Areas of particular interest:

Quantum Dot Morphology

A Roshko 50.81.52.B4379

Quantum dots have attracted a great deal of interest because of their unique properties and possibilities for optoelectronic applications. However, control of dot density, composition, position, size, and shape remain major obstacles for many device applications. We invite proposals to address these issues through an investigation of quantum dot morphology as a function of growth parameters, such as temperature, rate, thickness, composition, and dot stacking. Studies of the interrelations between these variables and strain state are also of interest. State-of-the-art molecular beam epitaxy with reflected high-energy electron diffraction, atomic force microscopy, high-resolution x-ray diffraction, and transmission electron microscopy are available for analyzing quantum dot distributions, heights, shapes, spacings, and strain fields. Correlation with optical properties, such as photoluminescence, is also of interest. The work will contribute to a more complete understanding of quantum dot morphology, how it correlates with device performance, and how it can be controlled through the choice of growth conditions.

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

KA Bertness 50.81.52.B5883

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

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

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

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

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 (EIT) should be observable.

MBE Growth of Quantum Dots

R Mirin 50.81.52.B5885

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 T Clement 50.81.52.B6460

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 (for example, 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.

Nanoscopic Wide-Bandgap Materials Characterization by CW and Ultrafast Nonlinear Optics

NA Sanford JB Schlager 50.81.52.B4766

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 multi-photon spectroscopy and nonlinear optics for examining local structural and electronic properties of the wide-bandgap III-nitride alloy semiconductors. The techniques include ultraviolet (UV) second-harmonic generation in addition to cw and time-resolved, multi-photon UV spectroscopy that employ NSOM and confocal techniques. We are particularly interested in the study of local defects, polytyping, inversion domains, and alloy segregation; spectroscopy on the scale of defect separation (roughly 100 nm); and ultrafast processes involving interactions with strong static polarization fields in these materials. The spectroscopic results are correlated with x-ray diffraction imaging, high-resolution cathodoluminescence, and TEM.

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

NA Sanford KBertness ARoshko 50.81.52.B5887

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), 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.

In-Situ Metrology of Epitaxial Crystal Growth for Semiconductor Optoelectronics

KA Bertness RK Hickernell 50.81.52.B1560

Semiconductor optoelectronic devices are being employed in a variety of applications, including telecommunications, computer interconnects, data storage, display, printing, and sensor systems. Most of these devices rely on accurate, reproducible epitaxial crystal growth; however, further reductions in growth cost will require further development of *in situ* and *ex situ* measurement tools. Our research focuses on optical *in situ* material probes (i.e., pyrometry, atomic absorption spectroscopy, and broadband normal-incidence optical reflectance) correlated with reflectance high-energy electron diffraction, *ex situ* x-ray diffractometry, photoluminescence spectroscopy, optical reflectance, and extensive modeling capabilities. Other resources include *in situ* mass spectrometry, atomic force microscopy, transmission electron microscopy, electrochemical profiling, and clean room facilities for processing test and device structures. We have recently demonstrated growth of GaN nanowires, and proposals specific to plasma nitrogen characterization and monitoring of rough surfaces are encouraged. We also examine the practical utility of various measurement tools through the growth of device structures, with emphasis placed on vertical-cavity surface-emitting lasers, in-plane lasers, quantum dot lasers, and saturable Bragg absorbers.

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

E Grossman 50.81.72.B1533

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).

Flat Panel Display Metrology

EF Kelley <u>(Boulder)</u> 50.81.11.B4369
<u>PA Boynton (Gaithersburg)</u>

NIST's flat panel display laboratory serves the display industry by developing and quantifying good electronic display metrology for industrial use. With the explosion of the information age, the Internet, and e-commerce, the use of flat panel displays has become a growing need for US industries. Good display measurement methods are needed for several reasons: (1) specification language needs to rest solidly upon good metrology, (2) fierce competition between technologies requires good metrology to distinguish features, (3) users and implementers of displays need accurate characterizations of displays for selection purposes. NIST is doing research in (1) equipment on improving measurements made on displays; (2) development of display metrology with various standards organizations; (3) development of display metrology assessment methods and equipment to provide guidance for the implementation of good measurement methods in the display industry; and(4) display reflectance characterization, measurements, and modeling using the bi-directional reflectance distribution function. Opportunities are available at both Boulder and Gaithersburg campuses.

High Speed Optoelectronics Measurements

PD Hale DF Williams 50.81.52.B4008

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 RP Mirin DF Williams 50.81.52.B4767

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 Pulse Characterization and System Monitoring

PD Hale KB Rochford 50.81.52.B4381
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 through measurements of optical signal amplitude, phase, jitter, and noise are needed. We are soliciting proposals for 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 50.81.52.B6461

PD Hale KB Rochford
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

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

The calibration of laser and optical fiber meters over wavelengths ranging from 200 nm to 1800 nm 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. We will demonstrate a variety of sources that are continuously tunable over the entire wavelength of interest (200 nm to 1800 nm) and deliver the output of these sources to various laboratories using optical fiber. 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.

Carbon Nanotube Coatings for Laser Power and Energy Measurements

JH Lehman 50.81.52.B5889

Several areas of research are currently being pursued: improved coatings for thermal detectors, ultraviolet detectors resistant to damage and aging, and improved transfer standards for pulsed-laser radiation measurements. In each case, our goal is to develop and maintain optical detectors that are traceable to electrical standards for the purpose of maintaining calibration services in the area of laser power and energy measurements. Nearly all of the primary standards for laser power and energy measurements at NIST are based on thermal detectors. Our goal is to establish carbon nanotube coatings as a practical choice for the next generation of standards. We also employ a variety of photodiode-based detectors as transfer standards for routine laser power calibrations for our customers. In each of these areas, the practical matters of providing cost-efficient, routine calibrations having low uncertainties must be considered. Topics of interest also include new technologies and/or methods for developing and transferring detector-calibration information from one area to another.

Ultraviolet Laser Metrology

J Lehman ML Dowell 50.81.52.B1563

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. Presently 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. Presently 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.

Optical Coherence Tomography

SD Dyer PA Williams 50.81.52.B5890

Optical coherence tomography (OCT) is an exciting technique to achieve high-resolution, three-dimensional, *in vivo* images of human tissue. OCT has excellent spatial resolution (1-10 micrometers), which is two orders of magnitude better than ultrasound. OCT has applications ranging from early detection of glaucoma to measuring the morphology of the arterial plaques that may be responsible for 70 % of heart attacks. Our work is focused on developing accurate, high-resolution OCT measurements. We are applying OCT to measurements of tissue dispersion and absorption for tissue identification and early disease diagnosis. We are particularly interested in proposals on the topic of Mie scattering theory applied in a multiple scattering geometry. Another interest is minimum phase and non-minimum phase filters, and their applications to tissue measurements. We are also developing high-accuracy polarization sensitive OCT measurements to assess tissue anisotropy as a measure of tissue health.. We are also studying the sources of the polarization speckle noise that degrades these measurements. The accuracy of OCT distance measurements is limited by the scattering, absorption, dispersion, and birefringence of the tissue, as well as the lack of high-accuracy data on the refractive indices of various human tissues. The refractive index is important because OCT measures the optical path length, which is the product of the layer thickness with the group refractive index. To address this problem, we would like to develop techniques to accurately measure both thickness and refractive index.

Fiber-Optic Sensors

SD Dyer 50.81.52.B5522

Fiber-optic sensors are lightweight, tiny, and flexible, with low power requirements and large dynamic range. They can detect a variety of measurands, including strain, temperature, pressure, and electromagnetic quantities. Much of our research focuses on fiber Bragg gratings (FBGs) for strain, temperature, and pressure sensing. We are interested in developing high-accuracy wavelength measurements for sensor calibration. Because hysteresis and nonlinearity due to the FBG's polymer coating and adhesives affects sensor calibration, we are also interested in novel measurement techniques to characterize these effects. Other important topics include techniques for distributed sensing with high-spatial resolution (<100 micrometers), and understanding and improving the process of writing Bragg gratings in optical fibers.

Infrared Frequency Comb Development and Application

NR Newbury 50.81.52.B5523

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 a spacing equal to that of the laser repetition rate. These frequency combs have the potential to revolutionize optical frequency metrology in the telecommunication band 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 using either Femtosecond fiber lasers or other laser technology that could be used for wavelength metrology. Other examples of proposals include developing a better understanding of the noise properties of the frequency comb, and exploring other uses of the frequency comb related to LADAR, coherent communication or optical coherence tomography applications.

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