# THE BOSTON UNIVERSITY PHOTONICS CENTER

## *ANNUAL REPORT 2007-2008*

The Boston University photonics center

# Table of Contents



# Letter from the Director

In the eleven years since its dedication, the Boston University Photonics Center (BUPC) has become a physical and intellectual centerpiece of the University's forward-looking programs in interdisciplinary research. On behalf of our faculty, students and staff, I appreciate your interest in BUPC and in our Annual Report.

In this report, you will find a variety of information regarding our photonics education programs, nationally renowned research efforts, business incubator, and cooperative agreement to develop innovative prototypes with the US Army. The first two missions – education and research – highlight our practice of engagement within the academic community, while the latter two missions – commercialization and technology development – highlight our complementary practice of working on problems of importance to society.

Our activities for the year reflect an escalating emphasis on biophotonics and nanophotonics by our faculty, commercial partners, and Department of Defense sponsors. These two closely related subfields represent an exciting frontier in photonics, promising practical applications of light in molecular medicine, single-cell science, and biomedical engineering. Our plans for the future include strategic growth of our facilities and personnel devoted to these areas.

This year we continued to strengthen our community through BUPC sponsored events and fellowships. The "Future of Light Symposium" highlighted the nexus between education and research, featuring invited talks by leading academic researchers, short courses taught by our faculty, and an extraordinary collection of student posters. We proudly launched a "Distinguished Lecture" series with an invited talk by Dr. Philip Russell, Director of Division Photonics & New Materials at the Max-Planck Research Group at the University of Erlangen-Nuremberg. Dr. Russell's engaging, and thought-provoking lecture on the photonic crystal-fiber materials that he pioneered, set a great precedent for this new annually-recurring event. In support of our core constituency, students, we provided fellowship support to ten BUPC doctoral students and expanded our undergraduate research program. This year, with additional support from the National Science Foundation and the Department of Defense, we also hosted more than forty undergraduate students in the laboratories of BUPC faculty.

While I am proud of our academic and educational achievements, I am equally proud of our continuing efforts to produce and field-test prototype hardware that meets critical and emerging needs for our national defense community. Through this BUPC-Army Research Laboratory Cooperative program, we develop photonics technology derived from compelling new research outcomes that emerge regularly from our faculty laboratories. The prototypes are then field-tested with the help of military partners and U.S. Department of Defense contractors. Our newest programs emphasize biophotonics and nanophotonics technology to combat biothreats. We have already produced results that show substantial promise in both defense and civilian applications.

It is the dedication of the faculty and staff at BUPC who make our efforts so successful. I am grateful for their contributions, and honored to work with them.

Regards,

Thomas Bifano, Ph.D.
Director, Boston University Photonics Center

# Executive Summary

The following report summarizes activities of the Boston University Photonics Center (BUPC) during the period July 2007 through June 2008. These activities span the Center's complementary missions in education, research, technology development, and commercialization.

Faculty research activity reached an all time high when evaluated by the accepted metrics of external funding, scholarly publications, honors and awards. The Center's educational programs were bolstered by two summer programs hosting more than 40 undergraduate interns, and by the renewal of a competitive graduate fellowship program sponsoring ten BUPC graduate fellowships. In technology development, the prototype RedOwl sniper detection system pioneered by Center faculty, staff, and industry partners was field-tested by the US Department of Defense. RedOwl has been officially transitioned to industry partners for further commercial development along with the soldier wearable Enhanced Acoustic Gear for Locating Enemies (EAGLE) system. Three defense/security prototypes were developed by BUPC to address critical national defense needs in the past year. Four faculty development projects were supported in collaboration with the Army Research Laboratory's Sensors and Electron Devices Directorate (ARL-SEDD) to fill the technology pipeline for our future defense-related prototyping efforts. The Center's business incubator is at capacity with various technology companies ranging from photonics to life sciences. The incubator provides a stimulating intellectual environment, outstanding facilities, and professional business expertise to participating companies.

## Activities highlights for the 2007-2008 fiscal year:

### *External grant funding for the 2007-2008 fiscal year: $18.5M*

Included in this figure is more than $11.6M in grant and contract support of fundamental photonics research conducted by the Center's 35 faculty members and $6.9M through a Cooperative Agreement with ARL-SEDD for photonics technology research and development in areas of critical national need.

### *Three professors joined the photonics center faculty*

Lee Goldstein, MD, Ph.D, is an Associate Professor of Psychiatry, Ophthalmology, Neurology, Pathology and Laboratory Medicine (Boston University Medical Center). His research includes continued investigation into Alzheimer's disease-associated amyloid pathology and laser based non-contact diagnostics based on spectroscopic interaction with the eye's lens. Also joining the Center is Assistant Professor Björn Reinhard who has an appointment in the Department of Chemistry. Professor Reinhard's work includes the design and implementation of new materials combining electronic and optical properties of inorganic materials for single molecule biophysics and spectroscopy. Franco Cerrina, Ph.D., is the newly appointed chair of the Electrical and Computer Engineering Department. His research includes work in nanotechnology, advanced semiconductor lithography and nanofabrication. More information about these new faculty members are discussed in Section II.

### *Significant new research thrusts launched in biophotonics*

Two new Bio-Safety Level 2, Class IIIb and IV laser labs were added to support increased demand for such facilities by new faculty research, bringing the Center's total to three. In addition, the shared Integrated Optics Lab (IOL) was consolidated into a smaller space to allow the construction of two laboratories for the newest BUPC faculty members: Franco Cerrina and Lee Goldstein. Professor Cerrina, who also will serve as the newly appointed chairman of Electrical and Computer Engineering, will be arriving in August, 2008. Professor Cerrina is the inventor of a maskless gene chip manufacturing process that has enabled extraordinary advances in biomolecular engineering. Professor Goldstein, the first BUPC faculty member with a primary appointment in the BU School of Medicine, is supported by the Center's New Faculty Initiative Award. This award supports his pioneering effort to early diagnosis of Alzheimers Disease and radiation exposure through the use of sophisticated biophotonic instrumentation. Nanophotonics and biophotonics have emerged as areas of strategic importance to the Center and University. These areas build upon the complementary and interdisciplinary strengths of Center faculty.

### *Pipeline development projects were introduced for defense and security applications.*

Four Faculty Technology Development Awards (FTDA) were funded as Phase I programs following the successful prototype development model that delivered the RedOwl System. Continued support was also provided to biothreat detection and diagnosis FTDA programs including COBRA Detection and COBRA Diagnosis. In total, we continued to support four previous FTDA programs: two progressing to Phase II- prototype enhancement and one is progressing to Phase III- prototype insertion.

### *Ten photonics center graduate fellows were supported*

The fellows initiated wide-ranging activities linking scholarship, education, and community. Fellows were selected competitively, and spanned six University departments. Working with faculty mentors and BUPC staff advisors, they engaged in equipment training, shared laboratory support, event planning, and the creation of a lively "Photonics Forum" seminar series highlighting emerging interdisciplinary research at the Center. Based on the success of the program, seven senior fellows and two junior fellows were selected for the coming academic year (2008 - 2009).

### *Five new companies join the incubator, three companies graduate*

Three companies are new to the incubator this year: eQuilibrium, Inc., Lumenz, Inc., and Nanosurfaces, Inc. Ninth Sense Inc. and Zoiray Technologies, Inc., both BUPC spin-off companies, will be joining the incubator this summer. Biomimetic Systems, Inc. (BMS) a spin off from the faculty research labs of Professors Allyn Hubbard and David Mountain, successfully exited the incubator facility this year. A123 Systems, a former incubator company, filed paperwork this year with the Securities and Exchange Commission relating to the proposed initial public offering of its common stock.

These companies represent the leading edge of emerging photonics and biotechnology industries. Their proximity to the academic community and to BU's unparalleled facilities gives them substantial leverage for growth. In a strategic realignment, the BU incubator program has expanded its connections to the University's core educational missions through its affiliation with the new Boston University Institute for Technology Entrepreneurship and Commercialization (ITEC) and revision of its model for cooperative business acceleration.

### *The 11th annual future of light symposium*

Professor Selim Ünlü chaired this year's Smposium Committee. To highlight the Photonics Center's new thrust in biophotonics, the symposium program provided a perspective into biophotonics research and development within the University and with outside collaborators. This year's conference included several faculty led short courses as well as a student poster session, judged by Photonics faculty and staff teams. Prizes were awarded to the three top ranking student posters.

## *Photonics Center at a Glance*

| | |
|---|---|
| Faculty Members | 36 |
| Students Funded by BUPC- ARL Cooperative Research Grant | 30 |
| Staff Members | 12 |
| Funded R&D Projects | 90 |
| Funding for R&D (New funds for current year) | $18.5M |
| Courses taught by Photonics Faculty Members | 61 |
| Publications in Archival Journals | 78 |
| Shared Laboratory Facilities | 3 |
| Photonics Center Square Footage | 235,000 |
| Incubator Square Footage | 23,000 |
| Year of Building Opening | 1997 |

# Mission and Highlights

***The Boston University Photonics Center will pioneer fundamental knowledge and innovative technology in the field of photonics. We aim to work on important and basic problems, to translate enabling discoveries into useful applications and to educate future leaders in the field.***

***This mission is executed through:***

- Basic research and scholarship in photonics
- Academic and entrepreneurial programs and initiatives for students
- Technology development for defense and security applications
- Business incubation and commercialization of photonics technology

***Example of basic research and scholarship in photonics:***

Terahertz radiation has emerged as an important photonics technology for both defense and civilian applications. Boston University Photonics faculty members are successfully exploring materials and processing techniques to generate detectors and sources. Terahertz radiation (submillimeter microwave radiation) provides the basis for detection and imaging and its properties are identical to infrared and microwave wavelengths where it is line of sight directed. Terahertz radiation however can penetrate non-conducting opaque objects such as ceramics, plastics, cardboard, etc. Terahertz technology utilizes the capability to not only image through an opaque (to standard wavelengths) object but also has the potential to identify the contents of what is contained in within the opaque object (i.e. non-contact spectroscopic identification). This technology has many applications ranging from military security, medical imaging, and spectroscopy for detection or manufacturing process control.

At the Boston University Photonics Center, two teams of researchers are investigating both the source and detector sides. Professor Theodore Moustakas, a specialist in III-V Nitride materials, is working alongside Professor Enrico Bellotti and Professor Roberto Paiella to generate quantum dot terahertz sources. This technology is still in its initial research phase and the expectation is for continued research to be generated over the next few years for performance and manufacturing viability. Another partnership pairs Manufacturing Engineering Professor Xin Zhang, with a specialty in MEMS device modeling and fabrication, with Physics Professor Richard Averitt, with a specialty of modeling and working with terahertz materials. This detector team received a six month FTDA in the past year to explore the development of a terahertz detector. This FTDA provided a strong platform from which initial results enabled the team to successfully apply for and receive two additional grants, one from the National Science Foundation (NSF) and one from DARPA. The excitement within these two groups continues to further advance technology that flows through the pipeline. More details on this FTDA and other development programs can be found in Section III.

### *Example of academic and entrepreneurial programs in photonics for undergraduate students*

Led by the efforts of Professors Michael Ruane and Theodore Fritz, over forty undergraduate students from all across the country enjoy a summer of learning how to apply the scientific method to a pertinent research project in a laboratory. The Research Experiences for Undergraduates (REU) program, an on-going program at Boston University, has proven to be an exciting opportunity for undergraduate students and the faculty, students, and staff with which they work.

Through this program, undergraduate students work alongside distinguished faculty and graduate students and design their own project to be completed by the end of the 10-week program. Not only are these undergraduates exposed to the technical conferences and seminars during the summer, but they are also trained to use state of the art equipment in the shared laboratories as part of their research project. The REU students are assigned to a laboratory at Boston University, and given a "problem" to solve that is of importance to the laboratory and will be utilized to assist in further experiments for graduate students and faculty members. Professors Theodore Fritz and Michael Ruane work with the United States Air Force (USAF) and the National Science Foundation (NSF) to provide funding for the REU program. More information about the REU program and other programs and initiatives in this sector of the mission can be found in Section V.

### *Example of technology development for defense and security applications*

The Boston University Photonics Center, through a cooperative agreement with the ARMY, continues to support substantial programs in development of prototype hardware based on enabling photonics research discoveries. This hardware is developed to meet urgent needs and fill critical technology gaps faced by our national defense community. In past years, the focus of these programs were on sniper detection, combining acoustics to localize the bullet and optics to visualize the threat. Recently, the focus has shifted to address the critical problem of biodefense and biothreat detection. The Photonics Center strengthened its connection with the U.S. Army through several new development collaborations including a cooperative agreement with the U.S. Army Medical Research Institute of Infectious Diseases (USAMRIID). Collaborations with homeland security and military facilities that have capabilities beyond Bio-Safety Level 2 has enabled new opportunities for research and development in areas of biodefense and biodetection based on biophotonics research outcomes from BUPC faculty and students.

Dr. Thomas Geisbert, former Chief of the Department of Viral Pathology and Ultrastructure, Virology Division at USAMRIID and current Associate Director of the Boston University National Emerging Infectious Diseases Laboratory (NEIDL), is working with the Photonics Center on several projects. Continued development and maturation of the Portable Raman Spectrometer Microscope and the Spectral Reflectance Imaging Biosensor have resulted in the interest and collaboration with military biodefense labs as well as from Dr. Geisbert and his team at BU Medical School. This year's continued programs of COBRA Detection and Diagnosis have resulted in Dr. Geisbert and his research team becoming an integral part of the Photonics Center teams – providing medical and microbiology expertise to interact with the photonics technology. These collaborations further enhance the programs at Boston University, providing a bridge between medical research and photonics for detection and diagnosis and thus providing a direct link to relevant military biodetection/diagnosis between BU NEIDL and military biodefense labs.

***Example of business incubation and commercialization of photonics technology***

The business incubator within the Photonics Center is the cornerstone of Boston University's entrepreneurial mission to accelerate business development. Biomimetic Systems, Inc. (BMS) is an incubator company led by Dr. Socrates Deligeorges, former graduate and post doctoral student of Prof. Allyn Hubbard (Photonics Faculty member) and Prof. David Mountain. BMS was spun-out from research programs in the laboratory with a technology that was developed from biomimetic modeling of human hearing functions translated into electronics and control algorithms for sniper detection systems. After two years, BMS successfully exited the incubator facilties this June to move into larger accommodations in Cambridge, MA.

In July 2008, Zoiray, Inc., led by Dr. David Bergstein, former post-doctoral fellow from Professor Selim Ünlü's research group, will join the Business Accelerator Program at Boston University. This Photonics faculty spin-off company is based upon the research and technology developed in Professor Ünlü's laboratory. This revolutionary photonics technology utilizes advanced tunable laser technology and advanced semiconductor processing and materials combined to be a label-free technique for identifying biomarkers present in serum of a symptomatic patient. This technology is one of the main technologies moving in the Photonics Center development pipeline and is central to the collaboration between Professor Ünlü's laboratory, the Photonics Center, and Dr. Geisbert's team for diagnosis of viruses. For more details about this past year's progress as a Phase I award, and for other pipeline development programs, see Section III.

Another Photonics faculty member, Professor Shyamsunder Erramilli, has started Ninth Sense Inc., a spin-off company from work on biosensors. Professor Erramilli has been collaborating with Professor Pritiraj Mohanty on this work. Ninth Sense will join the incubator in August, 2008. More information on these companies and their progress will be provided in next year's annual report. Further incubator updates can be found in Section VI.

# Faculty and Staff


From its inception, the Photonics Center has attracted scholarly pioneers to lead our academic program in Photonics. A vibrant multi-disciplinary environment is achieved through immersion of faculty from various schools and colleges within Boston University to have one location – the Photonics Center as a base for research, teaching and collaborating. The Center is supported by a dedicated technical and administrative staff. Working with the faculty, the staff is focused on advancing the mission of the Center and its faculty, students and industrial and U. S. Department of Defense partners.

# New Faculty Members

## *Lee Goldstein, Ph.D., M.D.*

Dr. Lee Goldstein is an Associate Professor in the Boston Univeristy School of Medicine. He is also the Director of the Molecular Aging and Development Lab (MadLab) and the Director of the Center for Biometals and Metallomics (CBM). Dr. Goldstein is a former clinical and research fellow at Massachusetts General Hospital. In 2003 Dr. Golstein's team discovered Alzheimer's disease molecular pathology in the lens of the eye. This discovery led to the development of novel laser-based molecular diagnostic technology for pre-symptomatic screening and early disease detection.

Dr. Goldstein's research initiatives have led to many interdisciplinary and cross campus collaborations, including the Center for Biometals and Metallomics (CBM). CBM is an interdisciplinary bioanalytical facility focusing on ultra-trace elemental and isotopic analyses. Dr. Golstein is currently collaborating with several BUPC Faculty members on large NSF and NIH grant applications.

The addition of Dr. Goldstein will enhance the Center's biothreat detetion and diagnosis programs as well has build a strong connection between BUPC and the BU Medical Campus. Professor Goldstein is the recipient of the Center's 2008 New Faculty Initiative Award. His start-up support will include equipment which will be specified collaboratively between Dr. Goldstein, Center Staff and the School of Medicine. More information regarding the New Faculty Initiative Award can be found in Section IV.

*Education*

M.D. and Ph.D., Neuroscience, Yale University

*Fields of Interests*

- The role of abnormal protein aggregation in chronic degenerative disorders of aging
- Alzheimer's disease, age-related cataracts, and other common diseases of aging that involve pathogenic protein aggregation
- Alzheimer's disease-associated amyloid pathology outside the brain, new transcription factors that play a crucial role in cellular differentiation within the lens and brain

## *Björn Reinhard, Ph.D.*

Dr. Björn Reinhard is an assistant professor in the Department of Chemistry. Professor Reinhard completed his post-doctorate in Material Science and Biophysics at the University of California Berkeley. At Berkeley, Dr. Reinhard developed novel tools for single molecule biophysics based on active nanostructures. He also co-invented the concepts of Plasmon rulers and force-sensors on entropic spring and Fluorescence Resonant Energy Transfer.

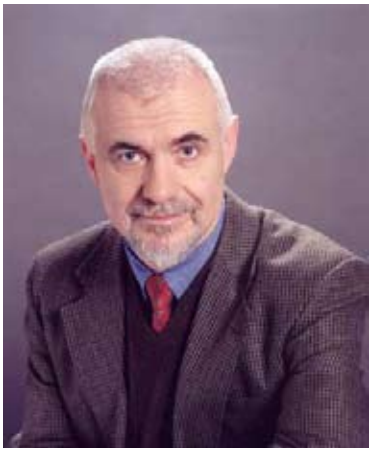
Currently Dr. Reinhard is developing a research group to design and implement active nanostructures for sensing application in biology and medical diagnostics. He brings to the center his expertise in the fields of single particle spectroscopy, nanoparticle synthesis, assembly of active nanostructures and their biointegration and compliments the Center's activities in biosensing and biophotonics.

*Education*
Ph.D., Chemistry, Technical University Kaiserslautern, Germany

*Fields of Interests*

- Design, implementation, and characterization of new tools for imaging and manipulation of "hard" (inorganic) and "soft" (biological) materials
- Hybrid materials combining electronic/optical properties of inorganic materials with the structural properties of biological materials

## *Francesco Cerrina, Ph.D.*



Since 1984, Dr. Cerrina has been a Professor in the Electrical and Computer Engineering department at the University of Wisconsin Madison (UWM). In 1988, Dr. Cerrina was appointed Director of the Center for NanoTechnology at UWM. Dr. Cerrina has procured and managed over $45 million in grants and research contracts and currently holds 11 patents. He is the President and Chief Technology Officer of Genetic Assemblies, Inc., a firm he co-founded in 2003. Professor Cerrina is also a member of the board of directors of NimbleGen Systems, Inc., a company he co-founded in 1999 to commercialize a novel method for rapid synthesis of DNA microarray chips.

Professor Cerrina's research focuses on the application of physical sciences and engineering to manufacturing and biological problems, with a current focus on nanotechnology and biotechnology. He is currently working on better ways to synthesize DNA microarray chips and developing new techniques for the synthesis of genetic material (long DNA sequences) de-novo, that is, by assembling the DNA base by base under computer control. These DNA molecules can be used for biological research, drug and vaccine development, and for genetic engineering.

Dr. Cerrina brings over 20 years of nanotechnology experience to the Photonics Center. His work with biotechnology will help to expand the Center's work in the biological detection and diagnosis arenas. Professor Cerrina's lab can be found on the fifth floor of BUPC.

*Education*

Ph.D., Physics (Solid State), University of Rome

*Fields of Interest*

- Biotechnology: DNA synthesis, DNA microarrays, oligomer synthesis, synthetic biology, DNA arrays, stem cells, and gene synthesis
- Nanotechnology: nanostructure fabrications, processing, and patterning
- Lithography: optical lithography, electron beam lithography, extreme ultraviolet lithography, modeling, masks, and imaging
- Optics: modeling, design, analysis, systems and components, lithography, and imaging theory
- Semiconductors: fabrication, process modeling, and process design
- X-rays: optics, modeling, synchrotron radiation, applications to imaging, microscopy, lithography, and spectroscopy

# Faculty Directory

## Dr. Hatice Altug

*Assistant Professor, Electrical and Computer Engineering*

Office:
8 Saint Mary's Street
Room 825

Phone: 617.358.4769
e-mail: altug@bu.edu

Research Interests:
- Nanophotonic devices for optical communications
- Label free biosensors

## Dr. Richard Averitt

*Assistant Professor, Physics*

Office:
590 Commonwealth Ave.
Room 213

Phone: 617.353.2619
e-mail: raveritt@bu.edu

Research Interests:
- Ultrafast Optical Spectroscopy
- Terahertz Spectroscopy
- Correlated Electron Materials
- Metamaterials and Plasmonics

## Dr. Enrico Bellotti

*Associate Professor, Physics*

Office:
8 Saint Mary's Street
Room 539 D

Phone: 617.358.1576
e-mail: bellotti@bu.edu

Research Interests:
- Computational Electronics
- Semiconductor Materials
- Power Electronics
- Parallel Computing

## Dr. Thomas Bifano

*Professor, Manufacturing Engineering*

Office:
8 Saint Mary's Street
Room 936

Phone: 617.353.8899
e-mail: tgb@bu.edu

Research Interests:
- Microelectromechanical Systems (MEMS)
- Adaptive Optics

## Dr. Irving Bigio

*Professor, Biomedical Engineering, Electrical and Computer Engineering*

Office:
44 Cummington Street
Room 233

Phone: 617.353.2619
e-mail: bigio@bu.edu

Research Interests:
- Biomedical Optics/Biophotonics
- Medical Applications of Optics, Lasers and Spectroscopy

## Dr. Francesco Cerrina

*Professor, Electrical and Computer Engineering*

Office:
8 Saint Mary's Street
Room 327

Phone: 617.353.2811
email: fcerrina@bu.edu

Research Interests:
- Nanostructure Fabrications, Processing and Patterning
-DNA Synthesis and Microarrays

## Dr. Supriya Chakrabarti

*Professor, Astronomy*

Office:
725 Commonwealth Ave.
Room 506

Phone: 617.353.5990
e-mail: supc@bu.edu

Research Interests:
- Experimental Astrophysics
- Spectral Imaging
- Planetary Atmospheres
- Interplanetary/Interstellar Media

## Dr. Luca Dal Negro

*Assistant Professor, Electrical and Computer Engineering*

Office:
8 Saint Mary's Street
Room 825

Phone: 617.353.2600
e-mail: dalnegro@bu.edu

Research Interests:
- Optical amplification phenomena
- Photonic crystals

## Dr. Kamil Ekinci

*Assistant Professor, Aerospace and Mechanical Engineering*

Office:
110 Cummington Street
Room 319

Phone: 617.353.8670
e-mail: ekinci@bu.edu

Research Interests:
- Ultra-thin metal films
- Nanomechanical sensors
- Nanomechanics

## Dr. Shyamsunder Erramilli

*Professor, Biomedical Engineering, Physics*

Office:
8 Saint Mary's Street
Room 214

Phone: 617.353.6114
e-mail: shyam@bu.edu

Research Interests:
- Infrared and Raman Microscopy
- Quantum Cascade Laser Sources

## Dr. Theodore Fritz

*Professor, Astronomy*

Office:
725 Commonwealth Avenue
Room CAS 501

Phone: 617.353.7446
e-mail: fritz@bu.edu

Research Interests:
- Space Plasma Physics
- Magnetosphere Physics
- Rocket and Satellite Experiments

## Dr. Rosina Georgiadis

*Associate Professor, Chemistry*

Office:
44 Cummington Street
Room 705

Phone: 617.353.7218
e-mail: rgeorgia@bu.edu

Research Interests:
- Surface Plasmon Resonance
- Label Free DNA Microarrays
- DNA/Protein Interactions
- DNA/Drug Interactions

## Dr. Bennett Goldberg

*Professor, Physics*

Office:
8 Saint Mary's Street
Room 936

Phone: 617.353.5789
e-mail: goldberg@bu.edu

Research Interests:
- Biological Sensors
- Single-mode waveguide devices
- Nanotubes and Nano-optics

## Dr. Lee Goldstein

*Associate Professor, BU School of Medicine*

Office:
8 Saint Mary's Street
Room 727

Phone: 617.414.8361
e-mail: lgold@bu.edu

Research Interests:
- Abnormal protein aggregation in chronic degenerative disorders
- Alzheimer's Disease

## Dr. Allyn Hubbard

*Associate Professor, Electrical and Computer Engineering, Biomedical Engineering*

Office:
8 Saint Mary's Street
Room 329

Phone: 617.353.2815
e-mail: aeh@bu.edu

Research Interests:
- Auditory Physiology
- Neurocomputing / Biosensors

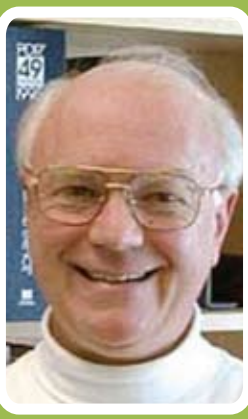
## Dr. James Jackson

*Professor, Astronomy*

Office:
725 Commonwealth Avenue
Room CAS 605

Phone: 617.353.7412
e-mail: @bu.edu

Research Interests:
- Radio and Infrared Astronomy
- Starburst Galaxies
- Star Formation
- Antarctic Astronomy



## Dr. Guilford Jones

*Professor, Chemistry*

Office:
8 Saint Mary's Street
Room 359

Phone: 617.353.2498
e-mail: giljones@bu.edu

Research Interests:
- Photochemistry
- Dye Probes
- Chromophore conjugates of polymers and proteins

## Dr. Amit Meller

*Associate Professor, Biomedical Engineering*

Office:
44 Cummington Street
Room 701 C

Phone: 617.358.4338
e-mail: ameller@bu.edu

Research Interests:
- Ultrafast DNA Sequencing
- Optical Methods for single molecule detection

## Dr. Michael Mendillo

*Professor, Astronomy*

Office:
725 Commonwealth Avenue
Room CAS 603

Phone: 617.353.2629
e-mail: mendillo@bu.edu

Research Interests:
- Planetary Atmospheres
- Space Physics
- Observations and Models

## Dr. Jerome Mertz

*Professor, Biomedical Engineering*

Office:
2 Cummington Street
Room 202

Phone: 617.358.0746
e-mail: jmertz@bu.edu

Research Interests:
- Development and applications of novel optical microscopy techniques for biological imaging

## Dr. Theodore Morse

*Professor, Electrical and Computer Engineering*

Office:
8 Saint Mary's Street
Room 505B

Phone: 617.358.1035
e-mail: tfmorse@bu.edu

Research Interests:
- Photonic Material Processing
- Optical fiber fabrication, lasers and sensors

## Dr. Theodore Moustakas

*Professor, Electrical and Computer Engineering*

Office:
8 Saint Mary's Street
Room 835

Phone: 617.353.5431
e-mail: tdm@bu.edu

Research Interests:
- MEMS
- III-Nitrides
-Amorphous Semiconductors

## Dr. Todd Murray

*Assistant Professor, Mechanical Engineering*

Office:
110 Cummington Street
Room 421

Phone: 617.353.3951
e-mail: twmurray@bu.edu

Research Interests:
- Laser Ultrasonics
- Optoacoustic imaging
-Optical Sensors and NDE

## Dr. Roberto Paiella

*Assistant Professor, Electrical and Computer Engineering*

Office:
8 Saint Mary's Street
Room 529

Phone: 617.353.8883
e-mail: rpaiella@bu.edu

Research Interests:
- Terahertz Photonics
- Surface-plasmon-enhanced light emitting devices

## Dr. Kenneth Rothschild

*Professor, Physics*

Office:
590 Commonwealth Avenue
Room 209

Phone: 617.353.2603
e-mail: kjr@bu.edu

Research Interests:
- Biomembrane technology and biomolecular photonics
- Energy transduction, Ion Transport ans signal recognition

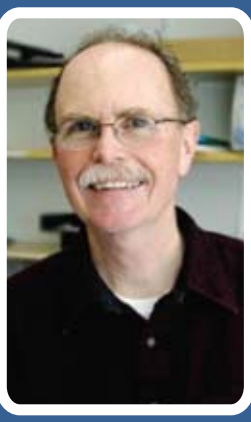
## Dr. Bjorn Reinhard

*Assistant Professor, Chemistry*

Office:
2 Cummington Street
Room 452

Phone: 617.353.2498
e-mail: bmr@bu.edu

Research Interests:
- Combining electronic/optical properties of inorganic materials with structural properties of biological materials.



## Dr. Michael Ruane

*Professor, Electrical and Computer Engineering*

Office:
8 Saint Mary's Street
Room 727

Phone: 617.353.3256
e-mail: mfr@bu.edu

Research Interests:
- Resonant Cavity Imaging Biosensor

## Dr. Bahaa Saleh

*Professor, Electrical and Computer Engineering*

Office:
8 Saint Mary's Street
Room 922

Phone: 617.353.7176
e-mail: besaleh@bu.edu

Research Interests:
- Statistical and quantum optics
- Optical Communications
- Nonlinear optics

## Dr. Alexander Sergienko

*Professor, Electrical and Computer Engineering*

Office:
8 Saint Mary's Street
Room 729

Phone: 617.353.6564
e-mail: alexserg@bu.edu

Research Interests:
- Ultrafast Quantum Optics
-Quantum Metrology

## Dr. Andre Sharon

*Professor, Manufacturing Engineering*

Office:
15 Saint Mary's Street
Room 101

Phone: 617.353.8776
e-mail: sharon@bu.edu

Research Interests:
- Electromechanical machine design
- Fiber optic manufacture

## Dr. Anna Swan

*Associate Professor, Electrical and Computer Engineering*

Office:
8 Saint Mary's Street
Room 827

Phone: 617.353.1275
e-mail: swan@bu.edu

Research Interests:
- Interactions of bio-material with nanostructutres
- Carbon nanotubes

## Dr. Malvin Teich

*Professor, Electrical and Computer Engineering*

Office:
8 Saint Mary's Street
Room 733

Phone: 617.353.1236
e-mail: teich@bu.edu

Research Interests:
- Neural coding
- Wavelet analysis of fractal biological signals

## Dr. Barry Unger

*Associate Professor, Metropolitan College*

Office:
755 Commonwealth Avenue
Room 226

Phone: 617.353.3000
e-mail: unger@bu.edu

## Dr. Selim Ünlü

*Professor, Electrical and Computer Engineering, Biomedical Engineering*

Office:
8 Saint Mary's Street
Room 826

Phone: 617.353.5067
e-mail: selim@bu.edu

Research Interests:
- Optical Characterization
- Nanophotonics

## Dr. Xin Zhang

*Assistant Professor, Manufacturing Engineering*

Office:
8 Saint Mary's Street
Room 724

Phone: 617.358.2702
e-mail: xinz@bu.edu

Research Interests:
- Nano and microsystems
- Microelectromechanical Systems
- Nanoelectromechanical Systems

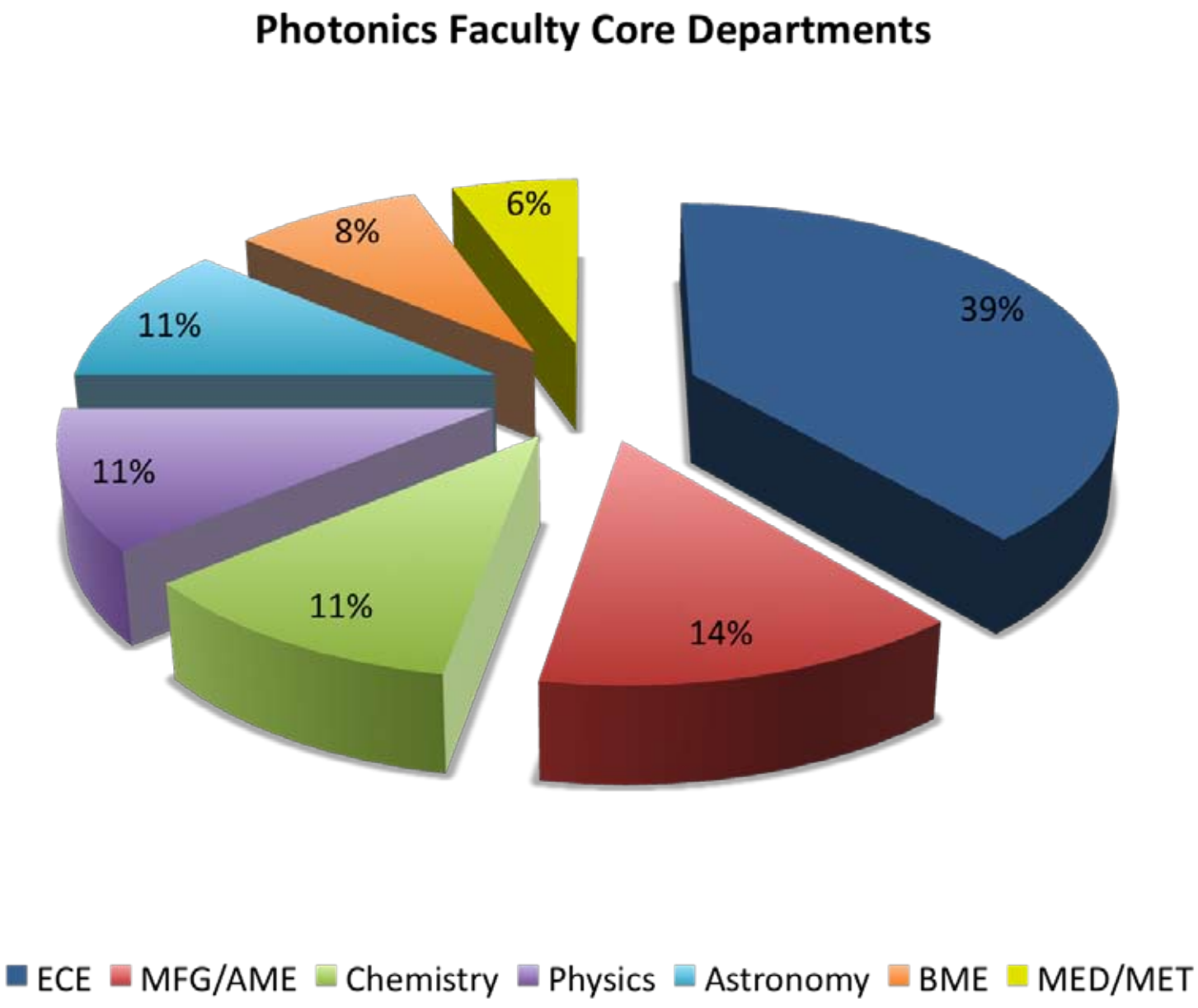
## Dr. Lawrence Ziegler

*Professor, Chemistry*

Office:
8 Saint Mary's Street
Room 718

Phone: 617.353.8663

e-mail: lziegler@bu.edu
Research Interests:
- Ultraviolet Pump-Probe Femto-second Spectroscopy
- Spontaneous Resonance Raman Studies of Photodissociative and Biological Chromophores


Photonics Faculty Core Departments
6%
8%
11%
39%
11%
11%
14%
ECE
MFG/AME
Chemistry
Physics
Astronomy
BME
MED/MET

# Faculty Committees

The Photonics Center has seven committees that support the staff and faculty members:

### *Distinguished Seminar Series:*

Chair - Malvin Teich
Invites distinguished leaders in the field of photonics to visit the Photonics Center and give seminars on subjects of importance in the field. The lecturers also meet with individual faculty members and students.

### *Education:*

Chair - Michael Ruane
Investigates methods for applying and enriching education of photonics within the community and BU programs.

### *Equipment:*

Chair - Xin Zhang
Recommends equipment upgrades or new equipment purchases that will enhance the research and development of faculty and students at the Center.

### *Executive Advisory:*

Chair - Bennett Goldberg
Advises the Director on educational and academic issues and is comprised of the chairs from the Center's affiliated departments.

### *Fellowship:*

Chair - Open
Selects candidates for Photonics Center graduate student fellowships. Fellows selected provide assistance to the Photonics Center community in shared lab training, scholarly events and community building activities.

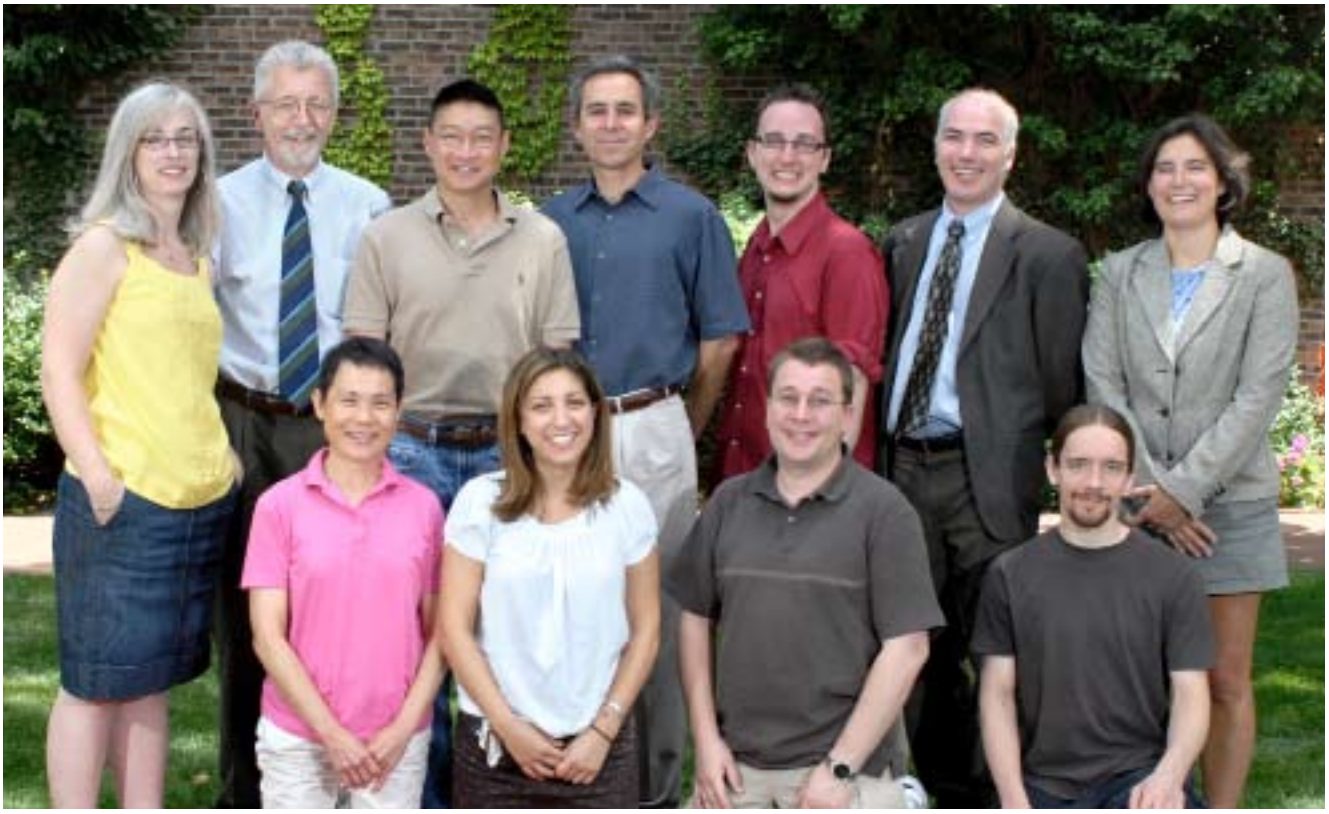
### *Space Allocation:*

Chair - Theodore Moustakas
Generates policy guidelines for space management.

### *Symposium:*

Chair - Selim Ünlü
Organizes the annual "Future of Light" symposium with a focus on research and development in an area relevant to the Photonics Center community. The symposium includes outside and internal faculty speakers. The symposium also includes a student poster session for Photonics Center students where their research can be discussed with distinguished members of the community.

# Staff Members



***Top Row (From Left):*** Meghan Foley, Robert Schaejbe, Paul Mak, Thomas Dudley, Keith Crook, Thomas Bifano, Helen Fawcett
***Bottom Row (From Left):*** Anlee Krupp, Ani Chaghatzbanian, Chad Demers, Ryan Midura
***Not Pictured:*** Leah Ziph-Shatzberg

**Dr. Thomas Bifano**
*Director*
Email: tgb@bu.edu
Tel: (617) 353-8899

**Ani Chaghatzbanian**
*Administrative Coordinator*
Email: anic@bu.edu
Tel: (617) 353-8899

**Keith Crook**
*Marketing & Communication Coordinator*
Email: kcrook@bu.edu
Tel: (617) 353-1334

**Chad Demers**
*Hardware Engineer*
Email: demers@bu.edu
Tel: (617) 353-8997

**Thomas Dudley**
*Assistant Director, Technical Programs*
Email: tjdudley@bu.edu
Tel: (617) 358-4924

**Dr. Helen Fawcett**
*Manager, Operations and Technical Programs*
Email: hfawcett@bu.edu
Tel: (857) 753-1719

**Meghan Foley**
*Administration Manager*
Email: megfoley@bu.edu
Tel: (617) 358-4438

**Anlee Krupp**
*Laboratory Manager*
Email: ahk@bu.edu
Tel: (617) 353-9044

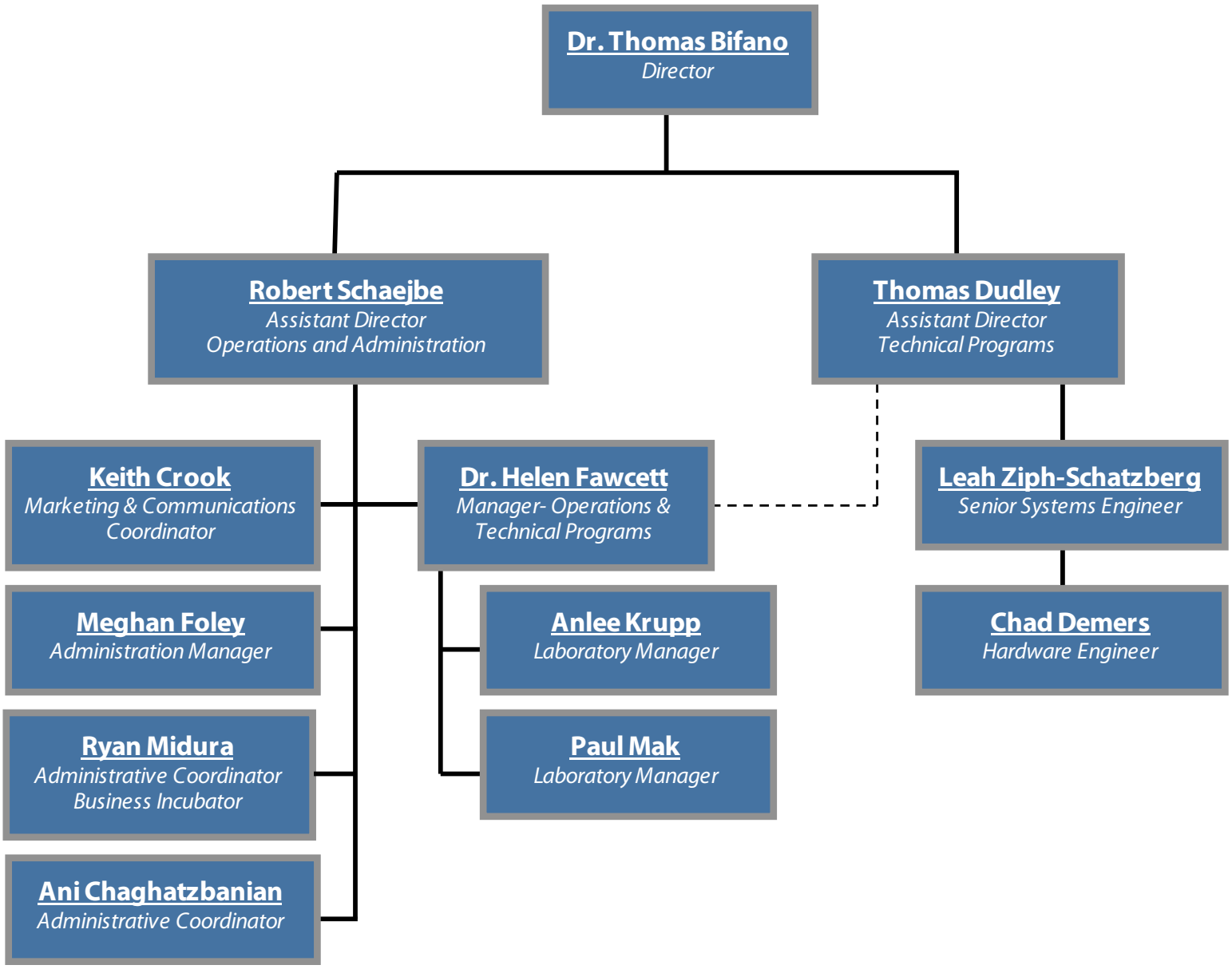
**Paul Mak**
*Laboratory Manager*
Email: pmak@bu.edu
Tel: (617) 353-8869

**Ryan Midura**
*Administrative Coordinator, Business Incubator*
Email: rmidura@bu.edu
Tel: (617) 358-0480

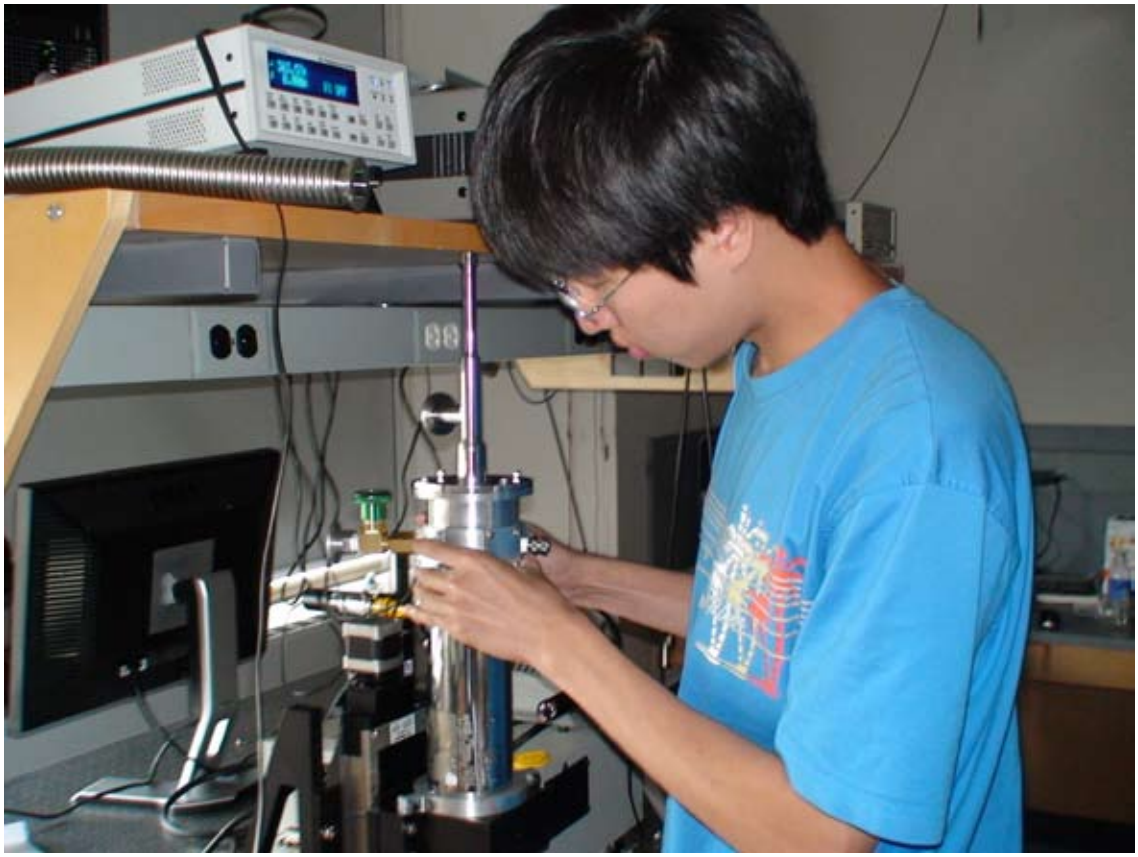
**Robert Schaejbe**
*Assistant Director, Operations & Administration*
Email: rschaejb@bu.edu
Tel: (617) 358-4257

**Leah Ziph-Schatzberg**
*Sr. Systems Engineer*
Email: lzs@bu.edu
Tel: (617) 353-8899

## *Staff Organization Chart*



# Research and Development



Scientific discovery, fundamental research and innovative development form and fill a continuous pipeline at the Boston University Photonics Center. The Center's scholarly research spans the traditional disciplines of the faculty members' academic departments: Astronomy, Biology, Chemistry, Physics, Mechanical Engineering, Biomedical Engineering, Electrical and Computer Engineering, and the School of Medicine.

On the following pages, outcomes from the Center's efforts in research and development for the past year are detailed. Photonics-focused grants are listed, as are archival journal publications.

The Photonics Center has become well known for its program of defense-related technology transfer through targeted prototype development. In the past year, the Center has continued to develop and field-test the acoustic direction finding system and expanded it to include soldier wearable and lower cost versions. The Center has also introduced two new prototype systems based on enabling outcomes from our faculty's research.

The cooperative agreement with ARL-SEDD provides the basis of funding to accelerate applied research, particularly in areas that lead toward development of prototype systems associated with the Center's defense and security mission. In the year covered by this annual report, $6.9M was awarded to Boston University for this mission.

In this section the broad range of R&D activities that occur in the Photonics Center, and the academic achievements of Photonics faculty and students and their team-based development projects are detailed.

# Faculty and Staff Research

The Center's research laboratories have pioneered breakthrough photonic devices that include blue LED's, quantum cryptography systems, deformable mirrors that improve telescope and microscope resolution, high-speed photodetectors and biophotonic sensors. Photonics faculty and staff receive support from industry and federal agencies including, but not limited to, the National Science Foundation (NSF), the Department of Energy (DoE), the National Institutes of Health (NIH) and the Department of Defense (DoD). This year Photonics faculty members and students published more than 75 articles in archival journals and several book chapters. Faculty members received more than $18.5M in external funding distributed among over 90 photonics related projects. The following table lists new funds that arrived at Boston University in the fiscal year, as reported by the Office of Sponsored Programs.

# Externally Funded Research

| P. I. | Dept. | Title of Project | Agency | Period | | Amount |
|---|---|---|---|---|---|---|
| Averitt | PHY | Metamaterial for Threat Reduction Applications: Imaging, Signal Processing and Cloaking (Subcontract via Los Alamos National Laboratory) | DOE | 5/8/07 | 9/30/08 | $66,902 |
| Averitt | PHY | Metamaterial Enhanced MEMS for Terahertz Technology (in conjunction with Photonics Center and CNN) | DOD/DARPA | 4/28/08 | 10/28/09 | $147,753 |
| Bellotti | ECE | New Sensing Capabilities for Situational Awareness (SBIR Phase II) (Subcontract via Photronix, Inc.) | DOD/Air Force | 3/20/07 | 3/20/09 | $25,000 |
| Bellotti | ECE | New Sensing Capabilities for Situational Awareness (SBIR Phase II) (Subcontract via Photronix, Inc.) | DOD/Air Force | 3/20/07 | 3/20/09 | $25,000 |
| Bellotti | ECE | Simulation Models for IR FPAs | CSC Computer Sciences, US/BAE Systems | 9/1/07 | 8/31/09 | $48,000 |
| Bellotti | ECE | Simulation Models for IR FPAs | CSC Computer Sciences, US/BAE Systems | 9/1/07 | 8/31/09 | $46,000 |
| Bifano | MFG | High Resolution Silicon Deformable Mirrors (SBIR) (Subcontract via Boston Micromachines Corporation) | NASA | 2/13/06 | 2/12/08 | $31,049 |
| Bifano | MFG | SBIR Phase II: Ultrafast Tip Tilt Piston MEMS Deformable Mirror (in conjunction with Photonics Center) Subcontract via Boston Micromachines Corporation) | NASA | 12/3/06 | 12/3/08 | $12,802 |
| Bifano | MFG | SBIR Phase II: Ultrafast Tip Tilt Piston MEMS Deformable Mirror (in conjunction with Photonics Center) Subcontract via Boston Micromachines Corporation) | NASA | 12/3/06 | 12/3/08 | $13,000 |
| Bifano | MFG | SBIR Phase II: Ultrafast Tip Tilt Piston MEMS Deformable Mirror (in conjunction with Photonics Center) Subcontract via Boston Micromachines Corporation) | NASA | 12/3/06 | 12/3/08 | $22,000 |
| Bifano | PHO | Photonics Research and Technology Insertion | DOD/Army | 6/6/07 | 6/30/08 | $6,885,000 |

| P. I. | Dept. | Title of Project | Agency | Period | | Amount |
|---|---|---|---|---|---|---|
| Bigio | BME | Polarized Probe for Fiberoptic in-vivo Spectroscopy (SBIR) (Subcontract via Optimum Technologies, Inc.) | HHS/NIH/NCI | 5/1/07 | 4/30/08 | $21,483 |
| Bigio | BME | Polarized Probe for Fiberoptic in-vivo Spectroscopy (SBIR) (Subcontract via Optimum Technologies, Inc.) | HHS/NIH/NCI | 5/1/07 | 4/30/08 | $43,992 |
| Bigio | BME | Optical Imaging of Fast Neutral Activation Patterns in Brain Tissue | HHS/NIH/NIBIB | 7/1/07 | 6/30/08 | $228,125 |
| Bigio | BME | NRSA: Optical Pharmacokinetics System (R. Reif) | HHS/NIH/NCI | 9/1/07 | 8/31/08 | $28,302 |
| Bigio | BME | NTROI: Optical Spectroscopy for Management of Cancer Treatment | HHS/NIH/NCI | 9/1/07 | 8/31/08 | $1,087,460 |
| Bigio | BME | Optical Imaging of Fast Neutral Activation Patterns in Brain Tissue | HHS/NIH/NIBIB | 7/1/08 | 6/30/09 | $199,063 |
| Chakrabarti | CSP | Planet Imaging Concept Testbed Using a Rocket Experiment (PICTURE) | NASA | 11/1/04 | 1/31/08 | $152,327 |
| Chakrabarti | CSP | Daytime Multiwavelength Ground-Based Optical Investigations of Precursors to Low-Latitude Plasma Irregularities | NASA | 5/26/06 | 5/23/09 | $71,065 |
| Chakrabarti | CSP | Daytime Multiwavelength Ground-Based Optical Investigations of Precursors to Low-Latitude Plasma Irregularities | NASA | 5/26/06 | 5/23/09 | $96,300 |
| Dal Negro | ECE | Biodegradable Communications System (Subcontract via Tufts University) | DOD/Army | 1/1/08 | 9/26/08 | $136,625 |
| Ekinci | AME | CAREER: Photonic Integration of Silicon Nanoelectromechanical Systems (in conjunction with Center for Nanoscience and Nanobiotechnology) | NSF | 3/1/07 | 2/28/09 | $77,841 |
| Ekinci | AME | Lincoln Scholar Program - Carl Hart (Subcontract via MIT/Lincoln Laboratory) | DOD/Air Force | 1/1/08 | 4/30/08 | $16,442 |
| Ekinci | AME | CAREER: Photonic Integration of Silicon Nanoelectcromechanical Systems (REU Supplement) | NSF | 5/1/08 | 2/28/09 | $6,000 |
| Ekinci Yakhot | AME | High-Frequency Nanofluidics of Bio-NEMS: Theory and Experiments (in conjunction with Center for Nanoscience and Nanobiotechnology) | NSF | 6/15/08 | 5/31/11 | $240,000 |
| Erramilli | PHY | Graduate Student Support (L. Qiu) (Subcontract via Beth Israel Deaconess Medical Center) | HHS/NIH/NIBIB | 5/1/08 | 8/31/08 | $11,990 |

| P. I. | Dept. | Title of Project | Agency | Period | | Amount |
|---|---|---|---|---|---|---|
| Erramilli<br>Mohanty | PHY | Gate-Controlled Silicon Based Nanoscale Processor for Multiple Analyte Assay | Ninth Sense, Inc. | 6/13/08 | 12/12/08 | $84,531 |
| Fritz | CSP | The Loss Cone Imager (LCI) | DOD/Air Force | 3/24/05 | 6/30/10 | $103,500 |
| Fritz | CSP | The Loss Cone Imager (LCI) | DOD/Air Force | 3/24/05 | 6/30/10 | $193,354 |
| Fritz | CSP | The Loss Cone Imager (LCI) - HST Supplement | DOD/Air Force | 3/24/05 | 6/30/10 | $19,646 |
| Fritz | CSP | The Loss Cone Imager (LCI) | DOD/Air Force | 3/24/05 | 6/30/10 | $588,634 |
| Fritz | CSP | The Cluster RAPID On-Orbit Operations and Data Verification | NASA | 4/1/05 | 3/31/08 | $125,100 |
| Fritz | CSP | BUSAT: The Boston University Student Satellite for Applications and Training (NANOSAT FY07) | DOD/Air Force | 2/15/07 | 3/31/08 | $55,000 |
| Fritz | CSP | The POLAR/CAMMICE Effort at Boston University | NASA | 4/1/08 | 3/31/09 | $183,300 |
| Georgiadis | CHEM | DNA Lattices for the Study of Biological Processes | HHS/NIH/NIGMS | 5/1/07 | 4/30/08 | $43,500 |
| Goldberg<br>Stevens | PHY | Summer Immersion Institutes | S.D. Bechtel, Jr. | 11/28/07 | 11/27/08 | $100,000 |
| Goldberg<br>DeRosa<br>Narain<br>Meller | PHY | PROSTARS: PROgram in STEM Academic Retention and Success (Participant Support) (additional co-p.i.: J. Snyder) (in conjunction with Center for Nanoscience and Nanobiotechnology) | NSF | 1/1/08 | 12/31/08 | $239,398 |
| Goldberg<br>DeRosa<br>Narain<br>Meller | PHY | PROSTARS: PROgram in STEM Academic Retention and Success (Participant Support) (additional co-p.i.: J. Snyder) (in conjunction with Center for Nanoscience and Nanobiotechnology) | NSF | 1/1/08 | 12/31/08 | $97,635 |
| Goldberg<br>Unlu | PHY | MURI: New Instrumentation for Nanoscale Subsurface Spectroscopy and Tomography (Subcontract via University of Rochester) | DOD/Air Force | 6/15/03 | 9/30/08 | $36,237 |
| Goldberg<br>Unlu | PHY | Nanoscale Measurements of Field Localization in Deterministic Aperiodic Arrays (Subcontract via University of Rochester) | DOD/Air Force | 6/15/06 | 1/14/08 | $48,622 |
| Jackson | IAR | Release and Analysis of the Galactic Ring Survey | NSF | 9/1/07 | 8/31/08 | $175,000 |
| Jackson | IAR | Protostars in Infrared Dark Clouds (Subcontract via California Institute of Technology/Jet Propulsion Laboratory) | NASA | 9/6/07 | 6/30/10 | $100,000 |
| Jackson | IAR | The Mid-Course Space Experiment Extended Source Catalog | NASA | 2/15/08 | 2/14/09 | $141,022 |

| P. I. | Dept. | Title of Project | Agency | Period | | Amount |
|---|---|---|---|---|---|---|
| Meller | BME | Folding Kinetics and Stability Studies of Individual RNA Molecules, Application to RNA Interference | Human Frontier Science Program (France) | 7/1/07 | 6/30/08 | $120,000 |
| Meller | BME | MRL - Summer Undergraduate Research Fellowship (A. Shah) | Merck Research Laboratories | 6/1/08 | 8/31/08 | $5,000 |
| Meller | BME | Optimization of Nanopore-Based Analysis for Nucleic Acids | Sequenom, Inc. | 6/1/08 | 5/31/09 | $649,935 |
| Meller Weng | BME | High Throughput DNA Sequencing Using Design Polymers and Nanopore Arrays | HHS/NIH/NHGRI | 9/1/07 | 8/31/08 | $437,823 |
| Meller Weng | BME | Electronic Recognition of Gene Regulatory Proteins Bound to DNA (in conjunction with Center for Nanoscience and Nanobiotechnology) | NSF | 8/1/08 | 7/31/09 | $195,000 |
| Mendillo | CSP | Saturn Thermosphere-Ionosphere Model (STIM) | NASA | 9/1/05 | 8/31/08 | $75,000 |
| Mendillo | CSP | CEDAR Post Doc: Imaging Studies of Ionospheric Instabilities (C. Martinis) | NSF | 12/1/06 | 11/30/08 | $80,944 |
| Mendillo | CSP | Mars Ionospheric Disturbances | NASA | 7/1/07 | 6/30/10 | $95,500 |
| Mendillo | CSP | Mars Ionospheric Disturbances | NASA | 7/1/07 | 6/30/10 | $92,381 |
| Mendillo | CSP | Large Scale Variability in Space and Time of Total Electron Content (TEC) Storm-Time Enhancements Driven by Penetration Electric Fields | NASA | 8/22/07 | 8/21/10 | $67,226 |
| Mendillo | CSP | Imaging Science and Modeling Investigations of the Upper Atmosphere | NSF | 12/1/07 | 11/30/08 | $255,000 |
| Mendillo | CSP | Multiple Characteristics of Ionospheric Variability Patterns | DOD/Navy | 1/1/08 | 12/31/08 | $155,000 |
| Mendillo | CSP | A Comprehensive Multi-Process Saturn-Thermosphere-Ionosphere-Model (STIM) | NASA | 1/29/08 | 1/28/09 | $90,000 |
| Mertz | BME | Widefield Fluorescence Macroscopy with Out-of-Focus Blur Rejection | HHS/NIH/NIBIB | 9/1/07 | 7/31/08 | $268,750 |
| Mertz | BME | Widefield Fluorescence Macroscopy with Out-of-Focus Blur Rejection | HHS/NIH/NIBIB | 8/1/08 | 7/31/09 | $159,250 |
| Morse | ECE | Doped Silica Preforms and Tubes: OVD Process | OFS Laboratories, LLC | 3/20/07 | 5/20/08 | $60,000 |

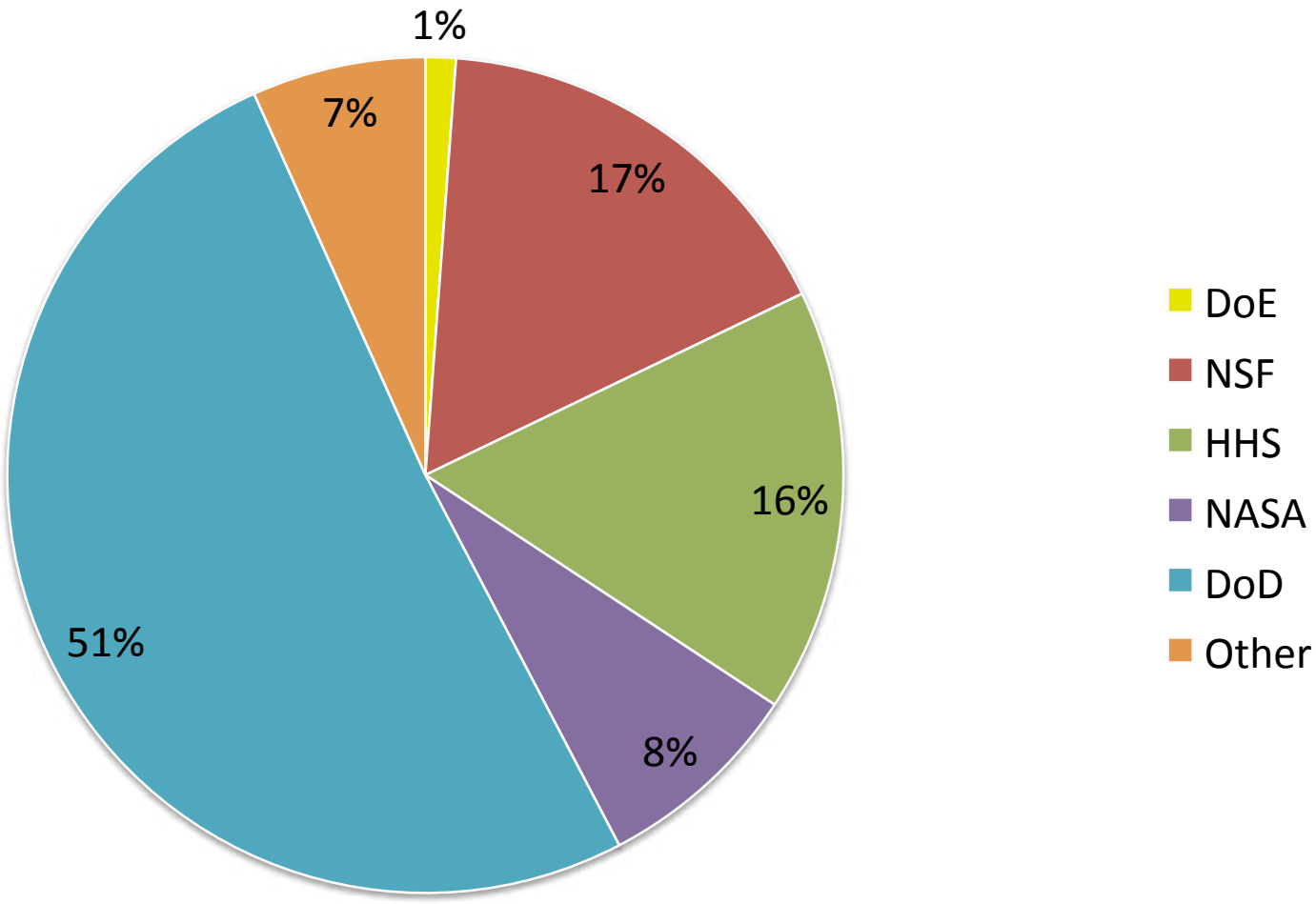
| P. I. | Dept. | Title of Project | Agency | Period | | Amount |
|---|---|---|---|---|---|---|
| Morse | ECE | A New Approach to High-Power, Eye-Safe, Laser Technology Applications (in conjunction with Center for Nanoscience and Nanobiotechnology) | DOD/Navy | 6/1/07 | 8/31/10 | $250,000 |
| Morse | ECE | A New Approach to High-Power, Eye-Safe, Laser Technology Applications (in conjunction with Center for Nanoscience and Nanobiotechnology) | DOD/Navy | 6/1/07 | 8/31/10 | $250,000 |
| Morse | ECE | Miniature Laser Therapy Endoscope (Subcontract via Massachusetts General Hospital) | HHS/NIH/NIBIB | 8/1/07 | 7/31/08 | $48,750 |
| Morse | ECE | Ultra-High Definition (1 um) Digital X-Ray Imaging | Comm. Of Mass./ Technology Transfer Center | 5/1/08 | 4/30/09 | $40,000 |
| Moustakas | ECE | Photonics Research and Development (Subcontract via University of Las Vegas Research Foundation) | DOE | 2/1/08 | 7/31/08 | $50,000 |
| Moustakas Bellotti | ECE | Deep UV Semiconductor Laser for in situ Organic and Biological Exploration (Subcontract via Photon Systems, Inc.) | NASA | 1/1/06 | 12/31/08 | $125,000 |
| Moustakas Paiella | ECE | Ultraviolet Electroabsorption Modulators Based on III-nitride Quantum Wells | NSF | 9/1/07 | 8/31/10 | $294,337 |
| Murray | AME | High Frequency Laser Ultrasonic Inspection System for in-situ Characterization of Nanoscale Materials (Subcontract via Bossa Nova Technologies, LLC) | NSF | 7/1/07 | 6/30/08 | $70,122 |
| Murray | AME | IPA: National Institute of Standards and Technology (NIST) | Department of Commerce/NIST | 9/4/07 | 8/29/08 | $55,402 |
| Paiella | ECE | Plasmonic Band-Structure Engineering for Light-Emission Efficiency Enhancement | DOE | 8/15/07 | 8/14/08 | $99,771 |
| Paiella Moustakas | ECE | Intersubband All-Optical Switching and Optically-Pumped Light Emission with III-Nitride Quantum Wells | NSF | 9/1/08 | 8/31/09 | $83,925 |
| Reinhard | CHEM | Plasmon Coupling Microscopy for the in vivo Detection and Tracking of Cytoplasmic RNA | HHS/NIH/NIBIB | 7/1/08 | 6/30/09 | $228,125 |
| Rothschild | PHY | FTIR Study of Signal Transduction in Sensory Rhodopsins | HHS/NIH/NIGMS | 2/1/08 | 1/31/09 | $229,697 |

| P. I. | Dept. | Title of Project | Agency | Period | | Amount |
|---|---|---|---|---|---|---|
| Ruane | ECE | Center for Subsurface Sensing and Imaging Systems (CenSSIS)--Education Program (Subcontract via Northeastern Univ.) | NSF | 9/1/07 | 8/31/08 | $59,537 |
| Ruane<br>Swan | ECE | REU Site: Research Experience for Undergraduate Students in Photonics | NSF | 5/1/08 | 4/30/09 | $2,704 |
| Ruane<br>Swan | ECE | REU Site: Research Experience for Undergraduate Students in Photonics- Participant Support Costs | NSF | 5/1/08 | 4/30/09 | $111,751 |
| Ruane<br>Swan | ECE | REU Site: Research Experience for Undergraduate Students in Photonics-Ethics Component | NSF | 5/1/08 | 4/30/09 | $4,000 |
| Saleh | ECE | Center for Subsurface Sensing and Imaging Systems (CenSSIS)--Research Thrust 1-Photonics (Subcontract via Northeastern Univ.) | NSF | 9/1/07 | 8/31/08 | $126,128 |
| Saleh<br>Nawab | ECE | Learning an Integrated View of Engineering (LIVE) | NSF | 1/15/08 | 12/31/09 | $150,000 |
| Saleh<br>Teich | ECE | Quantum Optical Coherence Tomography (CenSSIS Supplement)(Northeastern University) | NSF | 2/1/03 | 8/31/08 | $35,000 |
| Saleh<br>Teich<br>Sergienko | ECE | Quantum Imaging: New Methods and Applications (MURI) (Subcontract via University of Rochester) | DOD/Army | 5/1/05 | 4/30/08 | $89,711 |
| Saleh<br>Teich<br>Sergienko | ECE | Quantum Imaging: New Methods and Applications (MURI) (Subcontract via University of Rochester) | DOD/Army | 5/1/05 | 9/30/08 | $128,803 |
| Sergienko<br>Saleh<br>Teich<br>Jaeger | ECE | Phase-Sensitive Quantum-Optical Sensor (in conjunction with Photonics Center) | DOD/Army | 8/1/07 | 9/10/08 | $139,900 |
| Swan | ECE | Vibrational and Electronic Aspects of Carbon Nanotubes and Their Interactions (in conjunction with Photonics Center) | NSF | 9/1/07 | 8/31/10 | $300,000 |
| Unlu<br>Goldberg | ECE | New Instrumentation for Nanoscale Subsurface Spectroscopy and Tomography (in conjunction with Center for Nanoscience and Nanobiotechnology) (Subcontract via University of Rochester) | DOD/Air Force | 6/15/03 | 9/30/08 | $38,763 |
| Zhang | MFG | Uncooled Cantilever Microbolometer Focal Plane Arrays with MK Temperature Resolution: Engineering Mechanics for the Next Generation | DOD/Air Force | 12/1/06 | 11/30/08 | $99,851 |
| Zhang | MFG | Development of a MEMS Column Using SOI Wafers (in conjunction with Photonics Center) | Schlumberger-Doll Research | 7/23/07 | 12/31/07 | $25,000 |

| P. I. | Dept. | Title of Project | Agency | Period | | Amount |
|---|---|---|---|---|---|---|
| Zhang | MFG | NER: A Digital Bio/Nanoelectronics Interface for Single Cell Study (REU Supplement) | NSF | 8/9/07 | 8/31/08 | $6,000 |
| Zhang | MFG | Collaborative Research: Elastic and Viscoelastic Characterization and Modeling of Polymer-Based Structures for Biological Applications (in conjunction with Photonics Center) | NSF | 9/1/08 | 8/31/11 | $219,428 |
| Zhang | MFG | Design, Fabrication, and Characterization of an HT microTCD (in conjunction with Photonics Center) | Schlumberger-Doll Research | 6/1/08 | 12/31/08 | $10,000 |
| Zhang Averitt | MFG | Development of a Novel Optomechanical Uncooled Metamaterial-Enhanced Active Terahertz Detection Imager (in conjunction with Photonics Center) | NSF | 7/1/08 | 6/30/11 | $259,699 |

**TOTAL: $18,512,213**

## Breakdown by Granting Agency FY 07-08
## Total Funding: $18,512,213



# Patents and Publications

## *Archival Journal Articles*

**E. Bellotti**, K. Driscoll, **T.D. Moustakas**, **R. Paiella**, "Monte Carlo Study of GaN Versus GaAs Terahertz Quantum Cascade Structures," Applied Physics Letters, vol. 92, art. no. 101112, doi: 10.1063/1.2894508, March 2008.

M. Goano, M. Penna, F. Bertazzi, and **E. Bellotti**, "Electronic structure of wurtzite ZnO: non-local pseudopotential and ab-initio calculations," Journal of Applied Physics, 102, 083709, October 2007.

F. Bertazzi, M. Goano, and **E. Bellotti**, "Electron and hole transport in bulk ZnO: A full band Monte Carlo study," Journal of Electronics Materials, vol. 36, no. 8, pp. 857-863, August 2007.

**E. Bellotti**, F. Bertazzi, M. Goano, "Alloy Scattering in AlGaN and InGaN: A Numerical Study," Journal of Applied Physics, 101, 123706, 2007.

J. Stewart, A. Diouf, Y. Zhou, **T. G. Bifano**, "Open-loop control of a MEMS deformable mirror for large-amplitude wavefront control," Journal of the Optical Society of America, A [24], 3827-3833, 2007

J. Stewart, **T. G. Bifano**, S. Cornelissen, P. Bierden, B. Levine, T. Cook, "Design and development of a 331-segment tip-tilt-piston mirror array for space-based adaptive optics," Sensors and Actuators, A, Physical [138] 230-238, 2007

D. Biss, D. Sumorok, S. Burns, R. Webb, Y. Zhou, **T. G. Bifano**, D. Côté, I. Veilleux, P. Zamiri, C. Lin, "In vivo fluorescent imaging of the mouse retina using adaptive optics," Optical Letters [32], 659-661, 2007

R. Georgescu, D. Khismatulin, R.G. Holt, J.L. Castagner, and **I.J. Bigio**, "Design of a system to measure light scattering from individual cells excited by an acoustic wave," Optics Express, vol. 16, pp. 3496-3503, March 2008.

R. Reif, M.S. Amorosino, K.W. Calabro, O. A'Amar, S.K. Singh, and **I.J. Bigio**, "Analysis of changes in reflectance measurements on biological tissues subjected to different probe pressures," J. Biomed. Opt. Letters 13, 010502-1-3, January/February 2008.

R. Reif, O. A'Amar, and **I.J. Bigio**, "An analytical model of light reflectance for extraction of the optical properties in small volumes of turbid media," Applied Optics, vol. 46, pp. 7317-7328, October 2007.

R. Dallapiccola, A. Gopinath, F. Stellaci, and **L. Dal Negro**, "Quasi-periodic distribution of plasmon modes in two-dimensional Fibonacci arrays of metal nanoparticles," Optics Express, 16, 8, 5544, April 2008.

M. Saleh, **L. Dal Negro**, and **B. Saleh**, "Second-order parametric interactions in 1D photonic-crystal microcavity structures," Optics Express, 16, 8, 5261, April 2008.

M. Makarova, V. Sih, J. Warga, and **L. Dal Negro**, "Enhanced light emission in photonic crystal nanocavities with Erbium-doped silicon nanocrystals," Appl. Phys. Lett., 92, 161107, 2008.

**L. Dal Negro**, R. Li, J. Warga, S.N. Basu, "Sensitized Erbium emission from silicon-rich nitride/silicon superlattice structures," Appl. Phys. Lett., 92, 181105, 2008.

N. Feng and **L. Dal Negro**, "Plasmon mode transformation in modulated-index metal-dielectric slot waveguides," Optics Letters, 32, 21, November 2007.

**L. Dal Negro** and N-N. Feng, "Spectral gaps and mode locatlization in Fibonacci chains of metal nanoparticles," Optics Express, 15, 22, 14396, October 2007.

M. Hiltunen, **L. Dal Negro**, N.-N. Feng, L. C. Kimerling, and J. Michel, "Design of aperiodic fractal waveguide structures for multifrequency light transport," IEEE/OSA Journal of Lightwave Technology, vol. 25, no. 7, 1841, July 2007.

**L. Dal Negro**, N.-N. Feng, and A. Gopinath, "Electromagnetic coupling and plasmon localization in deterministic aperiodic arrays," J. Opt. A: Pure Appl. Opt., 10, 064013, 2008.

D. Karabacak, **K. Ekinci**, C. Gan, G. Gbur, **M. S. Ünlü**, S. Ippolito, **B. B. Goldberg**, P. Carney, "Diffraction of evanescent waves and nanomechanical displacement detection," Optics Letters, Vol. 32, No. 13, 1881-1883, July 2007

X. Wang, M. Hong, **S. Erramilli**, Y. Chen, R. Mohanty, "Nanoscale field effect transistor for biomolecular signal amplification," Applied Physics Letters, Volume 91, Number , Page 243511 December 14, 2007

J. Amsden, J. Kralj, L. Chieffo, X. Wang, **S. Erramilli**, E. Spudich, J. Spudich, **L. Ziegler, K. Rothschild**, "Sub-picosecond Protein Backbone Changes during the Green-Absorbing Proteorhodopsin Primary Photoreaction Detected," Journal of Physical Chemistry, B, 111, 11824-11831, 2007

X.Wang, Y. Chen, K. A. Gibney, **S. Erramilli**, P. Mohanty "Silicon-based Nanochannel Glucose sensor", Appl. Phys. Letters in press, 2008

Y. Chen, X. Wang, M. Hong, **S. Erramilli**, P. Mohanty, Carol Rosenberg, "Nanoscale Field Effect Transistor for Biomolecular Signal Amplification" Appl. Phys. Letters, 91, 243-511, 2007

J. Celli, B. Turner, N. Afdhal, R. Ewoldt, G. McKinley, R. Bansil, **S. Erramilli**, "Rhelogy of Gastric Mucin exhibits a pH dependent Sol-Gel transition," Biomacromolecules 8, 1580-1586, 2007

L. Chieffo, J. Shattuck, J. Amsden, **S. Erramilli, L. Ziegler**, "Ultrafast vibrational relaxation of liquid H2O following libration combination excitation," Chemical Physics, 341, 71-80, 2008

J. Amsden, J. Kralj, L. Chieffo, X. Wang, **S. Erramilli**, E. Spudich, J. Spudich, **L. Ziegler, K. Rothschild**, "Subpicosecond Protein Backbone Changes Detected during the Green Absorbing Proteorhodopsin Primary Photoreaction," Journal of Physical Chemistry, B, 111, 11824-11831, 2007

Walsh, B. M. ,**T. A. Fritz**, N. M. Lender, J. Chen, and K. E. Whitaker, "Energetic Particles Observed by ISEE-1 and ISEE-2 in a Cusp Diamagnetic Cavity on September 29, 1978," Ann. Geophys., 25, 2633–2640, 2007.

Whitaker, K.E., **T.A. Fritz**, J. Chen, and M.M. Klida, "Energetic particle sounding of the magnetospheric cusp with ISEE-1," Ann.Geophys., 25, No. 5, 1175-1182, 2007.

L. Wolf, Y. Gao, and **R. Georgiadis**, "Kinetic Discrimination of sequence DNA: Drug Binding Measured by Surface Imaging and Comparison to Solution," Journal of American Chemistry Society, 129, 10503-10511, 2008

B.J. Davis, M. Dogan, **B.B. Goldberg**, W.C. Karl, **M.S. Ünlü**, and **A.K. Swan**, "4Pi spectral self-interference microscopy," Nature, Virtual Journal of Nanoscale Science and Technology, January 14, 2008.

D. A. Bergstein, I. E. Ozkumur, A. C. Wu, A. Yalcin, J. Needham, R. Irani, J. Gershoni, **B. B. Goldberg**, C. DeLisi, **M. F. Ruane, M. S. Ünlü**, "Resonant Cavity Imaging: A Means Toward High-Throughput Label-Free Protein Detection," IEEE Journal of Selected Topics in Quantum Electronics, Vol. 14, No. 1, January/February 2008.

F. H. Koklu, J. I. Quesnel, A. N. Vamivakas, S. B. Ippolito, **B. B. Goldberg, M. S. Ünlü**, "Widefield Subsurface Microscopy of Integrated Circuits," Optics Express, Vol. 16, pp. 9501-9506, June 2008,

E. Ozkumur, J. Needham, D. A. Bergstein, R. Gonzalez, M. Cabodi, J. Gershoni, **B. B. Goldberg, M. S. Ünlü**, "Label-free and dynamic detection of biomolecular interactions for high-throughput microarray applications," Proceedings of the National Academy of Science, Vol. 105, pp. 7988-7992, June 2008.

J. R. Dupuis, J. Needham, I. E. Ozkumur, D. A. Bergstein, **B. B. Goldberg**, J. R. Engel, D. L. Carlson, **M. S. Ünlü**, "Hyperspectral Fourier transform spectrometer for reflection spectroscopy and spectral self-interference fluorescence microscopy," Applied Optics, Vol. 47, 20 March 2008, pp. 1223-1234

B. Davis, M. Dogan, **B. B. Goldberg**, W. Karl, **M. S. Ünlü, A. K. Swan**, "4Pi Spectral self-interference microscopy," Journal of the Optical Society of America, Vol. 24, 3762-3771, 2007

**G. Jones**, D. Yan, J. HU, B. Kia, V. Vullev, "Arylacridinium Conjugates in a Solid Glass Matrix," Journal of Physics, lll, 6921-6929, 2007

J.Wan, A. Ferreira, W. Xia, H. Chow, K. Takechi, V. Kamat, **G. Jones**, V. Vullev, "Solvent Dependence of the Charge-Transfer properties of a Quaterthiophene-Anthraquinone Dyad," Journal of Photochemistry and Photobiology A, in press.

**G. Jones**, P. Landsman, "Polymethacrylic acid enhances emission of dye stain extracted from bacterial spores: Fluorimetric quantitation in aqueous samples," Journal of Photochemistry and Photobiology. A, 189, 147-152 (2007).

O. Dudko, J. Mathé, A. Szabo, **A. Meller**, and G. Hummer, "Extracting kinetics from single-molecule force spectroscopy: Nanopore unzipping of DNA hairpins," Biophys. J. 92:4188-4195. 2007
J. B. Edel, J. S. Eid, and **A. Meller**, "Accurate single molecule FRET efficiency determination for surface immobilized DNA using maximum likelihood calculated lifetimes," Journal of Physics and Chemistry 111, 2986-2990, 2007

B. Hornblower, R. Coombs, A. Whitaker, S. Kolomeisky, J. Picone, **A. Meller**, M. Akeson, "Rapid Single-Molecule Kinetic Analysis of DNA-Protein Complexes," Nature Methods, 4:315-317, 2007

M. Kim, B. McNally, K. Murata, and **A. Meller**, "Characteristics of solid-state nanometre pores fabricated using a transmission electron microscope," Nanotech, 18, 205-302, 2007

G. Soni, and **A. Meller**, "Progress towards ultra-fast DNA sequencing using solid-state nanopores" Clin. Chem, 53, 1996-2001, 2007

M. Wanunu, B. Chakrabarti, J. Mathé, D.R. Nelson, and **A. Meller**, "Orientation Dependent Interactions of DNA with an α-Hemolysin Channel," Phys. Rev. E 77, 031904, 2008

M. Wanunu, and **A. Meller**, "Chemically-Modified Solid-State Nanopores," Nano Letters, 7, 1580-1585, 2007

**M. Mendillo**, S. Laurent, J. Wilson, J. Baumgardner, J. Konrad, and W.C. Karl, "The sources of sodium escaping from Io revealed by spectral high definition imaging," Nature, vol. 448, pp. 330-332, July 2007.

J. Baumgardner, J. Wilson and **M. Mendillo**, "Imaging the sources and full extent of the sodium tail of the planet Mercury," Geophys. Res. Lett., 35, L03201, doi: 10.1029/2007GL032337, February 2008.

C. Martinis and **M. Mendillo**, "ESF-related airglow depletions at Arecibo and conjugate observations," J. Geophys. Res., 112, A1031, doi: 10.1029/2007JA012403, October 2007.

L. Moore and **M. Mendillo**, "Are plasma depletions in Saturn's ionosphere a signature of time-dependent water input," Geophys. Res. Lett., 34, L12202, doi: 10.1029/2007Gl0s9381, July 2007.

J. Baumgardner, J. Wroten, J. Semeter, J. Kozyra, M. Buonsanto, P. Erickson, **M. Mendillo**, "A very bright SAR arc: implications for extreme magnetosphere-ionosphere coupling," Ann. Geophys., 25, 2593-2608, 2007.

S. Riyopoulos, **T. D. Moustakas**, J. S. Cabalu, "Plasma nanosheath formation with carrier accumulation and enhanced localized spontaneous emission at "quantum wedges" in textured GaN," Physics of Plasmas, 14, 053501, 2007.

S. Riyopoulos, **T. D. Moustakas** and J. S. Cabalu, "Enhanced transmission through quasirandom nanostructured dielectric interface via supercritical angle scattering," Journal of Applied Physics, 102, 043111, 2007.

K. Driscoll, A. Bhattacharyya, **T. D. Moustakas, R. Paiella,** L. Zhou, D. J. Smith, "Intersubband absorption in AlN / GaN / AlGaN coupled quantum wells," Applied Physics Letters, 91, 141104, 2007.

T. Xu, L. Zhou, Y. Wang, A. S. Ozcan, K. F. Ludwig, D. Smith and **T. D. Moustakas**, "GaN Quantum Dot Superlattice Grown by Molecular Beam Epitaxy at High Temperature," Journal of Applied Physics, Vol. 102, 073517, 2007. calculations," Physical Review B, 76, 245204, 2007.

Y. Li, A. Bhattacharyya, C. Thomidis, **T. D. Moustakas, R. Paiella**, "Ultrafast all-optical switching with low saturation energy via intersubband transitions in GaN /AlN quantum-well waveguides," Optics Express, Vol. 15, pp. 17922-17927, 2007.

J. Abell, **T. D. Moustakas**, "The role of dislocations as non-radiative recombination centers in InGaN MQWs," Applied Physics Letters, 92, 091901, 2008.

L. Zhou, R. Chandrasekaran, **T. D. Moustakas**, D. J. Smith, "Structural characterization of non-polar (1120) and semi-polar (1126) GaN films grown on r-plane sapphire," Journal of Crystal Growth, 310 pp. 2981-2986, 2008.

E. Dimakis, A. Nikiforov, C. Thomidis, L. Zhou, D. J. Smith. J. Abell, C. K. Kao, **T. D. Moustakas**, "Growth and properties of near-UV light emitting diodes based on InN / GaN quantum wells," Physica Status Solidi, (a) 205, 1070, 2008.

C. Thomidis, A. Nikiforov, T. Xu, **T. D. Moustakas**, "InGaN-based LEDs grown by plasma-assisted MBE on (0001) sapphire with GaN QDs in the nucleation layer," Physica Status Solidi, (c) 5, 2309, 2008.

J. Henson, A. Bhattacharyya, **T. D. Moustakas, R. Paiella**, "Controlling the recombination rate of semiconductor active layers via coupling to dispersion-engineered surface plasmons," Journal of Optical Society of America, 2008.

**T. D. Moustakas**, T. Xu, C. Thomidis, A. Nikiforov, L. Zhou and D. J. Smith, "Growth of III-Nitride quantum dots and their applications to blue-green LEDs," Physica Status Solidi, 2008.

A. Williams and **T. D. Moustakas**, "Development and application of an etch-back process for orientation independent planarization of GaN," Materials Science and Engineering B, 2008.

L. Zhou, M. R. McCartney, D. J. Smith, T. Xu and **T. D. Moustakas**, "Electrostatic Potential Measurement in Wurzite AlN/GaN Quantum Dot Superlattice," Physica Status Solidi, 2008.

S. Riyopoulos and **T. D. Moustakas**, "1-D carrier localization and quantum wire behavior in 'quantum wedges'," Journal of Applied Phys., 2008.

Y. Li, A. Bhattacharyya, C. Thomidis, Y. Liao, **T. D. Moustakas, R. Paiella**, "Refractive-Index Nonlinearities of Intersubband Transitions in GaN/AlN Quantum-Well Waveguides," Journal of Applied Physics, 2008.

Y. Wang, A. Ozcan, C. Sanborn, K. Ludwig, A. Bhattacharyya, R. Chandrasekaran, **T. D. Moustakas**, L. Zhou and D. Smith, "Real-Time X-Ray Studies of Gallium Nitride Nanodot Formation by Droplet Heteroepitaxy," Journal of Applied Physics, 102, 073522, 2007.

K. Driscoll and **R. Paiella**, "Design of n-Type Silicon-Based Quantum Cascade Lasers for Terahertz Light Emission," Journal of Applied Physics vol. 102, art. no. 093103, 2007.

**B. Reinhard**, S. Sheikholeslami. A. Mastroianni, A. P. Alivisatos, J. Liphardt, "Use of Plasmon Coupling to reveal the Dynamics of DNA cleavage by single restriction enzymes," proceedings of the National Academies of Sciences 104, 2667 (2007)

L. Skewis, **B. Reinhard**, "Spermidine Modulated Ribonuclease Activity Probed by RNA Plasmon Rulers," Nano Letters, 10, 1021/l072-5042, Dec. 2007

A. F. Abouraddy, T. Yarnall, **B. Saleh, M. C. Teich**, "Experimental Violation of Bell's Inequality in Spatial-Parity Space," Physical Review Letters, 99, 170408, November 2007.

A. F. Abouraddy, T. Yarnall, **B. Saleh, M. C. Teich**, "Synthesis and Analysis of Entangled Photonic Qubits in Spatial-Parity Space," Physical Review Letter, 99, 250502, December 2007.

T. Yarnall, **B. Saleh, M. C. Teich** and A. F. Abouraddy, "Spatial Coherence Effects in Second- and Fourth-Order Temporal Interference," Optics Express, 16, 7634-7640, May 2008.

M. B. Nasr, **B. Saleh, A. Sergienko**, S. Carrasco, **M. C. Teich**, J. P. Torres, L. Torner, D. S. Hum, M. M. Fejer "Quasi-Phase-Matched Optical Parametric Down-Conversion," Physical Review Letters, v. 100, 183601, 2008.
G. Jaeger and A. Sergienko, "Constructing Four-Photon States for Quantum Communication and Information Processing," International Journal of Theoretical Physics, DOI 10.1007/s10773-007-9569-x, October 2007.

**A. Sergienko**, "Beyond Singe-Photon Counting," Nature Photonics, v. 2, pp.268-269, 2008.

C. Bonato, P. Villoresi and **A. Sergienko**, "Two-photon spectral coherence matrix and characterization of multiparameter entangled states," Physics Letters A, v. 372, pp.3109-3117, 2008.

B. J. Davis, **A. K. Swan**, **M. S. Ünlü**, W. C. Karl, **B. B. Goldberg**, J. C. Schotland and P. S. Carney, "Spectral self-interference microscopy for low-signal nanoscale axial imaging," Journal of the Optical Society of America, Vol. 24, pp. 3587-3599, 2007.

M. Dogan, A. Yalcın, S. Jain, M. B. Goldberg, **A. K. Swan, M. S. Ünlü, B. B. Goldberg**, "Spectral Self-Interference Fluorescence Microscopy for Subcellular Imaging," IEEE J. Select. Topics in Quantum Electron: Special Issue on Biophotonics, vol. 14, no. 1, January/February 2008.

A. N. Vamivakas, M. Atature, J. Dreiser, S. T. Yilmaz, A. Badolato, **A. K. Swan, B. B. Goldberg**, A. Imamoglu, **M. S. Ünlü**, "Strong Extinction of a Far-Field Laser Beam by a Single Quantum Dot," Nano Letters, Vol. 7, No. 9, pp. 2892-2896, September 2007.

B. Davis, **A. K. Swan, M. S. Ünlü**, W. Karl, **B. B. Goldberg**, J. Schotland, P. Carney, "Spectral Self-Interference microscopy for low-signal nanoscale axial imaging," Journal of the Optical Society of America, Vol. 24, 3587-3599, 2007

A. Vamivakas, S. Ippolito, **A. K. Swan, M. S. Ünlü**, M. Dogan, E. Behringer, **B. B. Goldberg**, "Phase-sensitive detection of dipole radiation in a fiber-based high numerical aperture optical system," Optics Letters, Vol. 32, No. 8, 970-972, April 15 2007

A. G. Walsh, A. N. Vamivakas, Y. Yin, S. B. Cronin, **M. S. Ünlü, B. B. Goldberg, A. K. Swan**, "Scaling of exciton binding energy with external dielectric function in carbon nanotubes," Physica E , 40, 2375–2379, 2008.

M. Ghioni, G. Armellini, P. Maccagnani, I. Rech, M. K. Emsley, **M. S. Ünlü**, "Resonant-Cavity- Enhanced Single Photon Avalanche Diodes on Reflecting Silicon Substrates," IEEE Photon. Technol. Lett., Vol. 20, 20, No. 6, pp. 413-415, 2008.

J. R. Dupuis, **M. S. Ünlü**, "Time-Domain Surface Profile Imaging via HS-FTS," Optics Letters, Vol. 33, pp. 1368-1370, June 2008.

M. Ghioni, G. Armellini, P. Maccagnani, I. Rech, M. K. Emsley, **M. S. Ünlü**, "Resonant-Cavity-Enhanced Single-Photon Avalanche Diodes on Reflecting Silicon Substrates," IEEE Photonics Technology Letters, Vol. 20, No. 6, pp. 413-415, March 2008.

A. Walsh, A. N. Vamivakas, Y. Yin, S. B. Cronin, **M. S. Ünlü, B. B. Goldberg, A. K. Swan**, "Screening of Excitons in Single, Suspended Carbon Nanotubes," Nano Letters, Volume 7, Number 6, Pages 1485, May 09, 2007

Y. Yin, A. N. Vamivakas, A. Walsh, S. B. Cronin, **M. S. Ünlü, B. B. Goldberg, A. K. Swan**, "Optical Determination of Electron-Phonon Coupling in Carbon Nanotubes," Physical Review Letters, Volume 98, Number , Page 37404 January 07, 2007

H. Tao, N.I. Landy, CM.. Bingham, **X. Zhang, R.D. Averitt**, W.J. Padilla, "A Metamaterial Absorber for the Terahertz Regime: Design, Fabrication and Characterization," Optics Express, 16 (10) (2008) 7181-7188.

S. Huang and **X. Zhang**, "Study of Gradient Stress in Bimaterial Cantilever Structures for Infrared Applications," Journal of Micromechanics and Microengineering, 17 (7) (2007) 1211-1219.

S. Huang, H. Tao, I-K Lin, **X. Zhang**, "Development of Double-Cantilever Infrared Detectors: Fabrication, Curvature Control and Demonstration of Thermal Detection," Sensors and Actuators A: Physical, 145-146 (2008) 231-240.

Y. Liu, I-K Lin, **X. Zhang**, "Mechanical Properties of Sputtered Silicon Oxynitride Films by Nanoindentation," Materials Science and Engineering A, 489 (1-2) (2008) 294-301.

Y. Qiu, R. Liao, **X. Zhang**, "Real-Time Monitoring Primary Cardiomyocyte Adhesion Based on Electrochemical Impedance Spectroscopy and Electrical Cell-Substrate Impedance Sensing," Analytical Chemistry, 80 (4) (2008) 990-996.

Y. Zhao, **X. Zhang**, "Nanobiotechnology: an Engineering's Foray into Biology, Advances in Computers," Academic Press, 71, 39-102, 2007.

Y. Zhao, **X. Zhang**, "Profile Control in Silicon Nanostructures Using Fluorine Enhanced Oxide Passivation," IEEE Transactions on Nanotechnology, 7 (1) (2008) 40-47.

Y. Zhao, C.C. Lim, D.B. Sawyer, R. Liao, **X. Zhang**, "Simultaneous Orientation and Cellular Force Measurements in Adult Cardiac Myocytes Using Three-Dimensional Polymeric Microstructures," Cell Motility and Cytoskeleton, 64 (9) (2007) 718-725.

Z. Cao, **X. Zhang**, "Nanoindentation Stress-Strain Curves of Plasma Enhanced Chemical Vapor Deposited Silicon Oxide Thin Films," Thin Solid Films, 516 (8) (2008) 1941-1951.

J. Peng, **L. Ziegler**, "Optical Heterodyne Detected Accumulated Acoustic Grating Responses in Near Supercritical Fluids," Journal of Physical Chemistry, A, 111 13457-13465, 2007

I. Patel, W. Premasiri, D. Moir, **L. Ziegler**, "Barcoding Bacterial Cells: A SERS Based Methodology for pathogen Identification," in press, Journal of Raman Spectroscopy

## ***Book Chapters***

**M. Mendillo** and P. Withers, "Solar Flare Effects upon the Ionospheres of Earth and Mars," in Radio Sounding and Plasma Physics, P. Song, J. Foster, **M. Mendillo**, and D. Bilitza, eds., Springer, 2008.

T. Xu and **T. D. Moustakas**, "Growth and Characterization of III-Nitride Quantum Dots and their Applications to Emitters," in Self-Assembled Quantum Dots, Z. M. Wang, ed., Springer, 2008.

**B. E. A. Saleh** and **M. C. Teich**, "Noise in Classical and Quantum Photon-Correlation Imaging," in Advances in Information Optics and Photonics, A. T. Friberg and R. Dändliker, eds., SPIE Press, 2008.

**M. S. Ünlü**, E. Ozkumur, D. Bergstein, A. Yalcin, **M. F. Ruane**, and **B. B. Goldberg**, "Applications of Optical Resonance to Biological Sensing and Imaging: II. Resonant Cavity Biosensors," Biophotonics Biological and Medical Physics, Biomedical Engineering, L. Pavesi and P. Fauchet, eds., Springer and Verlag, 2008.

**M. S. Ünlü,** A. Yalcin, M. Dogan, L. Moiseev, **A. K. Swan**, **B. B. Goldberg**, and C. R. Cantor, "Applications of Optical Resonance to Biological Sensing and Imaging: I. Spectral Self-Interference Microscopy," Biophotonics Biological and Medical Physics, Biomedical Engineering, L. Pavesi and P. Fauchet, eds., Springer and Verlag, 2008.

## *Patents and Patent Applications*

**T. Bifano**, "Mems Based Retroreflector," U.S. Patent Application no. 20070297042 December 27,2007

**L. Goldstein**, K. O'Rourke, "Diagnosis of transmissible spongiform encephalopathy," U.S. Patent Application no. 20070224593 September 27, 2007

**L. Goldstein**, L. Chylack, "Ocular diagnosis of Alzheimer's disease," U.S. Patent no. 7,297,326 November 20, 2007

**L. Goldstein**, N. Ford, L. Chylack, P. Hartung, M. Friedman, E. Sherr, S. Fantone, "Ocular imaging," U.S. Patent Application no. 20080088795 April 17, 2008

**K. Rothschild**, J. Olejnik, S. Sonar, "Detection of markers in nascent proteins," U.S. Patent Application no. 20070172849 July 26, 2007

**K. Rothschild**, S. Gite, J. Olejnik, S. Mamaev, M. Lim "Methods for the detection, analysis and isolation of nascent proteins," U.S. Patent no. 7,252,932 August 7,2007

J. Olejnik, E. Krzymanska-Olejnik, S. Mamaev, **K. Rothschild**, " Methods for the preparation of chemically misaminoacylated tRNA via protective groups," U.S. Patent no. 7,288,372 October 30; 2007

**K. Rothschild**, S. Sonar, J. Olejnik, "Photocleavable bioreactive agents," U.S. Patent no. 7,312,038 December 25,2007

**K. Rothschild**, S. Gite, J. Olejnik, M. Lim, "Methods for the detection, analysis and isolation of nascent proteins," U.S. Patent no. 7,312,060 December 25,2007

J. Olejnik, **K. Rothschild** " Photocleavable isotope-coded affinity tags." U.S. Patent Application no. 20080032417 February 7, 2008

**K. Rothschild**, S. Sonar, J. Olejnik, "Bioreactive agents," U.S. Patent no. 7,339,045 March 4,2008

**T. D. Moustakas** and A. Williams, "Planarization of GaN by Photoresist Technique using an inductively Coupled Plasma," US Patent Application no. 60/880, 758, filed January 17, 2007.

**T. D. Moustakas** and A. Williams, "Planarization of GaN by Photoresist Technique using an inductively Coupled Plasma," International Application (PCT) no. PCT/US2007/002943, filed February 2, 2007.

**T.D. Moustakas**, "Semiconductor Device Having Highly Insulating monocrystalline Gallium Nitride Thin Films," Japanese Patent Application 2007-24009, filed February 2, 2007.

M. Klein, **T. Murray**, "Laser-ultrasonic detection of flip chip attachment defects," U.S. Patent no. 7,327,448 February 5, 2008

B. Li, **X. Zhang, T. Bifano, A. Sharon**, "Uncooled Cantilever Microbolometer Focal Plane Array with Mk Temperature Resolutions and Method of Manufacturing Microcantilever," U.S. Patent Application no. 20070272864 November 29, 2007

J. Martin, T. Brosnihan, M. Judy, **X. Zhang** "Sensor System," U.S. Patent no. 7,327,003 February 5, 2008

R. Premasiri, **L. Ziegler**, D. Moir, "Analyzer for Nanostructured Substrate for Surface Enhanced Raman Scattering," U.S. Patent Application no. 20080123093 May 29, 2008

# Development Projects

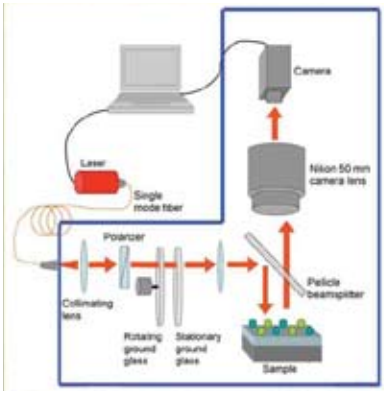
Since its inception, the Boston University Photonics Center has worked jointly with the Department of Defense to develop photonics technologies. Much of the original funding for the construction of the Center came from a grant from the Office of Naval Research (ONR). The Department of Defense (DoD) requires rapid access to advanced technologies to solve critical operational needs such as sniper detection, improvised explosive device (IED) detection and chemical and biological threat detection. Many potential solutions have emerged from the research efforts within Boston University. A core mission of the Photonics Center is to accelerate the development of new technology for use in defense and security applications. When the results of research are rapidly converted into useful prototypes and devices for these applications, more collaborations are formed. These collaborations often lead to new advanced technology development with DoD. The proven ability to develop prototypes for defense technology is a critical differentiator for the Photonics Center. To that end, the pipeline model has been developed at the Center with RedOwl being the initial project. From this model, the Center has developed a phased program: Phase I is prototype development; Phase II is prototype enhancement and integration including partnership with a spin-off company or outside commercial entity (preferably a defense contractor); Phase III is an effort to transfer the technology and prototype to the industrial partner for production (outside the hands of the University), thus resulting in insertion.

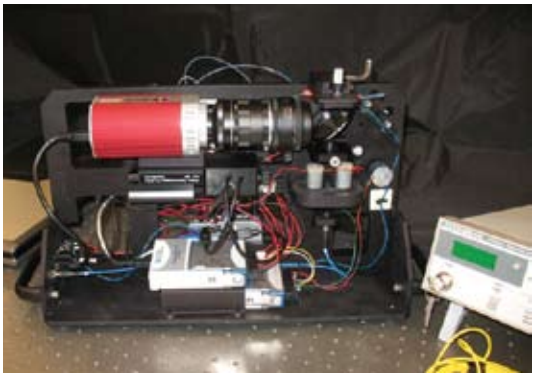
## ***The BUPC Pipeline Process:***

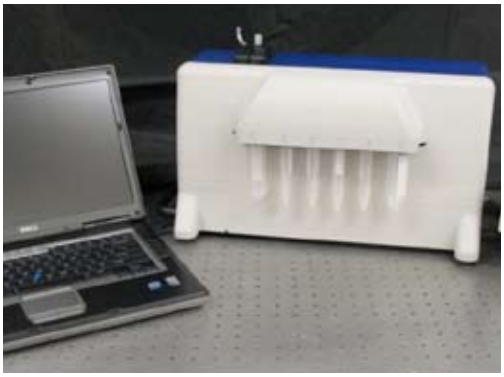
**PHASE 0: Research**
Individual faculty grants are monitored for potential pipeline insertion

**Phase I & II: Prototyping at BUPC**
Two year linear funding increase based on milestone achievements and direct applications/connections with national, homeland, and military security needs/pull

**Phase III: Insertion**
Final year, transition to industry partner receives technology to support continued national, homeland, and military security need





*COBRA Diagnosis as it progresses through the BUPC Pipeline.*

# Phase III Pipeline Projects

## Robot Enhanced Detection Outpost with Lasers (RedOwl)

*Acoustic direction finding: sound localization*

***Task Manager:***
Professor Allyn Hubbard / Leah Ziph-Schatzberg

***Objective:***
Transition Boston University acoustic direction finding (ADF) technology to industrial partners. The system responds after the first shot and is able to image the firing source and identify the range to it. RedOwl provides early warning information, situational awareness, intelligence, surveillance and targeting capabilities.

***BU Technology Basis:***
Researchers at Boston University have developed acoustic localization enabling technology based on the mammalian auditory system. This biomimetic technology is capable of accurate sound localization with a significantly smaller microphone separation than traditional sound localization systems. This technology has been integrated with a suite of optical sensors built for military use and mounted on an iRobot PackBot. RedOwl's integrated optical sensor suite includes: laser range finder, laser illuminators/pointer, ADF and classifier with acoustic sensors, zoom thermal imager, low light/day light color 300x zoom camera, digital compass with integrated GPS positioning, communications link and two wide angle driving cameras.

This was the year of RedOwl's transition to production by the industrial partners that participated in the project: Biomimetic Systems, Inc., Insight Technologies and iRobot. The system was tested extensively at local firing ranges. Special Operations Command (SOCOM) requested three systems be sent to Afghanistan for further testing. This deployment is planned for this fall. The RedOwl was also tested by Soldier Battle Lab in Fort Benning, GA. Initial reports from this test are very favorable.

As the year progressed, a digital ADF (without optical suite) was developed. This system is smaller, lighter and consumes less power than the original system and it will be easier and less expensive to manufacture. The digital system has been tested extensively in local ranges. Test results to date show similar accuracy to the analog ADF system.

Army Research Laboratories (ARL) has integrated a RedOwl head in their network as a sensor node.

***Timeline:***

- Proof of concept of ADF on a PackBot - 2005
- Integrated optics and acoustic suite - April 2006
- System test at AAEF - September 2006
- HMMWV mounted system - March 2007
- ADF technology and system improvements - Through 2008
- SOCOM deployment - Fall 2008
- Insertion to industry partner - Fall 2008

# Enhanced Acoustic Gear for Locating Enemies (EAGLE)

*Wearable acoustic direction finding: sound localization*

***Task Manager:***
Professor Allyn Hubbard / Dr. Helen Fawcett

***Objective:***
Transition RedOwl acoustics system to a warfighter wearable format in support of Future Force Warrior (FFW) program, with the first target being a helmet mounted system.

***BU Technology Basis:***
Researchers at Boston University have developed acoustic localization enabling technology based on the mammalian hearing apparatus. This biomimetic technology enables sound localization with a significantly smaller microphone separation than traditional sound localization systems. It is also far more accurate and immune to other noise sources and echoes and is designed to provide early warning information, gunshot/sniper detection and localization, intelligence, surveillance and targeting capabilities to military forces and government agencies. This technology has been integrated with the Future Force Warrior (FFW) helmet design to demonstrate the versatility of the technology base.

The Boston University Photonics Center, in partnership with Biomimetic Systems, participated in the Side Excursion at Fort Dix, New Jersey and the On-the-move C4ISR VIP Day in July successfully locating 12 test rounds for the demonstration. From the success at the VIP Day, the team met with groups from ARDEC and PM Soldier, Systems, and Lasers to gain feedback on the relevance and acceptance of the platform integrated onto the FFW helmet. This technology basis is being displayed as a proof-of-concept (lap top for leader display or command post, hand-held PDA or integrated optical display for field soldiers) promising integrability with FFW plans. This technology addresses a critical need for soldier-worn acoustic sensors as protection against snipers and to improve situational awareness in urban warfare environments. EAGLE has been transferred directly to BioMimetic Systems, Inc. for pursuit in SWAT/Homeland Security applications and other soldier wearable platforms. The last demonstration of the technology was in December 2007 at Fort Benning for a data collection opportunity.

***Timeline:***

- Prototypes to meet VIP FFW platform - July 2007
- Army tests, additional capabilities - December 2007
- Insertion to industrial partner - June 2008

# Phase II Pipeline Projects

## Compact Optical Bio-threat Rapid Analysis (COBRA): Detection
### Portable Raman Spectrometer Microscope with SERS Technology
*Spectroscopy: identification of biological contaminants*

***Task Manager*:**
Professor Lawrence Ziegler/Dr. Helen Fawcett

***Objective:***
Transition an evolving optical and nano-technology Surface Enhanced Raman Spectroscopy (SERS) to a portable, field ready platform that will assist in battlefield and homeland hospitals for bacterial detection in blood and sputum as well as detection of bacteria in water testing.

***BU Technology Basis:***
Researchers at Boston University Photonics Center have been developing SERS technology supported through the cooperative agreement with ARL-SEDD. A variety of nanoscale structured metal substrates have been utilized for the observation of SERS. A Boston University Photonics Center research team developed a new in-situ grown aggregated Au or Ag nanoparticle covered SiO2 matrix and demonstrated exceptionally strong and reproducible signal enhancements for bacteria. Patent applications for this technology and for the SERS substrate are pending.

The team has been moving forward to address some technology challenges. The software interface is one of the most important aspects of this project. The information from a post optical scan must run through mathematical computations and provide an accurate result of what material was just tested by the system. This information must be accurately and clearly displayed for the end user of the system. The team is also working toward a methodology to transfer a sample of bodily fluid to the substrate through the use of micro-fluidics. Sample processing to take a swab, vial of bodily fluid, etc. and process it to a sub-microliter volume that is then deposited onto the substrate is also being demonstrated. With the compact system, the team is demonstrating repeatability and exercising the portable system.

***Timeline:***
- Proof of concept on commercially available spectrometer - October 2005
- Diagnostic capabilities through data analysis - June 2006
- Portable Raman microscope station - March 2007
- Industrial partnership - November 2007
- Sample manipulation and preparation - October 2008
- Collaboration/insertion - March 2009

# Secure Communicating Optical Ultra-light Transponder (SCOUT)

*MEMs low power battlefield communications*

***Task Manager:***
Professor Thomas Bifano / Leah Ziph-Schatzberg

***Objective:***
Enable a new class of communications to assist in situational awareness using a military issued optical laser system already in theater and integrating innovative micro-mirrors to transmit sound securely.

***BU Technology Basis:***
Researchers at the Boston University Photonics Center have developed an enabling technology creating low power deformable microelectromechanical (MEMs) microcircuits. The silicon based MEMs circuits will be low cost, rugged and a high performance secure communication device. Easily retrofittable, this will add capability to thousands of soldiers using existing equipment in the field. The Boston University project team is continuing to develop the enabling technology for further enhancement capabilities that can be applied to a variety of platforms and imaging sensors.

A system prototype was integrated into a modified Insight Technology fielded weapon. The system's modules and performance characteristics have been tested and analyzed. Clear communication was demonstrated at ranges over 200 meters.

***Timeline:***

- Proof of concept - June 2005
- STTR award / BMC & BU - September 2006
- Development input PM soldier - December 2006
- Prototype - March 2007
- Improved prototype performance characterization - April 2008
- SOCOM demonstration - August 2008
- Seeking industrial partner - Summer 2008

# Phase I Pipeline Projects

## Compact Optical Bio-threat Rapid Analysis (COBRA): Diagnosis
### Spectral Reflectance Imaging Biosensor (SRIB)

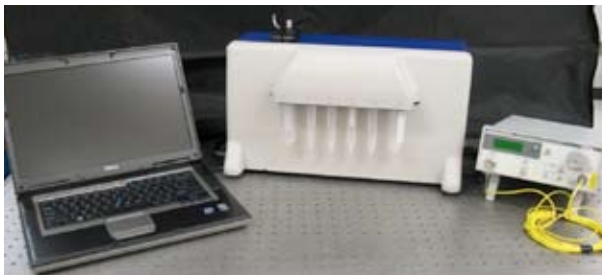
*Optical based molecular detection: identification of biological toxins*

***Task Manager:***
Professor Selim Unlu / Dr. Helen Fawcett

***Team:***
Principal Investigators: Dr. Selim Ünlü, Electrical and Computer Engineering Department, Dr. Rostem Irani, Center for Advanced Genomic Technology, Dr. Masoud Sharif, Electrical and Computer Engineering Department, Dr. David Bergstein, ECE postdoctoral researcher

***Graduate students:***
James Needham (BME), Emre Ozkumur (ECE). Ayca Yalcin (ECE), and Philipp Spuhler (BME)

***Objective:***
Evaluate the transition of evolving optical and semiconductor fabrication techniques of SRIB chips and a bench top set up to a portable platform for assistance in battlefield and homeland clinics. This is a diagnostic tool for rapid multiplexed label free diagnosis of symptomatic patients (bacteria, toxins, viruses, etc.).



***BU Technology Basis:***
The researchers have developed two primary label-free biological detection technologies. The resonant cavity imaging biosensor (RCIB) consisted of two highly reflecting low-loss reflectors that were positioned with their reflecting surfaces facing one another to form the cavity. The Spectral Reflectance Imaging Biosensor (SRIB) works in a similar method to RCIB except that the resonant signals are collected in reflection and the cavity is simply formed within an oxide layer on a silicon substrate. The benefits include a simpler more compact, inexpensive and robust instrument. Most importantly, the achievable sensitivity is sufficient for most immunosensing applications.

The team worked over the year to develop the prototype and evaluate it compared to the bench top set up. In addition, collaboration with BU NEIDL was established through discussions with Dr. Thomas Geisbert, Associate Director of the facility. He will become an active partner in the team for next year's funding as the program enters Phase II. Zoiray, Inc., a spin off company, will become the industrial partner for the program entering Phase II.

***Milestones:***
- Proof of concept demonstration using antibodies and antigens - December 2007
- Prototype - February 2008
- Performance upgrades to system prototype - November 2008
- Diagnostic capabilities of SRIB - February 2009
- Insertion/collaboration - July 2009
- Multiplexed chip demonstration - July 2010

# Development of Efficient SERS Substrates via "Rationally" Designed Novel Nanofabrication Strategies for COBRA: Detection

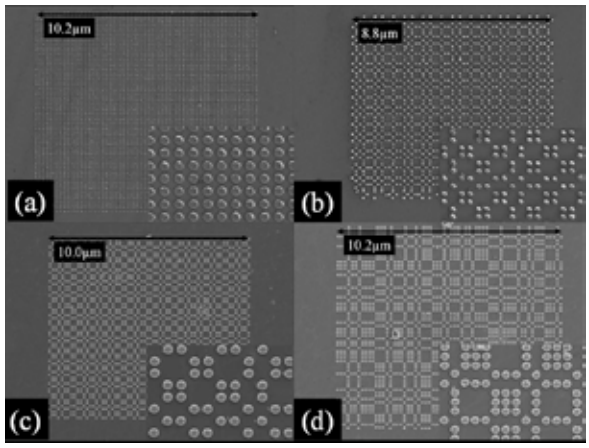
*Spectroscopy: substrate surface enhancement*

***Task Manager:***
Professor Lawrence Ziegler / Dr. Helen Fawcett

***Team:***
Principal Investigators: Professor Lawrence Ziegler, Department of Chemistry, Professor L. Dal Negro, Department of Electrical and Computer Engineering, Professor B. Reinhard, Department of Chemistry

***Graduate students:***
A. Gopinath (ECE), R. A. Shugayev (ECE), L. Skewis (CH)

***Objective:***
Evaluate use of electron beam lithography in combination with theoretical modeling of periodic and aperiodic structures and chemical nanodoping to create deterministic SERS substrates. These structures were performance evaluated against current sol-gel substrates and other commercially available SERS substrates.




***BU Technology Basis:***
The researchers supported the ongoing efforts at the BU Photonics Center of implementation of SERS-based instrumentation for the detection and identification of potential biothreat agents. This evolved by developing and evaluating SERS substrates produced by two novel nanofabrication-based techniques. The substrates resulting from these "rationally" designed procedures offered the possibility of improved reproducibility, large enhancement factors and increased shelf life as compared to the sol-gel SERS substrates. The strategies in both of these approaches was to create a high density of field enhancing "hot spots" at controllable, fixed sites on the SERS active substrate. These substrates were tested and compared with the current BU sol-gel SERS chips and a commercially available SERS substrate (Klarite) using both test molecular and bacterial samples.

Phase II funding was awarded to this team with a renewed effort to evaluate bacterial signatures and cost effective manufacturing methods.

***Milestones:***
- Demonstration of localized hot-spots: top down nanofabrication and bottom up chemical synthetic approaches - February 2008
- Optimization of engineered design - April 2009
- Determination of spore and virus capabilities - June 2009
- Industrial partner - October 2009
- Insertion/collaboration - July 2010

# Development of III-Nitrides Based Optoelectronics Devices from the UV to the THz for Biochemical Threat Detection

*Optoelectronics: materials development*

***Task Manager:***
Professor Theodore Moustakas / Leah Ziph-Schatzberg

***Team:***
Principal Investigators: Theodore D. Moustakas, Roberto Paiella, Enrico Bellotti, Department of Electrical Engineering

***Graduate Students:***
Adam Moldawer (ECE), Kristina Driscoll (ECE), Nuno Almeida (ECE)

***Objective:***
Evaluate the capabilities of III-Nitride materials to emit in the UV range (280 nm). The target was chosen based on the property that exposure to a wavelength of 280 nm can render some biological agents harmless.

***BU Technology Basis:***
The researchers worked to develop III-Nitride semiconductors emitters and detectors from the UV region of the electromagnetic spectrum for biochemical threats detection. The project addressed the development of UV-LEDs emitting at 280 nm and UV-detectors responding at 280 nm. These detectors will be designed to operate as avalanche photodetectors (APDs) in the Geiger mode.

This team was awarded Phase II funding for fiscal year 2008/2009 with a goal to integrate into ARL's UV-LED program with specifications for the LED substrates.

***Milestones:***
- Developed UV-LEDs emitting at 315 nm – March 2008
- Developed photoconductive UV-detector with peak sensitivity at 250 nm – March 2008
- Develop UV-LEDs emitting at 280 nm – June 2008

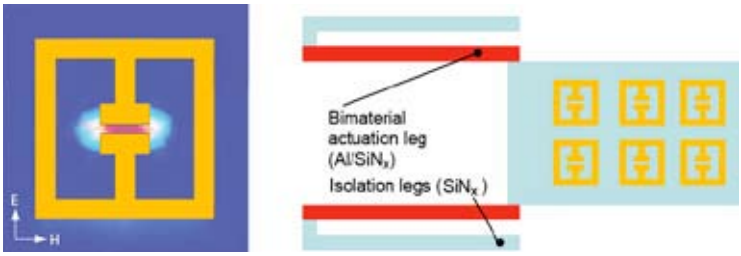
# Metamaterial MEMS Components for Spectroscopic Detection and Identification using Terahertz Radiation

***Task Manager:***
Professor Richard Averitt / Dr. Helen Fawcett

***Team:***
Principal Investigators: Richard Averitt College of Arts and Science Physics Department and Xin Zhang, Department of Manufacturing Engineering

***Graduate Students:***
Hu "Tiger" Tao (MFG), Drew Strikwerda (PHY)

***Objective:***
Evaluate ability to create active devices to enhance manipulation and detection of far-infrared, or terahertz, radiation by combining electromagnetic metamaterials with MEMS technology.




***BU Technology Basis:***
Motivating these efforts are the unique characteristics of terahertz radiation which includes transparency to materials that are opaque at other wavelengths, and sensitivity to molecular signatures of gas phase and solid phase materials including biological and chemical threats.This was done by combining metamaterials, which provide for the synthesis of design-specific electromagnetic resonances, with MEMS cantilever technology. To create a terahertz notch filter, the incorporation of MEMS cantilevers into the active region of the metamaterial elements enabled dynamic tuning through modification of the capacitance.

In addition, the team performed a feasibility study investigating the potential of metamaterial enhanced cantilevers detectors (MMECDs) for the room-temperature detection of terahertz radiation. These results were compared with existing room-temperature THz detectors such as antenna-coupled microbolometers thereby allowing determination:

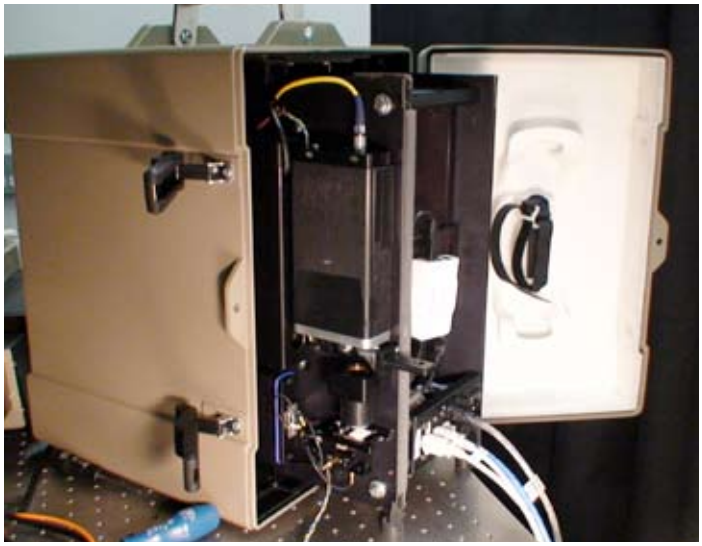
1. Of MMECDs as a competitive technology
2. The general potential of metamaterial absorbers to enhance the sensitivity of other types of THz detectors.

This team was awarded a Phase I FTDA for fiscal year 2008/2009 to develop a single pixel detector.

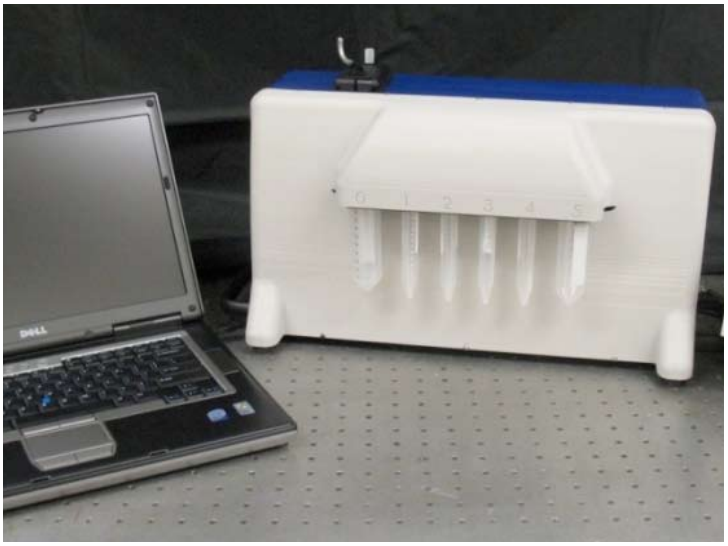
***Milestones:***
- Proof of principle cantilever - June 2008
- Continued development of a detector - October 2008
- Integration of detector with lab-bench source - February 2009
- Identification of enterprise partner for system development - February 2010
- Insertion/collaboration - July 2011

# Awards Selected in FY2007 for BUPC-ARL Cooperative Agreement Support in FY2008

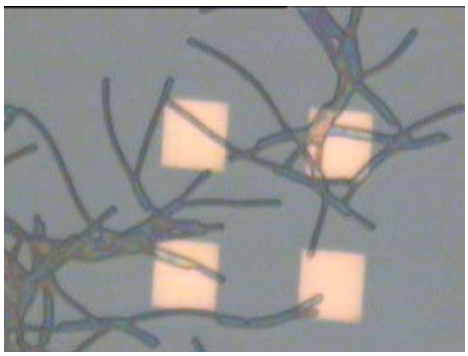
In support of the pipeline development program, the Photonics Center continued the Faculty Technology Development Awards Program (FTDA) selection process for programs starting July 1, 2008. After a general solicitation, proposals were rated by peers from industry, academia, and government agencies . Written evaluations were provided by the committee and a formal meeting was held with the Director of the Center present to gain feedback from the reviewers. For those programs that received FTDA awards last year, the teams were required to provide a 20 minute presentation addressing the alignment with project goals and military relevance/applicability. The program award totals varied depending upon PI request and committee recommendations to the Center Director. This year, additional funding was presented to program teams that aligned with the biophotonics programs and demonstrated unique relevance to military biodetection focus areas. These programs are identified as Phase 0 programs and are being seeded to be evaluated as FTDA Phase I applications in February 2009.



*COBRA Detection*



*COBRA Diagnosis*



*SERS Substrate for COBRA Detetion*

| Program | Faculty P.I. and Co-Investigators | Program Manager | FY 2008 Pipeline Status |
|---|---|---|---|
| COBRA: Portable Raman Spectrometer Microscope with SERS Technology | L. Ziegler, C. Klapperich, J. Connor, T. Geisbert, N. Miller | Helen Fawcett | Phase III |
| COBRA: Development of Efficient SERS Substrates via "Rationally" Designed Novel Nanofabrication Strategies | L. Ziegler, B. Reinhard, L. Dal Negro, T. Geisbert (BU Medical/NEIDL) | Helen Fawcett | Phase II |
| COBRA: Spectral Reflectance Imaging Biosensor | S. Unlu, T. Geisbert(BU Medical/NEIDL), J. Connor (BU Medical) | Helen Fawcett | Phase II |
| Development of III-Nitrides Based Optoelectronics Devices from the UV to the THz for Biochemical Threat Detection | T. D. Moustakas, E. Bellotti, R. Paiella | Leah Ziph-Schatzberg | Phase II |
| Molecular Bio-Dosimetry (Rapid Assessment of Bio Relevant Radiation Exposure) | L. Goldstein, A. Sergienko, E. Blakely (Lawrence Berkeley National Lab) | Helen Fawcett | Phase I |
| Metamaterial Enhanced Thermal Terahertz Imager | R. D. Averitt, X. Zhang | Helen Fawcett | Phase I |
| First Responders: Miniature MEMS Mid-Infrared Fiber Screener | S. Erramilli, K. J. Rothschild, E. R. Schildkraut (Block MEMS, LLC.) | Leah Ziph-Schatzberg | Phase I |
| Ultra-High Resolution (1 um) Digital X-rays for Clinical Applications | T.F. Morse, M. Bystrom, B. Saleh, M. Grinstaff, R. Gupta (Mass General Hospital Radiology) | Leah Ziph-Schatzberg | Phase I |
| Development of High Efficiency Non-Polar and Semi-Polar UV LEDs for Biochemical Threats Detection | T. D. Moustakas, E. Bellotti, R. Paiella | Leah Ziph-Schatzberg | Phase I |
| Miniaturized Digital Electronics for a Biomimetic Acoustic Sniper Detection and Localization System | A. Hubbard | Leah Ziph-Schatzberg | Phase I |
| Bio-Compatible Label-Free Colorimetric Responder | L. Dal Negro, F. Omenetto and D. Kaplan ( Tufts University Biomedical Engineering Dept.) | Helen Fawcett | Phase 0 |
| Rapid Portable Biosensor for Virus Detection | H. Altug, J. Connor (BU Medical), S. Unlu | Helen Fawcett | Phase 0 |
| High Performance Incoherent Light Source for FOG (Fiber Optical Gyro) | T.F. Morse, R. Shubochkin | Leah Ziph-Schatzberg | Phase 0 |

# Students Supported by BUPC- ARL Cooperative Agreement

**Dr. Hatice Altug (ECE)**
Alyssa Pasquale
Saban Bilek
Shahrooz Amin

**Dr. Enrico Bellotti (ECE)**
Nuno Almeida

**Dr. Thomas Bifano (MFG)**
Michael Gingris

**Dr. David Castanon (ECE)**
Rohit Kumar

**Dr. Luca Dal Negro (ECE)**
Ashwin Gopinath
Joseph Warga
Roman Shugayev

**Dr. Shyam Erramilli (PHY)**
Xihua Wang

**Dr. Allyn Hubbard (ECE)**
Cassandra Browning
David Freedman
Marianne Nourzad
Sarah Kelsall
Yirong Pu

**Dr. Catherine Klapperich (MFG)**
Sylvanus Lee

**Dr. Theodore Morse (ECE)**
Andrea Rosales Garcia

**Dr. Theodore Moustakas (ECE)**
Adam Moldawer
Josh Abell
Ramya Chandrasekaran

**Dr. Roberto Paiella (ECE)**
Kristina Driscoll

**Dr. Bjorn Reinhard (PHY)**
Lynell Skewis

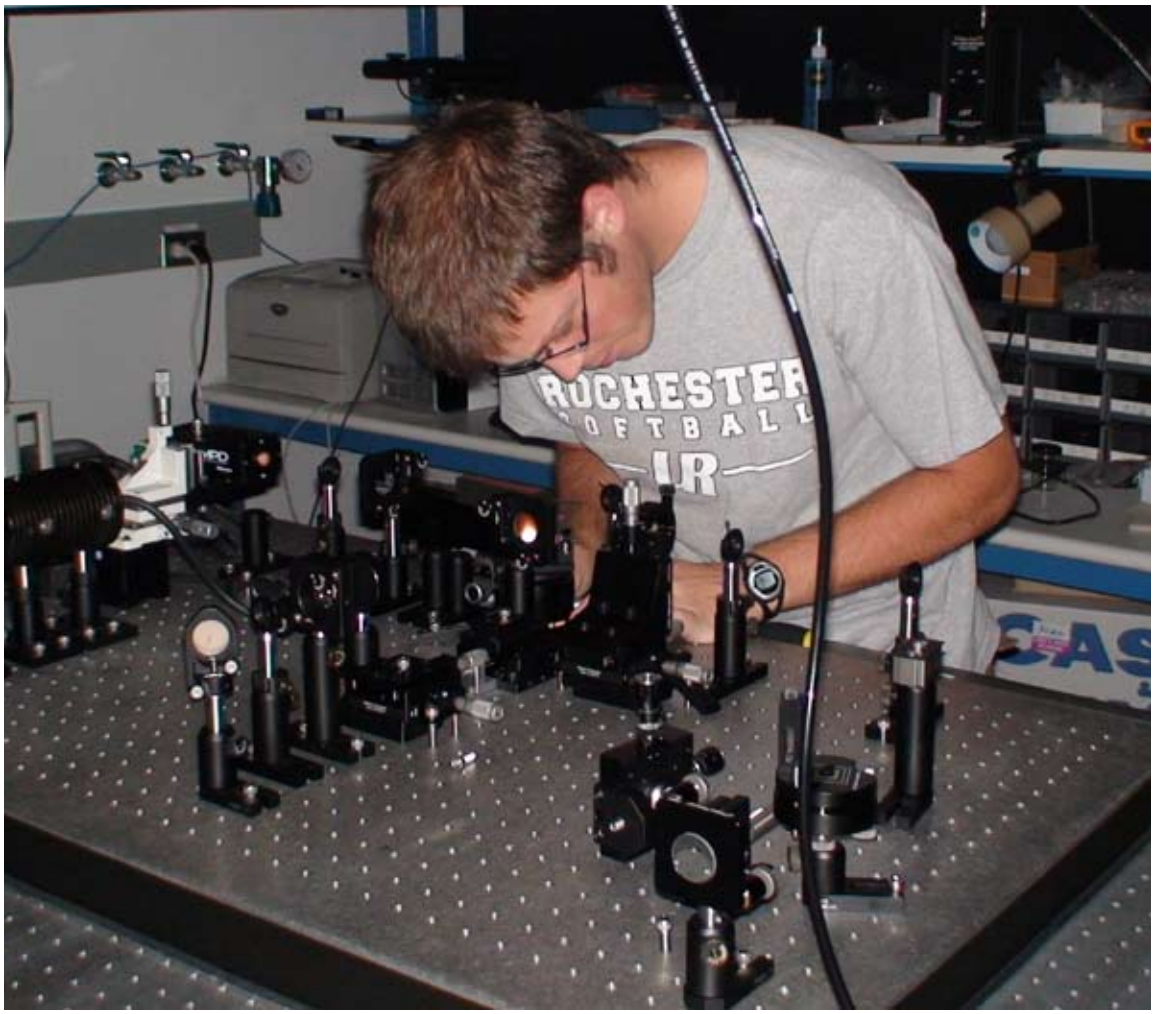
**Dr. Selim Ünlü (ECE) &**
**Dr. Bennet Goldberg (PHY)**
Ayca Yalcin
Ismail Emre Ozkumur
James Needham
Phil Spuhler

**Dr. Xin Zhang (MFG)**
Hu Tao
I-Kuan Lin

**Dr. Lawrence Ziegler (CHEM)**
Jeffrey Shattuck
Logan Chieffo

# Initiatives

The shared vision and support from members forms the foundation of the Photonics Center. Center-based initiatives are intended to accelerate and invigorate collective activities and catalyze new avenues of research and development while strengthening interdisciplinary efforts. Based upon previous success, two such initiatives were continued during 2007.



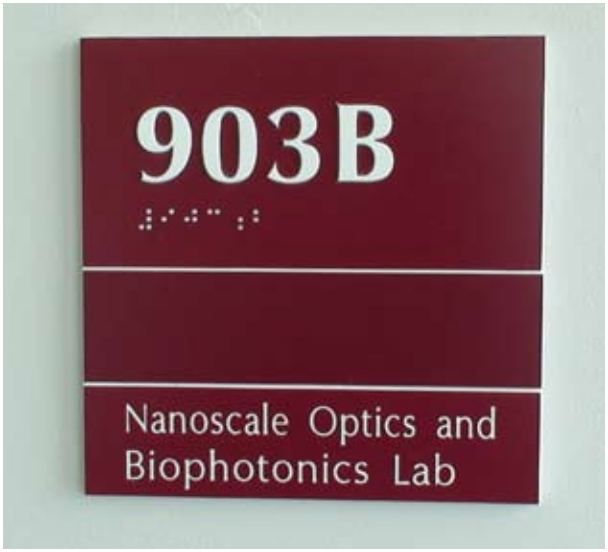
# Photonics Center New Faculty Initiative Program

The Center's New Faculty Initiative Program, successfully implemented with Professor Hatice Altug this past year, helps accelerate the scholarly career of a new biophotonics faculty member appointed to one of the Center's core departments. Biophotonics, the integration of "biology and light", is an area of strategic importance to the BUPC. Applications and devices in medicine, genetics and environmental science, for defense and non-defense models, form a strong base for faculty and students to pursue research in this area. A particular emphasis is placed on translational biophotonics that employ the Center's pipeline of innovation in this field.

This award is a part of the BUPC-ARL Cooperative Agreement and aims to provide support for academic equipment and program startup costs for a new tenured or tenure-track faculty position. The research conducted by these new faculty members must be complementary to the BUPC core intellectual and academic strengths. These areas of strength include:

- Biophotonics imaging, the study of optical imaging and how it is used to understand biological problems, including microscopy, subsurface probing of tissue, adaptive optics for retinal and neurobiological imaging.
- Biomedical photonics, the study of light-based systems for applications including detecting and treating disease, probing molecules and cells, sensing pathogens, microsurgery and wound healing.

The Center's leadership in this important area of research and development is strengthened by an unparalleled geographic concentration of biophotonics-related academic and commercial activities in the Boston area. The success of our program depends on our ability to attract, support, and retain the field's most promising academic researchers.




For this year's award, Professor Altug's laboratory has been completed and inspected by the Office of Environmental Health and Safety as the Photonics Center's second Class IIIb and IV laser laboratory with Bio-Safety Level 2 (BL2) rating. The equipment that Professor Altug purchased with her New Faculty Initiative Award included outfitting the BSL-2 lab with a biosafety cabinet, incubator, freezer, and oven. In addition, several laser systems were purchased to support the detection of biological entities as part of her focus area. Fulfilling the vision of this program, the funding allows for the purchase of new equipment that inspires collaboration with faculty members in the same and differentiating fields. Professor Altug, as the first supported faculty member, has established this path by not only collaborating with medical researchers at Harvard but also with the Boston University School of Medicine. Her establishment of a BL-2 laser facility, and the resulting collaboration with BU School of Medicine, has led to a successful entrance into the BUPC pipeline program with a Phase 0 award. This phase 0 project will focus on developing a rapid portable biosensor for virus detection. Thanks to this award, Professor Altug's team has begun work on a plasmonic and photonic crystal structure to develop label-free, high-throughput, portable and ultra-sensitive biosensors to detect biomolecules.

# Fellowship Awards Program

The success of interdisciplinary research at BUPC depends directly on the quality of our graduate students drawn from a wide range of academic backgrounds. To support those students and to ensure that BUPC will continue to maintain facilities and academic programs conductive to interdisiplanary research and education, the Center continued its doctoral fellowship program. This year, ten photonics graduate students were funded. Awardees are selected from nominees provided by those cognate graduate programs and BUPC faculty advisors. Final selections are made by an appointed committee of Photonics Center faculty and staff members.

## *2007 Fellowship Awardees*

| Student | Dept. | Advisor | Photonics Contact | Service |
|---|---|---|---|---|
| Emre Ozkumur | ECE | Ünlü | Anlee Krupp | AFM/ZYGO |
| Onur Basarir | AME | Ekinici | Anlee Krupp | E-beam Lithography |
| Andy Walsh | PHY | Swan | Anlee Krupp | SEM |
| Joel Kralj | PHY | Rothschild | Helen Fawcett | FTIR |
| Jude Schneck | CHEM | Ziegler | Helen Fawcett | Vis Spectrometer |
| Andrea Garcia | ECE | Morse | Helen Fawcett | Seminars |
| Nico DiFiori | PHY | Meller | Helen Fawcett | Seminars |
| Kengye Chu | BME | Mertz | Helen Fawcett | Seminars |
| Kristina Driscoll | ECE | Paiella | Paul Mak | OPF Coatings |
| Xiaoyu "Rayne" Zheng | MFG | Zhang | Paul Mak | OPF Testing |

**Top Row** ***(from left)*****:**
Andy Walsh, Kengyeh Chu, Onur Basarir, Xiaoyu "Rayne" Zheng, Jude Schneck and Nico DiFiori

**Bottom Row** ***(from left)*****:**
Andrea Garcia, Kristina Driscoll, Joel Kralj and Director Thomas Bifano

**Missing from Photo:**
Emre Ozkumur

For 2007, the Photonics Center Fellowship Committee was comprised of three Photonics Center faculty members: Professors Shyam Erramilli [Chair], Anna Swan, and Jerome Mertz. In the second year of this program, students worked alongside faculty and staff mentors to complete their fellowship duties. Students assigned to work in shared laboratory facilities received first-hand training on new capital equipment including: the Zeiss e-beam writer, ZYGO NewView 6300, and the Headway Photoresist spinner. Students also assisted in creating video-training sessions for equipment in conjunction with training other users and determining calibration routines and accessories for new equipment. Being a critical component to the shared laboratories and the success of researchers using advanced tools, these students assisted in community building in a technical and hands-on approach.

The students assigned to seminars were tasked with organizing and hosting the Photonics Forum. The students worked together with Photonics staff members to select faculty and student speakers to discuss photonics research. The Photonics Forums were held in the Colloquium Room with lunch served during the discussion sessions. A new addition to this year's responsibilities was a two part Incubator Forum. Each fellowship recipient was assigned an incubator company to introduce to the wider Photonics Center community. These forums were set in a similar way to the Photonics Forum, but with a less formal presentation style.

For 2008, the Photonics Center Fellowship Committee was comprised of three Photonics faculty members: Professors Anna Swan, Jerome Mertz, and Richard Averitt. Two fellowships were awarded for a full year supporting incoming graduate students. Seven senior fellowships were also awarded for the academic year (8 months). Fellows are expected to provide research and service support to the Photonics Center at a rate of 10-hours/per week for their designated services. Each month a senior fellow will be assigned to guide the junior fellows on which laboratories or speakers to request and introduce to the community.

## *2008 Fellowship Awardees*

| Student | Dept. | Advisor | Photonics Contact | Service |
|---|---|---|---|---|
| Ashwin Gopinath | ECE | Dal Negro | Anlee Krupp | Zeiss/E-beam |
| Danilo D'Orsogna | ECE | Bellotti | Anlee Krupp | ZYGO/AFM |
| F. Hakan Koklu | ECE | Unlu | Anlee Krupp | Zeiss |
| Katherine Calabro | BME | Bigio | Chad Demers | FTIR/Spectrometer/Fiber Polish |
| Utku Kemiktarak | PHY | Ekinci | Paul Mak | Photolithgraphy |
| Ashwinkumar SampathKumar | AME | Murray | Paul Mak | Coatings |
| Brian Hicks | ECE | Chakrabarti | Paul Mak | Ellipsometer/Thin Films |
| David Newby | PHY | TBD | Keith Crook | Seminars |
| Hengyi Ju | ME | TBD | Keith Crook | Seminars |

# Education

At the core of the Photonics Center's mission is the education of future leaders in the field. While BUPC does not offer academic degrees, it contributes substantially to the University's education programs. As an academic pillar for a leading large, private, urban university, the Boston University Photonics Center offers students a wide range of opportunities to learn in classrooms and laboratories led by leaders in the field, to develop their research and communication skills and to engage with renowned scholars in photonics.

The Center immerses its students in an environment that fosters collaboration, mentorship, and the unique opportunity to work with photonics companies and staff on prototype development through its partnership with BU's technology entrepreneurship program. BUPC sponsors a variety of events and awards to promote the spread of fundemental knowledge within our student population. These events and awards include: the Berman Award, the Future of Light Symposium Poster Competition and our monthly Photonics Forums (page 107). As part of our commitment to education, we sponsor annual tours of the facilities to undergraduate students from universities all over the country who participate in our yearly Research Experiences for Undergraduates (REU) program, teacher participants in the Bechtel Immersion Institute for elementary and middle school teachers, high school student tours, and many other groups interested in learning about the Photonics Center. The following pages highlight many of our educational activities.

# Graduated Photonics Students

## *Summer 2007*

| *Student* | *Degree* | *Advisor* |
|---|---|---|
| Azak, Nabi | M.S. Mechanical Engineering | Ekinci |
| Blaney, Philip | M.S. Electrical Engineering | Paiella |
| Campbell, Bryan | M.S. Electrical Engineering | Ruane |
| Georgescu, Ramona | M.S. Electrical Engineering | Bigio |
| Wu, Arthur | M.S. Biomedical Engineering | Mertz |

## *Fall 2007*

| *Student* | *Degree* | *Advisor* |
|---|---|---|
| Abell, Joshua | Ph.D. Electrical Engineering | Moustakas |
| Adams, Jason | M.S. Electrical Engineering | Fritz |
| Bozinovic, Nenad | M.S. Computer Systems Engineering / Ph.D. Electrical Engineering | Ünlü |
| Browning, Cassandra | M.S. Computer Systems Engineering | Hubbard |
| Chandrasekaran, Ramya | Ph.D. Electrical Engineering | Moustakas |
| Chen, Tai-Chou | Ph.D. Electrical Engineering | Moustakas |
| Helms, Matthew | M.S. Electrical Engineering | Hubbard |
| Ince, Gozde | Ph.D. Mechanical Engineering | Bifano |
| Karabacak, Devrez | Ph.D. Mechanical Engineering | Ekinci |
| Krzewick, William | M.S. Electrical Engineering | Ruane |
| Li, Wei | Ph.D. Electrical Engineering | Moustakas |
| Lu, Wen | M.S. Mechanical Engineering | Bifano |
| Needham, James | M.S. / Ph.D. Biomedical Engineering | Ünlü |
| Shah, Aditi | M.S. Computer Systems Engineering | Hubbard |

## *Fall 2007 (continued)*

| *Student* | *Degree* | *Advisor* |
|---|---|---|
| Squires, Allison | M.S. Aerospace Engineering / Ph.D. Mechanical Engineering | Ekinci |
| Steen, Thomas | Ph.D. Mechanical Engineering | Murray |
| Vamivakas, Anthony | Ph.D. Electrical Engineering | Ünlü |
| Waite, Stephanie | M.S. Electrical Engineering | Moustakas |
| Yarnall, Timothy | Ph.D. Electrical Engineering | Teich |
| Zhang, Jane | M.S. / Ph.D. Biomedical Engineering | Bigio |

## *Spring 2008*

| *Student* | *Degree* | *Advisor* |
|---|---|---|
| Castillo, Janice | M.S. Electrical Engineering | Bifano |
| Chen, Ying-Hsiang | M.S. Photonics | Teich |
| Do Valle, Bruno | M.S. Electrical Engineering | Fritz |
| Gallagher, Beth | M.S. Photonics | Swan |
| Gingras, Michael | M.S. Manufacturing Engineering | Bifano |
| Gonzalez Padilla, Axel | M.S. Manufacturing Engineering | Zhang |
| Hart, Carl | M.S. Mechanical Engineering | Ekinci |
| Kim, Duk | Ph.D. Electrical Engineering | Hubbard |
| Lin, Jin | M.S. Electrical Engineering | Hubbard |
| Moldawer, Adam | M.S. Electrical Engineering | Moustakas |
| Reif, Roberto | Ph.D. Biomedical Engineering | Bigio |
| Shin, Yongwoo | M.S. Electrical Engineering | Moustakas |

# Selected Photonics Related Courses

**ENG EC 560 Introduction to Photonics (Altug)**
Description: Introduction to ray optics, wave optics, Fourier optics, absorption, dispersion. Polarization, anisotropic media, and crystal optics. Guided-wave and fiber optics. Laboratory experiments: interference; diffraction and spatial filtering; polarizers, retarders, and liquid-crystal displays; fiber-optic communication links.

**CAS PY 522 Electromagnetic Theory II (Averitt)**
Description: Continuation of CAS PY 521. Magnetostatics, dipole moment, magnetic materials, boundary value problems. Electromagnetic induction, magnetic energy, Maxwell's equations. Electromagnetic waves in materials, reflection, refraction. Waveguides. Scattering and diffraction. Special relativity. Lorentz transformations, covariant electrodynamics. Interaction of charges with matter. Radiation, Lienard-Wiechert potential, synchotron radiation, antennas.

**ENG SC 765lBE 765 Biomedical Optics and Biophotonics (Bigio)**
This course surveys the applications of optical science and engineering to a variety of biomedical problems, with emphasis on optical and photonics technologies that enable real, minimally-invasive clinical applications. The course teaches only those aspects of biology itself that are necessary to understand the purpose of the application. The first weeks introduce the optical properties of tissue, and following lectures cover a range of topics in three general areas: 1) Optical spectroscopy applied to diagnosis of cancer and other tissue diseases; 2) Photon migration and optical imaging of subsurface structures in tissue; and 3) Laser-tissue interactions and other applications of light for therapeutic purposes. In addition to formal lectures, recent publications from the literature will be selected as illustrative of various topical areas, and for each publication one student will be assigned to prepare an informal presentation (with overhead slides or Powerpoint) reviewing for the class the underlying principles of that paper and outlining the research results. Same as ENG BE 765; students may not receive credit for both. 4 cr.

**ENG SC 770 Guided-wave Optoelectronics (Dal-Negro)**
Discussion of physics and engineering aspects of integrated optics and optoelectronic devices. Semiconductor waveguides, lasers, and photodetectors. Layered semiconductor structures, quantum wells, and superlattices. QW detectors, emitters, and modulators. OEICs. Photonic switching. 4 cr.

**ENG SC 700 Nano-photonics (Dal Negro)**
Fundamentals of electrodynamics, diffraction theory and optical response theory; Strongly confined fields and near-field optics: optics below the diffraction limit; Lightmatter interactions in confined systems: quantum dots, wires and nanotubes, energy coupling phenomena, introductory concepts on plasmonics, photonic crystals structures; Applications to optical devices: nano-lasers, random lasers, photonic crystals LEDs, plasmon waveguides, micro-ring and ultra high Q resonators, principles of near-field optical microscopy, optical antennas and optical tweezers.

**CAS PY 522 Electromagnetic Theory II (Erramilli)**
Description: Continuation of CAS PY 521. Magnetostatics, dipole moment, magnetic materials, boundary value problems. Electromagnetic induction, magnetic energy, Maxwell's equations. Electromagnetic waves in materials, reflection, refraction. Waveguides. Scattering and diffraction. Special relativity. Lorentz transformations, covariant electrodynamics. Interaction of charges with matter. Radiation, Lienard-Wiechert potential, synchotron radiation, antennas.

**CAS CH 351 Physical Chemistry I (Georgiadis)**
Description: Quantum Theory, atomic and molecular structure, molecular spectroscopy, statistical mechanics, solid state chemistry. Three hours lecture, one hour discussion.

**GRS CH 641 Physical Organic Chemistry (Jones)**
Description: Physical fundamentals of organic chemistry. Thermodynamics, kinetics, molecular orbital theory, and theory of concerted reactions. Isotope effects, aromaticity, linear free energy relationships, acidity functions, photo- and free-radical chemistry.

**ENG BE 517 Practical Optical Microscopy of Biological Materials (Mertz)**
Description: In this course students will learn the practice and the underlying theory of imaging with a focus on state-of-the-art live cell microscopy. Students will have the opportunity to use laser scanning confocal as well as widefield and near-field imaging to address experimental questions related to ion fluxes in cells, protein dynamics and association, and will use phase and interference techniques to enhance the detection of low contrast biological material. Exploration and discussion of detector technology, signals and signal processing, spectral separation methods and physical mechanisms used to determine protein associations and protein diffusion in cells are integrated throughout the course. Students will be assigned weekly lab reports, a mid-term and a final project consisting of a paper and an oral presentation on a current research topic involving optical microscopy.

**ENG SC 563 Fiber-Optic Communication Systems (Morse)**
Prereq: ENG SC 410, SC 31 1, SC 415, and SC 560 or consent of instructor. Introduction to fiber optics; components, concepts, and systems design techniques required for the planning, design, and installation of fiber-optic communication systems. Single- and multi-mode LED and semiconductor lasers, detectors, connectors and splicers, terminal and repeater electronics, wavelength division multiplexing optical amplifiers and solitons, and systems architecture for point-to-point and local area networks. Laboratory work on fiber and electronic measurements. 4 cr.

**ENG EC 568 Optical Fiber Sensors (Morse)**
Description: This course will cover the theory and practice of optical fiber sensors. This course will meet twice a week for two hours. In addition, there will be a three-hour laboratory each week. The focus of the course will be on laboratories involving various types of optical fiber sensors. Grades will be based on laboratory reports as well as a significant laboratory project

**ENG SC 575 Semiconductor Devices (Paiella)**
Prereq: ENG SC 410, SC 455, and CAS PY 313 or PY 354, or equivalent. Fundamentals of carrier generation, transport, recombination, and storage in semiconductors. Physical principles of operation of the PN junction, metal-semiconductor contact, MOS capacitor, MOSFET (Metal Oxide Semiconductor Field Effect Transistor), JFET (Junction Field Effect Transistor) and bipolar junction transistor. Develops physical principles and models that are useful in the analysis and design of integrated circuits. 4 cr.

**ENG EC 591 Photonics Lab I (Paiella)**
Description: Introduction to optical measurements. Laser safety issues. Laboratory experiments: introduction to lasers and optical alignment; interference; diffraction and Fourier optics; polarization components; fiber optics; optical communications; beam optics; longitudinal laser modes. Optical simulation software tools.

**ENG SC 700 Semiconductor Quantum Structures in Photonic Devices (Paiella)**
Optical properties of semiconductors: interband optical transitions; excitons. Low dimensional structures: quantum wells, superlattices, quantum wires, quantum dots, and their optical properties; intersubband transitions. Lasers: double-heterojunction, quantum-well, quantum-dot, and quantum-cascade lasers; high-speed laser dynamics. Electro-optical properties of bulk and low-dimensional semiconductors; electroabsorption modulators. Detectors: photoconductors and photodiodes; quantum-well infrared photodetectors.

**ENG SC 569 Introduction to Subsurface Imaging (Saleh)**
Prereq: Senior or graduate standing in ENG, PY, CH, MA, or CS. Introduction to subsurface imaging using electromagnetic, optical, X-ray, and acoustic waves. Transverse and axial imaging using localized probes (confocal scanning, time of flight, and interferometric techniques). Multiview tomographic imaging: computed axial tomography, diffraction tomography, diffuse optical tomography, electrical impedance tomography, and magnetic resonance imaging. Image reconstruction and inverse problems. Hyperspectral and multisensor imaging. 4 cr.

**ENG EC 763 Nonlinear and Ultrafast Optics (Saleh)**
Description: Tensor theory of linear anisotropic optical media. Second- and third-order nonlinear optics. Three-wave mixing and parametric interaction devices, including second-harmonic generation and parametric amplifiers and oscillators. Four-wave mixing and phase conjugation optics. Electro-optics and photo-refractive optics. Generation, compression, and detection of ultra short optical pulses. Femtosecond optics. Pulse propagation in dispersive linear media. Optical solitons.

**ENG SC 760 Advanced Topics in Photonics (Saleh)**
This is an advanced special topics course in photonics; topics will vary from year to year. It will be offered in the spring term when there is no other 700-level course in the photonics area. Students who take the course on two different topics would be able to receive credit for it twice. Some of these offerings may become a permanent part of the curriculum in the future. 4 cr.

**ENG SC 762 Quantum Optics (Saleh)**
Prereq: ENG SC 560, or equivalent, or consent of instructor. Review of the postulates of quantum mechanics. Quantization of the electromagnetic field. Coherent, thermal, squeezed, and entangled states, and their associated photon statistics. Interaction of light with matter. Spontaneous and stimulated transitions. Theory of optical detection. Quantum theory of the laser. Interaction of light with two-level atoms, including photon echo and self-induced transparency. Quantum theory of parametric interactions. 4 cr.

**ENG SC 764 Optical Measurement (Sergienko)**
Prereq: ENG SC 560. Detailed discussion of basic principles of major optical effects such as interference, diffraction, and polarization. Analysis of practical applications of interferometry, ellipsometry, photometry, and laser spectroscopy in modern optical measurement such as characterization of industrial processes, environmental control, communication, and laboratory research. 4 cr.

**ENG EC 764 Optical Measurement (Swan)**
Description: Detailed discussion of basic principles of major optical effects such as interference, diffraction, and polarization. Analysis of practical applications of interferometry, ellipsometry, photometry, and laser spectroscopy in modern optical measurement such as characterization of industrial processes, environmental control, communication, and laboratory research.

**ENG SC 560 Introduction to Photonics (Teich)**
Prereq: CAS PY 313. Introduction to ray optics, wave optics, Fourier optics and holography, absorption, dispersion. Polarization, anisotropic media, and crystal optics. Guided-wave and fiber optics. Elements of photon optics. Laboratory experiments: interference; diffraction and spatial filtering; polarizers, retarders, and liquid-crystal displays; fiber-optic communication links. 4 cr.

**ENG SC 763 Nonlinear and Ultrafast Optics (Teich)**
Prereq: ENG SC 560. Tensor theory of linear anisotropic optical media. Second- and third-order nonlinear optics. Three-wave mixing and parametric interaction devices, including second-harmonic generation and parametric amplifiers and oscillators. Fourwave mixing and phase conjugation optics. Electro optics and photorefractive optics. Generation, compression, and detection of ultra short optical pulses. Femtosecond optics. Pulse propagation in dispersive linear media. Optical solitons. 4 cr.

**MET AD 667 Technology Transfer, Innovation, and National Development (Unger)**
Description: Examines various approaches to developing "high tech" innovation based economies as a route to self sufficiency and growth. Factors studied include both structural reforms in the political, legal and economic areas, and government sponsored initiatives in higher education, basic research, private venture capital, grants to support new product development by promising ventures, and the creation of science and technology parks and "incubators." Students independently research, write, and present studies of the strategies of various countries. This will be augmented by case studies, reading, and guest speakers on strategies being employed in such countries as Taiwan, Thailand, and Brazil.

**MET AD 748 Commercializing Biotech And Medical Products (Unger)**
Description: Addresses special characteristics of the life science and medical fields that affect the process of turning new technologies and innovative approaches into successful useful products and services, in such areas as gene therapy, diagnostics, and pharmaceuticals, medical imaging systems and artificial hearts, computer/internet based "health care management information systems", telemedicine, and bio-informatics/ genomic research tools. Emphasizes development of skills in assessing complex markets and devising useful "business models" for cost effective commercialization and reduced time to market. Cases, readings, guest lectures, and group projects involving developing original commercialization plans and/or consulting to startup and established companies on these issues.

**ENG SC 570 Lasers (Unlu)**
Prereq: CAS PY313. Review of wave optics. Gaussian and Hermite-Gaussian optical beams. Planar-and spherical-mirror resonators. Photon streams. Absorption, spontaneous emission, and simulated emission. Laser amplification and gain saturation. Laser oscillation; pulsed lasers. Photon interactions in semiconductors. LEDs and semiconductor injection lasers. Photon detectors. Laboratory experiments: beams; divergence and collimation; electroluminescence; semiconductor injection lasers. 4 cr.

**ENG ME 555 MEMS: Fabrication and Materials (Zhang)**
Description: This course will explore the world of microelectromechanical devices and systems (MEMS). This requires an awareness of design, fabrication, and material issues involved in MEMS. The material will be covered through a combination of lectures, case studies, and individual homework assignments. The course will cover design, fabrication technologies, material properties, structural mechanics, basic sensing and actuation principles, packaging, and MEMS markets and applications. The course will emphasize MEMS fabrication and materials. Meets with ENGMS555. Students may not receive credit for both.

**ENG MN 777 Micromachined Transducers (Zhang)**
Prereq: ENG MN 555 or consent of instructor. The field of microelectromechanical devices and systems (MEMS) has been growing at an exciting pace in recent years. The interdisciplinary nature of both micromachining techniques and their applications can and does lead to exciting synergies. This course will explore the world of mostly siliconbased micromachined transducers, i.e., microsensors and microactuators. This requires an awareness of material properties, fabrication technologies, basic structural mechanics, sensing and actuation principles, circuit and system issues, packaging, calibration, and testing. The material will be covered through a combination of lectures, case studies, individual homework assignments, and design projects carried out in teams. 4 cr.

# Science and Engineering Research Symposium/Berman Award

*Monday, March 31, 2008*

The Science and Engineering Research Symposium, a yearly event at Boston University held in the George Sherman Union, is an opportunity for graduate students enrolled in a degree-granting program at Boston University to share research experiences and present their work to the larger BU community. Faculty and staff members judge the student posters and presentations and select several for awards. At the awards ceremony, all students who participated are acknowledged, and distinguished presentations receive an award and a monetary prize.

The Herbert J. Berman "Future of Light" Prize was established by the Boston University Photonics Center as one of the annual awards. The Berman Prize is intended to stimulate student interest in the rapidly growing field of Photonics - the practical application of light.

BUPC students were extraordinarily well-represented among the symposia's awardees, highlighting the central role BUPC plays in the Boston University research community. The list below highlights the Photonics Center graduate students who were award recipients this year.

***President's Award:***

High-throughput, label-free and dynamic monitoring of biomolecular interactions,
**Emre Ozkumur** (Prof. Selim Unlu)

***Provost Award:***

MEMS and Metamaterials: A Perfect Marriage at Terahertz Frequencies,
**Hu Tao** (Prof. Xin Zhang)

***Founder's Award:***

Back-end algorithm of a Biomimetic Acoustic Localizing System,
**Yirong Pu** (Prof. Allyn Hubbard)

***Office of Technology Development Award:***

Design and Fabrication of a Harsh Environment Thermal Conductivity Detector,
**Bradley Kaanta** (Prof. Xin Zhang)

***College of Engineering Dean's Award:***

Nanoscale Determination of Molecular Conformation on Layered Sufraces and Biological Applications,
**Ayca Yalcin** (Prof. Selim Ünlü)

***Center of Nanoscience and Nanobiotechnology Award:***

Mapping and decoupling distortions in polymeric periodic substrates for biological applications
**Xiaoyu Zheng** (Prof. Xin Zhang)

***Photonics Center Berman Prize:***

The MAIC: Bringing Darkness to Light
**Brian Hicks** (Prof. Supria Chakrabarti)

# Future of Light Symposium Poster Competition

The Center's second annual graduate student poster session was held as part of this year's Future of Light Symposium. Prizes were arranged by the Symposium Committee for the top ranked posters. Twelve Photonics faculty and staff members volunteered to judge the competition. The judges were divided into teams to rank the posters based on the following criteria:

a. Overall knowledge and ability to explain research
b. Quality of poster – overall presentation (visual)
c. Use of proper Photonics Center logo
d. Application of research to society
e. Discovery or uniqueness of approach
f. Knowledge of alternate methodology and how research is different
g. Overall presentation

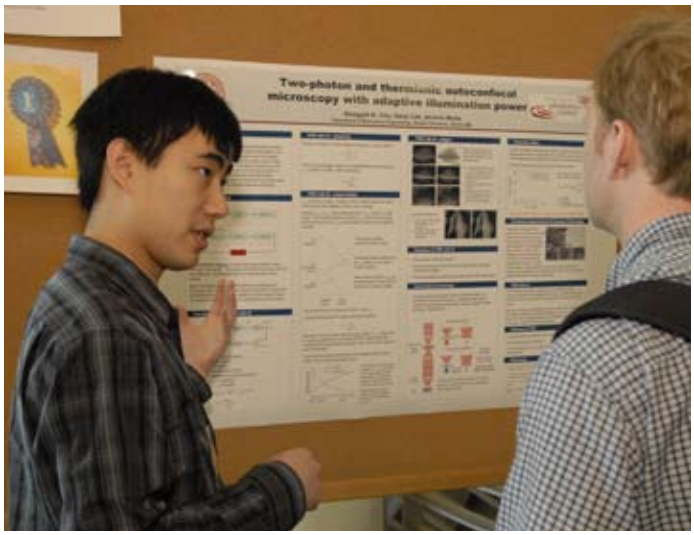
The prizes were awarded to:

*First Prize: $500*
**Kengyeh Chu** (Prof. Jerome Mertz)
"Two-photon and thermionic autoconfocal microscopy with adaptive illumination power"

*Second Prize: $300*
**Ayca Yalcin** (Prof. Selim Unlu)
"Nanoscale Determination of Molecular Conformation on Layered Surfaces"

*Third Prize: $200*
**Ashwin Gopinath** (Prof. Luca Dal Negro)
"Aperiodic SERS substrates"

*Chu accepting his first place prize from Director Dr. Thomas Bifano.*




*Chu discussing his research with a symposium attendee.*

# Bechtel Immersion Institute

Photonics faculty member Professor Bennett Goldberg led a group in the submission of a three year grant for elementary and middle school science teachers. With this program, elementary and middle school science teachers are immersed in a three-week content-based curriculum. The schools targeted are those currently in the six districts with which Boston University has programs at work at the high school level. The intent of the program is to enble teachers to:

(1) change the way they learn science and engineering themselves;
(2) implement the exploratory learning process in their classrooms and take the lead in inquiry-based professional development programs in their schools; and
(3) devote themselves to student achievement armed with a deeper understanding of the process of scientific discovery.

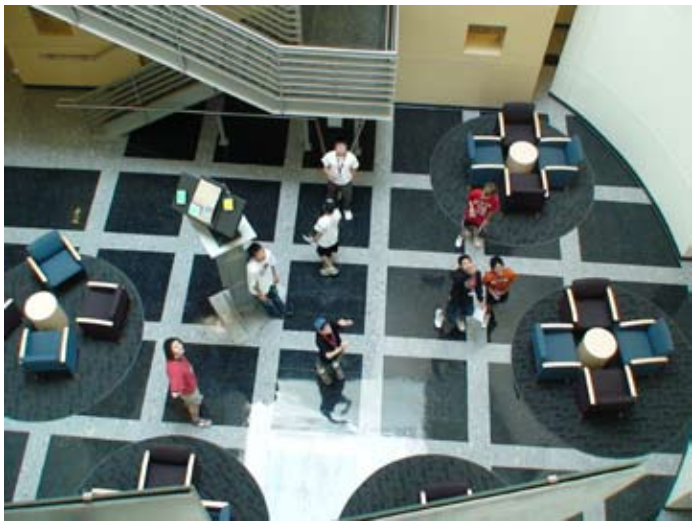
Through this program, teachers are immersed within the Boston University community, including exposure to the resources available (one example is the Scanning Electron Microscope). In conjunction with their course training, the expectation is that the teachers will begin to apply what they have learned and been engaged in during their summer course to the classroom. The teachers are encouraged to contact the technical resources through their mentor teachers in the departments of Physics and the School of Education to further the experiences of their classroom students.

# Upward Bound Math Science Grant

Ruth Shane, Director of the Boston University Boston Public Schools Collaborative Office in the School of Education and Professor Bennett Goldberg are co-principal investigators on this award from the United States Department of Education. Boston University was awarded $1.25 million over five years for this program.

The program hosts 50 high school students who are First Generation College bound students from low income families. Through this program, students gain the skills they need to succeed in college. Rising sophomores, juniors and seniors come to BU for a 7 week residency program, complete with courses, career counseling, peer and leadership training, and social and cultural activities.

The Upward Bound Math Science program is focused on math and science. This program consists of three "Science Wednesday" activities. Rising seniors participated in a nanotechnology camp and used the Curriculum Development Lab (PHO701) for experiments. In addition, students spent time with lab managers and super-users of equipment to see demonstrations of the use of a Scanning Electron Microscope (SEM) and Atomic Force Microscope (AFM). Photonics lab manager Anlee Krupp coordinated the demonstrations for the student groups.



# Facilities and Equipment

The Photonics Center's 235,000 net sq. ft. facility opened in June of 1997. Its ten floors house state-of-the-art research laboratories, laboratory support space, a business incubator, and instructional and seminar facilities specially designed for photonics research and development.

The building's structural steel frame is built on a reinforced concrete mat, as much as six feet deep, to minimize vibration. The basement level houses laboratories requiring low vibration and a light-free environment. Above-ground laboratories feature large windows, with a 1" airspace between the panes of glass to reduce the sound from the abutting Massachusetts Turnpike.

The Center has a number of shared facilities for use by Center members and affiliated partners. In addition to these shared laboratories, the Center contains four floors (100,000 sq. ft.) of academic research laboratories and office space dedicated to its faculty researchers.

The Center's sixth floor houses a business incubator that provides 23,000 sq. ft. of "greenhouse" space that can be flexibly configured to house up to 14 photonics start-up companies.

# Shared Laboratory Facilities

The Photonics Center operates three large shared laboratories. The Optoelectronic Processing Facility is a cleanroom facility that encompasses a wide range of equipment to aid in the research and processing from wafer to die level devices. The Integrated Optics Laboratory is sectioned into two main areas, a Class 100 cleanroom for bonding and sealing processes and a laboratory space for spectroscopy measurements and research. The Precision Measurement Laboratory encompasses analytical analysis of surfaces and materials with industry and research tools to enhance the research and scholarship of faculty and students.

The equipment in these labs is available for use by any faculty member or student who is trained on the equipment, or with the help of the laboratory manager. Outside industrial users of the shared labs that are sponsored by Boston University faculty members can contact the appropriate lab manager to discuss rate schedules and training for use of the equipment of interest. Multi-usage or separate lab agreements can be put into place for companies interested in using the processing, metrology, and spectroscopy capabilities.

## *Optoelectronic Processing Facility*

The Optoelectronic Processing Facility (OPF), comprising 2500 sq. ft. on the 8th floor of the Boston University Photonics Center, is a multi-user facility equipped with state-of-the-art equipment for fabricating semiconductor and other optoelectronic devices. The facility includes: both class 100 and 1000 clean rooms and equipment necessary for photolithography, wet chemical processing, thin film depositions, plasma etching and cleaning, thermal oxidation, thermal annealing, electrical characterization and device packaging.

The Class 100 cleanroom is established as a photolithography room. Last year's capital equipment committee purchased both a stand-alone Headway Research photoresist spinner with a programmable controller for spin-curves as well as a new flat top wet bench for soft bakes, developing, and photoresist stripping/wafer cleaning. This system complements the Suss Microtech Delta 80 photoresist spinner used for large wafers and mask blanks. These spinners provide students with hands-on experience running a piece of equipment commonly found in industry and research labs. The new programmable soft bake and hard bake ovens have assisted in further processing and cleanliness in OPF's Class 100 cleanroom. The photolithography room also has Suss Microtech MJB3 and MA6 exposure tools for UV exposure of photoresist using masks that are purchased from outside vendors or fabricated on the Heidelberg direct write system.

The Heidelberg direct write system has become a frequently utilized reasearch tool at Boston University. This tool allows students and professors to write their own photomasks (glass on chrome). Instead of purchasing a costly mask to try a pattern for research, researchers using this system can directly write onto a wafer or a mask with the one pattern to verify their theories. Another exceptional aspect of the direct write system is the grayscale capability. Any researchers with micro-lens arrays, specific patterns for surface roughening or blazed gratings can directly write these grayscale features into the photoresist and post process as necessary. This is an exciting field that most students are not exposed to even in industry. The ability to eliminate the need, cost, and errors from multi-layer mask designs and exposures can be explored with the grayscale capability. In one step, the errors and costs for multiple photomasks are eliminated writing directly onto one base and completing one processing step. Once completed with the spinning and exposures, students learn to develop their wafers and then can move on to the Class 1000 cleanroom to complete etching or deposition process steps.

In the Class 1000 cleanroom, a wide variety of options are available. With a Tencor surface profilometer, students learn how to measure the step height of features that they make on wafers. The capabilities and issues with stylus profilers become apparent when students can either create sharp profiles or find that the tip is too large to measure the shapes accurately. At that point, students must investigate other methods for measurement of step height and incorporate test structures in their wafers. In response to the long line of individuals waiting to use the high power microscope in OPF, this year's capital equipment committee agreed to purchase a new high power microscope to alleviate some of the demands on the one microscope available in the cleanroom. The new microscope will also have video capture to continue to improve the ability for faculty and students to make progress in their research by recording images for publications or presentations or for analysis of results.

Many processes are available in the OPF for student and faculty research. Plasma ashing, reactive ion etching and a deep reactive ion etching are all available for etching features into a substrate or thin film and cleaning a substrate prior to further processing. The STS deep reactive ion etcher is an excellent piece of equipment that few, if any, students are exposed to during their college career. It is a standard piece of equipment that many industrial users cannot accommodate in their fabrication facilities. This year's capital equipment committee recognized the need for improved safety in the use of Hydrofluoric Acid (HF) to release oxide films. Responding to the need for continuous improvement in the areas of safety, the committee agreed to purchase an HF Vapor release system that eliminates the need for liquid HF to be handled by students. This system will accommodate small pieces of wafers as well as 4 and 6 inch full wafers.

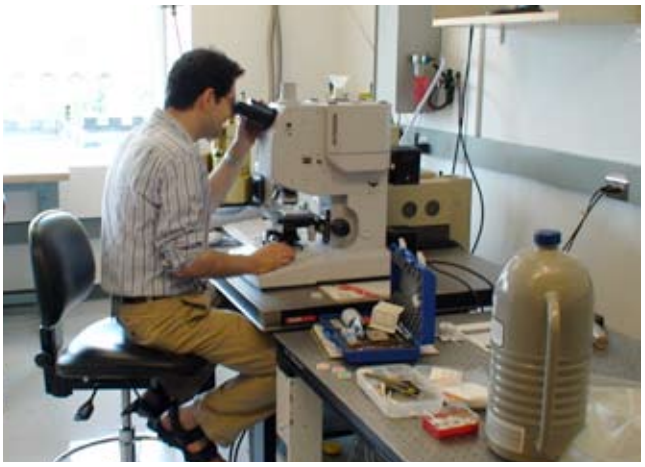
Thin film coatings are another area of processing available in the OPF. Thermal oxide furnaces, ion assisted deposition, evaporators and sputtering systems all provide students with the capability to learn various coating processes and how to measure the films deposited after processing. As requirements have been changing over the years and older equipment becomes less reliable, faculty and students provide input that is presented to the Equipment Committee. In response to the increased need for better and more uniform coatings, the purchase of a wafer system that would allow both thermal and e-beam evaporation of thin films was approved by the ARL-SEDD funding. To support this new equipment purchase and as part of this year's capital equipment committee, the Photonics Center community provided support to upgrade the thin film characterization in OPF. The equipment ultimately purchased was a J. A. Woollam Co., Inc V-VASE with AutoRetarder (angle of incidence 15 to 90 deg) Variable Angle Spectroscopic Ellipsometer with spectral range from 190-2250 nm. This is a turn-key system that will provide beneficial experience for students to learn how to use a sophisticated piece of equipment and how to analyze the results of their measurements. Once the wafer processing is complete, a dicing saw can be used to cut the wafer into smaller die and then wirebonding, wedgebonding, or testing can be completed. As part of the OPF probe station upgrades last year, high-frequency probes, a platen computer controlled lock-in amplifier, frequency generator, and impedance measurements capabilities were added. This system is currently used by many faculty members and students, allowing them to create, wire-bond and test devices in the same location.

## *Integrated Optics Laboratory*

The Integrated Optics Laboratory (IOL), comprising 400 sq. ft. of Class 100 cleanroom and 511 sq. ft. of laboratory space is located on the 5th floor of the Boston University Photonics Center. The IOL is a multi-user facility equipped with state-of-the-art equipment for bonding, testing, and spectroscopic analysis of components that were processed in the Optoelectronic Processing Facility or purchased from outside vendors as part of a research project.

In the Class 100 cleanroom, the door opens to a Miyachi Unitek benchmark lid seal machine and projection welding machine for coaxial welding of TO-Can style units. The lid seal system is commonly used in the packaging industry. An environment of dry nitrogen is infused into the gold-plated package and a welding operation fuses the metal lid to the package for hermetic sealing of the unit. A Suss Microtech FC-150, flip chip bonder is the next piece of equipment that is utilized by various researchers to seal and create eutectic bonds either through thermo-compression or soldering processes. This is a precise pick and place system that uses fiducials to aid in placement accuracy. To determine if the bonding will pass MIL-Standard testing, a DAGE die shear machine is used to die shear to failure bonded parts. A pull tester adaptor is also available to determine wire bond pull strengths and verify that they are within the specifications for the part that is bonded. An ESEC automated wire bonder is available for use and is especially helpful if repetitive bonds are required for devices. The equipment in the Class 100 cleanroom is equipment that is typically found in industry. Boston University is one of the only universities in the country to have such a unique set of equipment. The students at Boston University have the ability to learn how to use the equipment and to become more experienced workers in industry or research labs.

The Integrated Optics Laboratory includes a testing area with several spectroscopy tools. The Bruker FTIR along with

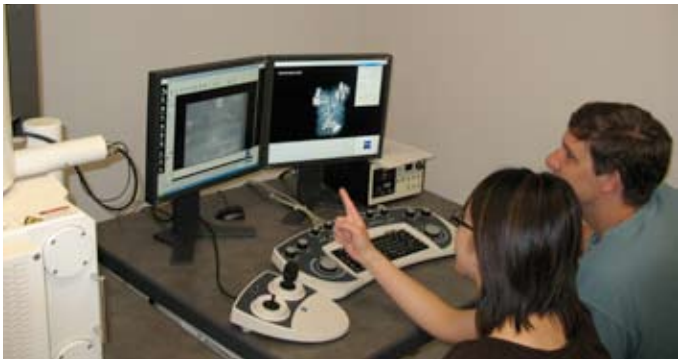


the Hyperion allows users to try various techniques to measure absorption, reflection, transmittance, and diffuse reflectance of materials to help determine what the composition is or the light penetration. An upgrade to the terahertz region with the addition of a silicon bolometer puts Boston University at the forefront of technology. Very few institutions have this technology available to students and faculty. Another former capital equipment purchase was the Varian Cary 5000 UV-VIS-NIR spectrometer. Wavelength ranges from 175 – 3300 nm and multiple accessories make this spectrometer an essential tool to multiple users and researchers in the Photonics Center and the BU Community. A large percentage of the existing testing equipment previously housed in the IOL was allotted to various faculty members in need of test and measurement equipment. As our standard policy, faculty members can request equipment. Our master list is checked, and if equipment is available at the Center under the shared equipment umbrella, the Photonics Center facilitates the exchange and sharing of equipment.

This year's capital equipment committee authorized the establishment of a fiber and fiber connector polishing area. Several pieces of equipment were in various laboratories and the faculty members graciously agreed to donate them to a centralized location for a place to find all fiber polishing needs. In response to the biophotonics community's requests, a soft lithography PDMS station was also established as part of the capital equipment purchases. Establishing this system was simplified by utilizing several pieces of equipment that were in storage. In the end, some facility upgrades and a vacuum desiccator were the only requirements for this capital equipment upgrade. This will not only benefit the Photonics community but also the nano-technology faculty as well.

## ***Precision Measurement Laboratory***

The Precision Measurement Laboratory (PML) is comprised of several laboratories located in the basement of the Photonics Center. The PML provides capabilities to measure material composition as well as surface morphology. In one of the lab spaces, a JEOL SEM is available for use to view the surface of samples. An equipment upgrade to the Oxford energy dispersive spectrometer (EDS) allows users to evaluate elemental composition, surface contaminants, and analyze samples in a variety of locations for surface composition uniformity. The JEOL was also upgraded with Gatan cathode luminescence (CL). This capability allows the detection of energy released in the visible spectrum from electrons in an atom returning to their original energy level after being excited by the bombardment of electrons from the e-beam in the SEM. From the spectrum, elements within the sample can be determined.



A larger area of the PML laboratory houses a Digital Instruments (Veeco) atomic force microscope (AFM) and a multi-mode Pico force scanning probe microscope. These two instruments allow the surface profiles in three-dimensional space to be acquired and measured. The Pico-force system allows polymers and samples in solution to be analyzed as the force is monitored, not the attraction of the tip to the sample.

The Zeiss field emission scanning electron microscope (FESEM) is a noteworthy acquisition for the university. The FESEM allows polymers and plastics to be viewed without coatings or destructive analysis, and also allows non-conductive samples to be viewed without gold coating the samples. This addition allows viewing of devices in-situ without destroying the unit with a coating. As an upgrade and in response to an overwhelming need for creation of nanostructures, the equipment committee added an e-beam upgrade to the Zeiss FESEM last year for the exclusive use of Photonics members. A chamber cleaner was installed to prevent contamination from the e-beam writing process to the imaging aspect of the SEM. Last year's addition to the Precision Measurement Laboratory is a heating and cooling stage for the ZYGO NewView 6300 with dynamic MEMs capability allowing various testing to occur on thermal effects or cantilevers and MEMS based devices. This instrument can be used to optically measure features on a sample, radius of curvature of lenses or slope of MEMs devices. With the dynamic MEMs capability, test stations can be set up to deflect or move MEMs devices and the entire sequence can be captured from the software. Surface roughness and flatness can also be measured on this system.

# Business Incubator

Located on the sixth floor of the Photonics Center building, Boston University's Business Incubator is currently fully occupied with fourteen technology start-up companies. This past year, three incubator companies successfully graduated from the incubation program and moved to commercial space off campus. Of these, two were Boston University spinout companies, Boston Microfluidics, Inc. and Biomimetic Systems, Inc. As these companies left, five new incubator companies entered the program. The companies include two new faculty spin-off companies, Zoiray, Inc. and Ninth Sense, Inc. The mix of companies includes life sciences, bio-tech, medical devices, photonics, clean energy and engineering. Currently, five of the companies originate from within BU and nine from outside of BU. All companies are engaged in the commercialization of new technologies of importance to society and support BU's educational mission to train students.

Companies in the incubator, which originate externally to BU, are held to the highest professional standards in the industry of new technology ventures. They represent the benchmark by which BU internal spin-out companies may be compared and act as exemplary living case studies for the teaching of entrepreneurship to our students. All are professionally managed by seasoned and credentialed CEO's and founders. All are professionally funded by reputable institutional investors. All have undergone external professional due diligence by their investors, and are commercializing revolutionary technologies developed at many of the region's leading research institutions, e.g. Dana-Faber Cancer Institute, Massachusetts General Hospital, Draper Laboratories, Massachusetts Institute of Technology and other universities as well as government agencies.

Total financing for all companies in the Business Incubation Program is approximately $40 million, mostly from established venture capital funds. About seventy employees work with the incubator companies on the Charles River Campus. In total, this represents a substantial concentration of entrepreneurial business activity on campus at Boston University.

In 2006, the Center began partnering students with incubator companies. Since that time, approximately forty BU students have worked directly with incubator companies as interns. The Institute of Technology Entrepreneurship and Commercialization (ITEC) in the Graduate School of Management has provided student interns through numerous entrepreneurial programs while other students have come from the College of Engineering. Two Ph.D. students have been hired full time by incubator companies.

A123 Systems, a former external incubator company, has filed paperwork with the Securities and Exchange Commission relating to the proposed initial public offering of its common stock. A123 Systems develops and manufactures advanced lithium-ion batteries and battery systems for the transportation, electric grid services and portable power markets. A123 Systems' patented Nanophosphate technology includes nanoscale materials initially developed at and exclusively licensed from the Massachusetts Institute of Technology.

| Company | External Origin | Technology | Market Sector | Funding |
|---|---|---|---|---|
| **Block MEMS** | Company Spin-Out, Block Engineering | Optical MEMS, Micro Chemical Sensors | Military, Industrial | DoD, Corporate |
| **Cyber Materials** | BU, Manufacturing Engineering | Process Control, Thin Film Deposition | Industrial Manufacturing | SBIR, Sales |
| **DNAR** | Dana-Farber Cancer Institute | BioMarkers for Cancer Diagnostics | BioTechnology Personalized Medicine | Venture Capital |
| **eQuilibrium** | Licensed IP from IT company | Software, IT | Corp. Sustainability Environmental | Angel |
| **First Founders Ltd** | MIT | Venture Mentoring Service | Not for Profit | N/A |
| **Hamlet** | Mass General Hospital | IT, Software | Medical Records, Professional Service | Venture Capital |
| **LightKey** | Company Spin-Out | Secure Communications, Optical Data Encryption | Optical Communications | Angel |
| **LumenZ** | MIT | Opto-Electronic Materials | Blue /UV LEDs | Venture Capital |
| **MTPV** | Draper Laboratories | Microgap Thermo PhotoVoltaics | Clean Energy | Angel |
| **Nano Surfaces** | Cornell University | Nano Structured Surfaces | Antifouling Coatings | Angel |
| **Ninth Sense** | BU, BME and Physics | Protein Biomarkers | Medical Diagnostics | Launch Award OTD |
| **PatientFlow Technologies** | BU, Management of Variability in Healthcare | Software, RFID | Hospital Management | Contracts, Sales |
| **Sand 9** | BU, Physics Dept. | NanoTechnology, Micro Resonators | Wireless Communications | Venture Capital |
| **Zoiray** | BU, BME and ECE Depts. | Immunoassay instrumentation | Medical diagnostics | Technology Award / Photonics Center |

# Building Projects

This year, the Photonics Center conducted a building-wide safety audit as part of our ongoing operational goal of continuous improvement. To achieve this goal, the Photonics Center community has joined forces with the Office of Environmental Health and Safety (EHS) to ensure that the building is operating safely and effectively for all researchers.

## *Safety Walk-Through*

With the help of the Office of Environmental Health and Safety, Photonics Center staff conducted its annual walk-through of the building to determine building deficiencies with regards to general laboratory safety and laser safety.

Below are some of the immediate outcomes of the safety walk-through:

- Laser Safety Electrical Upgrades: Safety upgrades included electrical interconnects for laser warning signage, lock-outs to alert occupants of the potential danger (laser light on) and EPO verification and labeling. From the walk through, it was determined that some laboratories have removed older lasers and installed new ones requiring twist lock upgrades.
- Laser Safety Roller Shades: Taking a proactive stance on laser safety, our laser safety officer Ron Slade has been working with Kentek Corporation to provide specifications for laser safety roller shades. The shades initially installed in the Photonics Center were specified as blackout shades and are typical vinyl shades often used in homes. Kentek is working with the Photonics Center and Office of Environmental Health and Safety to specify the proper shades and have them installed in the existing roller shade hardware.

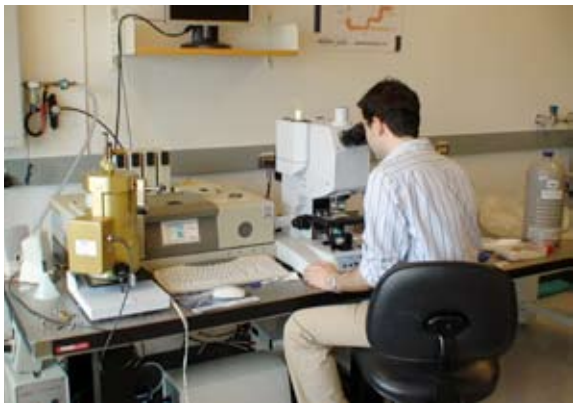
## *Photonics Center's "Go Green" Campaign*

The Photonics Center in coordination with the Electrical and Computer Engineering Department and Facilities Management launched a revitalized "Go Green" campaign. For years the Center has recycled paper and cardboard products, but in early 2008 the Center expanded it's recycling program to include aluminum, glass and plastic. This is a building-wide recycling program for all offices and departments housed in the Photonics Center. The expanded recycling program was made possible by collaboration with the Boston University Recycling Department and Save That Stuff Inc. In the 2008-2009 fiscal year, the Photonics Center plans to continue its green campaign with a focus on energy conservation.

## *Laboratory Upgrades*

***New Faculty Laser and BL2 Construction (PHO503)***:
The Photonics Center divided the existing shared laboratory space in Room 503 into three equally sized laboratories. The first space was set-up to accommodate spectroscopy, soft lithography, polishing and wet lab area (remaining as the Integrated Optics Laboratory). The second was designed as a BL2 and laser laboratory for Dr. Lee Goldstein. The final lab has been designed to accommodate Francesco Cerrina, the new chairman of the Electrical and Computer Engineering Department. He is scheduled to arrive at Boston University in August.

Integrated Optics Laboratory (shared lab): PHO503B



Prof. Goldstein: PHO503C

Prof. Cerrina: PHO503D

***Temporary Class IIIb/IV Laser Laboratory – PHO701A:***
Last year, the teaching lab's senior project laser room was retrofitted to accommodate Class IIIb and IV lasers. This year, new faculty member Lee Goldstein and his group used this room while the construction of their new lab on the 5th floor was completed. Once Dr. Goldstein moved to 503C, Richard Averitt, displaced as a result of the HVAC upgrades in the Metcalf Science building, was able to occupy the space and continue his research efforts with minimal disruption.

## ***Other Facilities Upgrades***

Ceiling Mounted Projector – PHO901: In response to faculty requests, the Center purchased a ceiling mounted projector for Room 901.

# Equipment Projects

## *Equipment Committee*

The Center was able to purchase and upgrade capital equipment critical to its research and development efforts. This year's equipment committee was formed by appointment by the Center's Director. The committee was comprised of Photonics staff (Helen Fawcett, Anlee Krupp, and Paul Mak) and chaired by a Photonics faculty member (Professor Zhang). This year we prefaced the decisions by having a brainstorming session for all Photonics Faculty members to have their voices heard. We also polled the faculty on several equipment purchases to ensure support of the majority of the faculty members.

This committee rated equipment upgrades based on the following criteria:

- The instrument will be widely usable as a shared resource in the Photonics Center to enhance the research and development programs
- The instrument will provide critical leverage for attracting additional support to the Center for research and development
- The instrument will enhance the careers and photonics-related research of junior faculty members of the Photonics Center
- The instrument will attract additional support for research and development

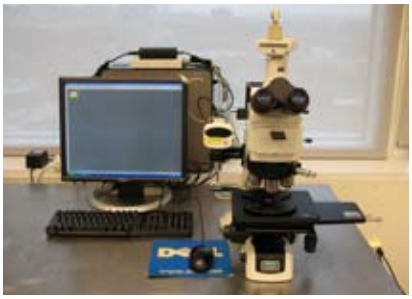
Using the previously established guidelines for identification and ranking of equipment improvements, the committee determined that the best use of capital equipment funds were to upgrade existing equipment in the shared facilities. These upgrades include:

### *Fiber Polishing Station*

In the integration of optics and light as well as in the biophotonics fields, the need for bare and connectorized fibers is relevant and having a station in a shared laboratory dedicated to this process is critical to future research and development efforts. Enlisting the assistance of several faculty, laboratory staff, and graduate students, we were able to outfit this area with a fiber polishing station, single mode and muliti-mode cleavers, connectors, cladding, and an inspection station. To complete the station, the Center provided manual polishing plates and epoxy to attach connectors to newly polished fiber.

### *PDMS – Soft Lithography Station*

Another addition to the Integrated Optics Lab is a soft lithography station. We were able to recycle some of the instruments (vacuum bake oven, plasma asher, etc.) to assist in building out this facility. It is expected that this addition will be used by many of the Photonics and BU faculty and graduate students who are directly involved in bio-related research.



***High Powered Optical Microscope***

With ever more users in the Optoelectronic Processing Facility, the line to use the high powered scope is longer than ever. In response to the suggestions of faculty and students a new high powered optical microscope will be added to OPF. The system will offer image capture and stage identification along with high power objectives.

***Hydrofluoric Acid Vapor Etch System***

In an effort for continuous improvement and safety and with overwhelming support from faculty members, the equipment committee added an HF Vapor Etching system to OPF this year. Eliminating the need for students or staff to handle liquid HF, this system is safer, will use less material and provides students with a new alternative to standard processing methodology. This system will accommodate chips, 4" wafers, and 6" wafers.

***Spectroscopic Ellipsometer***

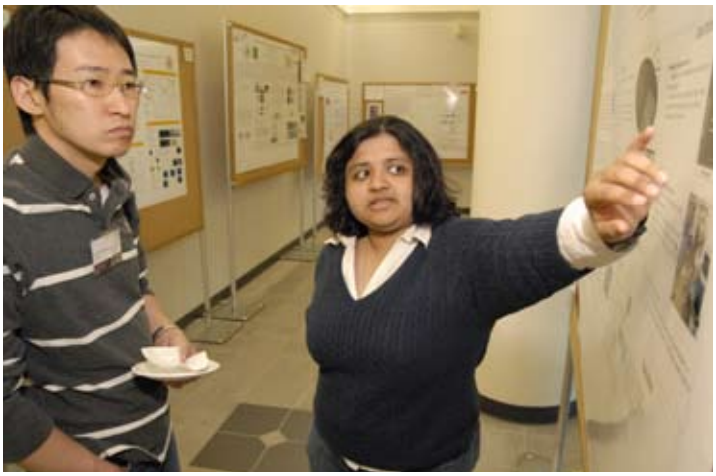
For years, OPF has housed a standard ellipsometer that rarely produced repeatable results, but the need for specific information on coatings was not a requirement of the faculty and students. As coatings become more specific and precise, an instrument to complement this is required. Again, overwhelming support by faculty and staff led to the purchase of a Variable Angle (angle of incidence 15 to 90 deg) Spectroscopic Ellipsometer with spectral range from 190-2250 nm. This is a turn-key system that will provide beneficial experience for students to learn state-of-the art surface measurements and the instrument will complement our final equipment purchase of a new evaporator.

## ***ARL Purchases***

***CHA Thermal and E-beam Evaporator***

In an effort to assist the faculty and students in their continued research efforts, the Photonics Center welcomes suggestions regarding methods to help further their existing usage of the shared laboratories. After several issues with existing equipment, it was recommended that the evaporator be upgraded or replaced. ARL funding was used to purchase an upgrade to the OPF's coating/deposition systems by procurement of a CHA thermal and e-beam evaporator. The system allows for both thermal and e-beam evaporation of thin films. The system is expected to arrive after the end of the fiscal year and is a welcome addition to the OPF lab. The existing system will be taken off-line and upgraded as a back-up system.

# Community Programs and Communications



The Photonics Center's faculty and students originate from several departments within Boston University. With this diverse community, annual programs and communications are essential aspects to furthering the Center's synergy and collaborative energy. The Photonics Center hosts a wide array of events designed to encourage collaborations between the BU academic departments and campuses.

Each year the Center opens its doors to outside academic institutions, industrial partners and to the greater BU community through symposia, seminars and the "Art is Light Challenge." These events not only increase awareness of our faculty's innovative research, but have also enouraged faculty and students to break away from their research to enjoy some time for community building.

# Community Events

This year the Center continued its bi-monthly community events: the Photonics Café and the Photonics Forum. The Photonics Café brings Photonics Center faculty, students, incubator company employees and staff together in an informal setting for conversation and collaboration. The cafés average 75 attendees and are hosted on the second Friday of each month in the seventh floor atrium.

The Photonics Forum is held on the fourth Monday of each month. The forum gives students, incubator company employees and staff the opportunity to experience a technical discussion in an open environment over lunch. The faculty and students discuss their current research endeavors and applications of their research. Like the cafés the forum series is well attended, averaging 60 attendees.

In November and January, the Photonics Center, in conjunction with the Photonics Fellowship recipients, hosted the Incubator Forum. This two-part forum gives the incubator companies an opportunity to share their business endeavors with Photonics Center Faculty and students. Students and faculty also have the opportunity to ask the incubator companies about how to start their own business, find venture capital, etc. The Forums were both well attended with nearly 70 people in each forum. All current incubator companies participated in the forums.

## *Photonics Forum Schedule*

**September**

*Presenter:* Thomas Bifano, Ph.D. - BU Photonics Center, Director
*Presentation:* MEMS Deformable Mirrors

*Presenter:* Janice Castillo - BU Photonics Center, Graduate Student
*Presentation:* Adaptive Scanning Optical Microscope

**October**

*Presenter:* Constanze Mezger, Ph.D - Ludwig-Maximilians Universitaet Muenchen, Germany
*Presentation:* Cavity Cooling of a Microlever

*Presenter:* Utku Kemiktarak - BU Photonics, Graduate Student
*Presentation:* Radio Frequency Scanning Tunneling Microscopy

**November**

*Presenter:* Francesco Bertazzi - BU Photonics Center, Graduate Student
*Presentation:* Hierarchical Simulation Methodology to Study III-Nitrides

*Presenter:* Danilo D'Orsogna - BU Photonics Center, Graduate Student
*Presentation:* Numerical Simulation of One and Two-Color Infrared Detector Arrays

**February**

*Presenter:* Roberto Reif - BU Photonics Center, Graduate Student
*Presentation:* Model of Light Reflection in Turbid Media and In Vivo Applications

*Presenter:* Kurt Schoener - BU Photonics, Graduate Student
*Presentation:* Field-induced Changes in Birefringence (FICB): A Novel Method for Tracking AP Propagation Without Contrast Agents

**March**

*Presenter:* Theodore Moustakas, Ph.D. - BU Photonics Center
*Presentation:* GaN Based Light Emitting Diodes for Solid State Lighting and UV Applications

*Presenter:* Lee Goldstein, Ph.D., M.D. - BU Photonics Center
*Presentation:* Laser-Based Non-Invasive Molecular Diagnostic Technology for Early Detection of Alzheimer's Diesase

**April**

*Presenter:* Michael Mendillo and Jeffery Baumgardner - Center for Space Physics, Boston University
*Presentation:* Imaging Science: Instrument Design and Applications to Planetary Science

# Annual Events

## *11th Annual Future of Light Symposium: Biophotonics*

This year, the 11th Annual Future of Light Symposium focused on biophotonics research and technology development. Nearly 150 people from Boston University as well as outside companies and academic institutions attended the two-day event. New this year, the symposium featured four unique short courses. The courses were led by Photonics faculty on June 16th. An active student poster session left judging teams with difficult choices for evaluation of the students' work. These events served as an introduction to the conference on June 17th.

The agenda for this year's symposium featured presentations from Photonics faculty members as well as researchers from leading photonics research institutions. The conference explored the applications of biophotonics research as well as current research endeavors.

To begin this year's conference, Dr. Andrei Ruckenstein, Boston University's Vice President and Associate Provost for Research, gave a speech highlighting past advances in photonics research conducted at the Photonics Center and Boston University. Following Dr. Ruckenstein, Dr. Karen Antman, Provost of the BU Medical Campus and Dean of the School of Medicine, introduced research at the medical school and encouraged continued connections between the BU School of Medicine and the Photonics Center. Our guest speakers included:

- Dr. Dennis Matthews - Director of CBST
- Dr. Peter So – MIT, So Labs
- Dr. Brian Wilson – Ontario Cancer Institute/University of Toronto



Nearly 30 posters were submitted to the graduate student poster competition. The poster session gives outside guests the opportunity to gain further insight into the center's education and research missions by giving students the chance to share their efforts.

Tuesday, June 17, 2008

# Future of Light Agenda

8:00 am - 9:00 am - REGISTRATION & BREAKFAST - Second Floor Atrium

***

## Session I

***Boston University's Photonics Integration with Biology and Medicine - Room 206***

9:00 am - Dr. Selim Unlu - Session Introduction
9:05 am - Dr. Andrei Ruckenstein - Photonics at Boston University
9:20 am - Dr. Karen Antman - Overview on Photonics in Medicine
9:45 am - Dr. Thomas Geisbert - Ebola and Marburg viruses: Containment, Pathogenesis and Development of Countermeasures.

***

**10:10 am - 10:30 am - BREAK - Second Floor Atrium**

***

## Session II

***Bioimaging - Room 206***

10:30 am - Dr. Irving Bigio - Session Introduction
10:35 am - Dr. Dennis Matthews - Director of CBST
11:00 am - Dr. Shyam Erramilli - Ultrafast Pump-Probe Studies of Photoactive Proteins and Membranes
11:25 am - Dr. Peter So - Advances in High Resolution, High Content Optical Biomolecular Imaging

***

**12:00 pm - 1:15 pm Lunch - Room 906**
**1:15 pm - Graduate Poster Session / Dessert and Espresso Bar**

***

## Session III

***Biophotonics Research and Integration - Room 206***

2:15 pm - Dr. Bennett Goldberg - Session Introduction
2:20 pm - Dr. Björn Reinhard - Active Nanostructures based on Plasmon Coupling: Applications in Biological Sensing and Single Molecule Biophysics.
2:45 pm - Dr. Brian Wilson - New Strategies in Photodynamic Therapy Exploiting Alternative Physics, Chemistry and Biology Pathways

***

**3:15 pm - 3:35 pm - BREAK - Second Floor Atrium**

***

## Session IV

***Biodetection - Room 206***

3:35 pm - Dr. Lawerence Ziegler - Session Introduction
3:40 pm - Dr. Lee Goldstein - Photonics Meets Alzheimer's Disease: Laser-Based Molecular Diagnostic Technology for Early Disease Detection
4:05 pm - Dr. Hatice Altug - In-vivo Cellular Response to Drug Therapy
4:30 pm - Dr. Thomas Bifano - Symposium Conclusion

***

**4:40 pm - Reception - Second Floor Atrium**

## *Laboratory Spring Cleaning Day*

This year, the Spring Cleaning and Laboratory and Laser Safety Training Day focused on eco-friendly lab practices and bio-safety training. Each year the Photonics Center partners with the Office of Environmental Health and Safety (EHS) and the Electrical and Computer Engineering Department to host this event.

This event features several training sessions open to all members in the building. As biophotonics continues to be a focus for the Center, Mike Penn of EHS organized an informational session on IBC submissions, BL2 practices and the proper departments to contact for assistance. In addition, this year the Photonics Center unveiled the "Go Green" Campaign.

The morning of the event, each lab received a recycle bin filled with cleaning supplies. Triumvirate Environmental completed satellite accumulation inspections, general chemical waste pickup and general lab "cleanliness" inspections. Kentek Corporation, the vendor of laser safety accessories and products, had a table and stayed at the event for the entire day. EHS sponsored annual lab and laser safety training sessions.

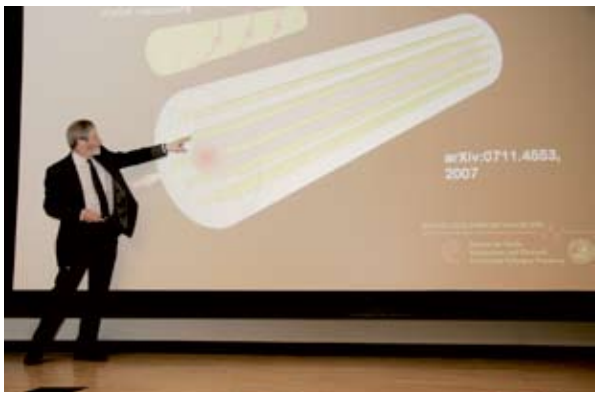
At the end of the event, awards were given to the labs that were: safest, most sparkling, most improved and most eco-friendly.

| | |
|---|---|
| **-Safest Lab** | **Quantum Optics Lab**<br>*Pricipal Investigator:* Professor Teich |
| **-Most Improved Lab** | **Optomechical Processing Facility**<br>*Principal Investigator:* Paul Mak |
| **-Most Sparkling Lab** | **Lightware Technology Laboratory**<br>*Priciple Investigator:* Professor Morse |
| **-Most Eco-friendly Lab** | **Optical Characterization and Nanophotonics Laboratory**<br>*Principle Investigator:* Professor Ünlü |

# Lectures and Seminars

## *Distinguished Lecturer Series*

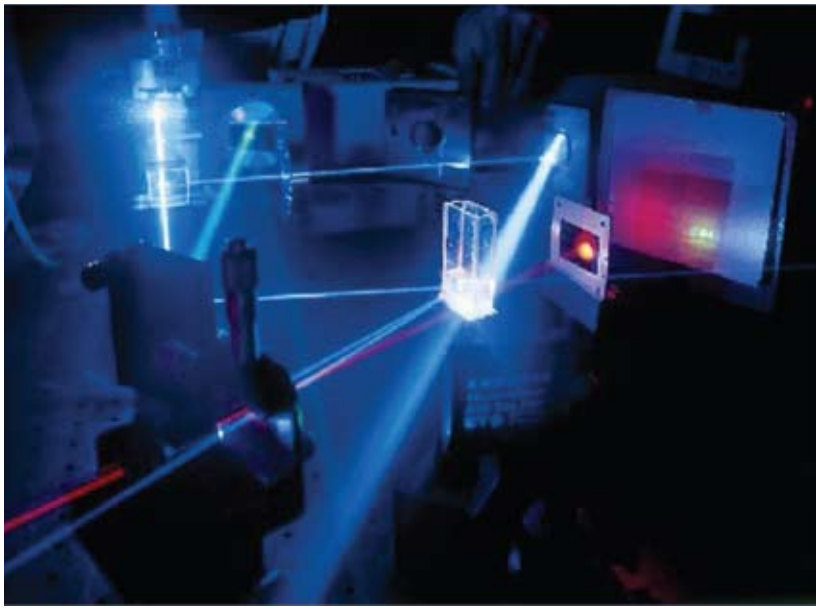
On December 6th, the Photonics Center hosted its first distinguished lecturer, Dr. Philip Russell. Dr. Russell discussed photonics crystal fibers in a lecture entitled: "Glass Cages for Catching Light". The lecture was followed by a reception for all who attended his lecture. After the reception, Dr. Russell met with small groups of Photonics faculty members with similar research interests. Graduate students enjoyed an afternoon tea, hosted by Center Director Thomas Bifano, where they could meet with Dr. Russell.




Dr. Russell is the Director for the Institute of Optics, Information and Photonics at the University of Erlangen-Nuremberg. The Distinguished Lecturer Series is organized by the Distinguished Lecturer Committee, chaired by Malvin Teich.

## *Photonics Seminars*

On January 29th Dr. Michael Wraback, Team Leader for Nitride Semiconductor Optoelectronics at Army Research Laboratory, led a Photonics Seminar on military needs in the area of nitrides. Nearly 50 people attended the seminar entitled, "Nitride Semiconductor Optoelectronics Research at Army Research Laboratory for Defense and Security Applications." In this seminar, Dr. Wraback discussed several optoelectronic devices covering the electromagnetic spectrum from terahertz to the ultraviolet along with their various applications.



On June 9th, Dr. Lorenzo Pavesi, Professor of Experimental Physics at the University of Trento, Italy, led the second seminar of the year. Over 60 people attended this seminar entitled, "Silicon Photonics: Challenges and Futures." In this seminar Dr. Pavesi discussed several silicon photonics devices and the advancement of new nanosilicon device development. Dr. Pavesi also discussed the technological and commercial challenges for implementing silicon photonics in the computing and semiconductor industries. Dr. Pavesi met with several faculty members during the day with a focused agenda to facilitate a graduate student exchange between Boston University and the University of Trento.

# Art is Light Design Challenge

Since the opening of the Boston University Photonics Center in June 1997, an annual competition sponsored by the Center has enriched the building with unique art installations. This competition gives students from the Boston University School of Fine Arts (SFA) a platform to permanently display their work. This challenge encourages SFA students to collaborate with students from the Photonics Center and the College of Engineering to create unique site-specific pieces of art. This year, the winner of the challenge was Jun Gao. Gao is a graduate of Boston University with an Masters in Fine Arts in Art Education.

A pinhole camera, designed and developed by Gao, was used to produce this photograph. The camera was placed in the West End Lounge of the Photonics Center where it remained untouched from April 5 through April 26, 2007. This long-term exposure gives the experience of the passage of time in an unfamiliar and poetic way. The white stripes show the movement of the sun through a unique representation. White voids indicate the weather during this period of time.

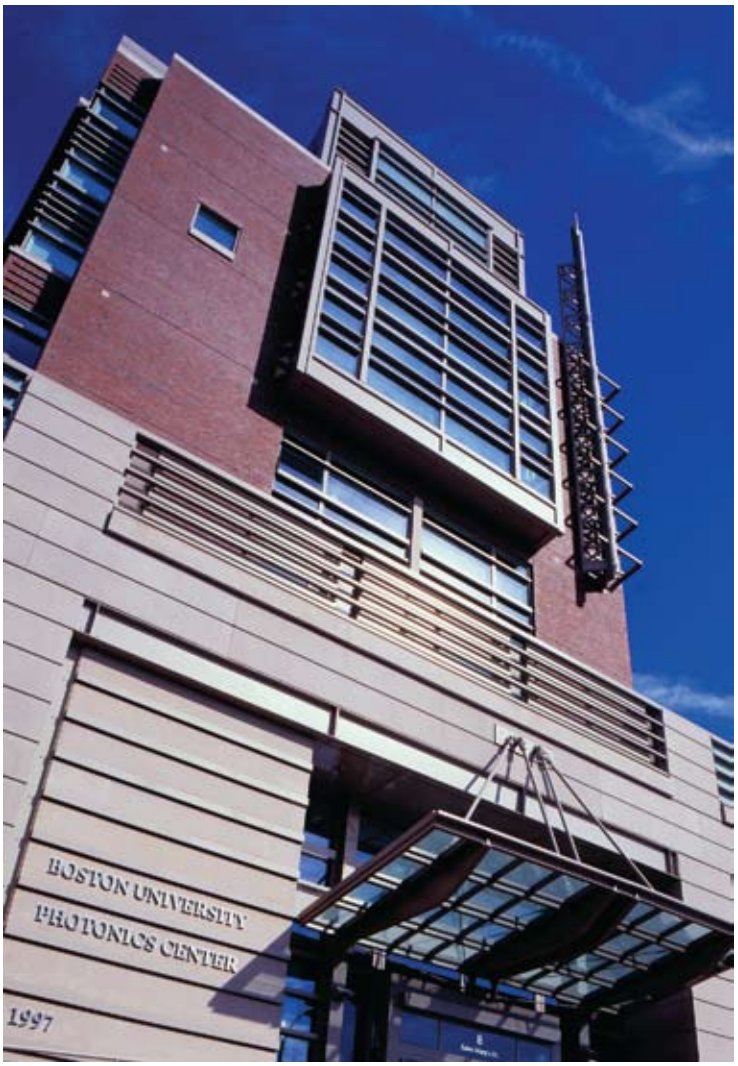
This photograph highlights the laser in use sign found within many research laboratories at the Photonics Center, and the vibrant lights of the BU campus on a single image. The colorful combination of the dynamic lights and the laser in use sign represents the fusion of science and art.

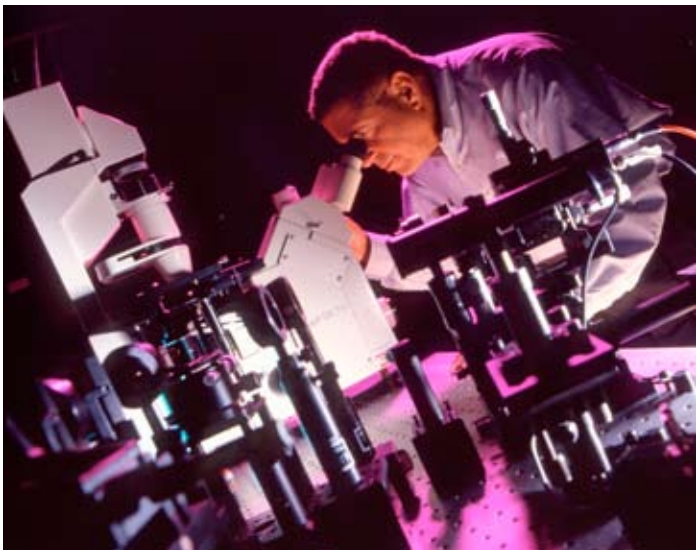
Jun Gao currently teaches in Massachusetts and his other works can be seen on display at the Hasbro Children's Hospital in Providence Rhode Island.

# Outside Company and Academic Interests

## *New England Society of Manufacturing Engineering, April 2008*

One example of the collaborative synergy the Photonics Center is our collaboration and communication with the Fraunhofer Center for Manufacturing Innovation. This year's New England Society of Manufacturing Engineers held its annual conference in Boston. After requesting a possible tour at Boston University, Fraunhofer contacted the Center to request collaborative tours of both facilities to highlight micro and nano fabrication. The Society's conference on micromanufacturing and nanomanufacturing highlighted this tour as a part of their program. Laboratory Managers Paul Mak and Anlee Krupp led informative tours of the facilities at the Center for micro and nano fabrication in the OPF and PML. This was a great opportunity for the facilities at the Photonics Center to be viewed and evaluated by a large audience that included industry, academic, and national laboratories.



## Thank you for your interest in the Boston University Photonics Center!

*For more information about the Center or its programs please contact:*

**Mailing Address:** 8 Saint Mary's Street
Suite 936
Boston, MA 02115

**Telephone:** 617.353.8899

**Website:** www.bu.edu/photonics