ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY

The research programs of the Electronics and Electrical Engineering Laboratory (EEEL) encompass nearly all key disciplines in electrical, electronic, electromagnetic, and electro-optic materials; components; instruments; and systems, with an emphasis on metrology. The Laboratory has laboratories in Gaithersburg, Maryland and Boulder, Colorado; its annual budget is approximately $80 million.

EEEL's programs encompass measurements and related research in the following areas: (1) fundamental electrical units; (2) superconducting electronics and Josephson-junction devices, quantum-Hall-effect devices, and application of single-electron tunneling phenomena; (3) high-critical-temperature and low-critical-temperature superconductors, devices, and systems; (4) magnetic materials, bulk, and thin films, including recording media and heads; (5) silicon and compound semiconductor materials, processes, and devices including power devices; (6) test structures for manufacturing control at nanoscale levels; (7) optoelectronics, including lightwave communications and sensing technology, lasers, and optical recording; (8) microwave and millimeter-wave materials, instruments, systems, and antennas, including monolithic microwave/millimeter-wave integrated circuits; (9) electromagnetic compatibility and interference, both radiated and conducted, including power quality; (10) radio frequency and microwave/millimeter-wave noise; (11) dielectric materials, over a range of frequencies ranging from power system to millimeter-wave and including materials for use at high voltages; (12) electric power transmission and distribution; (13) signal processing and waveform acquisition, including high-speed, high-bandwidth electronic and optical signals; (14) analog and digital electronic instrumentation and automatic test equipment; (15) product data exchange for electronic manufacturing and virtual enterprises; and (16) metrology in support of the criminal justice and law-enforcement communities.

In support of these programs, EEEL has a number of special research facilities, including (1) the Ampere-balance (watt balance) experiment leading to the "electronic kilogram"; (2) single-electron tunneling laboratories; (3) small- and nanoscale fabrication facilities for silicon and compound semiconductors and superconductors, including molecular-beam epitaxy systems for fabricating compound semiconductor devices and for developing *in situ* process measurements, a low-throughput semiconductor processing research laboratory, and facilities for fabricating both low-critical temperature and high-critical temperature superconducting electronics and materials; (4) microwave anechoic chambers, transverse electromagnetic cells, and mode-stirred chambers for electromagnetic compatibility and electromagnetic interference research; and (5) ranges for characterization of antennas and probes, including planar and spherical near-field scanning ranges, an extrapolation range, a ground-screen range (open-area test site), and a time-domain range.

EEEL's excellent facilities; internationally known professional staff; access to additional capabilities offered by other NIST laboratories and strong ties to universities, industrial research laboratories, other US Government laboratories, and to standards laboratories in other countries; combine to offer a dynamic, rich, and challenging research environment. For further details regarding a specific research opportunity, contact the listed Adviser. For other inquiries, contact the

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Single copies of a CD-ROM describing the technical programs of the Laboratory are available on request to the above, on an as-available basis.

Also see the World Wide Web site (URL) http://www.eeel.nist.gov.

Semiconductor Electronics Division
Gaithersburg, Maryland

Molecular Electronics: Electrical Metrology

CA Richter CA Hacker 50.81.21.B4752

KW Moletronics

KW Nanotechnology

KW Test structures

KW Nanofabrication

KW Self-assembled monolayers

KW Current-voltage

KW Capacitance-voltage

JS Suehle

In Molecular Electronics—a field that is predicted to have important technological impacts on the computational and communication systems of the future—molecules perform the functions of electronic components. We are developing methods to reliably and reproducibly measure the electrical properties of small ensembles of molecules in order to investigate molecular conduction mechanisms. Specifically, we are developing test-structures based on nanofabrication and MicroElectroMechanical Systems processing techniques for assessing the electrical properties and reliability of moletronic molecules. In addition to the complexity of the nanofabrication of test structures, the challenges associated with measuring the electrical properties (such as current-voltage and capacitance-voltage as functions of temperature and applied fields) of these small molecular ensembles are daunting. The measured electrical properties will be correlated with systematic characterization studies by a variety of probes and the results used in the validation of predictive models. This task is part of a cross-disciplinary, inter-laboratory effort at NIST whose overall role is to develop the measurement science that will enable molecular electronics to blossom into a viable industry.

Active Thin Film Electronics Test Platforms

DJ Gundlach CA Richter 50.81.21.B6188

KW Organic electronics

KW Transparent electronics

KW Flexible electronics

KW Oxide semiconductors

KW Organic semiconductors

KW Test structures
KW Current-voltage
KW Capacitance-voltage
The Macro Electronics (ME) Project at NIST is addressing critical metrology issues associated with active thin film electronic devices, which represent the critical building blocks for emerging large-area, flexible and printed electronics technologies. Examples include organic and inorganic (i.e. transparent oxide) electronic devices such as photovoltaic cells (PVs), thin film transistors (TFTs), light emitting diodes (LEDs). The ME Project is developing test structures and test methodologies to extract the fundamental electrical properties of novel thin film semiconductors. This task is part of a large interdisciplinary team of physicists, chemists, engineers, and material scientists at NIST whose goal is to develop an integrated measurement platform to predict the performance of active thin film electronic devices based on composition, structure, and materials properties. The approach is to correlate the results of unique, world-class characterization techniques such as NEXAFS and cold-neutron scattering with the electrical behavior of electrical test structures to determine the relationship between device performance and the structure, properties, and chemistry of critical materials and interfaces.

Organic Electronics

DJ Gundlach 50.81.21.B6435

KW Organic electronics
KW Thin-film transistor
KW OTFT
KW OPV
KW Photovoltaics
KW Macroelectronics
KW Flexible electronics
KW Optoelectronics
KW Sensors
We are interested in organic-based electronic devices for use in large-area low-cost electronic applications, such as displays, RFID, and sensor arrays. Thin films of organic semiconductors, insulators, and conductors are used to fabricate integrated devices and circuitry, and it is expected that printing and inexpensive roll-to-roll processing will be developed to manufacture low-cost electronics on large-area flexible plastic substrates. The organic thin-film transistor (OTFT) is a core device since most electronic applications require active switches or circuitry. Although research on the OTFT has spanned nearly 20 years, we still

lack a physically accurate, concise microscopic understanding of its electrical operation.

Developing predictive and physically-accurate models and theories is critical to establishing organic electronics as a mature and manufacturable technology. Core challenges hindering further development include (1) a poor understanding of the electronic structure at critical device interfaces; (2) a lack of detailed knowledge about defect generation, device reliability, and device lifetime; and (3) the extended use of in appropriate device structures, test methodologies, or models for extracting device parameters from measured electrical characteristics. The goal of this project is to solve these challenges by developing the appropriate electrical/optoelectrical characterization methods, test structures, and test methodology to quantitatively extract device properties and parameters, and to develop the microscopic models needed to describe the device operation and reliability.

Scanning Probe Metrology

JJ Kopanski 50.81.21.B1498

KW Atomic force microscopy
KW Electrical properties
KW Semiconductor doping
KW Nanoscale analysis

We are developing scanning probe microscopes to characterize and manipulate the physical and electrical properties of electronic devices, semiconductors, and related materials at the nanometer resolution scale. Projects are aimed at impacting silicon technology 5 to 10 years in the future or at characterization problems unique to compound semiconductors, molecular electronic devices, or quantum devices. We recently developed scanning capacitance microscopy as a tool for measuring the two-dimensional dopant profile across a silicon p-n junction. We are particularly interested in projects to develop techniques to measure material properties in three dimensions and that have spatial resolution below 1-nm. Our interests extend to other scanning probe techniques, including variable temperature scanning tunneling microscopy in UHV, surface photovoltage microscopy, and other optically pumped probes.

Electrical and Optical Characterization of Semiconductors and Devices

DG Seiler 50.81.21.B4754

KW Compound semiconductors
KW Hall effect
KW Optical spectra
KW Semiconductor doping

KW Semiconductor surfaces

Research focuses on understanding the electronic, optical, and magneto-optical behavior of semiconductor materials and devices. Areas of interest include the role of impurities and native defects in bulk crystals, and novel and useful properties induced by quantum confinement in reduced dimensional structures (heterostructures, quantum wells, superlattices, and quantum wires and dots). A broad range of optical techniques is available for reflection, transmission and absorption, and modulation spectroscopy; photoluminescence and photoluminescence excitation; Raman and resonant-Raman scattering; spectroscopic ellipsometry, and surface photovoltage. A wide variety of electrical and magnetotransport techniques are also utilized to characterize the electronic properties. Emphasis is placed on understanding fundamentals and technologically relevant properties as well as developing accurate measurement techniques.

Physics of Semiconductor Nano-Devices and Nano-Structures

HS Bennett 50.81.21.B5515

KW Si, SiGe, GaAlAs, InGaAs, GaSb, GaN, InP

KW Other compound semiconductors

KW Carbon and boron nitride nanotubes

KW Transport properties

KW Band structure and densities of states

Theoretical solid-state physics research for nano-electronic applications is in progress in order to understand the operation of advanced electronic and molecular electronic devices and to provide more physically correct and numerically robust carrier transport models. Such transport models are used to interpret measurements and to enable predictive computer simulations of nano-electronic devices. For example, topics include densities of states, band structures, high-concentration effects, carrier lifetimes, and carrier mobilities. The approach involves careful experimental verification of the device models for elemental and compound semiconductors; for metallic, semiconducting, and insulating nanotubes; and for molecular electronics. We are interested in extending our theoretical research to include magnetic semiconductors (spintronics) such as manganese-doped GaAs, nanotubes, ultrathin nanolayers, and confined electrons and photons in semiconductor nanostructures.

Theory and Models for Predicting the Reliability of Nanoelectronic Devices and Structures

HS Bennett 50.81.21.B6959

KW Si, SiGe, GaAlAs, InGaAs, GaSb, GaN, InP

KW Other compound semiconductors
KW Nanoelectronics reliability
KW Gate oxides
KW Ultrathin dielectrics
KW Transport properties
KW Band structure and densities of states

Nanoscale devices are very difficult to "see" and "measure." Understanding nanoscale devices places great demands on theory, modeling, computer simulations, and visualization of massive amounts of data. Nanoelectronics are also very difficult to optimize. A large variety of approaches are being explored. Such exploration can be much more efficient if theoretical guidance can be provided, which means that theory and computer simulations are now very critical for advances in nanoelectronics. Opportunities exist for research on predicting the performance and reliability of nanoelectronics based on the combination of theory and experiment, allowing a quicker and cheaper way to achieve better understanding of (1) how to choose and process advanced materials for nanoelectronics, (2) ways to design in reliability, and (3) new measurement methods at the nanoscale. Models that describe correctly the time, process, and size dependent behavior of materials and their interfaces are essential for device optimization in terms of performance, reliability, and cost. Our theoretical opportunities will have close collaborations with ongoing experimental investigations along the same line.

Silicon Building Blocks for Beyond-CMOS Circuits

JS Suehle CA Richter 50.81.21.B6457

KW Nanowires
KW Quantum electronics
KW Silicon
KW Resonant tunneling device
KW Quantum dots
KW Single-electron transistors

The complementary-metal-oxide-semiconductor (CMOS) field-effect-transistor is showing fundamental limits associated with the laws of quantum mechanics and the limitations of fabrication techniques. This is driving research on innovative solutions to augment or replace CMOS technologies. Our goal is to develop the metrology that will enable emerging information processing technologies to extend electronic device performance improvements beyond the incremental scaling of CMOS. Quantum devices compatible with Si technologies such as silicon nanowires (Si-NW), resonant tunneling devices, and single-electron transistors, deliberately exploit quantum and size effects. We are developing the electrical and physical metrology of the basic building blocks of these confined-silicon devices (e.g., quantum layers, wires, and quantum dots). Much of our focus has been on the fabrication of Si-NW FET devices. We are making and characterizing "top-down" fabricated Si-NW FETs based on pushing the fabrication limits of silicon-on-insulator (SOI) technology as well as Si-NWs grown using CVD then positioned and contacted to form "bottom-up" test structures and devices. Our interests include, but are not limited to fabrication, simulation, and characterization of device structures and constituent materials/processes. Our primary expectation is to be able to identify and address critical metrology issues for this emerging technology of silicon-based quantum devices.

Modeling Advanced Semiconductor Devices for Circuit Simulation

AR Hefner, Jr 50.81.21.B1507

KW Circuits
KW Computer-aided design
KW Computer simulation
KW Semiconductors

Accurate circuit simulator models for advanced semiconductor devices are required for effective computer-aided design of electronic circuits and systems. However, the semiconductor device models provided in most commercial circuit simulators (e.g., simulation program with integrated circuit emphasis) are based on microelectronic devices, and they do not adequately describe the dynamic behavior of advanced semiconductor devices. Therefore, research focuses on the following: (1) physics-based models—for advanced semiconductor devices such as power and compound semiconductor devices; these models are implemented into available circuit and system simulation programs; (2) parameter extraction algorithms—for obtaining model parameters from terminal electrical measurements; and (3) characterization procedures—for verifying the models' ability to simulate the behavior of the devices within application circuits. NIST also works closely with commercial software vendors to make the new models available to circuit design engineers, and has established the NIST/IEEE Working Group on Model Validation to develop comprehensive procedures for evaluating the performance of circuit simulator models. (For more information, see http://ray.eel.nist.gov/modval.html.)

MicroElectroMechanical Systems

M Gaitan 50.81.21.B1509

KW Integrated circuits
KW Microelectronics

KW Optoelectronics
KW Sensors
KW Semiconducting films
KW Micromechanics

The MicroElectroMechanical Systems (MEMS) project focuses on the development of new MEMS-based sensors and actuators for measurement applications. It functions in a multidisciplinary environment with collaborations in the NIST laboratories in Chemistry, Materials Science, Physics, Biotechnology, and Building and Fire Research. Current activities in the project include thermal-based elements, mechanically resonant structures, microwave elements, and microfluidic systems. The project is also developing MEMS test structures, test methods, and standards to characterize device properties for device performance and reliability testing. These MEMS-based test structures are being utilized to characterize thin-film properties in mainline semiconductor fabrication processes. We are interested in postdoctoral applications not only from individuals who have specialized in MEMS research but also from individuals of other science disciplines who wish to learn microfabrication methods and apply their expertise for new measurement applications.

NanoBioTechnology for Single Cell and Single Molecule Manipulation and Measurement

M Gaitan 50.81.21.B5516

KW Microfabrication
KW Nanofabrication
KW MicroElectroMechanical systems
KW MST
KW Microchannels
KW Microfluidic systems
KW Bioelectronics
KW Nanobiotechnology

Our work focuses on developing microfluidic systems and nanofluidic restrictions for cell and biomolecule transport and detection. We are interested in methods to pattern cells on surfaces, cell adhesion, sorting, and electronic and electrochemical monitoring of cell activity. We are also interested in nanofluidic systems for DNA, RNA, and protein transport and detection to determine the structure and function. This project is part of a multidisciplinary program with collaborations in the NIST laboratories in Chemistry, Materials Science, Physics, and Biotechnology. Research would focus on the development of new fabrication methodologies, design and fabrication of new and novel nanofluidic systems, and measurement methods.

Reliability of Integrated Circuit Dielectric Films

JS Suehle 50.81.21.B1510

KW Silicon-based materials
KW Integrated circuits
KW Dielectrics
KW Thin films

Aggressive scaling of gate oxide thickness used in silicon integrated circuits necessitates the understanding of physical mechanisms responsible for dielectric degradation and breakdown. We are particularly concerned with the reliability of ultrathin SiON gate oxides and high-dielectric constant stack dielectrics. Research focuses on (1) identifying parameters to determine the physics of time-dependent dielectric breakdown of dielectric films in the tunneling regime, (2) determining the effectiveness of highly accelerated stress tests to predict long-term reliability of thin dielectric films, (3) relating analytical characterization of oxide bulk and interfaces to electrical behavior, (4) identifying and controlling fabrication process parameters that affect intrinsic and extrinsic failure modes, and (5) characterizing MOSFET parameter drift phenomenon such as positive bias temperature instability and negative bias temperature instability.

Physical and Electrical Properties of Advanced Gate Dielectric Films

JS Suehle 50.81.21.B1512

KW Thin films
KW Dielectrics
KW Electrical measurements
KW Interfaces

It is increasingly difficult to characterize ultrathin gate dielectric films (typically 0.1 nm to 3.0 nm) used in MOS devices as technology drives them ever thinner. We are developing electrical test methods (using conventional techniques such as I–V and C–V, as well as low-temperature magnetotransport techniques) to measure the physical properties (e.g., film thickness and permittivity) of alternate gate dielectric materials such as high-k metal oxides as well as ultrathin SiO_2. Electrical results are compared with those of optical and other measurement methods, and fundamental physical models are developed to be effective for more than one measurement technique. Because the interface between the dielectric film and the silicon substrate is critical to understanding these measurements, we are developing techniques to characterize buried interfaces (i.e., interface roughness) and are determining how the interface and physical properties affect device performance and reliability.

Optical and Physical Characterization of Thin Films Used in Integrated-Circuit Devices

NV Nguyen 50.81.21.B5517

KW Ellipsometry
KW Internal photoemission
KW Thin films
KW Optical properties

The continued scaling of integrated-circuit (IC) technology requires more stringent precision and accuracy for the optical and physical measurements of thin films. Our research involves the development of optical measurement techniques, specifically spectroscopic ellipsometry, and internal photoemission and the enhancement of data analyses and modeling. Input from various physical, optical, and electrical techniques are needed to improve our knowledge of the electronic and optical properties of these thin films and their interfaces. With a broad collaboration from various thin-film measurement groups within NIST, our research will focus on relating the analyses of HRTEM, scanning probe methods, x-ray reflectance, Fourier-transform infrared, photo reflectance, Raman scattering, and various electrical techniques to improve our understanding of these films and also validate some of the optical models used in the analysis of the ellipsometric data. Simple actual IC devices can be fabricated in-house for electrical test structures.

DNA Transport in Single Nanopores

JJ Kasianowicz 50.81.21.B4789

KW Biosensors
KW Proteins
KW Membranes
KW DNA

We are studying the mechanism by which DNA partitions into and threads through single nanometer-scale pores. This experimental and theoretical effort focuses on understanding how genetic information is exchanged between organisms (e.g., between virus and host cells or between bacteria) and on adapting single nanopores for novel biological and biotechnological applications. It was recently shown that the interaction between polymers and a single nanopore provides the physical basis of a multi-analyte sensor. Work is also underway to determine whether this system could be used as tool to rapidly sequence long strands of DNA and RNA.

Structure-Function Determination of Bacterial Toxins

JJ Kasianowicz JWF Robertson 50.81.21.B5527

KW Proteins
KW Bacillus anthracis
KW Membranes
KW Genetic engineering
KW Toxins
KW Anthrax
KW Structure

Many bacteria, including *Bacillus anthracis,* secrete proteins that bind to cell membranes and that are toxic to cells and tissues. In some cases, the interaction between two or more such proteins secreted by the same type of bacteria is required to elicit lethal effects. In collaboration with other Federal laboratories, we are using neutron reflectometry, SPR and electrophysiology to determine the structure, function, and mechanism of assembly of these and other membrane proteins.

Physical and Chemical Characterization of Next Generation Technologies

CA Hacker 50.81.21.B6408

KW Surface science
KW Interfacial reactions
KW Semiconductor
KW Infrared spectroscopy
KW Atomic force microscopy
KW Nanotechnology
KW High-k-dielectrics
KW Molecular electronics
KW Bio electronics

As transistors continue to shrink, the electrical properties are increasingly the result of near surface or interfacial effects rather than bulk phenomena. As technology progresses, it has become clear that to truly characterize electronic devices, thorough physical and chemical characterization must accompany thorough electrical measurements. We are investigating next generation technologies such as molecular electronic and high-k-metal advanced gate stack devices to understand the underlying physical and chemical properties. Some of the techniques utilized include Fourier-transform infrared spectroscopy, spectroscopic ellipsometry, contact angle measurements, x-ray photoelectron spectroscopy, ultraviolet photoemission spectroscopy, and several scanned probe microscopies.

Functionalizing Semiconductor Surfaces

CA Hacker 50.81.21.B6418

KW Silicon
KW Self-assembled monolayer
KW Semiconductor
KW Infrared spectroscopy
KW Atomic force microscopy
KW Nanotechnology
KW Sensor
KW Molecular electronics
KW Bio electronics

Combining organic monolayers with semiconductor surfaces is of interest for many differing applications including molecular electronics, sensors, and bio-electronics. Monolayers on semiconductor surfaces take advantage of the increased electrical functionality, chemical and structural robustness, wealth of fabrication knowledge, and present a less disruptive technology compared with monolayers on typically used metal substrates. We are investigating various experimental approaches to form organic monolayers on semiconductor surfaces. The resulting films are characterized by using Fourier-transform infrared spectroscopy, spectroscopic ellipsometry, contact angle measurements, and atomic force microscopy. Key aspects of this work involve examination and optimization of alternative functionalization pathways for monolayer formation and thorough characterization of the resulting monolayer. More advanced applications include formation of biorepellent monolayers in addition to monolayers specifically tailored to bind differing biological moieties.

Sensor Networks for Next-Generation Factory

Y Li-Baboud

KW Sensor networks
KW Semiconductor manufacturing
KW Security
KW Network performance
KW Data quality
KW Data visualization
KW Embedded systems

Next-Generation Factory (NGF) is a current effort driven by industry to increase factory productivity by reducing cycle-times and cost of manufacturing. Achieving the productivity goals requires greater reliance on efficient, intelligent automation. Factory sensor networks are fundamental in realizing advanced process control, equipment predictive and preventative maintenance, as well as scheduling and dispatching of factory systems for both real-time and retrospective applications. We are investigating methods to characterize and improve data quality in sensor networks. Some of the key challenges include real-time embedded system performance, network performance, data visualization and data security.

Information Management for Electronics Product Authentication

Y Li-Baboud

KW Electronics
KW Semiconductor
KW Supply chain
KW Product life cycle
KW Uncertainty modeling
KW Risk modeling
KW Security
KW Information management
KW Identity management

The high profit opportunities, the diffused outsourcing of manufacturing and the structure of the supply chain render electronic products, components and materials susceptible to counterfeiting. We are investigating the types of information and statistical models necessary to make optimal, cost-effective decisions for managing uncertainty, risks, costs and authentication throughout the life cycle of electronic products and components. The key focus areas include uncertainty and risk modeling as well as exploring use of federated identity management models for managing product authentication.

Optoelectronics Division
Boulder, Colorado

Molecular Spectroscopy Using Ring-Down Cavities and its Application to Semiconductor Crystal Growth

KA Bertness 50.81.52.B5883

KW Cavity ring-down spectroscopy
KW Molecular spectroscopy
KW Semiconductor source gases
KW Impurity measurement
KW Semiconductor growth

Gases such as phosphine, ammonia, arsine, nitrogen, silane, and germane are widely used in semiconductor synthesis and processing. Most of these processes are highly sensitive to contamination, although the precise incorporation mechanisms and concentrations of concern are poorly known. We have developed cavity ring-down spectroscopy as a tool for high sensitivity measurements of impurities in gases along with the capability of using many of these gases in gas-source molecular beam epitaxy growth. The system has a sensitivity for measuring water as an impurity down to approximately 30 ppb in phosphine and 10 ppb in nitrogen using laser light near 935 nm. We anticipate the availability of new laser sources in the next few years that will significantly enhance the flexibility and sensitivity of the instrument. Because of its fast time response, cavity ring-down spectroscopy is also useful for measuring time-dependent effects and confirming the efficacy of purifiers. We invite proposals extending the capability of the instrument to new impurities or host gases (e.g, novel studies of correlations of gas properties with semiconductor crystal properties and fundamental studies of the impurity incorporation process).

Photonic Crystals

R Mirin 50.81.52.B3901

KW Photonic band engineering
KW Nanophotonics
KW Single-photon turnstiles
KW Photonic crystal lattice
KW Circular Bragg grating
KW Photonic bandgaps
KW Solitons
KW Optical filters
KW Microcavity

Photonic crystals are meta-materials whose optical properties are determined by the photonic band structure that arises from resonant photon scattering off the nanometer-scale physical structure, in direct analogy with well-established concepts of electronic bands in semiconductors. Photonic crystals offer the new possibility of creating materials with custom-tailored bandgaps and dispersion curves, liberating light-emitting devices from the constraints caused by the underlying material dispersion. We are pursuing an active program of photonic crystal dispersion engineering with the aim of vastly enhancing the performance of semiconductor light emitters. Specifically, we are designing, fabricating, and measuring photonic crystal nanocavities for Purcell-enhanced single-photon sources, circular Bragg gratings for enhanced light extraction in LEDs, chirped waveguide gratings for dispersion control in semiconductor mode-locked lasers, and waveguide arrays for nonlinear soliton formation. Our capabilities include electromagnetic modeling, nanofabrication, quantum-optical measurements, and ultrafast measurements.

Semiconductor Quantum Optics

R Mirin 50.81.52.B4380

KW Quantum dots

KW Quantum optics

KW Control of spontaneous emission

KW Photonic/electronic turnstiles

We are developing a regulated source of single photons by fabricating a single photon turnstile with a single quantum dot. Our goals include spontaneous emission control and delivery of the individual photons to any other on-chip location through photonic crystal waveguides. Important technologies for this project include microcavities, microdisks, photonic crystals, and nonlinear optics. We invite experimental and/or theoretical proposals that can complement and expand on this ongoing effort. Available resources include epitaxial semiconductor growth, e-beam lithography, fabrication facilities, and finite difference time domain software for electromagnetic modeling.

Optical Spectroscopy of Quantum Dots

R Mirin 50.81.52.B5884

KW Quantum dots

KW Quantum optics

KW Quantum information

KW Ultrafast

Self-assembled semiconductor quantum dots have been demonstrated for many optoelectronic devices (lasers, optical amplifiers, and photodetectors) and proposed for novel applications such as quantum computing. However, there is still a lack of fundamental knowledge about the optical and electronic properties of these quantum dots, such as homogeneous linewidth, oscillator strength, coupling, and carrier escape mechanisms, especially at the single quantum dot level. We invite proposals that will investigate these or other fundamental characteristics of self-assembled quantum dots.

Coherent Spectroscopy of Quantum Dots

R Mirin 50.81.52.B6459

KW Quantum dots
KW Quantum optics
KW Quantum information
KW Coherent control

We are currently performing high-resolution optical spectroscopy on self-assembled semiconductor quantum dots. Our technique employs narrow linewidth tunable lasers and heterodyne detection. Recent results from our group have shown that these structures are almost purely radiatively broadened at 9 K. We are soliciting proposals to extend this experimental method to investigate multi-exciton and charged exciton complexes. We are interested in the fundamental properties of these transitions as well as the coherence in these coupled-state systems. Optical phenomena such as electromagnetic-induced transparency should be observable.

MBE Growth of Quantum Dots

R Mirin 50.81.52.B5885

KW Quantum dots
KW MBE
KW Quantum optics
KW Quantum information

We are developing single photon sources based on epitaxially grown single quantum dots. Many quantum dots are deposited during growth and individual dots are isolated by masking and etching. The goal of this project is to use novel methods of controlling the exact placement and size of the quantum dots. This will enable schemes of coupling two or more quantum dots for applications in quantum information and quantum optics.

Engineered Quantum States of Light

R Mirin TS Clement 50.81.52.B6460

KW Quantum optics
KW Quantum metrology
KW Cat states
KW Fock states
KW Entanglement
KW Quantum tomography

SD Dyer

We are investigating methods of creating new quantum states of light such as Schrodinger cat states, NOON states, and Fock states. These new states have a variety of applications, including linear optical quantum computing, quantum metrology (e.g., Heisenberg limited interferometry), and fundamental physics (loop-hole free Bell measurements). We are particularly interested in utilizing our high quantum efficiency photon number resolving detectors to enable creation of these states. Our group includes both experimentalists and theorists. We invite proposals to further develop and utilize quantum states of light.

Spectroscopy of Wide-Bandgap Mesoscopic Materials Characterization by CW and Ultrafast Nonlinear Optics

NA Sanford JB Schlager 50.81.52.B4766

KW Gallium nitride
KW Three-nitride semiconductors
KW Nanowires
KW Near-field microscopy (NSOM)
KW Ultrafast nonlinear optics
KW Near-field spectroscopy
KW Multiphoton spectroscopy
KW Solid immersion lens microscopy
KW Confocal microscopy

Sacnning near-field and confocal microscopies provide unique methods of characterizing a wide variety of semiconductor, dielectric, and hybrid optoelectronic materials and interfaces. We are developing methods of nanoscopic multiphoton spectroscopy and nonlinear optics for examining local structural and electronic properties of the wide-bandgap III-nitride alloy semiconductors with particular emphasis on quantum-confined heterostructures formed in compound III-nitride nanowires. The techniques include ultraviolet (UV) second-harmonic generation in addition to cw and time-resolved, multiphoton UV spectroscopy that employ NSOM and confocal techniques. We are particularly interested in the study of local defects, polytyping, inversion domains, and alloy segregation. We are also interested in studies of nanoscale strain and piezoelectricity, and the impact of such phenomena on the spectroscopy of quantum confined wires and discs. Our efforts are generally collaborative with other NIST staff that specialize in high-resolution cathodoluminescence, TEM, EBSD, and CBED.

Nanowire Resonators, Oscillators, Mechanical Properties, and Applications

NA Sanford KA Bertness 50.81.52.B6728

KW Gallium nitride
KW Three-nitride semiconductors
KW Nanowires

KW NEMS
KW Clocks
KW Sensors
Nanowires fabricated in GaN and related III-nitride compound semiconductors offer compelling functionality for nanomechanical, NEMS, sensors, oscillators, resonators, and clocks. This work is a natural extension of our related efforts in the growth and characterization of wide-bandgap nanowire structures. We invite proposals that seek to explore studies of fundamental coupled piezoelectric and nanomechanical phenomena in III-nitride nanowires, as well as proposals that address application areas for these structures such as nanowire surface functionalization leading to advanced sensor development.

Metrology and Prototyping of Wide-Bandgap Semiconductor Quantum Nanowire Structures and Devices

NA Sanford KA Bertness 50.81.52.B5887
KW Three-nitride semiconductors
KW Quantum nanowires
KW Wide band-gap semiconductors
KW Nanotechnology
A Roshko
Semiconductor quantum nanowires offer new applications in areas such as chemical sensors, NEMs, nanolasers, and nanoscale thermoelectric devices. A key aspect of these structures that makes the research challenging and enables the utility of various nanowire devices is that many physical phenomena do not scale from the macro to nano regimes. Our research primarily focuses on nanowires grown from wide-bandgap semiconductors including the group III-nitride (GaN, AlN, InN) and ZnO material systems. We are interested in nanowire growth techniques that include MBE, vapor transport, and catalyst methods. We are interested in a range of research topics, from the applied to the fundamental, covering such areas as understanding the evolution of the microstructure of nitride semiconductors; development of nanotemplates for patterned growth of nanowires; optimization of p-type doping in nanostructures; developing methods of making electrical contact to single nanowires or arrays of nanowires; and development of new measurement methods for quantifying nanoscale piezoelectric, transport, and optoelectronic phenomena. Current device interests include nanowire lasers, LEDs, photodetectors (primarily in the UV), solar cells, UV and visible light emitters (i.e., for solid state lighting and water purification), and field emitting ion sources for mass spectrometry. We are also working on the design and fabrication of prototype nanowire electronic devices such as FETs. We welcome proposals aimed at new technological

aspects of semiconductor quantum nanowire research and application. Our characterization resources include triple-axis x-ray diffraction, atomic force microscopy, scanning electron microscopy, ultrafast nonlinear optical characterization, near-field scanning optical microscopy, cw and time-resolved photoluminescence, device processing, and electrical measurements. Opportunities exist for collaborative work within NIST for more specialized characterization such as TEM, field-emission SEM, STM, cathodoluminescence, nanoscale electrical and thermal measurements.

Our existing programs use gas-source molecular beam epitaxy growth of nitrides, phosphides, and arsenides with a focus on nanostructures. Other in-house collaboration includes vapor phase and catalyst growth methods for nanowire growth. Also, a wide range of clean room processing equipment is available in order to carry out prototyping of specialized nanostructures.

Quantum Structures within Semiconductor Nanowires

KA Bertness NA Sanford 50.81.52.B6960

KW Three-nitride semiconductors
KW Quantum nanowires
KW Wide band-gap semiconductors
KW Nanotechnology

JB Schlager

Semiconductor nanowires offer a unique template for arrays of quantum dots with a degree of spatial control not currently possible with planar growth methods. GaN nanowires allow unique coupling of mechanical, electrical, and optical properties which can be exploited to vary transport and optical transition efficiency between quantized nanostructures. For example, variations in nanowire alloy composition can be used to create tunnel junctions for single electron transistors which are grown in series with quantum dots. Quantum dots can be coupled with surface plasmons to create new probes with spatial resolution below 10 nm. The nanowires can also serve as a quasi-one-dimensional growth substrate with nonpolar surfaces onto which strings or shells of quantum dots can be grown. Our existing programs have extensive capability for group III nitride nanowire growth and characterization. (See opportunity 50.81.52.B5887). Proposals that involve simple extensions to other materials systems are also welcome.

Templates for Nanostructure Positioning

A Roshko KA Bertness 50.81.52.B6961

KW Nanostructures
KW Nanowires

KW Quantum dots
KW Position control
KW Templates
KW Morphology
KW Strain

Nanostructures are of significant interest due to their unique physical properties and potential for electronic, electromechanical, and optoelectronic devices. However, current growth methods lead to random spatial distributions and relatively large size distributions. Lack of homogeneity reduces the potential of nanostructures for many applications. We are interested in developing substrates with templates based on surface morphology, strain, or other means for controlled positioning of nanostructures including semiconductor quantum dots and/or wide bandgap nanowires. We have extensive facilities for nanostructure growth and characterization. (See opportunity 50.81.52.B5887.)

Superconducting and Nanometer-Scale Devices for Infrared to Millimeter-Wave Applications

E Grossman 50.81.52.B1533

KW Superconductivity
KW Millimeter waves
KW Infrared technology and processes
KW Radiometry
KW Nanotechnology

Our goal is to explore the physical mechanisms and limitations of devices operating in the frequency range from 0.1 to 100 THz, and to develop novel devices and measurement techniques. For the short wavelength end, we use electron-beam lithography to fabricate the submicron structures required to minimize parasitic impedances. One specific research area includes mixers and harmonic mixers for frequency synthesis and high-resolution spectroscopy; another research area involves IR to millimeter-wave imaging radiometry. Our main focus is on high-sensitivity bolometers and superconducting multiplexers based on SQUIDS. Other devices of interest include high-Tc superconducting bolometers; room-temperature, thin-film bolometers; lithographic and/or micromachined coupling structures, particularly antennas and integrating cavities; superconducting mixers/rectifiers; and room-temperature mixers/rectifiers (e.g., lithographic metal-insulator-metal diodes).

High Speed Optoelectronics Measurements

PD Hale DF Williams 50.81.52.B4008

KW Optoelectronics

KW Optical receivers

KW Heterodyning

KW Optical sampling photoconductivity

Increasing data rates and bandwidths of optical telecommunications, cable television systems, remote microwave antenna links, and computer data interconnections all require advanced techniques for accurately determining optical transmitter and receiver frequency response in both magnitude and phase. Methods being investigated at NIST include heterodyne and ultrashort pulse technologies. Current research focuses on fully calibratable measurement of frequency response with low uncertainty to 110 GHz and extension to 400 GHz in the near future. We are especially interested in the measurement of response phase with low uncertainty using high-speed sampling techniques and in methods for verifying these measurements in a coaxial or on-wafer environment. Future calibration artifacts will require fabrication of ultrafast photodetectors. We are also interested in theoretical studies of the modulation characteristics, frequency response, spectral response, saturation, and electrical characteristics of optical receivers that would further enhance our metrology effort.

High-Speed Optical Receivers and Optoelectronic Integrated Circuits

PD Hale R Mirin 50.81.52.B4767

KW Photoconductivity

KW Optical rectification

KW Microwave measurements

KW Optical receivers

DF Williams

The need for ever smaller size and increased bandwidth of optoelectronic devices is requiring these devices to be packaged in hybrid modules and optoelectronic integrated circuits. Characterization of the frequency response and electrical properties of these devices requires a change in measurement strategy away from coaxially connected modular devices to on wafer measurements. We are developing a new fully calibratable on-wafer measurement paradigm for calibrating optoelectronic and electronic devices to bandwidths exceeding 110 GHz. We are interested in fabricating new high-speed receivers that will be used as calibration artifacts in this new measurement strategy. Possible designs might include metal-semiconductor-metal photoconductive switches or p-i-n photodiodes grown in low-temperature GaAs or InGaAs. The work will result in artifacts that will be used to calibrate high-speed measurement equipment.

Optical Field Measurements Using Linear Optical Sampling

P. A. Williams T Dennis

KW Signal Sampling
KW Optical Communications
KW High-speed Measurements
KW Network Impairments
KW Optical Modulators
KW Optical Arbitrary Waveform Generation
KW Optical Nonlinearities

Linear optical sampling (LOS) is a technique by which picosecond laser pulses are combined interferometrically with the optical signal to be measured, enabling equivalent time sampling using low-bandwidth detection. The terahertz bandwidth potential of LOS is determined by the duration of the short optical pulses rather than the detection electronics. We have constructed an LOS system having milliradian phase resolution and polarization diversity using the pulses of a phase-stabilized NIST optical frequency comb. We have used the unique phase stability of our system to characterize the amplitude, phase, and polarization of optical telecommunications signals having complex modulation formats at data rates up to 40 gigabits per second.

We believe that LOS can be applied successfully to a wide range of applications. We are looking to use LOS for optical network performance monitoring, and in particular the characterization of chromatic dispersion, polarization mode dispersion, signal to noise ratio, and dynamic traffic effects. We seek to expand our measurement bandwidth to hundreds of gigahertz with higher sampling rates, and to adapt the technique to real-time sampling, single pulse characterization, and nonlinearities and dynamic effects in optical materials. LOS also appears well suited to the characterization of optical arbitrary waveforms, passive components such as optical fibers, and active components including optical modulators.

Optical Pulse Characterization and System Monitoring

PD Hale JA Jargon PA Williams T Dennis 50.81.52.B6436

KW Pulse measurements

KW Pulse noise
KW Optical communications
CM Wang KA Remley DF Williams
Optical component measurements alone will not be adequate to design and operate the next generation of optical communications, which will include dynamic channel add/drop switching, routing, gain control, equalization, and dispersion compensation. Accurate methods to dynamically characterize system impairment by thorough measurements of optical signal amplitude, phase, jitter, and noise are needed. Research opportunities are available to develop methods that will assess system impairment, particularly methods that will discriminate between failure modes and offer insight into the strengths and weaknesses of various modulation, error correction, and dispersion compensation schemes.

Characterization of Dispersion Compensation and Equalization Schemes
PD Hale JA Jargon 50.81.52.B6461
KW Optical communications
KW Wireless communications
KW Dispersion compensation
KW Importance sampling
CM Wang KA Remley DF Williams
Various optical and electrical methods of dispersion compensation and gain equalization are now being employed to extend the length of short and long reach optical communications systems. Electrical impairments known as frequency dependent loss and multipath interference also appear in board level electrical interconnects, wireless communications, and data storage. Although the impairments appear in systems that differ greatly and can affect vastly different time scales, they can be addressed through similar techniques of equalization and filtering. We are soliciting methods for characterizing equalization and dispersion compensation methods, and particularly their efficacy for correcting low probability impairments.

Waveform Metrology
PD Hale 50.81.52.B5521
KW Waveform metrology
KW High-speed measurements
KW Signal integrity
KW Deconvolution
KW Sampling
KW Oscilloscope
KW Eye pattern

KW Pulse

Current techniques used by industry for characterizing digital waveforms, both electrical and optical, are qualitative at best. As a result, the specifications for test equipment and communication systems are conservative and are not well understood. For example, the computer and communications industries both need measurements of different types of jitter and inter-symbol interference because these effects could cause erroneous bit transmission. We have developed a world-class capability for characterizing and calibrating equipment used in the acquisition of high-speed waveforms. We are looking for proposals that will investigate calibrated waveform measurement and the quantitative study of waveform metrics that characterize parameters such as random jitter, inter-symbol interference, and eye margin.

Tunable Laser Ensemble Development for Laser Radiometry

JH Lehman 50.81.52.B5888

KW Tunable laser

KW Optical detector

KW Laser radiometry

KW Optical fiber

KW Detector calibration

KW Measurement uncertainty

The calibration of laser power and energy, and optical fiber meters over wavelengths ranging from 0.2 µm to 10 µm requires laser sources that are stable, broadly tunable, and having well defined optical properties (e.g., polarization, beam quality). Our goal is to go beyond merely demonstrating what wavelengths may be produced by novel methods. This will enable cost-efficient, routine, calibration services having low uncertainties. We may employ new methods and equipment or optimize existing methods and equipment to ensure that NIST can provide laser power measurement comparisons with standards laboratories around the world as well as manufacturers of laser and optical fiber power measurement equipment. Several new projects are under consideration to provide novel, robust methods for the generation and transportation of tunable laser light.

Optical Properties of Carbon Nanotube Coatings

JH Lehman 50.81.52.B6729

KW Radiometer

KW Optical detector

KW Thermal coatings

KW Laser radiometry

KW Raman spectroscopy
KW Carbon nanotubes
KW Detector calibration
KW Dielectric function

Several areas of research are currently being pursued based on determination and modification of optical properties of bulk carbon nanotubes (CNTs) on a pyroelectric detector platform. Using this unique measurement platform, we seek to demonstrate improved coatings for thermal detectors, purification, separation, modeling, and quantitative metrology for bulk carbon nanotubes. We emphasize using laser sources and detector responsivity over wet chemistry and conventional spectroscopy. The dielectric function and topology of bulk single wall nanotubes is of interest and is relevant to modeling in addition to the experimental work. Raman spectroscopy measurements that are compatible with CNTs on the pyroelectric detector platform must be optimized to corroborate our detector measurement results and modeling.

Ultraviolet Laser Metrology

JH Lehman ML Dowell 50.81.52.B1563

KW Ultraviolet lasers
KW Carbon nanotubes
KW Radiometer
KW Optical detector
KW Thermal coatings
KW Laser radiometry
KW Detector calibration
KW Measurement uncertainty

In recent years, ultraviolet (UV) laser—specifically diode lasers—have found increased use in a variety of industrial, commercial, homeland security, and medical applications. For example applications range from high definition digital video to detection of chemical and biological aerosols. Currently there is no primary standard for calibration of high-power continuous laser power meters. Aging and hardening of materials exposed to UV laser radiation is among the challenges to developing new measurement tools. Currently we are pursuing carbon nanotube based coatings for thermal detectors as well as optoelectronic means of creating artificial spectra for calibration of chemical, biological, and explosive sensors. Our work includes the development of high-accuracy UV primary and transfer standard detectors, beam profile characterization, laser power, energy, and dose measurement services.

Infrared Frequency Comb Development

N Newbury 50.81.52.B5523

KW Nonlinear optics
KW Fiber optics
KW Supercontinuum
KW Frequency comb
KW Frequency stabilization
KW Wavelength standards

A supercontinuum of light that spans over an octave in frequency can be generated by launching pulses from femtosecond fiber lasers into highly nonlinear optical fiber. Through recently developed techniques, this supercontinuum can be phase-locked to a reference and thereby provide a stable frequency comb with spacing equal to that of the laser repetition rate. These frequency combs revolutionized optical frequency metrology since optical frequencies can now easily be measured relative to the time standard. We invite proposals that explore the generation, properties, and applications of infrared frequency combs. We are particularly interested in the generation of stable frequency combs in the telecommunications band at high repetition frequencies, with very robust configurations and with very low excess noise. Such combs could support the generation of low phase noise microwaves. We are also interested in expanding the spectral coverage of fiber-based comb sources into the mid-infrared spectral regions for eventual applications in spectroscopy.

Applications of Frequency Combs to Remote Sensing

N Newbury 50.81.52.BXXX

KW Nonlinear optics
KW Fiber optics
KW Supercontinuum
KW Frequency comb
KW LADAR
KW Spectroscopy

Frequency combs are finding greater applications outside of their initial area of optical frequency metrology. We are interested in exploring these applications using our existing fiber-based frequency combs. The two primary areas of exploration include precision LIDAR and precision spectroscopy. In terms of LIDAR, the comb acts as an ideal coherent, short pulsed source and it should be able to support a variety of different applications including high precision 3D mapping and synthetic aperture LIDAR. The comb is also an ideal source for spectroscopy because of its coherence and broad spectral output. Comb-based spectroscopy has the potential to combine the advantages of narrow band laser-based spectroscopy with classical broadband absorption spectroscopy. Our work focuses on both improving the basic technology for comb-based spectroscopy and demonstrating its advantages for different sensing applications.

Quantum Electrical Metrology Division
Gaithersburg, Maryland

Capacitance Standards and AC Measurements

Y Wang 50.81.71.B5185

KW Capacitance standards
KW Fundamental electrical units
KW SI farad, SI henry
KW SI ohm, ac bridge
KW ac quantum Hall
KW Single-electron tunneling

The Electrical Quantum Metrology Division ties the US legal system of electrical units for capacitance, inductance, and resistance to the SI system of units. First, we realize the SI farad from the SI meter through the calculable capacitor whose capacitance depends on only one length. We then realize the SI henry from a Maxwell-Wien bridge and the SI ohm from a quadrature bridge. However, routine calibrations demanded by the evolving industry call for research beyond these classical experiments used for the realization of the electrical units. Current research focuses on the frequency dependence, in the audio frequency range from 50 Hz to 20 kHz, of capacitance standards including the calculable capacitor, toroidal cross capacitors, and fused-silica capacitors. In close collaboration with other staff, we are also pursuing two alternative representations of the farad: (1) an ac Quantum Hall Resistor with a quadrature bridge and (2) a single electron pump with a cryogenic capacitor. To fully take advantage of these quantum effects, classical precision ac bridge methods must be re-examined and automated whenever possible.

Digital-Signal-Processing Techniques for Precision Resistance and Impedance Scaling

Y Wang RE Elmquist 50.81.71.B6730

KW Digital-Signal-Processing
KW SI electrical units
KW Josephson ac voltage
KW AC and DC bridge
KW Quantum Hall resistance
KW Quantum watt

The Quantum Electrical Metrology Division maintains a number of primary standards for the SI electrical units. In order to effectively disseminate these standards and provide the needed SI traceability to US industry, we also maintain and continuously improve precision scaling capabilities that allow us to link customer standards with the primary standards. For example, we provide traceable resistance calibrations over 20 orders of magnitude based on the quantum Hall effect and for capacitance, we cover a broad two-dimensional space from 0.1 pF to 100 μF at frequencies from 2 Hz to 10 MHz. We plan to employ Digital-Signal-Processing (DSP) techniques to improve and automate traditional, analog-based ac and dc bridges. The on-going research includes development of a floatable DSP-based signal generator and analyzer to realize a quantum Watt standard by linking power to the Josephson ac voltage standard. Future research focuses on linking all impedance standards to the DC quantum Hall resistance standard.

Electronic Kilogram Determining the Planck Constant and the Kilogram Unit of Mass

RL Steiner ER Williams 50.81.71.B1491

KW Electrical measurements
KW Quantum electrical standards
KW Optical interferometry
KW Fundamental measurement
KW Gravity measurement
KW Mass measurement
KW Force measurement
KW Instrumentation programming

This experiment uses an electromagnetic force balance to measure the SI (Systems International) unit of power, the watt. The result is a determination of the Planck constant and the electron mass, relative to SI reference units: volt (Josephson effect), ohm (Quantum Hall effect), meter (laser), second (atomic clock), and kilogram (artifact standard). As early as 2011, international standards committees will consider redefining the SI kilogram (the last artifact-based unit) by relating a kilogram mass to a defined Planck constant. With a goal of achieving reliable operability at 0.02 ppm combined relative standard uncertainty, this watt balance experiment is currently being attempted by only a few of the best international standards laboratories, with NIST in the lead to meet the desired goals. The complexity of this experiment arises from its broad range of precision measurements involving force and mass (local gravity determination, mechanical design, material properties), velocity and position (optical interferometry, electronic timing), and voltage and current (analog electronics, electromagnetism, superconductivity). Applicants need a strong familiarity in several areas of classical electromagnetism, mechanics, general electronics, or interferometer optics, and experience with modern instrumentation programming or servo-control techniques. Experience is also useful in superconductivity, material science, electromagnetic shielding, or vibration isolation.

Resistance Comparisons for Fundamental Electrical Standards

RE Elmquist 50.81.71.B5186

KW Nanoelectronics
KW Josephson effect
KW Solid-state physics
KW Single-electron tunneling
KW Metrology triangle

Converting single-electron tunneling (SET) devices into next-generation usable precision electronic will require precise cryogenic current-multiplication and a better understanding of highly resistive thin films. Our work would be aided by fabrication of improved thin-film resistance-material devices and studies of mesoscopic processes contributing to resistive noise at low temperature. This research would contribute to development of a precision three-way comparison of the SET current, lead to better measurements of the quantum hall effect’s Von Klitzing constant, and improve the uncertainty of precision SET-based current sources.

Electronic Kilogram: Measuring the Planck Constant and the Kilogram Unit of Mass

RL Steiner 50.81.71.B6227

KW Electrical measurements
KW Quantum electrical standards
KW Optical interferometry
KW Fundamental measurement
KW Gravity measurement
KW Mass measurement
KW Force measurement
KW Instrumentation programming

There are races in physics, and this is one of them. In 2011, an international standards committee will examine the results from several international metrology laboratories, including new results from NIST, and consider redefining the SI (Systems International) kilogram (the last artifact-based unit) by relating mass to electronic and quantum reference units, i.e., the Planck constant, (h). The best way to make this measurement so far has been a technique using an electromagnetic force balance to compare mechanical power (a watt related to mass) against electrical power (related to energy and the Planck constant). Measurements unite five different units and their reference sources: volt (Josephson effect), ohm (Quantum Hall effect), meter (laser), second (atomic clock), and kilogram (artifact standard). Historical evidence shows that the kilogram artifact has changed in its 120 year existence, so creating a new standard related to fundamental physical constants c (the speed of light) and h will provide a new mass standard, equivalent in stability to the measurement uncertainty in the complex measurement of the electronic standards, a goal of about 20 parts in 10^9. Other goals are in making the system easier to use, and in the long run, designing a robust and reliable calibration system meant to join a few other watt balance systems as the e-kilogram standard of the world for the next 30+ years. Applicants with an interest and good background in basic physics will be able to gain experience in a wide range of precision measurements involving force and mass (local gravity determination, mechanical design, material properties, vibration isolation), velocity and position (optical interferometry, electronic timing, servo control), voltage and current (analog electronics, Josephson effect, electromagnetism, superconductivity, RF shielding), plus, of course, data analysis (statistics, signal processing). Prior experience in instrumentation programming (LabVIEW, C) is beneficial.

Condensed Matter Physics Research on Graphene for New Intrinsic Quantum Electrical Standards

DB Newell 50.81.71.B6717

KW Fundamental electrical units

KW Condensed matter physics

KW Graphene

KW Quantum Hall resistance

KW Single electron tunneling

KW Josephson effect

KW Quantum standards
KW Electrical standards
The Fundamental Electrical Measurements group within the Quantum Electrical Metrology Division is pursuing the development of graphene metrology through the development of near-room-temperature quantum Hall devices and other quantum electrical standards. Initial investigations involve precise and accurate measurements of graphene's Hall and longitudinal conductivity against existing GaAs quantum Hall standarads as a function of charge carrier density, temperature, and applied magnitude field to determine the feasibility of using graphene as a metrological quantum conductance standard. Future investigations include the challenge of developing graphene metrology for Single Electron Tunneling (SET) and Josephson voltage devices as they apply to fundamental electrical standards.

Quantum Electrical Metrology Division

Boulder, Colorado

Quantum Voltage

SP Benz PD Dresselhaus 50.81.72.B6464

KW Josephson junction
KW Superconducting thin films
KW Voltage standard
KW Microwave
KW Integrated circuit
KW Fabrication
KW Digital waveform synthesis
KW Nanofabrication
We are looking for researchers who are interested applying their solid state physics or electrical/microwave engineering expertise to develop practical and useful superconducting circuits, devices, and systems. Currently, we have active research areas in the following: high-speed Josephson junctions with barriers near the metal-insulator transition for digital superconducting integrated circuits, low-loss microwave circuit with lumped superconducting passive components, tunable phase-locked oscillators, and extending precision quantum-based waveform synthesis from audio frequencies to rf and microwaves. We are also developing the measurement techniques for ac and dc voltage metrology, rf and microwave communication, high-speed digital computation, and precision

electronic thermometry. Web page: http://qdev.boulder.nist.gov/ under Quantum Voltage and JNT.

Superconducting Quantum Circuits and Quantum Limited Measurements

JA Aumentado 50.81.72.B6963

KW Single-electron devices
KW Nanoscale electronics
KW Quantum metrology

At low temperatures, the charge and flux in small superconducting circuits can be regarded as quantum mechanical variables. Recently, this phenomenon has been utilized as the basis of several superconducting qubit designs. However, there are a number of other applications which may also benefit from the coherent nature of these superconducting circuit modes. In our laboratory, we are primarily concerned with the fundamental limits that quantum mechanics places on the measurement of these circuit modes and whether these limits can be circumvented in practical applications. This approach will necessarily involve the physics of Josephson junctions and SQUIDs, as well as several nonlinear optical phenomena such as squeezed state generation and parametric amplification. In addition, this microelectronic approach relies heavily on nanolithography, low-temperature cryogenics (dilution refrigeration), and microwave engineering.

Microwave Polarimetry: Precision Measurements for Cosmological Physics

KD Irwin JN Ullom 50.81.72.B6732

KW Cosmic Microwave Background
KW Physics
KW Metrology
KW Focal plane arrays
KW SQUIDs
KW Superconducting
KW Lithographic

During the last decade, precise measurements of the Cosmic Microwave Background (CMB) have become a powerful probe of physics beyond the standard model, including dark energy, dark matter, neutrino mass, and inflation. The next generation of experiments may resolve the cosmological gravity-wave background and provide direct measurement of the inflaton potential. Such experiments require even more precise measurement of the polarization of the microwave background with exquisite control of systematic errors.

NIST is developing polarization-sensitive focal plane arrays for use in CMB measurements. The sensor elements are superconducting transition-edge sensors that are read out by multiplexed SQUIDs. The research will involve the development of beam-forming elements (including lithographic antennas or silicon micromachined corrugated feedhorns), superconducting elements for coherent processing of the microwave signals before detection (including filters, Stokes analyzers), and on-chip polarization modulators. Opportunities include the development, fabrication, and testing of polarimeter components; calibration and polarization standard development; system integration; and work with collaborators in the astronomical community to field and utilize polarimeter receivers in ground-based, balloon-borne, and ultimately a satellite experiment.

Metrology for Nuclear Nonproliferation

JN Ullom GC Hilton 50.81.72.B6733

KW Metrology
KW Spectroscopy
KW Sensors
KW X rays
KW Gamma rays
KW SQUIDs

KD Irwin

Energy dispersive photon and particle spectroscopy is a commonly used technique to analyze nuclear materials. Radioactive emission provides a fingerprint that can reveal the history, origin, age, and nature of the source material. Hence, spectroscopy is an essential tool for nuclear materials accounting, analysis, and safeguards. In some applications, higher resolution spectroscopy can provide significant additional information or eliminate the need for destructive analysis.

NIST is developing superconducting transition-edge sensors for the detection of hard x rays, soft gamma rays, and alpha particles. These sensors provide approximately an order-of-magnitude improvement in spectral resolution over state-of-the-art techniques. The sensors are read out using multiplexer circuits based on superconducting quantum interference devices. The sensors and multiplexer are integrated into compact, closed-cycle refrigerators that must operate in challenging environments. Opportunities include the design, fabrication, and test of microcalorimeter sensors. Sensor parameters needing optimization include energy resolution, area, response time, and stopping power. The development of absorber materials with high Z and good thermalization properties is particularly important. Opportunities also include work with outside collaborators on the measurement and analysis of nuclear material and the simulation of future measurement scenarios.

High-Performance Detectors for Synchrotron Measurements

CD Reintsema JN Ullom 50.81.72.B6734

KW Synchrotron measurements
KW X rays
KW Microcalorimeter arrays
KW SQUID
KW X-ray fluorescence

KD Irwin

Synchrotron light sources provide bright, focused beams of X rays and are used to perform a variety of condensed matter experiments. X-ray microcalorimeter arrays have the potential to provide exciting new capabilities for some experiments at synchrotron beamlines. We are collaborating with colleagues at NIST/Gaithersburg and the Brookhaven National Laboratory to develop and test a microcalorimeter array optimized for synchrotron applications at the National Synchrotron Light Source. We have developed transition-edge-sensor microcalorimeters to act as energy-dispersive-spectrometer elements and time-division SQUID multiplexers to read out multiple detectors through a single amplifier chain. The goal is to provide a ~200-pixel, multiplexed array with <1 eV energy resolution for 1-2 keV X rays. The array would have 8 mm^2 collecting area and a combined maximum photon count rate approaching 100 kc/sec. Such an instrument would provide a revolutionary advance in the field of light-element X-ray fluorescence. Research opportunities include detector design and fabrication, SQUID design and fabrication, system design and integration of the instrument, and taking and analyzing beamline data.

Superconducting Detectors for Photons from Millimeter Waves through Gamma Rays

KD Irwin CD Reintsema 50.81.72.B3587

KW Calorimetry
KW Thermal conditions and measurements
KW Photons and photon processes
KW Superconductivity

KW Integrated circuits
GC Hilton

Cryogenic detectors and electronics provide unprecedented sensitivity and energy resolution for the detection of photons. We are developing novel low-temperature (100 mK) superconducting microcalorimeters and bolometers for the detection of photons from X rays to millimeter waves. These devices, fabricated in our state-of-the-art clean room, consist of superconducting transition-edge sensors on micromachined structures. They are read out using unique high-speed, low-noise SQUID preamplifiers designed and fabricated here. Using these devices, we have demonstrated the highest energy resolution achieved with an energy-dispersive x-ray and gamma ray detector, and one of the most sensitive detectors of incident infrared/submillimeter power. We are employing these detectors in a system for x-ray microanalysis of materials on a scanning electron microscope and in a system for gamma-ray spectroscopy of nuclear materials. We are also developing arrays of x-ray microcalorimeters and infrared/submillimeter bolometers for astronomy and other applications. Research opportunities include improving our understanding of the nonequilibrium superconducting processes underlying the performance of superconducting detectors, developing novel micromachined structures to integrate detector arrays, developing and testing detector arrays, developing multiplexed superconducting integrated circuits for the readout of large arrays, and developing the first uses of these detectors in astronomy, materials analysis, nuclear non-proliferation, and other applications.

High-Resolution Microcalorimeters for X-Ray Microanalysis

JN Ullom GC Hilton 50.81.72.B3588

KW X-ray spectra
KW Calorimetry
KW Scanning electron microscopy
KD Irwin

As the size scale of microelectronics continues to shrink well below 1 micron, current semiconductor-based energy-dispersive spectrometers (EDS) on scanning electron microscopes can no longer provide the resolution needed to evaluate these structures. We are developing a high-resolution microcalorimeter-based EDS that provides revolutionary new capabilities for x-ray microanalysis. Microcalorimeter EDS provides more than an order of magnitude improvement in energy resolution (to 2 eV) compared to commercial semiconductor EDS. The spectrometer system consists of superconducting transition-edge sensor microcalorimeters cooled by a compact adiabatic demagnetization refrigerator and instrumented with SQUID current amplifiers. Using our microcalorimeter EDS mounted on a scanning electron microscope, we have resolved closely spaced x-ray peaks in complicated spectra and have made the first energy-dispersive chemical shift measurements. The excellent performance of this system enables a wide range of research opportunities in x-ray microanalysis, including improved particle analysis and chemical bonding state analysis.

Opportunities include the development of sensor arrays read out with a superconducting multiplexer in order to dramatically increase throughput and open new applications in real-time, in-process monitoring and process-stream monitoring. Opportunities also include the development of new materials analysis applications and the improvement of the spectrometer system used to couple microcalorimeters to microbeam instruments.

Superconducting Quantum Interference Device Development

KD Irwin CD Reintsema 50.81.72.B5189

KW SQUID

KW Superconducting electronics

KW Cryogenic detectors

KW Microfabrication

GC Hilton

We are developing superconducting electronics for applications in the measurement of electromagnetic signals. Our main focus is on the development of superconducting quantum interference device (SQUID) circuits to multiplex signals from superconducting microcalorimeters and bolometers. SQUID multiplexers are a practical requirement for the successful deployment of large-format cryogenic detector arrays for x-ray microanalysis and x-ray through millimeter-wave astronomy. We are also investigating other novel directions including the SQUID operational amplifier and the development of susceptometers for magnetic calorimeters. Research opportunities involve improving the noise and bandwidth of these devices, developing novel microwave reflectometer readout techniques for arrays of non-hysteretic rf-SQUIDS, fabricating SQUID circuits in our state-of-the-art superconducting fabrication facility, developing high-performance room-temperature electronics to drive our superconducting circuits, and exploring the device physics of SQUID circuits.

Thin-Film Refrigeration Using Normal-Insulator-Superconductor Tunnel Junctions

JN Ullom CD Reintsema 50.81.72.B5190

KW Refrigeration
KW Cryogenic detector
KW MEM
KW Microfabrication
KW Superconductor
KW NIS

We are developing a miniature, solid-state refrigerator using superconducting thin-film technology. In particular, we use the quantum-mechanical tunneling of electrons through a normal-insulator-superconductor (NIS) junction to produce cooling. Our goal is to build refrigerators that can cool a payload of cryogenic detectors from 0.3 to 0.1 Kelvin. Integrated packages of refrigerators and detectors are desirable for commercial x-ray microanalysis and long wavelength astronomy. We are currently working to lower the operating range of NIS refrigerators below 0.1 K and to build refrigerators capable of cooling separate pieces of user-supplied electronics. In order to design devices, applicants will acquire a solid understanding of electronic and thermal transport at very low temperatures. In order to fabricate devices, applicants will learn thin-film processing and MEMS techniques.

Superconducting Detectors for Mass Spectroscopy

RE Schwall 50.81.72.B6735

KW Superconducting detectors
KW Mass spectroscopy
KW Protein characterization
KW Structural virology

NIST's Quantum Devices Group has an ongoing program to develop new detectors for mass spectroscopy, which will extend the useful range of conventional (e.g., MALDI and electrospray) mass spectrometers into the mega-dalton range. There is intense interest in such instruments for applications such as the screening of anti-viral drugs, the differentiation of viral genomes, and for homeland security applications such as the rapid identification of pathogenic viruses. This program focuses on utilizing the group's expertise in detector design, microfabrication, and cryogenics to produce detectors with near unity quantum efficiency for particles with mass up to 10^6 daltons; incorporating these devices in working spectrometers; and developing protocols for applying the system to biological problems. This program is open to a broad range of disciplines including microfabrication, superconducting device design and test, microwave design, instrument development, and application of new biological diagnostic techniques.

Quantum Computing Using Superconducting Qubits

RE Schwall 50.81.72.B6467

KW Quantum computing
KW Quantum information
KW Josephson junctions
KW Mesoscopic physics

Quantum computing offers the possibility of solving certain classes of problems at speeds far in excess of those attainable by any classical computer. Because of their ease of integration and communication to conventional electronics, superconducting qubits based on Josephson junctions offer an attractive approach to quantum computing. Our program seeks to develop superconducting qubits with long coherence times along with methods for defining and reading qubit states and controlling their interactions. The program includes determining how materials properties and fabrication processes affect qubit performance, using this knowledge to develop higher performance qubits, and integrating qubits into quantum logic circuits. This program includes a broad range of disciplines from theory to materials science to experimental low-temperature physics; research opportunities exist in all areas.

Measurement and Characterization of Superconducting Qubits
R.E. Schwall
KW Quantum computing
KW Quantum information
KW Josephson junctions
KW Mesoscopic physics

Quantum computing offers the possibility of solving certain classes of problems at speeds far in excess of those attainable by any classical computer. Because of their ease of integration and communication to conventional electronics, superconducting qubits based on Josephson junctions offer an attractive approach to quantum computing. In its role as the nation’s metrology resource, NIST has been charged with developing a measurement facility and methodology for characterizing qubits produced by institutions worldwide.

Research opportunities in this area will include commissioning of the facility, development of new measurement techniques and collaboration with other institutions on the development of improved qubits.

Quantum Computing Materials Development

DP Pappas 50.81.72.B5893

KW Quantum computing
KW Tunnel junctions
KW Josephson junction
KW Qubit
KW Scanning tunneling microscopy
KW STM
KW Sputtering
KW Aluminum oxide
KW Epitaxial growth
KW Fabrication

We have recently identified de-coherence mechanisms in the tunnel junction in quantum bit (qubit) devices. Our devices are based on phase sensitive qubits and include a Josephson junction that is biased to provide a nonlinear potential. We have observed conductance fluctuations that give rise to resonances near the quantum phase transition. In order to reduce these resonances, we are developing new materials for the tunnel barriers. Possible materials include epitaxial aluminum oxide, amorphous aluminum nitride, and boron nitride. The successful candidate for this position will grow barriers in a UHV sputter chamber. The chamber is part of a cluster that has UHV surface characterization tools including low temperature STM, Auger, and LEED. The opportunity also includes fabrication of qubits in the cleanroom and testing.

Magnetoresistive Sensors for Medical and Other Applications

DP Pappas 50.81.72.B4781

KW Magnetoresistive field sensors
KW Magnetocardiography
KW Magnetoencaphalography
KW Measurement of iron
KW Biomagnetism
KW Medical applications of magnetism

We invite proposals for the development and electronic implementation of low-noise, high-sensitivity, ambient-temperature, magnetoresistive field sensors for applications in security, medicine, and magnetic disk drive read heads. Medical applications include magnetocardiography, magnetoencephalography, and *in-vivo* measurement of iron stores in the body. We have facilities for microelectronic device fabrication and testing.

Electromagnetics Division
Boulder, Colorado

Antenna Theory and Measurements I

MH Francis RC Wittmann 50.81.82.B1516

KW Antennas

KW Near-field measurements

KW Electromagnetic field theory

A "scattering matrix description of antennas and antenna-antenna interactions" has been developed and successfully applied by researchers in this Division. Radiated fields are determined from measurements made in the near field of the antenna under test, and the theory is suitable for describing antenna interactions at arbitrary distances (not just in the far-field region). Measurement techniques (and supporting theory) must continuously be extended to keep pace with the rapid advancement in antenna design and application.

Topics that need attention include (1) better accuracy—high performance systems, especially those that are satellite based, require maintenance of tighter tolerances; (2) higher frequencies—more sophisticated near-field measurement methods are needed to handle millimeter-wave applications (up to 500+ GHz); (3) complex phased-array antennas—large, often electronically steerable, phased arrays need special diagnostic tests to ensure optimum functionality; (4) low sidelobe antennas—military and commercial communication applications increasingly specify sidelobe levels 50 dB or more below peak, a range where measurement by standard technique is difficult; (5) *in situ* (or remote) evaluation—many systems cannot be transported easily to a measurement laboratory; robust methods are needed for on-site testing; and (6) multiple reflections—methods are needed to mitigate errors caused by multiple reflections between the probe and test antenna. Research facilities include two planar near-field scanners, a multipurpose range for cylindrical and spherical antenna measurements, a precision extrapolation range, an anechoic chamber, a ground screen, and other EM experimental facilities, as well as excellent computational resources. We welcome proposals in these or in related areas that extend or improve the application of near-field antenna measurement methods.

Antenna Theory and Measurements II

MH Francis RC Wittmann 50.81.82.B1525

KW Antennas

KW Near-field measurements

KW Electromagnetic field theory

In spherical near-field scanning, probe pattern information and data measured at points on a spherical surface are used to determine the fields of a test antenna anywhere beyond the measurement radius (especially in the far-field zone). Although the theory is well understood, a number of areas need further work, including (1) development of more efficient measurement and computation methods; (2) analysis of and correction for measurement errors; (3) practical pattern correction schemes for general probes; (4) development of a simplified theory for the “quasi-far-field region” where measurements are “almost” made in the far field; and (5) extensions of near-field antenna theory to other applications such as acoustics, field synthesis, and the evaluation of far-field (compact range) measurement systems. We welcome proposals on these and other topics that extend or improve the application of spherical near-field measurement techniques.

Theory for Electromagnetic Interference Problems

CL Holloway 50.81.82.B4756

KW Antennas

KW Electromagnetic field theory

KW Electromagnetic scattering

Theoretical research is conducted on both forward and inverse problems in electromagnetics (EM). To characterize complex EM interference environments, a wide variety of forward problems in antennas, propagation, and scattering need to be solved. Inverse source techniques are studied to synthesize near-field antenna arrays for use in EM susceptibility testing. Inverse-scattering techniques are of interest for nondestructive evaluation of various materials. Both frequency-domain and time-domain techniques are applicable, and statistical methods are used for characterizing complex EM environments and test facilities, such as reverberation chambers. In addition to superb computational resources, excellent experimental facilities are available for verifying theoretical work. These include a time-domain range; a reverberation chamber; an anechoic chamber; TEM cells; a ground screen; planar, cylindrical, and spherical near-field scanning ranges; and an extrapolation range.

Electromagnetic Theory for Complex Environments

PF Wilson 50.81.82.B4757

KW Complex electromagnetic environments

KW Electromagnetic field theory

KW Electromagnetic compatibility

KW Revereration chamber

KW Statistical electromagnetics

Most electromagnetic field measurements seek to create a simple, well-defined environment. However, real electromagnetic environments are typically complex and poorly defined. Multiple sources and scattering objects (possibly unknown or nonstationary), complicated geometries, proximity coupling, and other real world complications make electromagnetic field measurements difficult to interpret. Statistical electromagnetic approaches are needed to quantify both real environments and complex system responses. This need already exists for large systems (e.g., avionics, interconnected electronics) and the requirement will move to the component level as frequencies of operation continue to move higher (e.g., high-speed computers, digital wireless systems). Research opportunities exist for developing statistical electromagnetic models. Applications include reverberation chamber test methods, coupling to complex systems, shielding of ill-defined geometries, radiation from statistically defined sources, propagation in nonstationary environments, and characterization of complex electromagnetic environments. The goal is to develop analytical descriptions for the statistics of these environments. Numerical modeling and Monte Carlo techniques will be used to verify analytical models. Excellent experimental facilities exist to generate measured data for comparison with theoretical and simulation results.

Indoor Radio Frequency Propagation Characterization for Broadband Wireless: Modeling and Measurements

CL Holloway 50.81.82.B4373

KW Electromagnetic field theory

KW Propagation

KW Transmission lines

KW Electromagnetic capability

KW Electromagnetic scattering

Research for accurate characterization of general indoor propagation environments is important for the design of future wireless communications systems. It is essential to understand the efficacy of broadband wireless communications systems in office complexes and other types of building environments. The indoor radio propagation channel is a very complicated environment with a variety of propagation issues that must be defined and understood. Our research objective is to develop competence in the area of indoor and indoor-to-outdoor radio propagation, and the effects on wireless communications systems. A particular goal is to develop propagation models that will address the needs of the telecommunications industry as related to the design of state-of-the-art wireless systems that can be utilized in indoor environments. This will generally be accomplished by developing theoretical models and then designing and conducting experiments for the purposes of characterizing the indoor radio frequency (RF) propagation environment. This will lead to analytical tools that can be used by wireless system designers. Advanced computational tools, as well as excellent electromagnetic measurement facilities and instrumentation are available for experimentation. Topics that need attention include coupling of energy into building structures, propagation characterization of building materials, modeling of RF propagation into and within building structures, and measurements techniques for characterizing building environments.

Theoretical Development of Equivalent Generalized Impedance Boundary Conditions

CL Holloway 50.81.82.B4374

KW Electromagnetic field theory
KW Propagation
KW Transmission lines
KW Electromagnetic capability
KW Electromagnetic scattering

The interaction of electromagnetic fields with rough surfaces, composite materials, thin coatings, frequency selective surfaces, and particle scattering are a few of the challenging problems of current theoretical interest. Scattering problems of this type are complicated and usually require numerical techniques. However, when the detailed surface features (roughness dimension, fiber dimensions in composites, coating thickness, scattering shapes in FSS, and particle spacing) are small compared to a wavelength, equivalent generalized impedance boundary conditions (EGIBC) can be used. These EGIBC and Maxwell's equation are all that is needed to solve these types of scattering problems. EGIBC are also very efficient in analyzing reflection problems. For example, in large electromagnetic computational codes, the use of EGIBC can eliminate the need to spatially resolve the fine detail of a particular scattering feature, which results in the abilities to solve much larger numerical problems. The proposed research direction is to use various asymptotic techniques to derive EGIBC for various electromagnetic field interactions. Specific boundary conditions will be derived so that the coefficients in the EGIBC can be interpreted in terms of electric and magnetic polarizability densities.

Quantum-Based SI Traceable Electric-Field Probe

CL Holloway 50.81.82.B7116

KW Electric field
KW RF spectroscopy
KW Rydberg
KW SI
KW E field

This work will investigate the possibility of using RF spectroscopy with Rydberg atoms to develop a highly accurate, precise electric field probe that has traceability to fundamental physical constants and SI units. *E*-fields have typically been determined from calculations traced to a power reference, which gives an indirect *E*-field measurement. However in this quantum-based probe, Rydberg atoms contained in a glass cell are excited using two lasers into a state so that a transition can be induced through a radio frequency electric field causing the atoms to fluoresce. The strength of the fluorescence can be related to the applied electric field strength, allowing a measure of the electric field that is traceable to fundamental constants like Planks constant. Because of the accuracy, precision, and traceability, this method has the potential to open new areas of science in field measurements.

Fundamental Modeling for Electromagnetic Compatibility

CL Holloway 50.81.82.B4375

KW Electromagnetic field theory
KW Propagation
KW Transmission lines
KW Electromagnetic capability
KW Electromagnetic scattering

Analytic and numerical theoretical investigations are needed on a broad range of topics related to electromagnetic compatibility (EMC) and electromagnetic interference (EMI). The particular numerical models of interest are finite-difference time-domain, finite-elements, integral equations, and hybrid techniques. Suggested topics include printed circuit board radiation, signal integrity and coupling of high-speed digital lines and devices, lossy transmission lines, characterization and optimal design of large test facilities (e.g., reverberation, anechoic, and semi-anechoic chambers), properties of electromagnetic absorbing materials, design of advanced composite and frequency selective materials, shielding effectiveness of various materials, and other coupling problems. The broad objective is to develop accurate analytic and numerical models that will advance the fundamental understanding of critical EMC/EMI issues. Extensive measurement facilities are also available with which to assess the validity of the resulting models.

Quantum-Based Electromagnetic Field Measurements

TP Crowley 50.81.82.B5518

KW Microwave

KW Power

KW Electromagnetic fields

KW Laser cooling

KW Gas cell

KW Quantum-based measurements

KW Atomic clock

This research opportunity will involve developing a technique for measuring microwave magnetic fields based on quantum-mechanical principles. We have already performed a proof-of-concept experiment using a set of laser-cooled cesium atoms in an atomic clock fountain apparatus. Rabi oscillations between two hyperfine levels of the cesium ground state were measured to determine the RF magnetic field strength in a resonant cavity. The next step in this research is to improve the measurement accuracy by creating an apparatus specifically designed for making measurements in a rectangular waveguide. Either laser-cooled atoms or a gas cell of cesium may be used. A DC magnetic field will be employed to vary the RF measurement frequency. These experiments have a dual purpose. One purpose is to do basic research about the interaction between microwaves and atoms since the microwave industry is reliant on techniques whose fundamental principles were established decades ago. We need to study how new techniques for handling atoms can be used to understand and measure microwaves. The traditional measurement relies on heat absorption, which is very different from the proposed method. This will serve as a check of current techniques, as well as the first step in a potentially new standard for microwave power and field amplitude measurements. If successful, the new measurement techniques will revolutionize microwave measurements. The necessary microwave equipment and laboratory facilities are already well established. New laser systems and detectors used in the atomic measurements will be purchased and the applicant will be responsible for setting up the apparatus.

Millimeter Wave and Microwave Power Measurements

TP Crowley 50.81.82.B5519

KW Millimeter waves
KW Microwaves
KW Power
KW THz
KW Bolometer
KW Semiconductor processing

Research will focus on designing, building, and testing new sensors to measure millimeter-wave (30 to 300 GHz) power. The sensors will provide absolute measurements of the RF power by comparing the effects of RF and DC power absorption. They will be used as primary and secondary standards for the US. The goal is to replace our current standards with a new generation of devices that utilize semiconductor processing techniques to provide a more reliable standard that can be manufactured at NIST. The absorbing element will be thermally isolated from the bulk of the sensor by a thin membrane in the substrate. The membrane will be created by etching the back side of the substrate. Options for the absorbing element include a thin (≈ 1 skin depth) conducting film or a termination resistor. Options for the detection method include bolometric and thermoelectric detectors. Ideally, the new standards will be used as primary standards, although they could also be transfer standards whose efficiency is evaluated in a calorimeter. Our immediate goal is to replace bolometric standards in rectangular waveguide between 50 and 110 GHz. Our current standards in these waveguides cannot be replaced and are aging. A longer term goal will be to extend development of these sensors to the Terahertz range (i.e., 0.3 to 3 THz). The millimeter and THz frequency ranges have an increasing number of applications in astronomy, biology, and homeland security that will be enhanced by better power measurements. A wide range of microwave and mm wave components, sources, and existing standards are available as well as NIST's in-house capabilities for making integrated circuits for research.

Thermal Noise Measurements

TP Crowley 50.81.82.B1521

KW Electromagnetic noise
KW Fundamental microwave metrology
KW Microwave radiometry
KW Microwave theory and techniques
KW Terahertz noise

Theory, standards, methods, and systems are developed for highly accurate measurements of thermal electromagnetic noise from radio frequencies to terahertz waves. Current research comprises two major thrusts: developing improved methods for characterizing the noise properties of low-noise amplifiers and transistors, and developing systems and methods for noise measurement at terahertz frequencies. Research opportunities are supported by extensive theoretical and experimental expertise, as well as world-class noise-temperature measurement capabilities.

Theoretical and Experimental High-Frequency Dielectric and Magnetic Investigations, Biological Materials, Thin Films, Nanowires, Stochastic Fields, and Metamaterials

JR Baker-Jarvis 50.81.82.B1528

KW Dielectric measurements
KW Electromagnetic properties
KW Microwave theory and techniques
KW Microscopic electromagnetism
KW Negative-index materials

Research opportunities exist for investigations related to the precise characterization of the macroscopic and microscopic electromagnetic properties of biological, metamaterial, substrate, liquid, and thin-film materials in the radio-frequency to terahertz frequencies. Suggested research areas include the measurement of ultra low-loss dielectric and magnetic materials, magneto-electric thin films, nanowires, ferroelectric materials, metamaterials, and nanoscale materials. Current interests also include the development of information-theory based electromagnetic metrology, the relationships of complex permittivity to material mechanical stress, linear and nonlinear response theory, dielectric measurements of advanced thin films, stochastic EM, ferroic materials, metamaterials, and biased ferrite and ferroelectric measurements. In addition to excellent computational resources, a wide range of experimental resonators, well-characterized materials, laboratory instrumentation, environmental facilities (e.g., a cryostat, a high-temperature chamber, and a magnetic bias capability), and a diversity of related intellectual resources are available to facilitate research.

Precision High-Speed Waveform Measurement

DF Williams PD Hale 50.81.82.B5892

KW Electrical waveform

KW Electro-optic sampling

KW Ultrahigh-speed

We have developed an electro-optic sampling system that measures very fast electrical waveforms. This project will extend our current electrical models for the measurement system to 400 GHz and allow the precision measurement of waveforms with 5 ps rise times.

We have constructed an electro-optic sampling system with a measurement bandwidth near a teraHertz. The system is designed to accurately measure electrical pulses on transmission lines printed on special NIST-constructed electro-optic substrates, and now provides NIST's most fundamental measurements of high-speed electrical pulses. This system is now being used to calibrate the output of high-speed photodiodes and oscilloscopes to 110 GHz.

Distortion in the probes we use to inject electrical signals onto the electro-optic substrate currently limits our measurement bandwidth to 110 GHz. This project will focus on using data from the electro-optic sampling system itself to characterize these probes to 200 GHz and beyond. The result of the effort will be models for the probes that will allow us to break our current 110 GHz measurement barrier and characterize the fastest photodiodes, pulse sources, and oscilloscopes in the world.

On-Wafer Microwave Measurements and Standards

DF Williams P Kabos 50.81.82.B1530

KW Microwave theory and techniques

KW Microwave metrology

KW On-wafer measurements

KW Microwave electronics

KW Impedance

Research opportunities exist for theoretical and experimental studies of wafer-level microwave measurement techniques in the frequency range of 50 MHz–110 GHz. Work focuses on the on-wafer measurement of S-parameters and signal characterization, including the development of new measurement methodologies, and modeling and analysis of single and coupled planar transmission lines. Unique opportunities exist to compare both the theoretical and experimental results.

Characterization of High-Speed Digital Interconnects and Signals

DF Williams P Kabos 50.81.82.B3584

KW Microwave theory and techniques

KW High-speed digital circuits

KW Fundamental microwave metrology

KW On-wafer measurements

This project provides unique opportunities for theoretical and experimental studies of high-speed digital interconnects and signals. Current research focuses on adapting microwave measurement methods to noncontracting characterization of high-speed signals and the characterization of conventional, differential, and coupled differential transmission lines fabricated on silicon substrates. This research has strong relevance to industry and collaborators will have access to measurement equipment at frequencies beyond 110 GHz.

Ultrafast Signal Measurement for High-Speed Integrated Circuits

DF Williams P Kabos 50.81.82.B5188

KW Electrical signal measurement

KW Integrated circuits

We study methods for measuring and calibrating ultrafast signals with 110 GHz to 400 GHz bandwidths on high-speed integrated circuits. Methods that we are currently investigating include the use of electro-optic interactions with bandwidths of many THz. Research focuses on fully calibratable measurement of signals in printed transmission lines with low uncertainty, extension of measurements to 110 GHz in the near future, and extension to 400 GHz in the next five years.

Broadband Nanoscale Probing, Material Characterization and Field Imaging, for Beyond-CMOS Electronics

P Kabos TM Wallis 50.81.82.B5520

KW Nanoscale

KW Microwave

KW Scanning probe microscopy

Few experimental tools are currently available that can characterize and probe high-speed/frequency properties of materials and devices on a nano/molecular scale. Proposals are invited for high-frequency noninvasive nanoscale probing and theory; including electromagnetic field imaging; as well as measurements of voltage, current, and materials properties. The objective is to develop the fundamental metrology; i.e., the instruments and standards that will make it possible to perform high-speed voltage and current measurements necessary for the characterization of high-speed, high-performance ultrahigh-density nano and molecular electronics devices. Also of interest are broadband measurements of the electromagnetic properties of nano-engineered, artificial, nanowire, and carbon-nanotube-based materials and devices. Film deposition, lithography and state-of-the-art microwave test systems, probe stations, and atomic force microscopy facilities are available for the proposed research.

Superconductor Measurements

LF Goodrich 50.81.82.B1541

KW High-temperature superconductors
KW Superconductivity
KW Physics
KW Electrical engineering

We develop and evaluate measurement techniques to determine the critical parameters and matrix properties of superconductors. Capabilities include variable-temperature critical-current measurement, low-noise current supplies up to 3000 amperes, high-field magnets up to 18 teslas, and voltage sensitivity to 1 nanovolt. We study conventional superconductors (NbTi and Nb_3Sn) and the newer high-transition-temperature materials. We conduct fundamental studies of the superconducting-normal transitions and the parameters that affect their accurate determination, such as current transfer, strain, or inhomogeneities in materials and fields. We develop theoretical models to interpret current redistribution and component interactions in composite superconductors.

High-Field Superconductor Research

LF Goodrich 50.81.82.B1542

KW Fatigue mechanics
KW Flux pinning
KW High-field superconductors
KW Transport measurements

This interdisciplinary research program encompasses the physical, mechanical, and electrical properties of high-field superconducting materials and composites. Research is conducted on new types of high current density superconductors

(Nb_3Sn, MgB_2, Bi-2212, Y-Ba-Cu-O) being developed for high energy physics accelerators, fusion energy magnet systems (ITER), and medical diagnosis and therapy systems, such as magnetic resonance imaging and proton radiation cancer treatment. Experimental programs include the study of the electromechanical properties of superconductors, high-flux pinning materials, internal reinforcement, and advance composite design. Very high-field magnet systems, power supplies, servohydraulic mechanical test systems, and analytic microscopy facilities are available. In particular, a facility was recently developed for integrated and sensitive measurements of critical current over a broad range of the essential parameters: longitudinal strain, temperature, and magnetic field. Theoretical studies concentrate on flux pinning and the intrinsic effect of strain on the superconducting state.

High T_c Superconductor Research

LF Goodrich 50.81.82.B1550

KW High-temperature superconductors
KW Transport properties
KW Superconducting films
KW Intrinsic strain effect

The goal of this research program is to better understand the superconducting state of high-temperature superconductors. Strain will be used as a new tool to study superconductivity, in which the reversible effect of strain is measured on the superconducting properties of clean structures such as single- and bi-crystalline thin films. These fundamental studies are also designed to help explain the superconducting properties of multi-granular superconducting wires and tapes such as thick-film Y-Ba-Cu-O coated conductors. A unique feature of this program is that we use our expertise in electromechanical measurements to work with research laboratories, industry, and major universities to develop high-temperature superconducting wires for large-scale applications, such as the electric power grid, high-power-density rotating machinery, and high-field magnets. We are interested in all aspects of high-temperature superconductor research including the mechanical, magnetic field, and electrical limits of practical wires and tapes.

Molecular and Nano Magnetism

S Russek 50.81.82.B3595

KW Nanomagnetism
KW Molecular nanomagnets

KW Carbon nanotubes
KW MN-12
KW Electron spin resonance
KW Ferromagnetic resonance
Ultra-small magnetic structures will be fabricated using both conventional nano-lithography techniques (e-beam and scanned probe lithographies) and chemical synthetic techniques. The systems studied may include molecular nanomagnets (e.g., Mn-12), carbon nanotubes grown on magnetic nanoparticles, patterned longitudinal and perpendicular media, and nano-devices. The goal of this research will be to understand the physics of ultrasmall magnetic structures, their implications for the limits of magnetic data storage, and to develop novel nanoscale devices. The magnetization and switching processes will be studied as a function of size, shape, and temperature to characterize thermally activated and quantum mechanical tunneling transitions. The high-frequency properties (1 GHz to 150 GHz) will be studied using high-frequency electron spin resonance, ferromagnetic resonance, and transport properties. The molecular nanomagnets and magnetic nanostructures will be incorporated into thin-film device structures to explore potential device applications.

High-Frequency Characterization of Novel Thin-Film Materials

S Russek JR Baker-Jarvis 50.81.82.B4777

KW Metamaterials
KW Ferroelectric
KW Ferromagnetic
KW High frequency
KW Photonic bandgap
KW Frequency-tunable materials
KW Microwave materials

P Kabos

The goal of this project is to fabricate novel nano-engineered thin-film materials and measure their electromagnetic properties in the 1-100 GHz regime. The materials include nanostructured materials, composite ferromagnetic-ferroelectric materials, “left-handed” materials, and frequency-tunable materials. The materials can be fabricated using an ultra-high vacuum, eight-source sputtering system; a laser ablation system; and optical and e-beam lithography systems. The dielectric and magnetic properties can be engineered by patterning arrays of elements on two different length scales. Patterning on a scale comparable to the excitation wavelength—about 1 mm—will allow the development of artificial crystals (photonic band gap materials) in the microwave regime. Patterning on a scale much shorter than the wavelength, 10-100 nm, will allow the permittivity, permeability, and conductivity to be engineered and controlled to have new functionalities. Examples of such materials engineering include light- and field-tunable exchange coupling, low loss amorphous/nanoparticle composites, negative-epsilon negative-mu ("left handed") systems, and ferroelectric-ferromagnetic multilayers. Measurements will be conducted on state-of-the-art, 100 GHz microwave test systems and cryogenic microwave probe stations.

High-Frequency Dynamics in Magnetic Nanostructures

TJ Silva 50.81.82.B6964

KW Ferromagnetic resonance
KW Magnetic nanostructures
KW Magneto-optic Kerr effect
KW Nanomagnets
KW Microwave measurements
KW Device fabrication

We are studying patterned nanomagnet arrays fabricated using the e-beam lithography tools available at NIST Boulder. We have already demonstrated the ability to fabricate arrays of 40 nm nanomagnets in a variety of materials. We have developed a novel magneto-optic microscope for measuring the dynamic response of nanomagnet arrays at microwave frequencies. This particular tool, the microwave magneto-optic microscope (MOMM), is especially sensitive to details of the ferromagnetic resonance spectrum. We are studying the homogeneity of the dynamic response in dense arrays of nanomagnets. We have already measured profound differences in static properties when different procedures are used for the fabrication of nanomagnet arrays. We are interested in pushing the MOMM technique to identify the spectra of defects in such nanostructures. For example, we have already extended MOMM into a quasi-spatially sensitive technique through the measurement of both "edge" modes (modes with large amplitude at the edge of a nanostructure) and "center" modes. Analysis of linewidth and the frequency response of these different modes will offer information about different locations within a nanostructure. Currently, such information cannot be resolved by any other technique. Our goal is to further improve the signal-to-noise of the technique in order to measure magnetization dynamics in single nanomagnets at bandwidths approaching 50 GHz.

Graphene for Spintronics

TJ Silva MW Keller 50.81.82.B6965

KW Graphene

KW Spintronics

KW Device fabrication

KW Spin valve

Graphene has intriguing possibilities as a material for spintronic applications. Theory predicts that spin diffusion lengths in graphene may be as long as 10 micrometers, which would make graphene an efficient spin conductor. Graphene exhibits high electron mobility, making it a candidate material for high speed spintronics. Theory also predicts the possibility of forming ferromagnetic/antiferromagnetic graphene through doping and/or defects. Epitaxially grown graphene has a 0.25 eV band gap, which might be ideal for low dissipation applications. We are also investigating the potential for *epitaxial* graphene as a spintronic material. We are fabricating non-local spin valve structures using epitaxial graphene that is grown by collaborators at Georgia Institute of Technology. In such non-local devices, spin current is physically separated from the charge current, permitting spin transport properties in a non-ohmic configuration. Using such structures, we will characterize the spin diffusion length in epitaxial, bilayer graphene. We will also examine ballistic spin transport as a function of temperature and applied magnetic field. The opportunity exists to collaborate with the new NIST Center for Nanoscale Science and Technology in Gaithersburg, Maryland.

Ferritin and Other Magnetic Nanoparticles in Protein Shells

RB Goldfarb 50.81.82.B6628

KW Ferritin

KW Magnetic nanoparticles

KW Oxyhydroxide crystal

KW Magnetic resonance imaging

Ferritin is nature's ubiquitous iron-storage molecule, found in species ranging from microbes to man. It consists of a roughly spherical apoferritin protein shell, inside which iron accumulates in the form of a ferric oxyhydroxide crystal. The outer diameter is 12 nm, irrespective of the amount of iron stored within. Although its physical, chemical, and magnetic properties have been studied for more than 60 years, ferritin remains a subject of current research, with many implications for biology and medicine. In particular, ferritin is an important contributor to T_1 and T_2 relaxation, which effectively determine image contrast in magnetic resonance imaging. Applicants with backgrounds in physical chemistry, chemical synthesis, magneto-chemistry, magnetometry, nuclear magnetic resonance, and electron paramagnetic resonance are invited to apply. Equipment available includes a 7-tesla SQUID magnetometer and a 7-tesla/300-megahertz nuclear magnetic resonance system.

Terahertz Imaging and Spectroscopy for Biomedical Applications

RB Goldfarb 50.81.82.B6763

KW Terahertz frequencies
KW Biology
KW Hot electron bolometers
KW Terahertz radiation
KW Heterodyne detector

Imaging and spectroscopy at terahertz frequencies (between millimeter and mid-infrared wavelengths) have great potential for biomedical applications such as cancer diagnostics. Terahertz frequencies correspond to energy level transitions of important molecules in biology. The ability of terahertz waves ("T-rays") to penetrate certain materials to variable depths (such as clothing and human and animal tissues) facilitates a new and innovative approach to biomedical imaging. Because of its shorter wavelength, terahertz radiation also offers higher spatial resolution than microwaves or millimeter waves. We are developing a new family of heterodyne detectors known as hot electron bolometers (HEB). This type of superconducting detector provides unprecedented sensitivity and spectral resolution at terahertz frequencies. State-of-the-art terahertz imagers based on HEB technology have sufficient sensitivity to operate in a passive imaging mode, thus eliminating the need for active illumination. The terahertz radiation couples to the heterodyne detector through a quasi-optical system consisting of an elliptical lens and a monolithic terahertz antenna. Applicants should have expertise in areas such as experimental electromagnetics, device development, and optics. Clean-room experience, including e-beam lithography, is also required. Research will be conducted in collaboration with Dr. Eyal Gerecht.

Linear and Nonlinear Damping and Relaxation in Magnetic Information Storage Materials

P Kabos S Russek 50.81.82.B5981

KW Magnetic dynamics
KW Magnetic recording

KW Nanotechnology
KW Ferromagnetic resonance
KW Effective linewidth
KW Brillouin light scattering
KW Spintronics
KW Magnetic thin films
KW Magnetoelectronics

As magnetic recording moves well into the gigahertz frequency regime, the mechanisms that limit the precession dynamics and decay time of the spin system in magnetic thin films become limiting factors in recording head design, materials selection, and magnetoelectronics applications. Low- and high-power ferromagnetic resonance (FMR), microstripline FMR, off-resonance effective linewidth techniques, and Brillouin light scattering provide critical tools needed to elucidate these processes and develop optimum thin-film materials for these applications. In this program, metallic thin materials, metal-oxide multilayers, and nano-oxide films will be fabricated and used for research on the fundamental loss processes that limit magnetic switching and large-angle precession dynamics response times. Effectively all of the established tools of high-frequency magnetics research will be used on this topic. The use of FMR techniques over a wide range of frequencies from 1 to 100 GHz and different static and pumping field geometries will help separate intrinsic loss processes (e.g., magnon-electron scattering) from extrinsic processes (e.g., two-magnon relaxation). Effective linewidth and spin-wave instability measurements will be used to probe the wave vector dependences of the intrinsic processes. High-power above-threshold spin-wave instability, Brillouin light scattering, micro-Kerr effect, and FMR force microscopy techniques will give new information on the actual nonlinear response of these film materials systems. This program will utilize facilities and capabilities developed at both NIST and in the laboratory of Professor Carl Patton at Colorado State University.

Chip-Scale Magnetic Resonance Imaging Microscope

JM Moreland 50.81.82.B5895

KW Magnetic resonance
KW Computer-aided image processing
KW Microscopy
KW Cryogenics
KW Scanning probe
KW Spin dynamics

KW Nanotechnology

Conventional magnetic resonance imaging (MRI) systems are limited in resolution because of the noise of inductive detector which limits sensitivity as well as difficulties generating field gradients sufficient for narrow sample slice discrimination. By using micromechanical cantilever oscillators as magnetic sensors and by reducing the dimensions of the gradient coils significant improvements in sensitivity and resolution can be made. In particular, we have recently demonstrated several micromechanical magnetometers including a magnetic resonance force microscope, a torque magnetometer, and a micromechanical calorimeter. These magnetometers operate on the principle of modulating the magnetic resonance excitation of a sample attached to a microcantilever at the cantilevers resonance frequency. Our goal is to optimize these novel detectors for biological applications including *in vivo* imaging of cell organelles and membranes. The main challenge is to develop integrated microsystems with microfabricated dc and rf field sources, magnetic sensors, and field gradient coils. Ideally, the chip should be adaptable to microfluidic environments.

Nanoscale Imaging for Magnetic Technology

JM Moreland 50.81.82.B1547

KW Computers and computer science

KW Scanning tunneling microscopy

KW Images and image processing

KW Nanoscale analysis

KW Scanning probe

KW Nanotechnology

The magnetic storage industry has advanced to the stage where nanometer-scale morphological and physical properties play an important role in current and future disk drive performance. In its many forms, scanned probe microscopy (SPM) can be used to measure roughness, device dimensions, electromagnetic field patterns, and various physical processes at nanometer scales, which provides important information about the fundamental operation and limitations of drive components. Our goal is to help tailor SPM techniques for these applications. We are investigating scanning tunneling microscopy, atomic force microscopy, magnetic force microscopy, scanning potentiometry, and scanning thermometry for their usefulness.

Micro-Electromechanical Systems for Metrology

JM Moreland 50.81.82.B4001

KW Micromechanics

KW Microelectronics

KW Silicon-based materials

KW MEMS

KW Nanotechnology

We are developing micro-electromechanical systems (MEMS) with integrated components for precision measurement purposes. Work focuses on the following goals: (1) improving the performance of fundamental standards instrumentation by developing novel detectors and more fully integrated measurement systems, (2) exploring the impact of MEMS and MEMS-based metrology on the future development of the microelectronics and data storage industries, and (3) improving the manufacturing yield with MEMS probe assemblies designed for production line testing. Our cleanroom facility is fully equipped for bulk and surface micromachining of silicon wafers including design, fabrication, and testing tools. We are interested in all aspects of research including the development of novel MEMS structures, as well as the testing and integration of MEMS structures into precision measurement instruments.

Single-Molecule Manipulation and Measurement

JM Moreland 50.81.82.B5192

KW MicroElectroMechanical systems

KW Microfluidics

KW Nanotechnology

KW Proteins

KW DNA

KW RNA

KW Single molecule

KW Biotechnology

We are developing a Nano-Electro-Mechanical System platform change for single biomolecule manipulation and measurement. Measurements to determine the structure and function of protein and DNA are currently made using large populations of molecules rather than single molecules. Researchers in biotechnology have shown that the behavior of single molecules in living systems can be different from results obtained by measuring the statistical average of large populations of molecules. The limitation in making single molecule measurements is primarily due to the lack of measurement tools and methods that are capable of isolating, manipulating, and probing the behavior and structure of the molecules. As a result, there is a rapidly growing interest in the development and application of nanotechnology to support single-molecule measurements.

Superconductor Critical Current Density Determination by Nonlinear Microwave Response

JC Booth 50.81.82.B6228

KW High-temperature superconductor
KW Microwave devices
KW Nonlinear response
KW Critical current density

One of the fundamental properties of superconductors is the critical current density (J_c), which sets the upper bound for the current-carrying capacity of a superconductor. Our recent measurements of the nonlinear response of YBCO thin films have demonstrated good agreement with theoretical predictions for nonlinear response due to pair-breaking in d-wave superconductors, and our measurement system yields values for the pair-breaking current density that agree remarkably well with theoretical predictions of this quantity for YBCO thin films. Our nonlinear measurement technique could provide an entirely new path to determining critical current densities in superconductors, and will likely yield intrinsic J_c values closer to theoretical predictions than conventional J_c measurement techniques. We plan to apply this measurement technique to experimentally determine the critical current density of YBCO, MgB2, Nb, and other technologically important superconductor thin-film materials, and also to explore the role of the symmetry of the superconducting energy gap on the nonlinear microwave response. In addition, we will also explore the use of these reproducible nonlinear effects in superconductors to develop standard devices to aid in the calibration of next-generation nonlinear measurement systems.

Biomagnetic Imaging

S Russek P Kabos 50.81.82.B6229

KW Magnetic resonance imaging
KW MRI
KW Nanomagnetism
KW Nuclear magnetic resonance
KW NMR
KW Electron spin resonance
KW ESR

KW Biomagnetism

KW Molecular nanomagnets

This research will focus on developing advanced magnetic resonance imaging (MRI). Nanomagnetic contrast agents will be fabricated and characterized. The nanomagnets to be investigated include molecular nanomagnets, such as Fe-8, and nanoparticles formed by novel thin-film self assembly techniques. The nanomagnets will be characterized using SQUID magnetometry and electron spin resonance (ESR) at fields up to 7 T and frequencies up to 140 GHz. The affect of the nanomagnets on nuclear magnetic resonance (NMR) properties of protons in biological solutions will be studied. Systems that can simultaneously measure NMR, ESR, and nanomagnet magnetization will be developed. A detailed understanding of how the nanomagnet properties, such as anisotropies and fluctuations, affect proton relaxation in biological solutions will be developed. MRI imaging of potential nanomagnetic contrast agents will be done on commercial MRI systems at local hospitals. Materials with different relaxation times will be investigated for use in MRI standards and phantoms.

Broadband Impedance Measurements of Thin-Film Electronic Materials and Devices

JC Booth 50.81.82.B6230

KW Impedance spectroscopy

KW Thin-film materials

KW Electronic materials

KW Broadband impedance measurements

Electrical impedance measurements provide important information about the response of materials to electromagnetic stimuli. Therefore, impedance is a key parameter for the evaluation of new thin-film materials that are being developed for next-generation electronic applications. A detailed understanding of the evolution of the electrical impedance of thin-film materials and devices with increasing frequency is required for determining the suitability of new materials for high-speed applications, and can also provide valuable insight into the underlying physical processes relevant for advanced electronic materials.

We are developing new broadband impedance measurements of thin-film materials and devices in order to address these issues. Using on-wafer measurements of thin-film devices allows us to measure the impedance of planar thin-film-based structures at frequencies up to 100 GHz. When combined with more traditional impedance analysis at lower frequencies, we can obtain frequency-dependent impedance data over the extremely broad frequency range from several 100 Hz to 100 GHz. The electrical impedance of planar measurement structures can be used to extract intrinsic material quantities, such as the conductivity or dielectric permittivity, of the constituent thin-film materials. Such measurements techniques are applicable to a wide range of electronic thin-film materials, and are currently being used to study thin-film material systems such as dielectrics, ferroelectrics and high-temperature superconductors.

Microwave Bioelectronics

JC Booth 50.81.82.B6231

KW Microwave devices
KW Microfluidic devices
KW Biological materials
KW Electromagnetic characterization

Electromagnetic characterization can be a viable alternative to chemical or optical detection schemes to analyze biological samples. An exciting new option in dielectric characterization is dielectric spectroscopy: the measurement of a sample's dielectric response across a very broad range of frequencies. This technique has the potential to rapidly characterize a wide variety of biological materials, from macromolecules like hemoglobin to live bacterial samples to proteins and DNA. By combining lithographically-defined broadband microwave structures with microfluidic chambers produced by state-of-the-art micromachining techniques, it is possible to determine the dielectric response of extremely small sample volumes (picoliters) over 9 decades in frequency (100 Hz – 100 GHz). Integration with other micro-electromechanical systems (MEMS), such as microfluidic pumps and circuits, could enable rapid analysis of large numbers of different samples in high-throughput screening systems.

Knowledge of the dielectric properties of biological samples (e.g., tissue, blood) is also necessary for the development of new microwave or millimeter-wave based medical treatments and/or diagnostics, and could also be applied to determine the effect of electromagnetic signals at the cellular level. For example, such measurements could provide valuable data on the possible health hazards posed by the proliferation of commercial wireless devices. Currently, data on the dielectric properties of many biological substances, if existent, are rarely available at frequencies above 20 GHz. By extending the frequency range for dielectric analysis up to at least 110 GHz, we will create a new tool for characterizing and understanding the interaction between organic materials and microwave radiation.

Spin Electronics

WH Rippard S Russek 50.81.82.B6412

KW Spin electronics
KW Nanotechnology
KW Magnetism
KW Microwave circuitry
KW Spintronics
KW Magnetodynamics

TJ Silva

Until recently, the only means known to control the magnetization state of ferromagnetic structures was through the use of applied magnetic fields. However, within the last several years it has been demonstrated that this can also be accomplished through the transfer of the electron spin angular momentum from current-carrying electrons to the magnetization of magnetic films, generally referred to as the spin-momentum-transfer effect. Spin transfer represents a fundamentally new way to control and manipulate the magnetic states of devices, and allows hysteretic switching and coherent microwave dynamics to be excited in magnetic nanostructures using a DC current. This project seeks both to understand the fundamental characteristics of the interaction between spin polarized currents and magnetic materials, and also to examine the suitability of such nanoscale devices for microwave electronics. We are specifically pursuing research in (1) increasing output power from nanoscale oscillators through materials engineering and incorporating tunnel junctions into the device structures, (2) understanding the interactions between mutually synchronized nanoscale oscillators in order to develop device arrays, (3) characterizing and understanding the thermal contributions to both oscillator linewidths and the current induced switching distributions in patterned elements, (4) understanding the interactions between individual magnetic nanostructures and AC fields and AC currents, and (5) investigating the current-induced switching properties of patterned magnetic nanostructures for magnetic random-access memory applications.

Magnetic Sensors, Spintronic Materials, and Nanomagnetic Imaging

S Russek WH Rippard 50.81.82.B6629

KW Magnetic sensors
KW Spintronic materials
KW Spin-dependent transport

KW GMR
KW MTJ
KW MRAM
KW Nanoscale magnetic structure
KW BEMM
Spin-dependent transport is a widely used, yet poorly understood, phenomenon. Giant magnetoresistive (GMR) devices and magnetic tunnel junctions (MTJ) are being developed for use in magnetic recording heads, magnetoresistive random access memories (MRAM), and magnetic sensors for industrial and biomedical applications. The goal of this research opportunity is to develop a better fundamental understanding of spin-dependent transport in magnetic metals, normal metals, conducting oxides, and semiconductors. Research areas include understanding spin polarization in exotic materials, examining the effects of interfaces, and looking at the nanomagnetic structure that gives rise to noise and device-to-device variation. This research involves fabrication of novel magnetic devices such as GMR, MTJ, and spin-transfer devices using a state-of-the-art, eight-source, ultrahigh vacuum deposition system and a combination of optical, electron-beam, and scanned-probe lithography. Electrical measurements, over a wide range of temperature, field, and frequency, will be used to characterize spin-dependent transport properties with a particular emphasis on high-frequency and noise properties of the devices. Lorentz and magnetic force microscopy will be used to characterize nanoscale magnetic structures. New types of dynamical nanoscale imaging, such as those based on ballistic electron magnetic microscopy (BEMM), will be developed.

Metrology for Magnetic Resonance Imaging Artifacts and Stability

LF Goodrich S Russek 50.81.82.B6468

KW Superconductivity
KW Magnetics
KW Electromagnetism
KW Biomagnetics
KW MRI
KW NMR
KW Biomedical engineering
KW Medical physics
KW Medical imaging
Research focuses on developing metrology for magnetic resonance imaging (MRI) system stability and intercomparability and image distortion. This is part

of a new NIST effort to assist the medical imaging community in developing more quantitative images that are traceable to the International System of Units (SI). We intend to conduct studies to assess MRI system stability and intercomparability using NIST-generated artifacts and assess methods to identify sources of instability in MRI coils systems: superconducting solenoid, shim coils, gradient coils, and RF coils. We plan to develop metrology to analyze magnetic imaging distortions as a result of implants such as stents and coils. This will involve evaluating magnetic properties of MRI system components and implants that could lead to image distortion. Measurements will be made using a 7 T SQUID magnetometer, a 7 T 300 MHz nuclear magnetic resonance system, and other superconducting high-magnetic field systems at NIST-Boulder. All of these studies will also involve measurements conducted in commercial MRI systems at local hospitals and at the National Institutes of Health (NIH). This opportunity is appropriate for physicists, chemical-physicists, or engineers interested in medical physics or medical engineering.

High-Dynamic Range Electrical Measurement Systems

DF Williams PD Hale 50.81.82.B6470

KW Electrical waveform measurement

KW Microwave measurement

KW Electro-optic sampling system

KA Remley

The ability to characterize signals that cover a high dynamic range is becoming important for many applications in both wireless and optoelectronics. Applications for high-dynamic-range measurement systems are both diverse and of high impact. They include network impairment studies for broadband wireless and optical networks, improved amplifier distortion measurements and models, detection of weak signals, and analog to digital converter characterization. We anticipate these measurement systems will also be useful in improving our traceability path for microwave phase standards. We wish to develop high-dynamic-range electrical measurement systems with measurement bandwidths up to 50 GHz. These new measurement systems will be based on a mixture of temporal sampling and frequency-domain down-conversion schemes. A high priority will be establishing measurement traceability to our electro-optic sampling system. This project will advance the state-of-the-art for electrical measurements and includes a good mix of both theoretical and laboratory work.

Metrology for Wireless Systems

KA Remley 50.81.82.B6411

KW Wireless systems
KW Electrical measurements
KW Broadband wireless
KW Microwave circuitry
KW Modulated signal calibration
KW RF electronics

New wireless devices are often both multi-mode and multi-frequency, operating with a variety of modulations and carrier frequencies simultaneously. Ensuring that system-level specifications are met is difficult because of the sheer number of potential operating states. This requires development of creative solutions for the measurement of broadband, high-dynamic-range signals, both in terms of intentional signals and distortion. Development of measurement techniques that uncover key performance parameters of broadband modulated signals for wireless systems will be the focus of the project. The work will provide a good mix of theoretical development and hands-on experiment in an area of intense commercial growth.

Millimeter-Wave Wireless Systems

KA Remley DF Williams

KW Wireless systems
KW Electrical measurements
KW Broadband wireless
KW Microwave circuitry
KW Modulated signal calibration
KW RF electronics
KW Millimeter-wave electronics

In October 2003, the Federal Communications Commission issued an historic ruling, freeing 13 GHz of previously unused spectrum between 71 and 95 GHz for high-density fixed wireless services in the United States. This is 50 times the bandwidth of the entire cellular spectrum. For the first time, true gigabit-speed wireless communications over distances of a mile or more became realizable. Above 100 GHz even larger chunks of unallocated or under-utilized bandwidth are waiting in the wings. However, the electrical metrology for broadband modulated wireless communication links at these frequencies is virtually nonexistent. Vector measurements must be made at 60-300 GHz frequencies and 1-20 GHz bandwidths that can only be attained by ultrafast electro-optic metrology and novel scattering-parameter, modulated-signal, and antenna metrology that are unfamiliar to the industry, but are being developed at NIST. This project will focus on developing procedures for characterizing vector modulated sources, frequency converters, antenna systems, and receivers with gigahertz bandwidths at millimeter-wave frequencies. Both electronic and free-field test measurement science will be developed.

Theoretical Investigations of High-Frequency Fields and their Interactions with Dielectric and Magnetic Materials: Nanowires, Metamaterials, Fluctuation-Dissipation Phenomena, Nonequilibrium Modeling and Noise

JR Baker-Jarvis 50.81.82.B6966

KW Dielectric and magnetic theory
KW Statistical mechanics
KW Microwave theory and techniques
KW Microscopic electromagnetism
KW Negative-index materials

Research opportunities exist for theoretical investigations of metrology areas related to the characterization of the macroscopic and microscopic electromagnetic properties of materials in the radio-frequency to terahertz frequencies. Suggested research areas include statistical mechanics of EM; plasmonics and probe-material interface modeling; theoretical development of information-theory based electromagnetic metrology; nonequilibrium EM; and the relationships of complex permittivity to material mechanical stress, entropy production, spin momentum transfer, microscopic dielectric interactions, ferroic materials, and metamaterials.