results from measurements of the temperature dependence of the dynamic coefficient of friction between commercially pure copper and TFE. The effect of the copper surface finish was also determined. The effects of load and speed were evaluated over a small range, but nearly all data were taken at a surface speed of  $5.4 \text{ cm}\cdot\text{s}^{-1}$  with a load of  $1.63 \text{ N}\cdot\text{cm}^{-2}$ . These values are typical of those encountered by the moving parts of some cryogenic machinery.

[Contact: Fickett, (303) 497-3785]

**ELECTROMAGNETIC INTERFERENCE**

Released for Publication

Jesch, R.L., **Susceptibility of Emergency Vehicle Sirens to External Radiated Electromagnetic Fields** [paper provides technical basis for proposed National Institute Justice Standard.]

This report provides the results of an exploratory study to determine the susceptibility of sirens to interference from communications equipment (transmitter and associated antennas) typical of that likely to be operated in and around the automobile as a law-enforcement vehicle.

Tests were performed on five sirens at frequencies representing the frequency bands of 25 to 50, 150 to 174, 400 to 512, and 806 to 866 MHz. The sirens were mounted on top of a vehicle

equipped with transmitters and roof-mounted antennas and subjected to levels of field strength that are generated by mobile transmitting equipment having output levels up to 100 W. The control units of the sirens were also subjected to various levels of field strength inside a TEM cell and an anechoic chamber to determine the unit's susceptibility to electromagnetic fields.

[(303) 497-3496]

Jesch, R.L., **Personal/Mobile FM Transceivers** [paper provides technical basis for proposed National Institute of Justice Standard].

This document establishes minimum performance requirements and methods of test for frequency modulated personal/mobile transceivers and their associated antennas and power systems. The standard applies primarily to the law enforcement community, and as such covers the two frequency bands 150-174 MHz and 400-512 MHz. [(303)-497-3496]

Wilson, P.F. and Chang, D.C., **An Inversion Routine to Determine Certain Two-layer Parameters Based on Two Loop Mutual Induction.**

Electromagnetic coupling between a pair of small current-carrying loops is used as the basis for a numerical scheme to determine the thickness and conductivity contrast of a two-layer lossy structure. Extracting these parameters directly requires the inversion of complicated Sommerfeld-type integrals. In order to facilitate the search routine, and avoid spurious roots, good initial values are needed. Because two-loop induction is primarily a low-frequency technique, a quasi-static limiting solution, readily inverted, is used to generate trial values. The accuracy of these initial values and the results of the iterative procedure are discussed.

[(303) 497-3842]

Wilson, P.F. and Ma, M.T., **Small Aperture Analysis of the Dual TEM Cell**

Electromagnetic Interference, cont'd.

**and an Investigation of Test Object Scattering in a Single TEM Cell, to be published as Technical Note 1076.**

Small aperture theory is used to investigate the dual TEM cell. Analyzing coupling through an empty versus a loaded aperture leads to a model of dual TEM cell for making shielding effectiveness measurements. Small obstacle scattering yields results for both the field perturbation, and the change in a cell's transmission line characteristics due to the presence of a test object in a TEM cell. In each case, theoretical values are compared to experimental data.  
[(303) 497-3842]

## Recently Published

Kanda, M., **An Electromagnetic Near-Field Sensor for Simultaneous Electric and Magnetic-Field Measurements**, IEEE Trans. on Electromagnetic Compatibility, Vol. EMC-26, No. 3, pp. 102-110 (August 1984).

This paper describes the theory of a single sensor to perform simultaneous electric and magnetic near-field measurements. The theory indicates that it is possible to measure the magnetic-loop and electric-dipole currents using a loop antenna terminated with identical loads at two diametrically opposite points. The theory also indicates that it is possible to choose an ideal load impedance for achieving equal electric and magnetic-field responses of the loop. Preliminary experiments have been performed using a plane-wave field to verify these results.

[(303) 497-5320]

Wyss, J.C., Anson, W.J., and Orr, R.D., **Building Penetration Project**, NBSIR 84-3009.

This report documents a computer program which calculates building attenuation of electromagnetic radiation over the

frequency range 10 kHz - 10 GHz. Attenuation (in dB) is computed from building shape, dimensions, room layout, and the electrical properties of construction materials; no electromagnetic measurements are required. Details of the structure and use of the program are given.

[Contact: Anson (303) 497-3989]

**1985 CEEE CALENDAR**

April 29 - May 10 (Boulder, CO)

**NBS Electromagnetic Interference (EMI) Metrology Seminar.** [Contact: Charles K.S. Miller (303) 497-3131]

July 23-25 (Vail, CO)

**Short Course on Optical Fiber Measurements.** [Contact: Robert L. Gallawa (303) 497-3761]

September 9-10

**VLSI Packaging Workshop.** Contact: George G. Harman (301) 921-3621]

also planned for May - June period

- Shortcourse on Near-Field Techniques for Antenna Measurements [Contacts: Ramon C. Baird (303) 497-3301; Richard L. Lewis (303) 497-5196]
- Seminar on Electrical Measurements in Diagnostic X-Ray Units [Contact: Robert E. Hebner (301) 921-3121]

**NEW STANDARD REFERENCE MATERIAL**

The first practical superconducting standard reference material (SRM) has been released by the Electromagnetic Technology Division to the NBS Office of Standard Reference Materials for sale to the public. The certified parameter of SRM 1457, Superconducting Critical Current -- NbTi Wire, is critical current at magnetic fields of 2,4,6, and

## NEW STANDARD REFERENCE MATERIAL, cont'd.

8 tesla at a temperature of 4.2 K and an electric field criterion of 0.2  $\mu\text{V}/\text{cm}$ . Information is given to permit the user to determine critical current for temperatures in the range 3.90 to 4.24 K and electric field criteria from 0.05 to 0.2  $\mu\text{V}/\text{cm}$ .

SRM 1457 consists of a 2.2-m length of a multifilimentary, niobium-titanium, copper-stabilized wire, wound in a single layer on a spool having a core diameter of 8.7 cm. The wire is evaluated for 34 parameters relating to current, voltage, magnetic field, temperature, strain, and physical specimen characteristics.

In conjunction with ASTM Standard Test Method B714-82, D-C Critical Current of Composite Superconductors, the new SRM is intended to provide means for calibrating apparatus used to measure key parameters of superconductor products and thus should be useful to buyers and sellers of superconductors, users of superconducting equipment, and researchers in superconducting technology.

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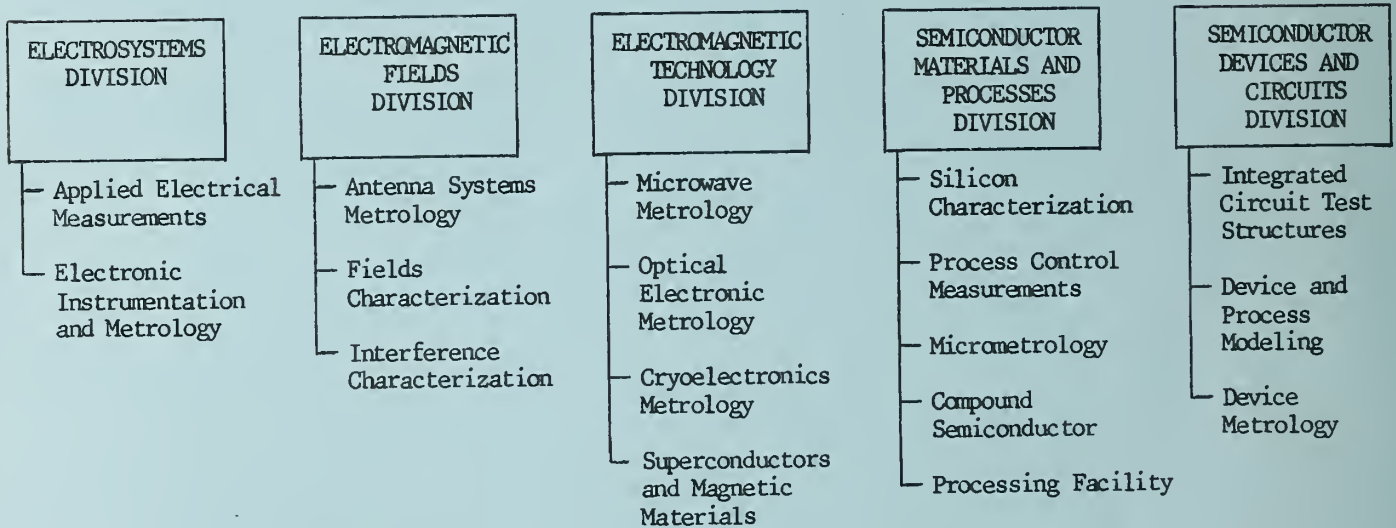
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