NISTIR 6318

Electronics and Electrical Engineering Laboratory

J. M. Rohrbaugh
Compiler

Technical Progress Bulletin

98-4

Covering Laboratory Programs,
April to December 1998,
with 1998 EEEL Events Calendar

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

NIST

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Semiconductor Electronics Division
Gaithersburg, MD 20899-0001

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U.S. DEPARTMENT OF COMMERCE
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TECHNOLOGY ADMINISTRATION
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AND TECHNOLOGY
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ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY
TECHNICAL PROGRESS BULLETIN, May 1999 ISSUE

INTRODUCTION

This is the fifty-ninth issue of a publication providing information on the technical work of the National Institute of Standards and Technology Electronics and Electrical Engineering Laboratory (EEEL). This issue of the EEEL Technical Progress Bulletin covers the third quarter of calendar year 1997.

Organization of Bulletin: This issue contains abstracts for all relevant papers released for publication by NIST in the quarter and citations and abstracts for such papers published in the quarter. Entries are arranged by technical topic as identified in the Table of Contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication." This does not imply acceptance by any outside organization. Papers published in the quarter appear under the subheading "Recently Published." Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Laboratory conferences and workshops planned for calendar years 1997 through 1998 and a list of sponsors of the work.

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

The work of the Laboratory is conducted by five technical research Divisions: the Semiconductor Electronics and the Electricity Divisions in Gaithersburg, MD, and the Electromagnetic Fields, Electromagnetic Technology, and the Optoelectronics Divisions in Boulder, CO. The Office of Law Enforcement Standards conducts research and provides technical services to the U.S. Department of Justice and State and local governments, and other agencies in support of law enforcement activities. In addition, the Office of Microelectronics Programs (OMP) coordinates the growing number of semiconductor-related research activities at NIST. Reports of EEEL work funded through the OMP are included under the heading "Semiconductor Microelectronics."

Key contacts in the Laboratory are listed at the end of this publication; readers are encouraged to contact any of these individuals for further information. To request a subscription or for more information on the Bulletin, write to EEEL Technical Progress Bulletin, National Institute of Standards and Technology, Metrology Building, Room B-358, Gaithersburg, MD 20899 or call (301) 975-2220.

Laboratory Sponsors: The Laboratory Programs are sponsored by the National Institute of Standards and Technology and a number of other organizations, in both the Federal and private sectors; these are identified on page 23.

Note on Publication Lists: Publication lists covering the work of each division are guides to earlier as well as recent work. These lists are revised and reissued on an approximately annual basis and are available from the originating division. The current set is identified in the Additional Information section, page 21.

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

TO LEARN MORE ABOUT THE LABORATORY...

Two general documents are available that may be of interest. These are ***EEEL 1996 Technical Accomplishments, Advancing Metrology for Electrotechnology to Support the U.S. Economy*** and ***Measurements for Competitiveness in Electronics***. The first presents selected technical accomplishments of the Laboratory for the period October 1, 1995 through September 30, 1996. A brief indication of the nature of the technical achievement and the rationale for its undertaking are given for each example. The second identifies measurement needs for a number of technical areas and the general importance of measurements to competitiveness issues. The findings of each chapter dealing with an individual industry have been reviewed by members of that industry. A longer description of both documents follows:

EEEL 1998 Technical Accomplishments, Advancing Metrology for Electrotechnology to Support the U.S. Economy, NISTIR 6271 (December 1998).

The Electronics and Electrical Engineering Laboratory, working in concert with other NIST Laboratories, is providing measurement and other generic technology critical to the competitiveness of the U.S. electronics industry and the U.S. electricity-equipment industry. This report summarizes selected technical accomplishments and describes activities conducted by the Laboratory in FY 1996 in the field of semiconductors, magnetics, superconductors, low-frequency microwaves, lasers, optical fiber communications and sensors, video, power, electromagnetic compatibility, electronic data exchange, and national electrical standards. Also included is a profile of EEEL's organization, its customers, and the Laboratory's long-term goals.

EEEL is comprised of five technical divisions, Electricity and Semiconductor Electronics in Gaithersburg, Maryland, and Electromagnetic Fields, Electromagnetic Technology, and Optoelectronics in Boulder, Colorado. Through two offices, the Laboratory manages NIST-wide programs in microelectronics and law enforcement.
[Contact: JoAnne Surette, (301) 975-5267]

Measurements for Competitiveness in Electronics, NISTIR 4583 (April 1993).

Measurements for Competitiveness in Electronics identifies for selected technical areas the measurement needs that are most critical to U.S. competitiveness, that would have the highest economic impact if met, and that are the most difficult for the broad range of individual companies to address. The document has two primary purposes: (1) to show the close relationship between U.S. measurement infrastructure and U.S. competitiveness and show why improved measurement capability offers such high economic leverage, and (2) to provide a statement of the principal measurement needs affecting U.S. competitiveness for given technical areas, as the basis for a possible plan to meet those needs, should a decision be made to pursue this course.

The first three chapters, introductory in nature, cover the areas of: the role of measurements in competitiveness, NIST's role in measurements, and an overview of U.S. electronics and electrical-equipment industries. The remaining nine chapters address individual fields of electronic technology: semiconductors, magnetics, superconductors, microwaves, lasers, optical-fiber communications, optical-fiber sensors, video, and electromagnetic compatibility. Each of these nine chapters contains four basic types of information: technology review, world markets and U.S. competitiveness, goals of U.S. industry for competitiveness, and measurement needs. Three appendices provide definitions of the U.S. electronics and electrical-equipment industries.
[Contact: Ronald M. Powell, (301) 975-2220]

TABLE OF CONTENTS

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Released for Publication

Burroughs, C.J., Benz, S.P., Hamilton, C.A., and Harvey, T.E., **1 Volt DC Programmable Voltage Standard System**.

NIST has developed a programmable JVS (Josephson voltage standard) that produces intrinsically stable voltages that are programmable from -1.1 V to ± 1.1 V. The rapid settling time (1 μs), large operating current margins (2 to 4 mA), and inherent step stability of this new system make it superior to a conventional JVS for many dc measurements. This improved performance is made possible by a new integrated circuit technology using intrinsically shunted SNS (superconductor-normal-superconductor) Josephson junctions. These junctions operate at lower excitation frequencies (10 GHz to 20 GHz) than a conventional JVS and have 100 times greater noise immunity. The Josephson chip consists of a binary array sequence of 32 768 SNS Josephson junctions. The chip has been integrated into a completely automated system that is finding application in mechanical/electrical watt balance experiments, evaluation of thermal voltage converters, electron counting capacitance standards, and metrology triangle experiments.
[Contact: Charles J. Burroughs, (303) 497-3906]

Hamilton, C.A., and Tang, Y.-H., **Evaluating the Uncertainty of Josephson Voltage Standards**.

A general method is proposed to evaluate the uncertainty of Josephson voltage standard measurements. The method is largely based on a statistical evaluation of the results of measurements of a short circuit under conditions that exactly duplicate the procedure used for normal calibrations. It gives a rigorous Type A evaluation of many uncertainty components that have typically been considered Type B uncertainties and often assigned worst case values.
[Contact: Clark A. Hamilton, (303) 497-3740]

Kenyon, M., Amar, A., Song, D., Lobb, C.J., Wellstood, F.C., Zimmerman, N.M., and Cobb, J.L., **Dynamics of a Charged Fluctuator in an Al-AlO_x-Al Single-Electron Transistor**.

We report detailed observations of random-telegraph charge fluctuations in a two-junction Al-AlO_x-Al single-electron transistor (SET). We measured the fluctuations from 85 mK to 3 K and observed that the SET switched between two states, causing charge shifts of $\Delta Q_o = 0.1 \pm 0.025\ e$ on the SET's island. The transition rate out of each state was periodic in the gate voltage, varied non-monotonically with the device bias voltage, and was independent of the temperature below about 0.3 K. We present a model which explains these unusual features as arising from a charged ion located in the tunnel junction which undergoes quantum tunneling, single-phonon scattering and inelastic scattering with the electrons flowing through the SET. 72.10.Fk, 72.70.+m, 73.23.Hk.
[Contact: Neil M. Zimmerman, (301) 975-5887]

Williams, E.R., Steiner, R.L., and Newell, D.B., **An Accurate Measurement of the Planck Constant**.

Using a moving coil watt balance, electric power measured in terms of the Josephson and quantum Hall effects is compared with mechanical power measured in terms of the meter, kilogram, and second. We find the Planck constant $h = 6.62606891(58) \times 10^{-34}$ J s. The quoted standard uncertainty (one standard deviation estimate) corresponds to 8.7×10^{-8} h. Comparing this measurement to an earlier measurement places an upper limit of 2×10^{-8}/year on the drift rate of the Si unit of mass, the kilogram.
[Contact: Edwin R. Williams, (301) 975-4206]

FUNDAMENTAL ELECTRICAL MEASUREMENTS

Recently Published

Cage, M.E., Jeffrey, A., and Elmquist, R.E., **Suggested Triple-Series Connection Measurement Tests of the AC Quantized Hall Resistance and the ac Longitudinal Resistance**, Conference Digest on Precision Electromagnetic Measurements Conference, Washington, DC, July 6-10, 1998, pp. 341-342.

Based on the equivalent circuit calculations, a single ac ratio bridge can be used to accurately determine the ac quantized Hall resistance and to provide an independent value of the ac longitudinal resistance in a quantum Hall device. This may be achieved by making quantized Hall resistance measurements for

two different combinations of triple-series connections to a standards-quality device.
[Contact: Marvin E. Cage, (301) 975-4224]

Elmquist, R.E., **Cryogenic Current Comparator Measurements at 77 K Using Thallium-2223 Thick-Film Shields**, Conference Digest on Precision Electromagnetic Measurements Conference, Washington, DC, July 6-10, 1998, pp. 223-224.

This paper describes resistance ratio measurements using cryogenic current comparator devices that operate at 77 K. The magnetic shields are Thallium-based thick films on MgO substrates. The effectiveness of three shield geometries is determined using one-to-one and ten-to-one winding ratios.
[Contact: Randloph E. Elmquist, (301) 975-6591]

Jeffrey, A., Elmquist, R.E., Shields, J.Q., Lee, L.H., Cage, M.E., Shields, S.H., and Dziuba, R.F., **Determination of the von Klitzing Constant and the Fine-Structure Constant through a Comparison of the Quantized Hall Resistance and the Ohm Derived from the NIST Calculable Capacitor**, Metrologia, Vol. 2, No. 35, pp. 83-96 (1998).

This paper describes a recent determination of the von Klitzing constant and the fine-structure constant by comparisons of values of the ohm as defined in the International System of Units (Si), derived from the National Institute of Standards and Technology calculable cross-capacitor, and values of the international practical unit of resistance derived from the integral quantum Hall effect. In this determination, the comparisons were made in a series of measurements lasting three years. A small difference is observed between this determination and an earlier comparison carried out in this laboratory and reported in 1988. The most recent value of the fine-structure constant based on the experimental value and theoretical expression for the magnetic moment anomaly of the electron, which has the smallest uncertainty of any value currently available, is consistent with both of these results. The new value exceeds the 1990 conventional value of the von Klitzing constant $R_{K\text{-}90}$ by slightly more than twice the relative standard uncertainty of the present measurement, which is 2.4×10^{-8}.
[Contact: Ann Marie Jeffrey, (301) 975-4246]

Jeffrey, A.-M., Lee, L.H., and Shields, J.Q., **Model Tests to Investigate the Effects of Geometrical Imperfections on the NIST Calculable Capacitor**, Conference Digest on Precision Electromagnetic Measurements Conference, Washington, DC, July 6-10, 1998, pp. 454-455.

A calculable capacitor links the U.S. capacitance unit to the Si unit and has a relative standard uncertainty of 2×10^{-8}. Geometrical imperfections are one of the largest sources of this uncertainty. Tests with a model calculable capacitor have been done to better evaluate and reduce this uncertainty.
[Contact: Anne-Marie Jeffery, (301) 975-4246]

Keller, M.W., Martinis, J.M., and Zimmerman, N.M., **A Capacitance Standard Based on Counting Electrons: Progress Report**, Conference Digest on Precision Electromagnetic Measurements Conference Digest, Washington, DC, July 6-10, 1998, pp. 134-135.

We have combined an electron pump and a vacuum-gap capacitor to create a prototype capacitance standard based on electron counting. We are testing various components individually to determine whether a standard with an overall uncertainty of 1 part in 10^8 is feasible.
[Contact: John M. Martinis, (303) 497-3597]

Lee, K.C., **Dependence of Contact Resistance on Current for Good and Bad OHMIC Contacts to Quantized Hall Resistors**, 1998 Conference on Precision Electromagnetic Measurements, Conference Digest, Washington, DC, July 6-10, 1998, pp. 477-478.

Dependence of contact resistance on current has been measured for a large number of ohmic contacts to quantized Hall resistors under quantum Hall effect conditions. A definite trend is observed in the current dependences of resistances of good and bad contacts, regardless of the physical cause of the poor contact.
[Contact: Kevin C. Lee, (301) 975-4236]

Newell, D.B., Steiner, R.L., Williams, E.R., and Picard, A., **The Next Generation of the NIST Watt Balance**, Conference Digest on Precision Electromagnetic Measurements Conference, Washington, DC, July 6-10, 1998, pp. 108-109.

Reduction in the total uncertainty of the NIST watt balance is limited by the present configuration of the experiment. Most of the major uncertainty components arise from the fact that the experiment is performed in air. To reduce the contribution of these components, a vacuum system for the NIST watt balance has been constructed. The vacuum system and other future modifications to the NIST watt balance are discussed.
[Contact: Richard L. Steiner, (303) 497-4226]

Steiner, R.L., Newell, D.B., and Williams, E.R., **Experimental Noise Sources in the NIST Watt Balance**, Conference Digest on Precision Electromagnetic Measurements Conference, Washington, DC, July 6-10, 1998, pp. 621-622.

The Present NIST watt balance has a relative combined standard uncertainty of about 145 nW/W. The final results of this phase of the experiment are presented. Improvements in the Type B (nonstatistical) uncertainty contributions, along with several correction factors and noise sources, are also discussed.
[Contact: Richard L. Steiner, (303) 497-4226]

Tang, Y.-h., **Comparison of Two Josephson Array Voltage Standard Systems Using a Set of Zener References**, Conference Digest on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998, pp. 357-358.

Two Josephson Array Voltage Standard Systems using different calibration algorithms are operated at the National Institute of Standards and Technology. A manual switch system is designed to make system comparisons by measuring against the 1.018 V of three Zener references. The difference of the average of the three Zener references is smaller than 1 nV.
[Contact: Yi-hua Tang, (301) 975-4691]

Zimmerman, N.M., and Cobb, J.L., **Charge Offset and Noise in SET Transistors**, Conference Digest on Precision Electromagnetic Measurements Conference, Washington, DC, July 6-10, 1998, pp. 138-139.

We report on several previous and ongoing investigations into the source of, and the amelioration of, the charge offset noise in SET (single-electron tunneling) transistors, made of Al/AlO_x/Al tunnel junctions. Previous work has shown that significant time-dependent noise will arise from locations outside the tunnel junctions, as well as within the junctions. Our ongoing work includes attempts to reduce or eliminate the charge offset and noise in fabricated devices.
[Contact: Neil M. Zimmerman, (301) 975-5887]

SEMICONDUCTOR MICROELECTRONICS

Silicon Materials

Released for Publication

Roitman, P., Edelstein, M., and Krause, S.J., **Electrical Detection of Defects in SIMOX Buried Oxides: Pipes and Precipitates**, Extended Abstracts of the 1998 IEEE International SOI Conference, Stuart, Florida, October 5-8, 1998.

Two defect types have been identified in the buried oxide of low dose SIMOX: conductive silicon paths through the buried oxide (pipes) and silicon precipitates in the buried oxide. Both types are caused by the same general mechanism; the tendency of the Si-SiO_2 system at high temperature to separate into regions of Si and SiO_2 rather than forming SiO_x. Below, an oxygen dose of ~4 x 10^{17} cm^{-2}, the buried oxide is not continuous, and as the dose is lowered, the implanted region becomes a layer of SiO_2 precipitates. Above the dose of ~4 x 10^{17} cm^{-2}, the buried oxide is continuous, but Si precipitates ~50 nm thick are present in the oxide.
[Contact: Monica Edelstein, (301) 975-2078]

Silicon Materials

Recently Published

Chandler-Horowitz, D., Amirtharaj, P.M., and Stoup, J.R., **High-Resolution, High-Accuracy, Mid-IR (450 cm^{-1} ≤ ω ≤ 4000 cm^{-1}) Refractive Index Measurements in Silicon**, Proceedings of the 1998 International Conference on Characterization of Metrology for ULSI Technology, Gaithersburg, Maryland, March 23-27, 1998, pp. 207-211.

The real and imaginary parts of the refractive index of silicon, $n(\omega)$ and $k(\omega)$, have been measured by using Fourier Transform Infrared (FTIR) transmission spectral data from a double-sided-polished grade Si wafer. An accurate mechanical measurement of the wafer thickness, t and $k(\omega)$. Independent analysis of

each spectrum gave initial $n(\omega)$ and $k(\omega)$ estimates which were then used together as starting point values determined using this procedure is dependent upon the measurement error in the sample thickness, the absolute transmission values obtained from a sample-in and sample-out method, and the modeling of the influence of wafer thickness nonuniformity and the degree of incident light beam collimation. Our results are compared with previously published values for $n(\omega)$ and $k(\omega)$ in the 450 cm^{-1} spectral region. The error in $n(\omega)$ is < 1 part in the 10^4, a factor of 10 better than published values. The $k(\omega)$ values are in good agreement with previous measurements except in the vicinity of the 610 cm^{-1} peak feature where our values are ~20% lower.
[Contact: Deane Chandler-Horowitz, (301) 975-2084]

Dura, J.A., Richter, C.A., Majkrzak, C.F., and Nguyen, N.V., **Neutron Reflectometry, X-Ray Reflectometry, and Spectroscopic Ellipsometry Characterization of Thin SiO_2 On Si**, Applied Physics Letters, Vol. 73, No. 15, pp. 2131-2133 (12 October 1998).

We present here a comparison of neutron reflectometry, X-ray reflectometry, and spectroscopic ellipsometry on a thin oxide film. These three probes each independently determine the structure of the film as a function of depth. We find an excellent agreement between the three techniques for measurements of thicknesses and interfacial roughnesses for both the SiO_2 and surface contamination layers found in the sample. Realistic models based on interface parameters measured herein indicate that as the SiO_2 layers decrease to sizes projected for future generations of electronic devices, both spectroscopic ellipsometry and neutron reflectometry can easily measure SiO_2 films to 2 nm thick or less.
[Contact: Curt A. Richter, (301) 975-2082]

Integrated-Circuit Test Structures

Recently Published

Allen, R.A., and Ghoshtagore, R.N., **Evaluation of Surface Depletion Effects in Single-Crystal Test Structures for Reference Materials Applications**, Proceedings of the 1998 International Conference on Characterization and Metrology for ULSI Technology, Gaithersburg, Maryland, March 23-27, 1998, pp. 357-362.

Monocrystalline silicon test structures are being investigated for critical dimension reference materials applications. The goal of this work is to produce samples which do not exhibit the phenomenon of "methods divergence," where the measurement of a single sample, fabricated in an electrical conductor, by multiple techniques leads to results that differ from one another by more than the total known error budgets of the measurements. In this paper, measurements are described to determine the sources of differences observed between electrical and other measurements.
[Contact: Richard A. Allen, (301) 975-5026]

Cresswell, M.W., Allen, R.A., Guthrie, W.F., Sniegowski, J.J., Ghoshtagore, R.N., and Linholm, L.W., **Electrical Linewidth Test Structures Fabricated in Monocrystalline Films for Reference-Material Applications**, IEEE Transactions on Semiconductors Manufacturing, Vol. 11, No. 2, May 1998, pp. 182-193.

The physical widths of reference features incorporated into electrical linewidth test structures patterned in films of monocrystalline silicon have been determined from Kelvin voltage measurements. The films in which the test structures are patterned are electrically insulated from the bulk-silicon substrate by a layer of silicon dioxide provided by SIMOX (Separation by the Implantation of Oxygen) processing. The motivation is to facilitate the development of linewidth reference materials for critical-dimension (CD) metrology-instrument calibration. The selection of the (110) orientation of the starting silicon and the orientation of the structures' features relative to the crystal lattice enable a lattice-plane-selective etch to generate reference-feature properties of rectangular cross section and atomically planar sidewalls. These properties are highly desirable for CD applications in which feature widths are certified with nanometer-level uncertainty for use by a diverse range of CD instruments. End applications include the development and calibration of new generations of CD instruments directed at controlling processes for manufacturing devices having sub-quarter-micrometer features.
[Contact: Michael W. Cresswell, (301) 975-2072]

Microfabrication Technology

Recently Published

Milanović, V., Gaitan, M., and Zaghloul, M.E., **Micromachined Thermocouple Microwave Detector by Commercial CMOS Fabrication**, IEEE Transactions on Microwave Theory and Techniques, Vol. 46, No. 5, pp. 550-553 (May 1998).

This paper reports on the design and testing of a thermocouple microwave detector fabricated through a commercial CMOS foundry with an additional maskless etching procedure. The detector measures the true rms power of signals in the frequency range from 50 MHz to 20 GHz, and input power range from -30 to +10 dBm. The device has linearity better than ± 0.4% for input power versus output voltage over the 40 dB dynamic range. Measurements of the return loss, obtained using an automatic network analyzer, show acceptable input return loss of less then -20 dB over the entire frequency range. The sensitivity of the detector was measured to be (1.007 ± 0,004) mV/mW.
[Contact: Michael Gaitan, (301) 975-2070]

Plasma Processing

Released for Publication

Cooper, G.D., Sanabia, J.E., Moore, J.H., Olthoff, J.K., and Christophorou, L.G., **Total Electron Scattering Cross Section for Cl_2.**

Absolute measurements of the total electron scattering cross section, $\sigma_{scat}(e)$, for chlorine, Cl_2, are reported for electron energies, e, ranging from 0.3 eV to 23 eV. The present data are in reasonable agreement with previous measurements of the cross sections for total electron scattering and total rotational excitation, and indicate significant indirect vibrational excitation due to negative ion resonances.
[Contact: James K. Olthoff, (301) 975-8113]

Power Devices

Released for Publication

Zhu, H., Tang, Y., Lai, J., and Hefner, Jr., A.R., **Accurate Modeling and Analysis of PWM Inverters for Electromagnetic Compatibility Performance Evaluation**, Proceedings of the Sixteenth Virginia Power Electronics Seminar Proceedings, Blacksburg, Virginia, September 6, 1998.

For the purpose of electromagnetic compatibility (EMC) performance investigation and prediction, accurate modeling and analysis are performed on IGBT PWM inverters. In this paper, parasitic components and their measurement methods are addressed. Modeling and characterization of parasitic inductance and capacitance within device modules, in inverter assemblies, and inside motor or inductor load are carried out. IGBT device modeling and parameter extraction issues are discussed. A physics-based IGBT model is chosen for the simulation study, which is necessary to obtain correct switching waveforms with high-frequency effects such as dv/dt and current tailing. Experiments have been conducted on hard switching and zero-voltage-transition (ZVT) soft-switching prototype inverters.
[Contact: Allen R. Hefner, Jr., (301) 975-2071]

Reliability

Recently Published

Suehle, J. S., **Reliability Characterization of Ultra-Thin Film Dielectrics**, Proceedings of the 1998 International Conference on Characterization and Metrology for ULSI Technology, Gaithersburg, Maryland, March 23-27, 1998, pp. 115-119.

The reliability of gate oxides is becoming a critical concern as oxide thickness is scaled below 4 nm in advanced CMOS technologies. Traditional reliability characterization techniques must be modified for very thin gate oxides that exhibit excessive tunneling currents and soft breakdown. As intrinsic reliability limits are approached by increasing chip temperature and electric fields, it becomes essential to understand fully the physical mechanism(s) responsible for gate oxide wear-out and eventual breakdown. Issues relating to the reliability testing of ultra-thin oxides are discussed with examples.
[Contact: John S. Suehle, (301) 975-2147]

SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

DC and Low-Frequency Metrology

Released for Publication

Chang, Y.M., **The Transfer, Maintenance, and Dissemination of LF Impedance at NIST**, to be published in the Proceedings of the Third International Seminar on Electrical Metrology, Rio de Janeiro, Brazil, September 15-17, 1998.

A brief description is presented of the low frequency impedance calibration facility at the National Institute of Standards and Technology (NIST). Included are the calibration capabilities of impedance standards, measurement systems, the reference standards, and the path to transfer the unit of capacitance from the NIST calculable capacitor and the quantum Hall resistors to the customer's capacitance and inductance standards.
[Contact: Y. May Chang, (301) 975-4237]

DC and Low-Frequency Metrology

Recently Published

Burroughs, C.J., Hamilton, C.A., Harvey, T.E., Kinard, J.R., Lipe, T.E., and Sasaki, H., **Thermoelectric Transfer Difference of Thermal Converters Measured with a Josephine Source**, Conference Digest on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998, pp. 643-644.

We have measured the thermoelectric transfer difference of two thermal voltage converters using a Josephson source and compared the results to similar measurements made with a conventional semiconductor source. Both sources use the fast reversed DC method. The Josephson source is an array of 16 384 superconductor-normal-superconductor Josephson junctions that is rapidly switched between voltage states of +0.5 V, 0 V, and -0.5 V. A marginally significant difference is detected between measurements with the two different sources.
[Contact: Charles J. Burroughs, (303) 497-3906]

Chang, Y.M., and Tillett, S.B., **Recent Developments in the Capacitance Calibration Services at the National Institute of Standards and Technology,** Workshop and Symposium of the 1998 National Conference of Standards Laboratories, Albuquerque, New Mexico, July 16-23, 1998, pp. 49-61.

Since 1994, a bank of four 10 pF oil-bath type fused-silica dielectric capacitors has been maintained in the NIST Impedance Calibration Laboratory for use as reference standards to assign values to the secondary reference and check standards used for performing calibrations on customer's standards. The values of the reference standards in this bank are determined via comparisons with a 10 pF air-bath type fused-silica capacitor from the NIST primary capacitance laboratory. This laboratory maintains the U.S. capacitance unit in a primary bank of 10 pF oil-bath type, fused-silica dielectric capacitors, traceable to the NIST calculable capacitor. The database for these reference standards is now established, and the algorithms for maintaining their values with statistical prediction methods are developed. Also discussed is a preliminary investigation of the frequency dependence of the transfer standard, which significantly affects the present capacitance calibration uncertainties.
[Contact: Y. May Chang, (301) 975-4237]

Dziuba, R.F., and Sims, J.E., **Resistance Measurement Assurance Program at NIST**, Workshop and Symposium of the 1998 National Conference of Standards Laboratories, Albuquerque, New Mexico, July 19-23, 1998, pp. 767-777.

The National Institute of Standards and Technology (NIST) offers resistance Measurement Assurance Program (MAP) transfers at the 1 Ω and 10 kΩ levels to provide a method of assessing and maintaining the quality of a customer's measurement process. The NIST resistance MAP calibration service is described, including the measurement procedures for participating in the program. A discussion of the data analysis follows, along with an explanation of the estimate of the uncertainty of the MAP transfer. Presentation of past resistance MAP data is also included.
[Contact: Ronald F. Dziuba, (301) 975-4239]

Jarrett, D.G., **A Guarded Transfer Standard for High Resistance Measurements**, Conference Digest on Precision Electromagnetic Measurements Conference, Washington, DC, July 6-10, 1998, pp. 100-101.

An improved design for a guarded transfer standard in the resistance range 1 MΩ to 100 GΩ is described. Existing transfer standards and limitations are

reviewed. Interchangeable guard networks are used in the improved transfer standards to ensure complete guarding during all phases of the measurement process thus reducing errors caused by leakages to ground.
[Contact: Dean G. Jarrett, (301) 975-4240]

Kinard, J.R., Lipe, T.E., Childers, C.B., and Avramov-Zamurovic, S., **Comparison of High Voltage Thermal Converter Scaling to a Binary Inductive Voltage Divider**, Conference Digest on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998, pp. 381-382.

High-voltage thermal converters (HVTCs) are used as standards of ac-dc difference for the measurement and calibration of ac voltage up to 1000 V and 100 kHz. Their multiplying resistors can be compensated to yield small ac-dc differences by using adjustable internal shields; however, the ac-dc differences of HVTCs may vary as functions of warm-up time, applied frequency, and applied voltage. Voltage coefficients between 100 V and 1000 V can be quite significant compared to calibration uncertainties, and can be major sources of error in the buildup process used to characterize the HVTCs. Formal and informal international intercomparisons of HVTCs have revealed variations among the participating laboratories. The present work was undertaken to compare the scaling accuracy of HVTCs to the completely independent principle of a binary inductive voltage divider.
[Contact: Joseph R. Kinard, (301) 975-4250]

Koffman, A.D., Waltrip, B.C., Oldham, N.M., and Avramov-Zamurovic, S., **Capacitance and Dissipation Factor Measurements from 1 kHz to 10 MHZ**, Workshop and Symposium of the 1998 National Conference of Standards Laboratories, Albuquerque, New Mexico, July 19-23, 1998, pp. 63-68.

A measurement technique developed by K. Yokoi et al. at Hewlett-Packard in Japan, Ltd., has been duplicated and evaluated at the National Institute of Standards and Technology (NIST) to characterize four-terminal pair capacitors. The technique is based on an accurate three-terminal measurement made at 1 kHz using a capacitance bridge and wideband single-port measurements made between 30 MHZ and 200 MHZ using a network analyzer. The measurement data are fitted to the four-terminal pair admittance model defined by R. Cutkosky to compute capacitance and dissipation factor at any frequency up to 10 MHZ. Capacitors characterized using this technique will be used as impedance reference standards for a general-purpose digital impedance bridge recently developed at NIST to calibrate inductors and ac resistors. The technique could also lead to a future NIST Special Test for dissipation factor.
[Contact: Andrew D. Koffman, (301) 975-4518]

Lipe, T.E., Kinard, J.R., and Childers, C.B., **Recent Improvements and Revised Uncertainties In the NIST ac-dc Difference Calibration Service for Thermal Transfer Standards**, Workshop and Symposium of the 1998 National Conference of Standards Laboratories, Albuquerque, New Mexico, July 16-23, 1998, pp. 385-389.

This paper describes recent developments in the ac-dc difference calibration service for thermal transfer standards at the National Institute of Standard and Technology. Related developments include the revision of calibration uncertainties, with substantial reductions at many points, and an expansion of the calibration parameters space for thermal current converters and shunts. New research programs include a prototype thermal transfer standard using a superconducting temperature sensor.
[Contact: Thomas E. Lipe, (301) 975-4251]

Simmon, E.D., FitzPatrick, G.J., and Petersons, O., **Calibration of Dissipation Factor Standards**, Conference Digest on Precision Electromagnetic Measurements Conference, Washington, DC, July 6-10, 1998, pp. 203-204.

[See Power Systems Metrology.]

Souders, T.M., **Code Probability Distributions of A/D Converters with Random Input Noise**, Proceedings of the 1998 IEEE Instrumentation and Measurement Technology Conference, St. Paul, Minnesota, May 18-21, 1998, pp. 84-87.

The specific architecture of an A/D converter influences the code probability distributions that result from random input noise. In particular, the output codes of successive approximation A/D converters have a spiked distribution, and its variance is half that of the corresponding input noise. In addition, the distribution has a small bias. These and other related

results are derived, and are qualitatively supported by measurement data on a real 16-bit A/D converter.
[Contact: T. Michael Sounders, (301) 975-2406]

Waveform Metrology

Recently Published

Deyst, J.P., Paulter, Jr., N.G., Daboczi, T., Stenbakken, G.N., and Souders, T.M., **A Fast Pulse Oscilloscope Calibration System**, Proceedings of the 1998 IEEE Instrumentation and Measurement Technology Conference, St. Paul, Minnesota, May 18-21, 1998, pp. 166-171.

A system is described for calibrating high-bandwidth oscilloscopes using pulse signals. The fast pulse oscilloscope calibration system (FPOCS) is to be used to determine the stop response parameters for digitizing oscilloscopes having bandwidths of ~20 GHz. The system can provide measurement traceability to standards maintained at the U.S. National Institute of Standards and Technology (NIST). It is comprised of fast electrical step generation hardware, a personal computer and software, and a reference waveform, i.e., a data file containing an estimate of the step generator output signal. The reference waveform is produced by prior measurement by NIST of the step generator output signal (calibration step signal). When the FPOCS is in use, the calibration step signal is applied to the device under test, which is an oscilloscope sampling channel. The measured step waveform is corrected for timebase errors, then the reference waveform is deconvolved from it. The results are impulse, step, and frequency response estimates, and their associated parameters (e.g., transition duration, transition amplitude, -3 dB bandwidth) and uncertainties. The system and its components are described, and preliminary test results are presented.
[Contact: John P. Deyst, (301) 975-2437]

Cryoelectronic Metrology

Released for Publication

McDonald, D.G., Phelan, Jr., R.J., Vale, L.R., Ono, R.H., and Rudman, D.A., **Passive, Transition Width, and Noise for $Yba_2Cu_3O_{7-x}$ Bolometers on Silicon**.

We are developing $Yba_2Cu_2O_{7-x}$ (YBCO) thermometers for large area bolometers that include a heater for calibration by the electrical substitution of power. Because YBCO on buffered Si is under mechanical stress, and must be very thin to avoid cracking, we find it is electrically sensitive to its passivation layer. For example, passivation by in situ SrT_1O_3 raised the noise in our films by about a factor of 100. An alternative is to first cap YBCO with Au, for passivation, and then add an insulator, for electrical isolation. Such devices have a narrower transition, by a factor of 3.9 (to 0.4 K). A model with a shunt resistor across the superconductor predicts a narrowing of the transition, but by less than the observed amount. We find experimentally that the noise equivalent temperatures, about 4 nK $Hz^{-1/2}$, of our thermometers are not degraded by the normal metal shunt, although the resistance is decreased. The resistance can be raised using AgAu alloy in place of Au, with equivalent performance.
[Contact: Ronald H. Ono, (303) 497-3762]

Xu, Y., Ekin, J.W, and Clickner, C.C., **Low-Frequency Noise of YBCO/Au Junctions**.

We have fabricated ex-situ *c*-axis YBCO/Au junctions with low contact resistivities. These devices exhibit low-frequency resistance fluctuations. At room temperature, the junction noise spectrum if 1/f like. At liquid nitrogen temperature and lower, the noise spectrum depends sensitively on the bias level, with certain bias levels producing clear two-level fluctuation behavior. The normalized resistance noise for these junctions at low temperatures had an average value of (2-3) x 10^{-5}. We discuss consequences of junction resistance noise behavior for the applications.
[Contact: John W. Ekin, (303) 497-5448]

Antenna Metrology

Released for Publication

Kawalko, S.F., and Motohisa, K., **Comparison of Numerical and Analytical Monopole Nonplanarity Correction Factors**.

In the calibration of a monopole antenna using another monopole, the separation distance can be comparable to the length of one or both of the antennas. In this case, the magnitude and phase of the incident field may very along the length of the antenna user test. This variation in incident field can

lead to an error in the measured characteristics of the antenna under test. This paper presents a numerical procedure for evaluating a correction factor to account for the effect of the nonuniform field and also to account for effects due to mutual coupling between the two antennas. Results for this numerically computed correction factor are compared with results obtained from an analytical expression for some representative cases.
[Contact: Stephen F. Kawalko, (303) 497-5854]

Antenna Metrology

Recently Published

Hill, D.A., **Spherical-Wave Characterization of Interior and Exterior Sources**, Proceedings of the 1998 International Symposium on Electromagnetic Compatibility, Denver, Colorado, August 24-28, 1998, pp. 848-853.

This paper presents the theoretical basis for spherical, near-field scanning in the general case where radiating sources exist both inside and outside the measurement region. The fields are expanded in terms of outgoing spherical waves (due to interior sources) and standing spherical waves (due to exterior sources). Additional information is required to solve for the increased number of unknowns, and results for the spherical-wave coefficients are derived in terms of the tangential electric and magnetic fields on the surface of a sphere. The special case of an electrically small emitter is examined in detail, and several formulations are presented for the equivalent electric and magnetic dipole moments.
[Contact: David A. Hill, (303) 497-3472]

Noise Metrology

Released for Publication

Dunleavy, L., Randa, J., Billinger, R., and Rice, J., **Characterization and Applications of On-Wafer Diode Noise Sources**.

A set of wafer-probeable diiode noise source transfer standards are characterized using on-wafer noise-temperature methods developed at the National Institute of Standards and Technology. We review the methods for accurate measurement and prediction of on-wafer noise temperature of off-wafer noise source standards. In analogy with the excess noise ratio (ENR) for hot noise temperatures, we introduce a decibel representation for cold noise temperatures called the cold noise ratio (CNR). The ENR and CNR representations share the intuitive value that the off-wafer and on-wafer decibel difference is approximately the probe loss. This provides an intuitive check of the results from more rigorous calculations. We present measurements of the on-wafer ENR and reflection coefficient information for a prelinminary set of on-wafer diode transfer standards at frequencies from 8 to 12 GHz. Such transfer standards could be used in interlaboratory comparisons, as a noise calibration verification tool, as direct calibration artifacts, or as the basis for a new "noise-source probe" conceptualized here.
[Contact: James P. Randa, (303) 497-3150]

Randa, J., Rice, J., Achkar, T., Colard, M., Sinclair, Williams, G., Buchholz, R.-Im, and Schubert, D., **International Comparison of Noise-Temperature Measurements at 2, 4, and 12 GHz**, to be published in the Proceedings of the Conference on Precision on Electromagnetic Measurements, Washington, DC, July 6-10, 1998.

We report results of a recent international comparison of thermal noise-power measurements, performed under the auspices of CIPM/CCE. The noise temperatures of two solid-state sources with GPC-7 connectors were measured at 2, 4, and 12 GHz. All results agreed within the expanded uncertainties. The comparison was performed in accordance with the guidelines recently adopted by the CCE.
[Contact: James Randa, (303) 497-3150]

Microwave and Millimeter-Wave Metrology

Released for Publication

Degrade, D., and Williams, D., **Electrical Measurements for Electronic Interconnections at the National Institute of Standards and Technology**, to be published in the Proceedings of the Topical Meeting on Electrical Performance of Electronic Packaging, West Point, New York, October 25-28, 1998.

The National Institute of Standards and Technology operates a number of research projects to advance measurement science and technology for the microelectronic industries. We report here on one

component of the NIST program, the fundamental characterization of electronic interconnections through accurate electrical measurements. To address our mission, we identified a number of challenges and designed approaches to tackle them. As a result, we have developed, and are now developing, measurement techniques for fully calibrated multiport network analysis, low-k thin-film materials, and at-speed test.
[Contact: Donald Degrade, (303) 497-7212]

Microwave and Milimeter-Wave Metrology

Recently Published

Milanović, V., Gaitan, M., and Zahloul, M.E., **Micromachined Thermocouple Microwave Detector by Commercial CMOS Fabrication**, IEEE Transactions on Microwave Theory and Techniques, Vol. 46, No. 5, pp. 550-553 (May 1998).

[See Microfabrication Technology.]

Electromagnetic Properties

Released for Publication

Baker-Jarvis, J., Riddle, B., and Young, A., **Including Effects of Excluded Volume in Counterion Dynamics**.

The goal of this paper is to analyze frequency-dependent counterion relaxation around an electrode, taking into account finite ion volume. A new solution is developed of an electrostatic one-dimensional, modified Poisson-Boltzmann equation in rectangular coordinates that includes the effects of steric hindrance. A time-dependent wave equation for the potential is developed in the Lorentz gauge. The potential satisfies the sinh-Gordon equation. New solutions to the nonlinear time-dependent equation are developed. It is shown that in the low voltage limit, the equation reduces to the Klein-Gordon equation. We also present equations for capacitance and surface charge.
[Contact: James Baker-Jarvis, (303) 497-3906]

Geyer, R.G., **Complex Permittivity and Permeability of Ferrite Ceramics at Microwave Frequencies**.

Accurate rf dielectric and magnetic characterization of ferrite ceramics requires combined measurement techniques. The chosen techniques depend on the frequency of interest and expected dielectric and magnetic losses of the specimen. Coaxial transmission line waveguide methods are used for magnetic characterization at frequencies less than gyromagnetic resonance, where specimens have high magnetic loss. Specimen complex permittivity is evaluated with either a TM_{OuO} cavity, or by saturating the specimen when operated as a cylindrical H_{011} dielectric resonator. Complex permeability at frequencies above natural gyromagnetic resonance, where magnetic losses are low, are either evaluated with H_{011} dielectric sleeve resonators or by employing the specimen as an H_{011} dielectric resonator in the demagnetized state.

Measurements of various ferrites having different compositions and saturation magnetizations are performed. The tuning range of a ferrite increases above natural gyromagnetic resonance as saturation magnetization increases, but at the expense of increased magnetic loss. Measured real permeabilities compare well with theoretical real permeability predictions of a cylindrical specimen model having 2-domain structure parallel and anti-parallel to the applied rf magnetic, but only at frequencies significantly greater then natural gyromagnetic resonance. Microwave magnetic losses, which depend on composition and ceramic microstructure, must be experimentally evaluated. Cooling the ferrite specimen yields smaller dielectric, but larger magnetic loss.
[Contact: Richard G. Geyer, (303) 497-5852]

Complex System Testing

Recently Published

Engler, H., Souders, M., and Stenbakken, G.N., **Efficient Testing of Electronic Devices**, Proceedings of the 29th Symposium on the Interface, Houston, Texas, May 14-17, 1997, Vol. 29, No. 1, pp. 592-596.

Testing electronic devices in order to assure the quality of individual products can be time-consuming and expensive. To speed up this process without compromising on reliability, testing strategies have been developed at NIST. They are based on the extraction of low-dimensional linear error models,

using a priori knowledge of the structure of the device or data from an exhaustively tested training and validation set. Production testing then is performed only on a small subset of all possible test points which must be chosen optimally. This paper describes statistical and computational aspects of these procedures and reports on the theoretical background, heuristics, algorithms, and practical experiences.
[Contact: Michael Souders, (301) 975-2406]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Stricklett, K.L., Petersons, O., and Vangel, M.G., **An Analysis of Efficiency Testing Under the Energy Policy and Conservation Act: A Case Study with Application**, to be published as NIST Technical Note.

The protocols for efficiency testing promulgated by 10 CFR part 430 as established under the Energy Policy and Conservation Act of 1975 as amended (EPCA) are discussed. The case of distribution transformers, which is under construction for possible rule-making, is treated in detail. Model calculations are presented that estimate the probability of demonstrating compliance and the average number of units tested under the 10 CFR part 430 sampling plans. The results of model calculations for the sampling plan contained in NEMA Standard TP 2 are presented and compared with the 10 CFR part 430 sampling plans.
[Contact: Kenneth L. Stricklett, (301) 975-3955]

Walton, S.G., Tuck, J.C.D., Champion, R.L., and Wang, Y., **Low Energy, Ion-Induced Secondary Emission from Stainless Steel: The Effects of Oxygen Coverage and the Implications for Discharge Modeling**.

Absolute yields of secondary electrons and negative ions resulting from positive ions impacting a stainless steel surface have been determined as a function of the impact energy, with the surface conditions ranging from a surface free of adsorbates to one with several monolayers of adsorbed oxygen. Photon-induced electron emission has been used to monitor the effects of oxygen coverage on the surface work function. The emission of negative ions and secondary electrons has been described by combining the collision cascade model with an excitation mechanism similar to that used in the Menzel-Gomer-Redhead model. Finally, we illustrate the implications of the present observations for discharge modeling and diagnostics by citing a parallel-plate, rf discharge in oxygen as an example.
[Contact: Yicheng Wang, (301) 975-4278]

Power Systems Metrology

Recently Published

Mansoor, A., and Martzloff, F., **The Effect of Neutral Earthing Practices on Lightning Current Dispersion in a Low-Voltage Installation**, IEEE Transactions on Power Delivery, Vol. 13, No. 3, pp. 783-792 (July 1998).

Computer modeling with the EMTP code has been applied to several configurations and earthing practices in use in various countries to show the effect of any differences in the dispersion (sharing) of a lightning stroke current among the available paths for the earth-seeking lighting current. Simplifying assumptions have been made to some details of the configurations to focus on the main difference -- earthing practices. Identifying such differences provides the necessary perspective on their significance and the strong need to take them into consideration when developing international standards on surge-protective applications.
[Contact: François, Martzloff (301) 975-2409]

Nelson, T., **Power and Energy Measurements at NIST**, Workshop and Symposium of the 1998 National Conference of Standards Laboratories, Albuquerque, New Mexico, July 16-23, 1998, pp. 489-494.

The NIST calibration service that provides electric energy traceability for the U.S. utility industry is described. Electronic watt-hour meters, submitted for test, are measured using the NIST Power Bridge, in which complex ac power is defined in terms of the more basic units of voltage, resistance, and capacitance. By integrating power over a known time period, the unit of energy is defined. Calibrations are performed using a synthetic loading technique at power levels between 0 and 60 kW. The basic uncertainty of the NIST Power Bridge is about 15 ppm at 120 V, 5 A, 0 to 1.0 power factor, at 60 Hz.

However, calibration uncertainties depend on the power level and the instrument type. Typical uncertainties (k = 2) are between 50 and 500 parts per million. A Measurement Assurance program for 60 Hz energy is also available.
[Contact: Thomas Nelson, (301) 975-2986]

Petersons, O., Nelson, T.L., Oldham, N.M., and FitzPatrick, G.J., **Extension of Voltage Range for Power and Energy Calibrations**, Conference Digest on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998, pp. 607-608.

A special purpose ac voltage divider system having voltage ratios of 600 V, 360 V, and 240 V to 120 V has been developed to extend the voltage range of primary electric power calibrations from 120 V to 600 V at power frequencies of 50 Hz and 60 Hz. The system consists of a special two-stage resistive divider compensated with an active circuit, thereby reducing the error contributions to below 1 μV/V. The developmental goal to realize ac voltage scaling within 5 μV/V uncertainty in a device verifiable with dc resistance ratio measurements has been attained.
[Contact: Oskars Petersons, (301) 975-2417]

Simmon, E.D., FitzPatrick, G.J., and Petersons, O., **Calibration of Dissipation Factor Standards**, Conference Digest on Precision Electromagnetic Measurements Conference, Washington, DC, July 6-10, 1998, pp. 203-204.

Dissipation factor (DF) standards obtained by connecting a shielded three-terminal capacitor in series with a shielded resistor have been developed for calibration purposes. An analysis of these DF standards, including precautions in their construction and use, is presented and calibration procedures using the NIST high voltage capacitance bridge are discussed.
[Contact: Eric D. Simmon, (301) 975-3956]

Waltrip, B.C., and Nelson, T.L., **A System to Measure Current Transducer Performance**, Conference Digest on Precision Electromagnetic Measurements, Washington, DC, July 6-10, 1998, pp. 272-273.

A special purpose ac current transducer measurement system capable of intercomparing transducers with ac output rations from 1:1 to 50:1 has been developed to extend the range and accuracy of current transformer, current shunt, and mutual inductor calibrations at power frequencies of 50 Hz and 60 Hz. The system consists of a two-stage binary inductive voltage divider, an amplifier-aided two-stage current transformer, a precision shunt, a wideband buffer, and a commercial, sampling digital multimeter. When comparing current transducers with ac output voltage ratios of 1:1 to 50:1, the system attains an overall relative standard uncertainty of the ratio of 10^{-5} to 10^{-4}, respectively. The basic system can be used to calibrate transducers with input currents of 0.1A to 200 A (RMS) and can be extended to measure devices handling input currents up to 15 kA.
[Contact: Bryan C. Waltrip, (301) 975-2438]

Wang, V., Han, X., Van Brunt, R.J., Las, T., Slowikowska, H., Horwath, J.C., and Schweickart, D.L., **Digital Recording and Analysis of Partial Discharges In Point-Dielectric Gaps**, Conference Record of the 1998 IEEE International Symposium on Electrical Insulation, Arlington, Virginia, June 7-10, 1998, pp. 440-443.

Pulsating partial discharges (PD) occurring in point-dielectric gaps under an alternating voltage have been measured with a newly developed digital recording system. The dielectric is a cast epoxy resin with Al_2O_3 filler. In this paper, we analyze and report statistical characteristics of the PD including amplitude distribution, phase-of-occurrence distribution, as well as the phase distributions of the individually selected PD pulses, e.g., the first-occurring or second-occurring pulse in each cycle.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Magnetic Materials and Measurements

Released for Publication

Arnold, C.S., Dunlavy, D., Venus, D., and Pappas, D.P., **Magnetic Susceptibility Analysis of the Relaxation-Time for Domain-Wall Motion in Perpendicularly Magnetized, Ultrathin Films**.

The temperature dependence of the magnetic relaxation-time t(T), is investigated in perpendicularly magnetized, ultrathin Fe/2 ML Ni/W(110) films by magnetic susceptibility measurements. Complex magnetic susceptibilities X (T) = X'(T) + iX"(T) were measured via the polar Kerr effect as a function of

temperature T. In all cases, X'(T) and X"(T) have broad peaks that are not obviously related to the Curie temperature Tc. An experimental relaxation-time, t(T), is determined from the ratio X"(T)/X'(T). The results support previous arguments that the susceptibility measures contrast from domain-wall motion.
[Contact: C. Stephen Arnold, (303) 497-3381]

Geyer, R.G., and Kabos, P., **Magnetic Switching**.

Almost all present-day applications of ferromagnetic materials are based on the fact that magnetization may move from one stable state to another. The manner in which the magnetization moves, together with the time necessary for completing the magnetization state change, comprises the magnetic switching process. Phenomenological and atomic models of magnetic moments and magnetic domain structure are discussed for both bulk and thin-film materials. Theoretical analyses for quasi-static and dynamic magnetization reversal of single and multiple domains that rotate coherently or incoherently are presented. The switching analysis includes the effects of damping and the anisotropy, demagnetization, and exchange fields.
[Contact: Richard G. Geyer, (303) 497-5852]

Itoh, N., Rochford, K.B., Minemoto, H., and Ishizuka, S., **High Frequency Response of Optical Magnetic Field Sensors Using Rare-Earthy Iron Garnet Films**, to be published in the Proceedings of the 13th International Conference on Optical Fiber Sensors, Kyongju, Korea, April 12-16, 1999.

We have measured high frequency response of optical magnetic field sensors using Bi-substituted rare-earth iron garnet films up to 1 GHz. A resonance peak was observed in the frequency response spectrum, but flat response to 230 MHZ was observed. The cause of the resonance phenomenon can be understood from domain wall resonance.
[Contact: Kenneth B. Rochford, (303) 497-5170]

Silva, T.J., and Crawford, T.M., **Methods for Determination of Response Times in Magnetic Head Materials**.

Measurements of magnetization response times in thin-film permalloy are made by both electrical and optical methods. The electrical method measures the inductive voltage generated in a waveguide by the changing magnetization. The optical technique uses standard pump-probe sampling methods combined with the second-harmonic magneto-optic Kerr effect to directly measure magnetization angle as a function of time. Results of these measurements for a 75 nm thick permalloy film are in good qualitative agreement.
[Contact: Thomas J. Silva, (303) 497-7826]

Rice, P., and Russek, S.E., **Observation of the Effects of Tip Magnetization States on Magnetic Force Microscopy Images**.

The effect of the orientation between the tip and the tip-magnetizing field on the subsequent magnetic force microscopy images has been investigated. We have observed that commonly used CoCr coated tips have a component of the remanent magnetization pinned parallel to the tip axis. In order to study the pinned component of the tip, saturating fields were applied at various angles relative to the tip axis. Each time the tip was magnetized, we imaged a sample specifically designed to allow us to find, image, and compare images of the same nanometer-sized magnetic feature. We have also observed a component of the tip magnetization that is free to rotate dynamically due to the stray magnetic fields of the sample being imaged. To study this effect, an external bias field was applied parallel to the tip axis while imaging. This effectively pinned the tip magnetization. With these techniques, we are thus able to compare two effects of tip magnetization on magnetic force microscope images.
[Contact: Paul Rice, (303) 497-3841]

Russek, S.E., Oti, J.O., Kaka, S., and Chen, E.Y., **High-Speed Characterization of Sub-Micrometer GMR Devices**.

A microwave test structure has been designed to measure the high-speed response of giant magnetoresistive (GMR) devices. The test structure uses microwave transmission lines for both wiring and sensing the devices. Pseudo spin-valve devices, with line widths between 0.4 μm and 0.8 μm, have been successfully switched with pulses whose full width at half maximum are 0.5 ns. For small pulse widths, t_{pw}, the switching fields are observed to increase linearly with $1/t_{pw}$. The increase in switching fields, at short pulse widths, is characterized by a slope which, for the current devices, varies between 4.0 kA/m ns to 16

kA/m ns (50 Oe ns and 200 Oe ns). The magnetoresistive response during rotation and switching has been observed. For small rotations (~45° between layer magnetizations) the GMR response pulse had widths of 0.46 ns, which is at the bandwidth limit of our electronics. For larger rotations (~90°) the response pulses broaden considerably as the magnetic layers are rotated near the unstable equilibrium point perpendicular to the device axis. Full 180° switches of both soft and hard layers have been observed with switching times of approximately 0.5 ns.
[Contact: Stephen E. Russek, (303) 497-5097]

Magnetic Materials and Measurements

Recently Published

Morillo, J., Su, Q., Panchapakesan, B., Wuttig, M., and Novotny, D., **Micromachined Silicon Torsional Resonator for Magnetic Anisotropy Measurement**, Review of Scientific Instruments, Vol. 69, No. 11, pp. 3908-3912 (November 1998).

A novel method for measuring the out-of-plane magnetic anisotropy of thin films has been developed using the existing techniques of silicon micromachining. The torsion pendulum, which is commonly used to measure the perpendicular magnetic anisotropy energy constant, K_u, is modified into a single crystal silicon high-Q torsional resonator. This article describes the principle of a silicon torsional resonator, the experimental procedure for measuring magnetic anisotropy, and the results. The theoretical values of K_u for Terfenol-D and Metglas® thin films were compared to the experimentally determined values and found to be within the error limits, which for Metglas© are better than 1%. The agreement is poorer, 5% to 15%, for amorphous show that this is a viable method for measuring the magnetic anisotropy.
[Contact: Donald B. Novotny, (301) 975-2699]

Superconductors

Released for Publication

Booth, J.C., Beall, J.A., Rudamn, D.A., Vale, L.R., and Ono, R.H., **Simultaneous Optimization of Linear and nonlinear Microwave Response of YBCO Films**, to be published in the Proceedings of the 1998 IEEE Applied Superconductivity Conference, Desert Springs, California, September 14-18, 1998.

We present results of a systematic study of the effect of film deposition temperature on both the linear and nonlinear response of superconducting $Tba_2Cu_30_{7-\delta}$ (YBCO) thin films and devices at microwave frequencies. Measurements of the unpatterned films show that samples grown by temperature residual surface resistance compared to films grown at a higher deposition temperature (780 °C). However, the same films which display low residual surface resistance also show increased nonlinearity (measured by third harmonic generation) at all temperatures. Analysis of these results suggests that increased levels of disorder present in the films growth at the lower deposition temperature are responsible for the lower surface resistance and the higher third harmonic generation observed in these samples. We discuss the consequences of these results for the simultaneous optimization of both linear and nonlinear microwave properties of HTS thin films and devices.
[Contact: James C. Booth, (303) 497-7900]

Goodrich, L.F., **II-4: Critical-Current Measurement Methods for Oxide/Superconductor Tapes and Wires**.

Measured verification and considerations in transport critical-current , I_c measurements on Ag-sheathed Bi-2223 conductors are discussed. A number of interlaboratory comparisons of I_c measurements have been performed under Versailles Project on Advanced Materials and Standards (VAMAS), and these will form the basis for a future International Electrotechnical Commission (IEC) standard. Measurements of the unique voltage-current curves and magnetic hysteresis of the I_c are presented. This hysteresis is well known; however, the implications for the measurement standard are presented in detail. The effect of the orientation of the applied magnetic field on the I_c was determined with different sequences of conditions. For example, the I_c at a given angle determined by sweeping the angles in a given field can be 20% different from the I_c determined after the angle was fixed in zero field and then ramping the magnet to the given field. Which value is correct is addressed in the context that the proper sequence of conditions is determined by the

application. The hysteresis in angle-sweep data is related to the hysteresis observed when the field is swept u and down. The necessity of heating the sample to remove the magnetic hystereis between measurements at different angles and temperatures is discussed.
[Contact: Loren F. Goodrich, (303) 497-3413]

Xu, Y., Ekin, J.W, and Clickner, C.C., **Low-Frequency Noise of YBCO/Au Junctions**.

[See Cryoelectronic Metrology.]

Superconductors

Recently Published

Blank, D.H.A., Bijlsma, M.E., Moerman, R., Rogalla, H., Stork, F.J.B., and Roshko, A., **Surface Roughness and Height-Height Correlations Dependence on Thickness of YBaCuO Thin Films**, Journal of Alloys and Compounds, Vol. 251, pp. 31-33 (April 1997).

For high T_c superconducting multilayer applications, smooth interfaces between the individual layers are required. However, in general. YBaCuO grows in a 3D screw-dislocation or island nucleation growth mode, introducing a surface roughness. In this contribution, we study the surface layer roughness as a function of different deposition techniques, as well as deposition parameters. Special attention will be paid to the increase in film roughness with increasing film thickness. For these studies, we used scanning probe microscopy. From these experiments, we obtained an island density decreasing with a square root dependence on the film thickness. Furthermore, height-height correlations indicate that the film growth can be described by a ballistic growth process, with very limited effective surface diffusion. The correlation lengths ξ are on the order of the island size, inferring that the island size forms the mean diffusion barrier. This results in a representation of non-correlated islands, which can be considered as autonomous systems.
[Contact: Alexana Roshoko, (303) 497-5420]

ELECTROMAGNETIC INTERFERENCE

Radiated

Released for Publication

Hill, D.A., **A Plane-Wave, Integral Representation of Fields in Reverberation Chambers**.

A plane-wave, integral representation is presented for well-stirred fields in a reverberation chamber. The representation automatically satisfies Maxwell's equations in a source-free region, and the statistical properties of the fields are introduced through the angular spectrum, which is taken to be a random variable. Starting with fairly simple and physically appropriate assumptions for the angular spectrum, a number of properties of the electric and magnetic fields and the power received by an antenna or a test object are derived. Many of these properties and test object responses are in agreement with other theories or with measured results. An important result for radiated immunity testing is that the ensemble (stirring) average of received power is equal to the average over plane-wave incidence and polarization.
[Contact: David A. Hill, (303) 497-3472]

Radiated

Recently Published

Hill, D.A., **Spherical-Wave Characterization of Interior and Exterior Sources**, Proceedings of the 1998 International Symposium on Electromagnetic Compatibility, Denver, Colorado, August 24-28, 1998, pp. 848-853.

[See Antenna Metrology.]

OPTOELECTRONICS

Released for Publication

Craig, R.M., Gilbert, S.L., and Hale, P.D., **Accurate Polarization Dependent Loss Measurement and Calibration Reference Development**, to be published in the Technical Digest, Symposium on Optical Fiber Measurements, Boulder, Colorado, September 15-17, 1998.

We have implemented an automated, nonmechanical approach to the measurement of polarization dependent loss (and, equivalently, gain). We use a deterministic fixed-states method to derive Mueller matrix elements from intensity measurements at specific polarization states. Voltage-modulated liquid-crystal variable retarders set the polarization states.

Synchronous detection is employed to increase the signal-to-noise ratio of the system and thereby allow measurement resolution to better than 0.001 DB. We present polarization-dependent loss measurements from 0.0016 to 0.56 DB at 1550 NM to verify performance. We also present results from potential artifact standards of an all-fiber design.
[Contact: Rex M. Craig, (303) 497-3359]

Funk, D.S., Veasey, D.L., Peters, P.M., Sanford, N.A., Fontine, N.H., and Hayden, J.S., **Erbium/Ytterbium Co-Doped Glass Waveguide Laser Producing 170 mW Output Power at 1540 NM**, to be published in the Proceedings of the 1999 Optical Fiber Communications Conference, San Diego, California, February 21-26, 1999.

The fabrication and performance of ion-exchanged, channel waveguides in erbium/ytterbium co-doped phosphate glass, which have produced up to 163 mW of cw power near 1540 NM, are described.
[Contact: David Funk, (303) 497-5514]

Gilbert, S.L., and Swann, W.C., **Accurate Wavelength Calibration References for WDM**, to be published in the Proceedings of the 1999 Optical Fiber Communications Conference, San Diego, California, February 21-26, 1999.

NIST has developed transfer standards and high-accuracy internal standards for wavelength calibration in the 1500 NM region. The Standard Reference Material transfer standards are based on the absorption of light by acetylene and hydrogen cyanide.
[Contact: Sarah L. Gilbert, (303) 497-3120]

Itoh, N., Rochford, K.B., Minemoto, H., and Ishizuka, S., **High Frequency Response of Optical Magnetic Field Sensors Using Rare-Earthy Iron Garnet Films**, to be published in the Proceedings of the 13th International Conference on Optical Fiber Sensors, Kyongju, Korea, April 12-16, 1999.

[See Magnetic Materials and Measurements.]

Obarski, G.E., and Hale, P.D., **Measurement of Laser Relative Intensity Noise**.

In this article, we give a description of laser relative iintensity noise (RIN) as it relates to the measurement process. We consider its decomposition into Poisson RIN and excess RIN, and include the concepts of total RIN and RIN frequency spectrum. The effect is also given.
[Contact: Gregory E. Obarski, (303) 497-5747]

Peters, P.M., Veasey, D.L., Funk, D.S., Sanford, N.A., Houde-Walter, S.N., and Hayden, J.S., **Ion Exchange Er^{3+}/Yb^{3+} Glass Waveguide Laser Producing 20 mW Output Power**.

A waveguide laser producing 20 mW of cw output near 1.54 μm has been demonstrated. The device was fabricated in an Er^{3+}/Yb^{3+} co-doped silicate glass by K^+ ion exchange from a nitrate melt. The waveguides supported a single transverse mode at 1.5 μm which had dimensions of 20.5 ($\pm$1) μm wide by 11.5 ($\pm$0.6) μm deep. Efficient coupling into the lowest order pump mode led to excellent pump-signal overlap. With a 70% transmitting output coupler, a slope efficiency of 6.5% was achieved, and the device generated 19.6 mW of signal light for 398 mW of launched 974.5 NM pump light.
[Contact: Philip M. Peters, (303) 497-7300]

Rochford, K.B., and Dyer, S.D., **Demultiplexing and Measurement of Interferometrically Interrogated Fiber Bragg Grating Sensors Using Hilbert Transform Processing**.

We demonstrate accurate demultiplexing of fiber Bragg grating sensors with closely spaced reflection wavelengths. The peak reflectance wavelengths of gratings with reflectance maxima separated by less than 2 NM can be accurately determined through a demultiplexing method based on Hilbert transforms of interferograms. We demonstrate a wavelength demultiplexing accuracy of 19 pm, limited by interferometer alignment, with less then 4 pm crosstalk and repeatability. Based on our results, we expect that a large number of gratings can be demultiplexed with a single broadband source and a single receiving interferometer, provided that the interferogram is sampled with accurate intervals near the Nyquist rate.
[Contact: Kenneth B. Rochford, (303) 497-5170]

Rose, A.H., Etzel, S.M., and Rochford, K.B., **Electro-Optic Kerr Effects in Optical Fiber Current**

Sensors, to be published in the 13th International Conference on Optical Fiber Sensors, South Korea, April 12-16, 1999.

We discuss theoretically and experimentally the affects of the electro-optic Kerr effect on optical fiber current sensors in a simulated GIS environment. We show that current, voltage, and phase can be measured using one transducer.
[Contact: Kenneth B. Rochford, (303) 497-5170]

OPTOELECTRONICS

Recently Published

Ata, E.P., Gökkavas, M., Onat, B., Islam, M.S., Tuttle, G., Mirin, R., Knopp, K.J., Bertness, K.A., Christensen, D.H., Ünlü, M.S., and Özbay, E., **High Bandwidth-Efficiency GaAs Schottky Photodiodes for 840 NM Operation Wavelength**, Proceedings of the 1997 International Semiconductor Device, Charlottesville, Virginia, December 11-13, 1997 (unpaged).

The bandwidth capabilities of optical-fiber telecommunication systems are still not fulfilled with present performance of optoelectronic devices, and high-speed photodetectors have been an active research area for the past two decades. It has been shown that a Schottky photodiode, with 3-DB operating bandwidth exceeding 200 GHz, is one of the best candidates for high-speed photodetection. However, like p-I-n photodiode, Schottky photodiode also suffers from bandwidth-efficiency trade off. A recent family of photodetectors, resonant cavity enhanced (RCE), has the potential to overcome this trade-off as compared to conventional photodetectors. The RCE detector operation is principally the same as the conventional one, with the main difference being an increased internal optical field by virtue of a Fabry-Perot resonant cavity. The higher field enables high efficiencies with thinner absorbing layers, resulting in high-quantum efficiency with low photo-carrier transit times. The Schottky photodiode has its advantages in its simplicity, compatibility with monolithic integration processes and use of thin Schottky metal as the top mirror of the resonant cavity. However, high-speed RCE photodetector research has mainly concentrated on p-I-n type photodiodes, where near 100% quantum efficiencies along with a 3-DB bandwidth of 17 GHz have been reported. There are only a few reports on RCE Schottky photodiodes. We briefly report our work on design, fabrication, and testing of high-speed RCE Schottky photodiodes for operation at 840 NM.
[Contact: Kevin J. Knopp, (303) 497-7368]

Lehman, J.H., and Aust, J.A., **Bicell Pyroelectric Optical Detector Made From a Single $LiNbO_3$ Domain-Reversed Electret**, Applied Optics, Vol 37, No. 19, pp. 4210-4212 (1 July 1998).

Using electric-field poling at room temperature, we selectively reversed the direction of the spontaneous polarization in a 200 μm thick, z-cut $LiNbO_3$ electret to produce a bicell pyroelectric detector. The detector required only a single set of electrodes, one electrode on the front surface and one on the back surface. Microphone noise that is typical of monocell pyroelectric detectors is reduced in the present device. Our spatial uniformity data indicate that the optical response of one half of the bicell detector area was equal to and opposite the other half within 1.2%. The microphone suppression of the bicell pyroelectric detector was less than -36 DB from 10 Hz to 50 Hz and less than -118 DB at 35 Hz of that of a reference monocell pyroelectric detector. The substrate thickness is significantly greater than those of other domain-engineered pyroelectric detector designs and allows us to build practical, large-area detectors for radiometric applications.
[Contact: John H. Lehman, (303) 497-3654]

Mirin, R.P., Gossard, A.C., and Bowers, J.E., **Characterization of InGaAs Quantum Dot Lasers with a Single Quantum Dot Layer as an Active Region**, Physica E, Vol. 2, No. 1-4, pp. 738-742 (July 4, 1998).

Quantum dot lasers with an active region consisting of just a single quantum dot layer have been grown using molecular beam epitaxy and characterized from 80 K to 300 K. The quantum dot lasers lase from excited states over the entire temperature range. The characteristic temperature is 185 $\pm$ 10 K over the temperature range 80 K to 141 K and decreases to 111 $\pm$ 2 K from 141 K to 304 K. The effects of scattering by the quantum dots have been analyzed and shown to be unimportant in these quantum dot lasers.

[Contact: Richard P. Mirin, (303) 497-3317]

Schlager, J.B., and Franzen, D.L., **Differential Mode Delay Measurements On Multimode Fibers in the Time and Frequency Domains**, *NIST Special Publication 930*, Technical Digest-Symposium on Optical Fiber Measurements, 1998.

Multimode fiber bandwidth is currently measured using an overfilled launch condition. Such a launch is achieved by uniformly exciting the core and launching with a numerical aperture (NA) that exceeds the NA of the fiber. This launch provides a reproducible way to predict the bandwidth performance of LED-based fiber networks. New high-speed fiber networks, however, take advantage of the faster modulation capabilities of laser sources like vertical cavity surface emitting lasers (VCSELs) and Fabry-Perot lasers. These sources typically underfill the available mode volume of the fiber. In most cases, these underfilled or restricted laser launches give bandwidth performances that meet or exceed the bandwidth performances predicted with overfilled launches. The specific behavior, however, depends on the differential mode delay (DMD) of the fiber's refractive index profile. We have developed a frequency-domain DMD measurement system with a temporal resolution of 0.2 ps. This represents a more than 50 times improvement over more conventional time-domain DMD measurement systems. The new system allows accurate DMD measurements on shorter fiber samples, and the DMD results compare well with those obtained using the time-domain technique.
[Contact: John B. Schlager, (303) 497-3542]

Young, M., **Mode-Field Diameter of Single-Mode Optical Fiber by Far-Field Scanning**, Applied Optics, Vol. 37, No. 24, pp. 5605-5619, August 20, 1998.

I used the direct far-field method to measure the mode-field diameter of a single-mode fiber with an expanded uncertaintly of 30 NM, with a coverage factor of 2. For a step-index fiber with a mode-field diameter of approximately 9 μm, the major sources of uncertaintly are nonlinear in the electronics, angular error and scattered light in the apparatus, and the polarization and noncircularity of the mode of the fiber. This paper concludes by showing an inconsistency in the derivation of the far-field expression for mode-field diameter.
[Contact: Matt Young, (303) 497-3542]

PRODUCT DATA SYSTEMS

Released for Publication

Goldstein, B.L.M., Kemmerer, S.J., and Parks, C.H., **A Brief History of Early Product Data Exchange Standards**.

The following paper traces the history of product data exchange standards from the physical model through electronic representations such as IGES. This paper provides an understanding of the early efforts leading to ISO 10303--Standard for the Exchange of Product Model Data (STEP), but does not cover STEP's development.
[Contact: Barbara L.M. Goldstein, (301) 975-2304]

VIDEO TECHNOLOGY

Boynton, P.A., and Kelley, E.F., Can We Make Accurate Front-Projection Display Measurements in Stray Light Conditions?

Specifications of electronic projection displays, such as contrast ratio, are often based on measurements made in ideal darkroom conditions. However, not everyone has access to such a facility. Stray light from other sources in the room (both direct and reflected off of surfaces, such as walls and tables) as well as back-reflections, contribute to the measurement, giving an inaccurate measurement of the projector light output. So how can we verify that the projector that we have purchased is operating according to its specifications? A few simple solutions are offered.
[Contact: Paul A. Boynton, (301) 975-3014]

Boynton, P.A., and Kelley, E.F., **Small-Area Black Luminance Measurements on White Screen Using Replica Masks**, Conference Digest of the 1998 SID International Symposium, Anaheim, California, May 17-22, 1998.

Luminance measurements of small areas of black pixels on white-screen backgrounds are often used as metrics in display measurements, such as

character-stroke contrasts or deep modulation transfer functions. Serious errors may be made in measurements and subsequent ergonomic conclusions if glare contributions of the measurement are not considered. We show a simple method for accounting for glare corruption of luminance measurements by using replica masks.
[Contact: Paul A. Boynton, (301) 975-3014]

Kelley, E.F., Jones, G.R., and Germer, T.A., **Three Components of Reflection**.

Beautiful darks in bright light. That's another way of saying that reflections from the display surface are under control. Perhaps we will see advertisements like this in the future. However, such a description is vague unless the reflection properties are clearly indicated. If we were to only state the familiar diffuse and specular reflection properties, would the specifications be adequate? Not really you may still not know how the display will look to your eye. This article will show that there are three components of reflection with which we must contend in order to properly describe display reflection as it is perceived by the eye. This is not a criticism of existing reflection measurement methods and recommended practices. The appearance of an electronic display to the eye. This is not a criticism of existing reflection measurement methods and recommended practices. The appearance of an electronic display to the eye may require a more complete description than the appearance of fabric or paint. What we offer here is an extension to existing reflection specifications.
[Contact: Edward F. Kelley, (301) 975-3842]

VIDEO TECHNOLOGY

Recently Published

Boynton, P.A., and Kelley, E.F., **Assessment of Colour Measurement Systems Using Interference Filters**, Proceedings of the Commission Internationale de L'Eclairage (CIE) Expert 1997 Symposium, Scottsdale, Arizona, November 21-22, 1997, pp. 22-27 (1998).

Spectroradiometers and tristimulus colorimeters are used in display measurements to measure color in one of several color space coordinate systems. How well these instruments can measure the color coordinates can be checked simply by using interference filters. If a narrow-band interference filter is measured, the chromaticity coordinates obtained from the instrument should fall very near the spectrum locus of a standard color space. Assuming the instrument is linear and the white point calibrated accurately, if the colors on the spectrum locus are measured correctly, then all other colors within the color gamut should be measured accurately. The filter bandwidth and background noise in the instrumentation are modeled and shown to contribute to the distance of the color coordinates from the spectrum locus. Error sources within the measuring system are identified which could explain these observed anomalies. This method serves as a diagnostic tool, not a calibration.
[Contact: Paul A. Boynton, (301) 975-3014]

Fiske, T.G., Silverstein, L.D., Penn, C., and Kelley, E.F., **Viewing Angle: A Matter of Perspective**, Digest of Technical Papers, Society for Information Display International Symposium, Anaheim, California, May 17-22, 1998, pp. 937-940.

Setting viewing-angle requirements and specifications for displays depend on how viewing-angle is defined. There is significant confusion in the industry regarding the definition and use of horizontal and vertical viewing-angle. Moreover, the relations between viewing-angle defined in Cartesian coordinates and common representations in spherical and goniometer-specific coordinates are often confused. This paper will show how incorrect definitions of viewing-angle and failures to apply appropriate transformations between coordinate systems lead to errors in setting specifications and reporting results.
[Contact: Edward F. Kelley, (301) 975-3842]

Jones, G.R., and Kelley, E.F., **Bidirectional Reflectance Factor Measurements on Flat Panel Displays**, Proceedings of the Commission Internationale de L'Eclairage (CIE) Expert 1997 Symposium, Scottsdale, Arizona, November 21-22, 1997, pp. 28-33 (1998).

Commonly used methods for measuring reflections from the surface of an electronic display are often subject to large errors and ignore critical aspects of reflection from modern-day displays. This is largely

due to an over simplication of the reflection process, namely, considering reflection to be a simple combination of diffuse (Lambertian) and regular specular reflections. The Flat Panel Laboratory at the National Institute of Standards and Technology is developing an alternative method that accurately predicts the reflected luminance from a flat panel display from known lighting conditions using the bidirectional reflectance distribution function (BRDF) of the display. The BRDF reflection model separates the reflection into three components: diffuse (or Lambertian), specular, and haze. The simplifications made and methods to obtain the required coefficients are discussed. Calculated values for the reflected luminances are compared to measured values for several lighting conditions.
[Contact: Edward F. Kelley, (301) 975-3842]

Jones, G.R., and Kelley, E.F., **Reflection Measurement Problems Arising from Haze**, Proceedings of the Commission Internationale de L'Eclairage (CIE) Expert 1997 Symposium, Scottsdale, Arizona, November 21-22, 1997, pp. 945-946 (1998).

Irreproducibility in some reflection measurement methods arises from the observance of the haze component of reflection (non-regular-specular, non-Lambertian). Because of the haze component, the measured reflection is sensitive to the apparatus configuration. We show the effects of detector lens aperture and detector distance on the measurement of the reflected luminance. Only for detectors with small subtense angles can reproducibility be assured when haze reflection is nontrival.
[Contact: Edward F. Kelley, (301) 975-3842]

Kelley, E.F., **Flat-Panel Display Measurements and Standards**, Society for Information Display, Applications Seminars, Anaheim, California, May 19-21, 1998, pp. A-4/1-34.

Display metrology as applied to flat-panel displays is discussed. Topics include the importance of proper set-up, expected measurement uncertainty vs. repeatability, and problems in making accurate light measurements. The role played by measurement diagnostics is considered, and the routine use of such diagnostics is encouraged. A review of the status of international display standards is provided.
[Contact: Edward F. Kelley, (301) 975-3842]

Kelley, E.F., Jones, G.R., and Germer, T.A., **Display Reflectance Model Based on the BRDF**, Displays, Vol. 19, No. 1, pp. 27-34, June 30, 1998.

Many flat panel displays (FPDs) have anti-reflection surface treatments that differ in character from those of traditional cathode-ray-tube displays. Specular reflection models (mirror-like, producing a distinct image) combined with diffuse (Lambertian) reflection models can be entirely inadequate to characterize the reflection properties of such displays. A third reflection component, called haze, exists between specular and diffuse. Display metrology should account for the haze component of reflection. That is best done using the bidirectional reflectance distribution function (BRDF). The effects of using oversimplified reflectance models are discussed in contrast with a parameterized BRDF.
[Contact: Edward Kelley, (301) 975-3842]

ADDITIONAL INFORMATION

Announcements

Knight, S., and Settle-Raskin, A., **Project Portfolio FY 1997 - The National Semiconductor Metrology Program**, NISTIR 5851 (May 1997).

The National Semiconductor Metrology Program (NSMP) is a NIST-wide effort designed to meet the highest priority measurement needs of the semiconductor industry as expressed by the *National Technology Roadmap for Semiconductors* and other authoritative industry sources. The NSMP was established in 1994 with a strong focus on mainstream silicon CMOS technology and an ultimate funding goal of $25 million annually. Current annual funding of approximately $11 million supports the 24 internal projects which are summarized in the Project Portfolio booklet.

The NSMP is operated by NIST's Office of Microelectronics Programs, which also manages NIST's relationships with the Secmiconductor Industry Association (SIA), SEMATECH, and the Semiconductor Research Corporation (SRS). These

Seiler, D. G., Diebold, A. C., Bullis, W. M., Shaffner, T. J., McDonald, and Walter, E. J., Editors, **Characterization and Metrology for ULSI Technology**, American Institute of Physics (AIP), 1998.

This book contains a collection of papers presented at its 1998 International Conference. The Conference summarized major issues and gave critical reviews of important semiconductor techniques crucial to the advancement of our technology. The editors responsible for putting together this almost 1,000-page hardbound tome are names well-known in the semiconductor industry: David Seiler of NIST; Alain Diebold of SEMATECH; W. Murray Bullis of SEMI; Thomas Shaffner, formerly of Texas Instruments, now with NIST; Robert McDonald, formerly of Intel, and E. Jane Walters formerly with NIST, now retired. The information obtained in this book range from metrology needs of the semiconductor industry for the next decade and a long-term business consideration of metrology and wafer inspection equipment to integrated metrology. Other papers deal with models, materials and gate dielectric subjects for front-end processes, 300 mm wafer issues, interconnect, lithography, packaging and materials characterization.

The various subjects covered by the book are collected under the main headings of Front End, Interconnect, Back End of Line, Lithography, Packaging, Review of Critical Analytical Techniques and 300 mm and Beyond.

All of the papers are authored by leaders in their fields, who are involved in edge-of-technology work. This collection of material provides up-to-date reviews of major issues, problems, and characterization techniques for semiconductor R&D and manufacturing. The book also contains a keyword searchable CD-ROM version of the text and figures as well.

Characterization and Metrology for ULSI Technology is an extremely useful reference too for anyone involved in these areas of the industry, whether in the equipment or semiconductor manufacturing sectors. It is available from the American Institute of Physics (800) 777-4643.
[Contact: David G. Seiler, (301) 975-2054]

include NIST's memberships on the SIA committees that develop the *Roadmap* and numerous SRC technical management committees. In addition, NIST is active in the semiconductor standards development activities of American Society for Testing and Materials (ASTM), Deutsches Institut für Normung (DIN), Electronic Industries Association (EIA), International Organization for Standardization (ISO), and Semiconductor Equipment and Materials International (SEMI).
[Contact: Steven Knight, (301) 975-2871]

Lists of Publications

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

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NIST during the period from January 1970 through publication of this report. A few earlier references that are directly related to the present work of the Division are also included. This edition of the bibliography is the first since the Electromagnetic Technology Division split into two Divisions, and it includes publications from the areas of cryoelectronic metrology and superconductor and magnetic measurements. The optical electronic metrology section found in earlier editions is now being produced separately by the new Optoelectronics Division of NIST. That companion bibliography to this publication is NISTIR 5052.
[Contact: Ann G. Bradford, (303) 497-3678]

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

This bibliography lists the publications by the staff of

the National Institute of Standards and Technology's Electromagnetic Fields Division for the period January 1970 through July 1996. It supersedes NISTIR 5039 which listed the publications of the Electromagnetic Fields Division from January 1970 through July 1995. Selected earlier publications from the Division's predecessor organizations are included.
[Contact: Ruth Marie Lyons, (303) 497-3132]

Schmeit, R.A., **Electrical and Electronic Metrology: A Bibliography of NIST Electricity Division's Publications, NIST List of Publication 94** (March 1997).

This bibliography covers publications of the Electricity Division (and predecessor organizational units), Electronics and Electrical Engineering Laboratory, National Institute of Standards and Technology, for the period of January 1968 through December 1997. A brief description of the Division's technical program is given in the introduction.
[Contact: Ruth A. Schmeit, (301) 975-2401]

Smith, A.J., **A Bibliography of Publications of the NIST Optoelectronics Division**, NISTIR 5065 (September 1997).

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

Walters, E.J., **NIST List of Publications 103, National Semiconductor Metrology Program and the Semiconductor Electronics Division, 1990-1996** (March 1997).

This List of Publications includes all papers relevant to semiconductor technology published by NIST staff, including work of the National Semiconductor Metrology Program and the Semiconductor Electronics Division, and other parts of NIST having independent interests in semiconductor metrology. Bibliographic information is provided for publications from 1990 through 1996. Indices by topic area and by author are provided. Earlier reports of work performed by the Semiconductor Electronics Division (and its predecessor divisions) during the period from 1962 through December 1989 are provided in NIST List of Publications 72.
[Contact: E. Jane Walters, (301) 975-2050]

1998 Calendar of Events

March 10-12, 1998 (San Diego, California)

Fourteenth **Annual IEEE Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM) 1998**. Co-sponsored by NIST and IEEE, the symposium will present papers on current thermal management, modeling and measurement work on electronic components and systems in the following areas: thermal characterization - component through system; analytical and computational modeling and simulation; experimental methods and applications; thermal design and testing for reliability; and thermal aspects of high temperature electronics.
[Contact: David L. Blackburn, (301) 975-2068] July 20-21, 1998 (Breckenridge, Colorado)

International Workshop on Ferroelectric Integrated Optics. This workshop targets the science and technology of optical ferroelectric materials, emphasizing on areas such as optical telecommunications and remote sensing. Also, optical ferroelectric materials and advances will be discussed.
[Contact: Norman A. Sanford, (303) 497-5239]

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NIST SILICON RESISTIVITY SRMs

The Semiconductor Electronics Division of NIST provides Standard Reference Materials (SRMs) for bulk silicon resistivity through the NIST Standard Reference Materials Program. An improved set of resistivity SRMs, on 100 mm wafers, are now available. These wafer SRMs improve upon the earlier 50 mm diameter SRM sets 1521, 1522, and 1523.

The new SRMs have similar values of nominal resistivity as the earlier set, but offer improved uniformity and substantially reduced uncertainty of certified values due both to material and procedural improvements. The most significant feature of the new SRMs is in their certification, which is performed using a dual-configuration four-probe measurement procedure rather than the single-configuration measurements specified in ASTM F84. Extensive testing has shown that the dual-configuration procedure reduces random variations of measurement and probe-to-probe differences.

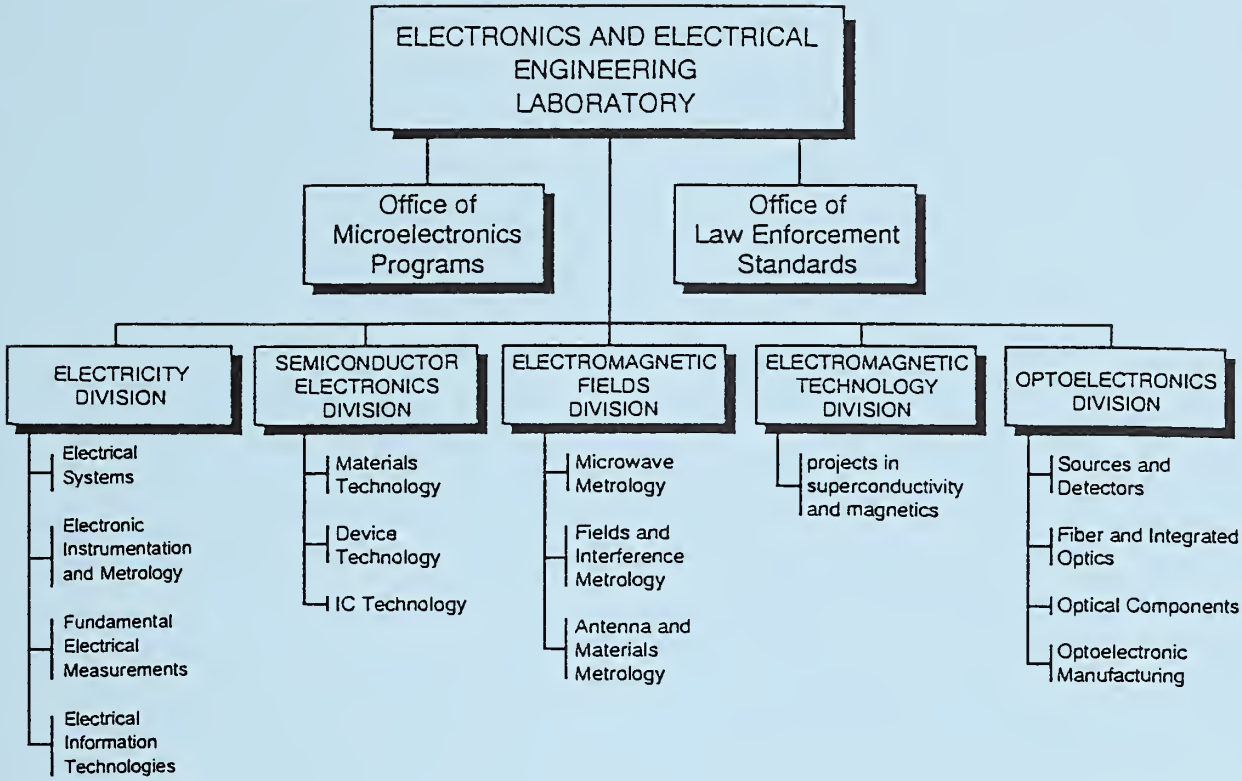
Technical insights presented by the rigorous certification process are available in NIST Special Publication 260-131, *Standard Reference Materials:* The Certification of 100 mm Diameter Silicon Resistivity SRMs 2541 through 2547 Using Dual-Configuration Four-Point Probe Measurements. Individual data for each wafer are supplied along with the SRM certificate.

NIST SILICON BULK RESISTIVITY STANDARD REFERENCE MATERIALS

DATE UPDATED: APRIL 1999

NOMINAL RESISTIVITY (ohm·cm)	NEW SRMs	2-Sigma Uncertainty
0.01	2541	0.14%
0.1	2542	0.11%
1	2543	0.35%
10	2544	0.16%
25	2545	0.12%
100	2546	0.12%
200	2547	0.29%

NIST sells SRMs on an as-available basis. For technical information, contact James R. Ehrstein, (301) 975-2060; for ordering information, call the Standard Reference Materials Program Domestic Sales Office: (301) 975-6776.



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