

Faculty Research Topics

Craig Arnold's Group: (Princeton)

Research in the Dr. Arnold's group focuses on laser processing and transport in materials for applications in energy storage, photonics, bioengineering, and nanotechnology. Current projects include laser direct-write and non-traditional patterning of small-scale and flexible structures such as microbatteries, nanomaterials, organic molecular electronics, and living cells and organisms. Other work in the group looks at photo-modifiable materials and processing for mid-infrared photonics. The research is primarily experimental in nature with a mix of fundamental and applied projects.

Claire Gmachl's Group: (Princeton)

Our special focus is currently on Quantum Cascade (QC) lasers. Current projects include the development of high temperature, high power QC lasers for sensing of explosives and toxic chemicals. Widely tunable, monolithic and external cavity, QC lasers are being developed for optical sensors in environmental and medical applications. While my group is focused mainly on the development of the lasers, we maintain strong collaborations with many expert spectroscopists in academia, government and industrial labs, who are building sensor systems. Another application of QC lasers is in mid-infrared free-space optical wireless communication. My team is developing lasers for this purpose, and conducts research into some of the fundamental, physical layer issues of long-wavelength optical wireless communication.

Recently, we have developed a new kind of QC laser, capable of simultaneously acting as pump laser and resonant nonlinear optical medium. We have demonstrated efficient second harmonic generation, and are quickly expanding our efforts to other nonlinear optical effects. We are looking into the development of electronic-Raman QC lasers, as well as difference frequency generation and parametric down-conversion. Our ultimate goal is to generate an efficient non-classical semiconductor light source. In the process, we will also develop detection systems capable of measuring the photon statistics of mid-infrared light. With the development of efficient photon-pair sources, we will venture into the field of applied quantum communication and secure communication.

In the future, I am planning to develop a material synthesis effort, centered around III-V and/or group-IV crystal growth, that plays well into our above described projects, and will also open up a wider range of development opportunities for innovative optical quantum devices.

James Smith's Group: (Princeton)

I lead the Hydrometeorology Research Group where we are focused on two main research projects under MIRTHE:

Coupled Water, Carbon, and Nitrogen Cycles in Urban Environments

The long-term goal of this project is to develop technology for monitoring coupled water, carbon and nitrogen cycles in urban environments, based on quantum cascade laser (QCL) spectrometers. This includes development and deployment of eddy covariance systems in Princeton and Baltimore urban research sites, and interfacing the QCL based gas sensors to the wireless sensor network to monitor trace gas fluxes. In the first year research will focus on design of QCL-based eddy covariance system for CO₂, electronic interface specification, partial deployment of instrumentation, and CO₂ data collection using traditional and currently available technologies for comparison.

Monitoring Aerosol Properties in the Urban Environment

The objective of this project is to develop technology for monitoring urban aerosol properties based on mid-IR quantum cascade lasers. The project will be implemented through "testbed activities" which will include the northeastern corridor between NYC and Baltimore and focus on NYC and Princeton study sites during the first year. Testbed activities will provide the resources for development and demonstration of aerosol measurement technologies which have broad application to problems of public health and environmental assessment in urban regions. The Princeton team will focus on applications concerning precipitation modification by urban aerosols. A core element of the measurement technology will be differential absorption lidar (DIAL). Sensor systems for measuring aerosol properties will include both remote sensing (lidar) and in-situ measurement technologies

Mark Zondlo's Group: (Princeton)

The Zondlo group uses novel optical instrumentation to address important issues in atmospheric chemistry, cloud microphysics, and aerosol processes. Below are two examples of projects in the group: water vapor measurements on the NSF Gulfstream-V aircraft using state-of-the-art vertical cavity surface emitting lasers (VCSELs) near 1.8 microns and new development of ammonia instrumentation using quantum cascade (QC) lasers near 9 microns. Water vapor is the most important species in the climate and dynamics of the Earth's atmosphere, and its distribution also impacts atmospheric chemistry significantly. Ammonia plays critical roles in the nucleation, growth, and composition of aqueous aerosol particles that are integral in clean particle formation in the remote atmosphere to urban air quality. Despite their importance to the atmospheric sciences, both species are surprisingly not well measured, limiting our ability to predict cloud formation and the affects of aerosols on air quality and climate.

Gerard Wysocki's Group: (Princeton)

The group conducts research which is primarily focused on the development of mid-infrared laser spectroscopic instrumentation for applications in trace gas detection and chemical sensing. The target applications range from atmospheric chemistry, environmental monitoring and bio-medical research, to industrial emissions and process control.

Our current research activities include:

- Development of ultra-sensitive mid-IR laser spectroscopic systems for remote or in-situ, non-invasive, rapid chemical analysis.
- Development of widely tunable external cavity quantum cascade lasers (EC-QCLs) for high resolution molecular spectroscopic application
- Development of distributed spectroscopic trace-gas sensor networks

Jason Fleischer's Group: (Princeton)

My research treats nonlinear optics within the broader context of general wave physics. The emphasis is on propagation problems that are universal to wave systems, taking advantage of the fact that optical systems allow easy control of the input and direct imaging of the output. Using a healthy mix of theory and experiment, my group studies both basic nonlinear physics and advanced design issues for photonic applications. As a prime example, my group is developing an optical hydrodynamics in which the nonlinear propagation of light is described in terms of the equations for ideal fluid flow. Propagation in waveguide arrays can be interpreted in terms of solid-state physics, while interactions between array sites can be described by coarse-grained hydrodynamics. There are two primary results of these mappings: 1) optical modeling and observation of condensed-matter behavior that is difficult, if not impossible, to see by other means, and 2) a framework for the discovery of new optical physics. This latter consequence is particularly important, as better understanding of optical dynamics inevitably leads to the design of new photonic devices. Active areas along these lines include advanced waveguide systems, improved holographic techniques, and all-optical image/signal processing.

Paul Prucnal's Group: (Princeton)

Research in my group, the Lightwave Communications Laboratory, is focused on investigating ultrafast optical techniques with application to communication networks, as well as on testing and measurement systems. In the area of communication networks, we have been the first to demonstrate a 100 gigabit/sec packet switching node, which is one hundred times faster than any previous packet switch with comparable functionality. This project has resulted in numerous publications on the subjects of the physics of nonlinear semiconductor optical switches, ultrafast optical timing synchronization and routing control, ultrafast demultiplexing, fabrication and measurement of ultrafast time delays, high-dimensionality switching in the time domain, simulation of transmission effects with ultrashort pulses, simulation of multihop network performance, and finally, the node demonstration.

With a high degree of interaction between government and industrial research laboratories, the Lightwave Communications Laboratory offers students an opportunity to be involved in the creation of the next generation Internet, the development of all-optical computer networks, and in research into novel optical imaging and sampling systems.

Alexey Belyanin's Group: (Texas A&M)

We are trying to develop a new approach in physics and design of nonlinear optical devices based on fully resonant interaction of light with electrons confined in quantum wells and monolithic integration of nonlinear elements and pump sources. Our aim is to combine the tunability and flexibility of nonlinear optical sources with advantages that only semiconductor injection lasers can offer: compactness, high efficiency, injection pumping scheme, low cost, and possibility of monolithic integration with electronic chips. This work is a collaboration with groups led by Federico Capasso (Harvard) and Claire Gmachl (Princeton).

The lasers that we design and fabricate are injection-pumped quantum-cascade lasers, in which the laser field serves as an optical pump for the resonant, nonlinear optical interaction in the very same active region. In other words, the optical pump source and the nonlinear optical medium are integrated in a single, injection-pumped device. Such a design takes full advantage of giant resonant optical nonlinearities of coupled quantum wells (QWs) that have been observed since late 1980s. Indeed, since the optical pump is generated inside the nonlinear medium, resonant absorption is not a problem anymore. Therefore, we can have all fields participating in the nonlinear interaction to be resonant with corresponding intersubband transitions. As a result, the second-order nonlinear susceptibility $\chi^{(2)}$ is enhanced by orders of magnitude, up to hundreds nm/V.

Michael Weimer (Texas A&M):

Dr. Weimer's group research in the Scanning Tunneling Microscopy (STM) Laboratory at Texas A&M is aimed at developing a comprehensive experimental picture of the structure and electronic properties of III-V semiconductor surfaces and interfaces. Our current work has taken advantage of the nanometer-scale spatial resolution afforded by STM to advance our understanding of two especially significant problems in III-V epitaxial growth: the precise structure of the interfaces in type-II semiconductor superlattices and quantum wells, and the onset of atomic ordering in III-V semiconductor alloys.

Christi Madsen (Texas A&M):

Dr. Madsen's research interests include photonic signal processing including novel signal generation and characterization and microwave photonics, integrated optics including polarization control, mid-infrared devices, sensors, and ring resonators, fiber-optic intrusion sensor/perimeter

monitor, optical filters (synthesis, analysis, adaptive and active filters), and dispersion and high-speed optical signals.

Junichiro Kono's Group: (Rice)

Our research is currently focused on the physics and applications of semiconductor nanostructures and quantum device structures. We use state-of-the-art spectroscopic techniques to study charge, spin, and vibrational dynamics in a variety of nanostructures. The impact of our research includes: increased understanding of the quantum states and dynamics of interacting, confined, or strongly driven electrons in nanostructures; new spectroscopy techniques; novel device concepts and implementations (especially towards all-optical switches and spin-based devices); establishment of the quantum nature of semiconductor-light interaction; progress towards the solid-state realization of quantum information processing, computation and communications; and provision of a controlled environment in which to address unanswered questions in many-body physics.

Rebekah Drezek: (Rice)

Research in my laboratory focuses on development of novel optical imaging technologies for in vivo assessment of tissue pathology. Projects emphasize design, prototyping, and clinical testing of optical tools for the detection, diagnosis, and monitoring of the molecular signatures of precancerous conditions and early malignancies. We approach our projects from an interdisciplinary perspective and actively collaborate with clinicians, molecular biologists, biochemists, and other researchers located within Rice and the Texas Medical Center.

In our laboratory, areas of current emphasis include:

- 1) development of novel optical spectroscopy and imaging instrumentation for tissue diagnosis
- 2) validating developed optical instrumentation through systematic studies using biological samples of progressively increasing complexity, beginning at the cellular level and culminating in small scale clinical trials
- 3) development of molecular specific optical contrast agents
- 4) experimental studies to elucidate the biophysical origins of measured optical signals
- 5) computational modeling of the interaction of light with biological tissue in order to understand the relationships between measured optical signals and underlying tissue biochemistry, morphology, and architecture

Katalin Szlavercz: (Johns Hopkins)

My main MIRTHE related research projects are the following:

Origin and distribution of soil fauna on a heterogeneous landscape: biodiversity in urban environment.

This project focuses on the effect of past and present land use on diversity and distribution of soil invertebrate assemblages. We are assessing soil fauna in urban and rural forest fragments, parks, and anthropogenic land uses, such as lawns and planting beds. This study is a contribution to the [Baltimore Ecosystem Study](#) (BES). BES is part of the NSF supported [LTER](#) (Long Term Ecological Research) Network. Collaborators: Csaba Csuzdi (Hungarian Natural History Museum), Elisabeth Hornung (Szent Istvan University, Budapest), Richard Pouyat (USDA Forest Service), Zoltan Korsos (Hungarian Natural History Museum)

Wireless sensors in soil ecology:

The availability of inexpensive, low power wireless sensors is changing the way we can acquire environmental information. This type of monitoring is especially necessary in soil ecology, where conditions vary at different spatial and temporal scales. Our understanding of soil organism dynamics, and, more importantly the role these organisms play in important ecosystem processes is limited due to the complexity of this environment and lack of continuously collected abiotic data. The proposed

research will customize, test, and deploy a network of low-cost wireless sensors to monitor the soil and aboveground conditions. The data will be collected automatically and uploaded into an online database. Collaborators: Wei Hong (Intel Berkeley Research Laboratory), Dan Wertheimer (Space Sciences Laboratory, UC Berkeley), Alex Szalay (JHU Physics and Astronomy), Jim Gray (Microsoft Research), Randal Burns and Andreas Terzis (JHU Computer Science), Josh Cogan (JHU physics major). A pilot study is supported by Microsoft Research and by the Gordon and Betty Moore Foundation.

Andreas Terzis (Johns Hopkins University):

Dr. Terzis leads the Hopkins InterNetworking Research Group (HiNRG) that performs research in the general area of computer networks. The two main current research themes are sensor networks and network security. They work at multiple aspects of sensor networks, from application development, to network protocol design, information processing, and data management. In network security we focus on modeling or large scale self replicating malware, forensic analysis, botnets, and emerging threats.

Barry Gross (CCNY):

My research areas of expertise are nonlinear optics, photonic devices, and soliton communications.

Fred Moshary (CCNY):

My research areas of expertise are atmospheric remote sensing using multi-wave LIDAR/DIAL, and optical sensors.

Samir Ahmed (CCNY):

My research areas of expertise are remote sensing optical communications.

Maria Tamargo (CCNY):

Maria Tamargo's group is investigating the growth and properties of a new family of wide bandgap II-VI semiconductors, ZnCdMgSe, grown lattice-matched to InP substrates by MBE. By optimizing the growth conditions they have reduced defect densities to the level of other more well-known II-VI compounds grown on GaAs. These new alloys and their heterostructures possess properties (band structures, lattice constants, band offsets and doping) that are attractive and offer advantages for the design of improved visible semiconductor lasers and LEDs. These devices are of interest for optical recording, displays and communications applications.

Other areas of research include, saturable Bragg reflectors (SBR) made of III-V materials for laser mode locking, hexagonal II-VI structures for visible emitters, selective area epitaxy of CdTe detector array-like structures and hybrid semiconductor/molecular aggregates for photonic applications.

Beth Wittig (CCNY):

Dr. Wittig's research interests are instrument design, ambient air quality chemistry and transport/dispersion, indoor air quality transport/dispersion, and engineering pedagogy relating to air quality research.

Fow-sen Choa (UMBC):

Dr. Choa's current research focuses on the optoelectronic devices, optical network, and optical materials.

Joel Morris (UMBC):

Dr. Morris' research focuses on topics including stochastic and deterministic system theory with applications to communications and statistical signal processing, joint-time frequency/time-scale analysis and applications, robust signal processing, fading channel communications, and adaptive signal processing and applications.

Anthony Johnson (UMBC):

General area of ultrafast optics and optoelectronics - the ultrafast photophysics and nonlinear optical properties of bulk, nanoclustered, and quantum well semiconductor structures, ultrashort pulse propagation in fibers and high-speed lightwave systems.

Curtis Menyuk (UMBC):

Dr. Menyuk's research focuses on optical fiber communications and switching, solid state device simulations, and nonlinear optics.

John Zweck (UMBC):

Dr. Zweck's research interests are optical fiber communications, computational anatomy, human and computer vision, differential geometry, and simulation-based engineering science. Some of his ongoing research projects include working with Anatoliy Kosterev in the Laser Science Group at Rice University, Sue Minkoff (Math and Stat, UMBC) and Curtis Menyuk (CSEE, UMBC) on computational modeling of quartz-enhanced photoacoustic spectroscopy sensors.