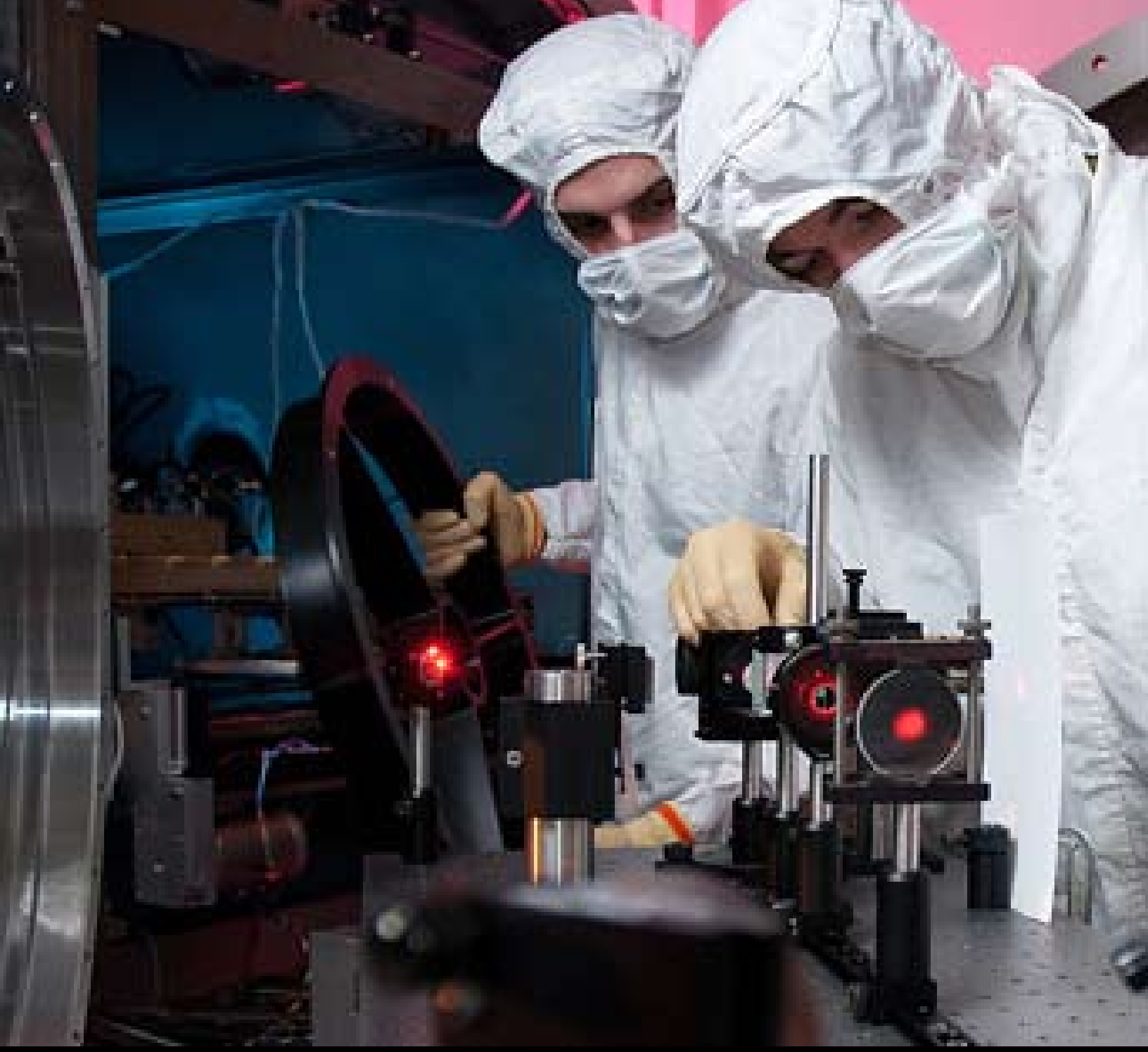

The Boston University photonics center

Annual Report 2009 - 2010

annual report 2009 - 2010

Letter from the Director

letter from the director

This annual report is intended to serve as a synopsis of the Boston University Photonics Center's activities for the period from July 2009 through June 2010. In it, you will find quantitative and descriptive information regarding our photonics educational programs, our interdisciplinary research efforts, our photonics business incubator, and our cooperative program with the US Department of Defense to develop innovative prototypes that serve critical military needs. It is my hope that the document conveys our complementary missions in education, research, innovation, and technology development. The first two reflect our core values in scholarship, while the latter two reflect our commitment to work on problems that are important to society.

Now entering my fifth year as director, I am delighted to report the bottom line: BUPC has become a premier national asset for advancing science and technology in the interdisciplinary field of photonics. Its thirty-eight faculty from departments in engineering, science, and medicine lead pioneering research efforts on critical problems in defense, medicine, and industry. Photonics Center researchers have made fundamental discoveries and developed unprecedented technology in diverse application domains that range from solid-state lighting, adaptive optics, and laser-based pathogen detection, to terahertz imaging systems, quantum communication, and plasmonic biosensing.

An exciting new facet of the Photonics Center's research program that coalesced in the past year centers on neurophotonics, the use of light to understand and interact with brain tissue. BUPC research teams are now using advanced imaging techniques to understand the molecular basis of neurological disease and traumatic brain injury. They are at the forefront of an emerging revolution in optogenetics, the use of light to inhibit, stimulate, control, and repair neural circuitry. They have also begun to use photonic tools to advance medical treatments and core scientific understanding of brain function at cellular and molecular scales. We expect to see this program expand in coming years.

Another compelling new program launched this year is our Industry/University Collaborative Research Center (I/UCRC). Sponsored by the National Science Foundation and led by BU, this program aims to address commercially relevant research and technology development in the area of biophotonic sensors and systems. Joining us in this effort are colleagues from the University of California at Davis, and a founding membership group comprised of seven industry partners. The I/UCRC is part of a broad new initiative to increase Photonics Center engagements with industry, complementing our already well-developed programs in support of defense and government needs.

The good news I report here on behalf of the Photonics Center is tempered by one profound note of sadness. This year our community lost one of its brightest lights when Professor Franco Cerrina passed away unexpectedly. Franco was Chair of the Electrical and Computer Engineering Department, and a senior Photonics Center member. He inspired us with his personal warmth, his profound intellect, his copious achievements, and his boundless imagination. I am grateful to have known him, and will sorely miss his thoughtful advice and guidance.

On behalf of the Photonics Center's diverse and talented collection of faculty, staff, and students, I thank you for your interest in our annual report, and welcome your feedback.

Dr. Thomas Bifano
Director, Boston University Photonics Center

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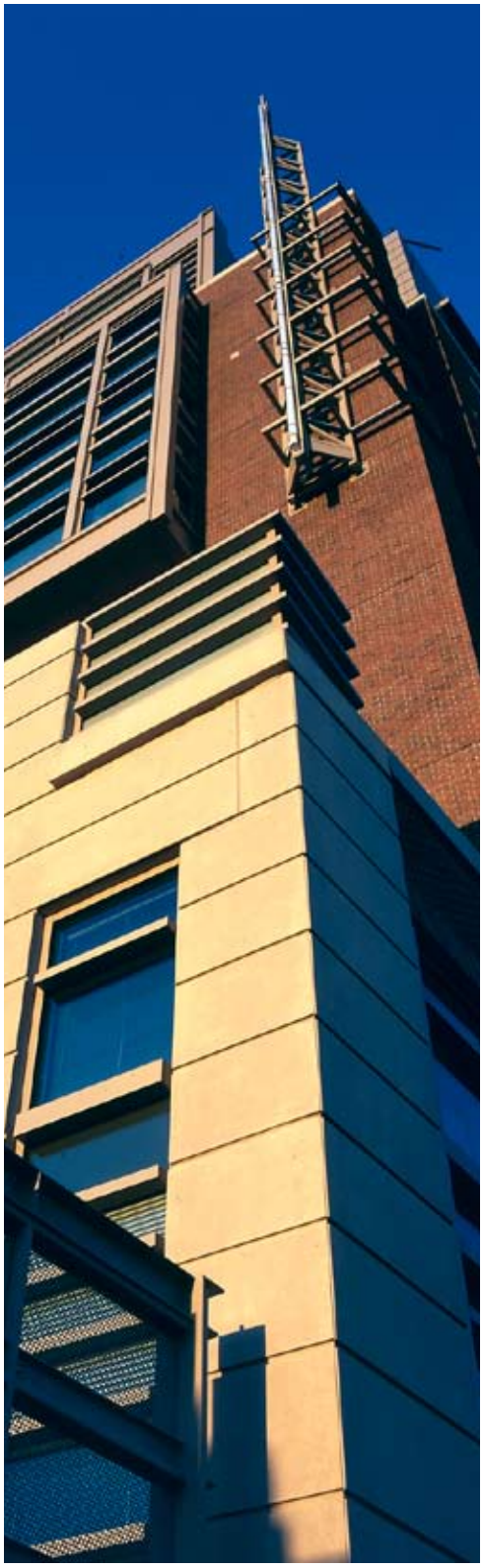
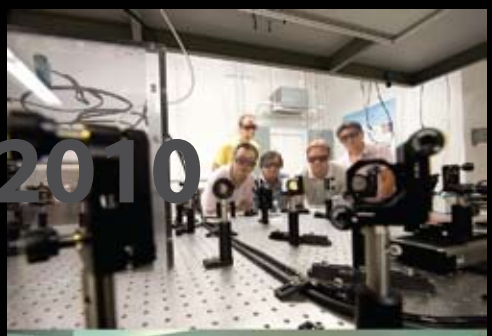
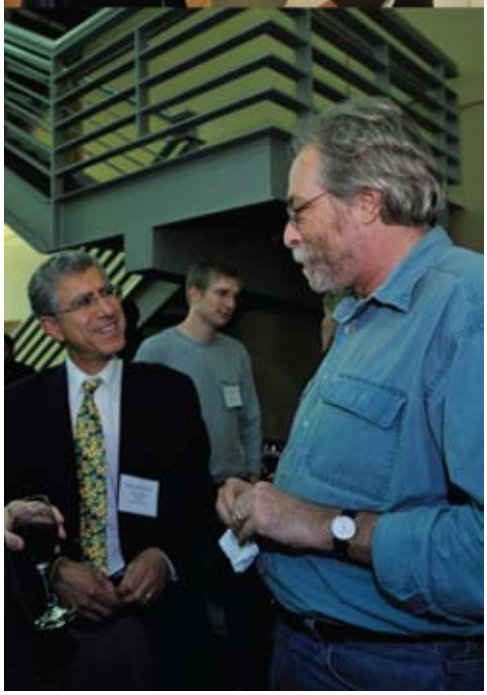


Summary FY 2009 - 2010

summary fy 2009 - 2010





This report summarizes activities of the Boston University Photonics Center (BUPC) during the period July 2009 through June 2010. These activities span the Center's complementary missions in education, research, technology development, and commercialization.

In education, twenty-three BUPC graduate students received Ph.D. diplomas. BUPC faculty taught thirty-one photonics courses. Five graduate students were funded through the Photonics Fellowship Program. BUPC supported a Research Experiences for Undergraduates (REU) site in Photonics, which hosted summer interns in a ten-week program. Each REU student presented their research results to a panel of faculty and graduate students. Professors Goldberg and Swan continued their work with K-12 student outreach programs. Professor Goldberg's Boston Urban Fellows Project started its sixth year. Professor Swan's collaborative Four Schools for Women in Engineering program entered its third year. For more on our education programs, turn to the Education section on page 67.

In research, BUPC faculty published journal papers spanning the field of photonics. Twelve patents were awarded to faculty this year for new innovations in the field. A number of awards for outstanding achievement in education and research were presented to BUPC faculty members. These honors include NSF CAREER Awards for Professors Altug, Dal Negro and Reinhard. New external grant funding for the 2009-2010 fiscal year totaled $21.1M, including $4.0M through a Cooperative Agreement with the U.S. Army Research Laboratory (ARL). For more information on our research activities, turn to the Research section on page 24.

In technology development, the Department of Defense (DoD) continued to support the COBRA prototype systems. These photonics-technologies were pioneered by BUPC faculty and staff and have been deployed for field test and use at the United States Army Medical Research Institute for Infectious Diseases. New technology development projects for nuclear weapon detection,

biodosimetry and terahertz imaging were launched and previously developed technologies for bacterial and viral sensing advanced toward commercial transition. For more information on our technology development pipeline and projects, turn to the Technology Development section on page 54.

In commercialization, the business incubator continues to operate at capacity. Its tenants include more than a dozen technology companies with core business interests primarily in photonics and life sciences. It houses several companies founded by current and former BU faculty and students and provides students with an opportunity to assist, observe, and learn from start-up companies. For more information about business incubator activities, turn to the Business Incubation chapter in the Facilities and Equipment section on page 84.

In early 2010, the BUPC unveiled a five-year strategic plan as part of the University's comprehensive review of centers and institutes. The BUPC strategic plan will enhance the Center's position as an international leader in photonics research. For more information about the strategic plan, turn to the BUPC Strategic Plan section on page 8.

Highlights for FY 2009 - 2010

External Grant Funding for the 2009-2010 Fiscal Year: $21.1M

Included in this figure is more than $17.1M in grant and contract support awarded directly to one or more of BUPC's 38 core faculty members for fundamental photonics research and $4.0M through a Cooperative Agreement with the U.S. Army Research Laboratory for photonics technology research and development in areas of critical national need.

Seven New Photonics Center Faculty Members

This year, the Photonics Center welcomed Professors John Connor (MED), Helen Fawcett (ME), Christopher Gabel (MED), Ajay Joshi (ECE), Catherine Klapperich (ME), Siddharth Ramachandran (ECE) and Jason Ritt (BME) to the community. The new faculty members are aligned with the Center's continuing and new thrusts in the biophotonics and neurophotonics arenas.

Biophotonics Research Thrust Strengthens Bridge Between the Charles River and Medical Campuses

Several new collaborative research projects were launched across the Charles River and Medical Campuses by BUPC faculty, including: Elastic Scattering Spectroscopy: Clinical Application to Thyroid Cancer with Professors Bigio and Rosen; Resonant Optical Virus Reader with Professors Altug and Connor; Novel CCD-Based Widefield Sectioning Endomicroscope with Professors Mertz and Singh; and Clinical Utility of a Lab-on-a-Chip Diagnostic with Professors Klapperich and Odell. Many of these exciting new collaborative efforts were supported or led jointly with the Center for Nanoscience and Nanobiotechnology.

Pipeline Development Projects Transitioned to Commercial Partners for Defense, Security and Healthcare Applications

Three Faculty Technology Development Award (FTDA) projects exited the BUPC Prototype Development Pipeline. These devices were developed under the Compact Optical Biothreat Rapid Analysis (COBRA) program and are focused on healthcare applications in addition to defense and security. The projects exiting the pipeline this year include: Portable Raman Microscope with Surface Enhanced Raman Spectroscopy Technology (SERS), Spectral Reflectance Imaging Biosensor (SRIB) and Portable IR Laser

Bio-Dosimetry Radiation Scanner (RADSCAN). The SRIB prototype has been successfully transitioned to a BU spinout company, Zoiray Technologies Inc., for commercialization and insertion. The SERS prototype has been delivered to USAMRIID for testing and evaluation. RADSCAN has been transferred to several defense related laboratories for evaluation.

Two Companies Graduate from the Business Incubator

PatientFlow Technology, Inc. and Sand 9, Inc. graduated from the Business Incubator. Sand 9, a BU spin-out company, recently received $12M in funding for further development of their GPS and mobile wireless technologies. The core businesses of the current group of incubator companies includes: life sciences, biotechnology, medical devices, photonics, clean energy and engineering. Several incubator companies have hired Photonics Center graduate students and continue to work with students from the BU School of Management as part of the University's internship program.

The 13th Annual Future of Light Symposium

Professor Irving Bigio chaired this year's Symposium highlighting the Photonics Center's thrust in Biophotonic Sensors and Systems. The symposium provided a perspective into point of care diagnostics research and development within the University and with outside collaborators.

Congressman Michael Capuano Visits the Photonics Center

Congressman Michael Capuano visited the Photonics Center on April 30, 2010. President Robert Brown, Vice President of Government & Community Affairs Edward King, and Center Director Thomas Bifano toured the facility with the Congressman. The tour included demonstrations of Professor Ahlen's Neutron Detector and Professor Ziegler's COBRA prototype. In addition, Professor Hubbard, and representatives of Biomimetic Systems, Inc., demonstrated the RedOwl sniper detection system and related soldier wearable technologies.

BUPC Unveils Strategic Plan For The University's Comprehensive Review of Centers and Institutes

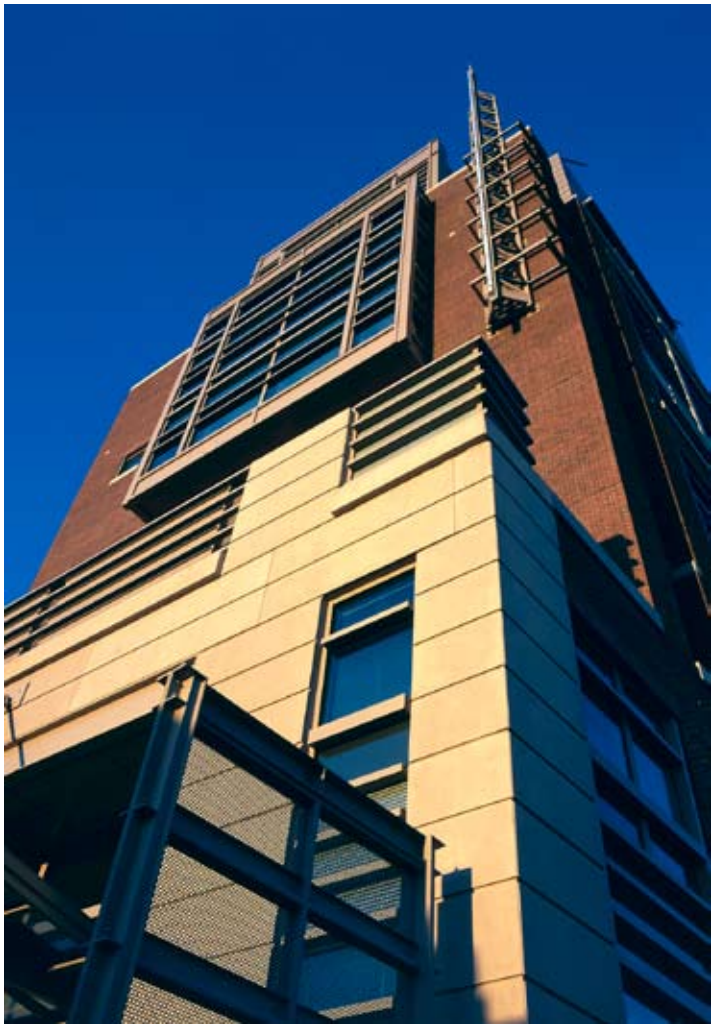
BUPC unveiled a five-year strategic plan in January, 2010 as part of the University's comprehensive review of centers and institutes. In May, 2010, we hosted the Photonics Center review meeting, coordinated by Vice President for Research Andrei Ruckenstein. The review committee was comprised of Andre Ruckenstein, Associate Deans Scott Whitaker and Selim Unlu, MIT Professor Lionel Kimerling and BU department chairs, Ronald Roy and Claudio Rebbi. The committee's feedback indicated strong support for BUPC's strategic plan.

Photonics Center at a Glance

Faculty Members	38
Students Funded by BUPC- ARL Cooperative Research Grant	18
Staff Members	12
Funded R&D Projects	107
Funding for R&D (New funds for current year)	$21.1M
Graduate Courses taught by Photonics Faculty Members	31
Publications in Archival Journals	180
Shared Laboratory Facilities	3
Photonics Center Square Footage	235,000
Incubator Square Footage	23,000
Year of Building Opening	1997

Mission

The Boston University Photonics Center generates fundamental knowledge and develops innovative technology in the field of photonics. We work on challenging problems that are important to society, we translate enabling research discoveries into useful prototypes, and we 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, security, and healthcare applications
- Business incubation and commercialization of photonics technology

The BUPC community of faculty, students, and staff engage in numerous interdisciplinary collaborations to further the field. Below are examples of how the Photonics Center and its diverse community execute our four-pillar mission.

Basic Research and Scholarship in Photonics

Rapid detection and diagnosis of biothreats has emerged as an area of national importance for the U.S. Department of Defense. In support of this work, the Center has continued its thrust into biophotonics research. Several collaborations between Photonics Center and BU Medical Campus faculty have formed in the past year. One such collaboration is between Professor Hatice Altug (ECE) and Professor John Connor (MED) on their Portable Biosensors for Virus Detection project. This project is supported by a Faculty Technology Development Award (FTDA) and has entered the development pipeline. This collaboration has given both researchers the opportunity to identify a variety of viral samples in a laboratory setting. More details on this FTDA program and other development programs can be found in the Research and Technology Development sections.

Neurophotonics research is another area of strategic importance to the Photonics Center. This year, Center faculty members and collaborators submitted several proposals for research awards. These proposals focus on traumatic brain injury, post traumatic stress disorder, and a variety of diagnostics and therapeutic technologies. Several newly appointed faculty members to the Center align with photonics based neurology research.

Academic and Entrepreneurial Programs and Initiatives for Students

Three students participated in the 2009 Research Experience for Undergraduates (REU) Program in Photonics. This program, in its final year of funding through the NSF, gives undergraduate students the opportunity to engage in hands-on research with Photonics Center professors. Led by Professors Ruane and Swan, this program gives participants experience in completing an individual research project that directly impacts the research activities in their assigned laboratory. At the end of the ten-week program, the REU students present their research to a panel of faculty and graduate students. Students involved in this program work on applicable topics in the lab and learn to use shared laboratory equipment. The REU Program in Photonics is funded through the NSF, with contributions from the College of Engineering and the Photonics Center. More information about the REU in Photonics as well as other educational initiatives can be found in the Education section.

Technology Development for Defense, Security, and Healthcare Applications

As COBRA prototype systems exit the pipeline, several new projects focused on a variety of healthcare and homeland security applications have entered. The Chemically Enhanced Photonic-Plasmonic Crystals for Explosive Vapor Detection (Photonic Sniffer) is one such project. The Photonic Sniffer project is led by Professor Bjoern Reinhard and includes collaborations with Professor Luca Dal Negro's plasmonics group. The goal of the project is to develop a lightweight "photonic nose" capable of detecting traces of explosive vapor. The device uses a two-dimensional array of gold nanoparticles that support photonic-plasmonic resonances with extremely narrow line shapes in extinction and scattering. More information about the Photonic Sniffer and our other prototype development projects can be found in our Technology Development section.

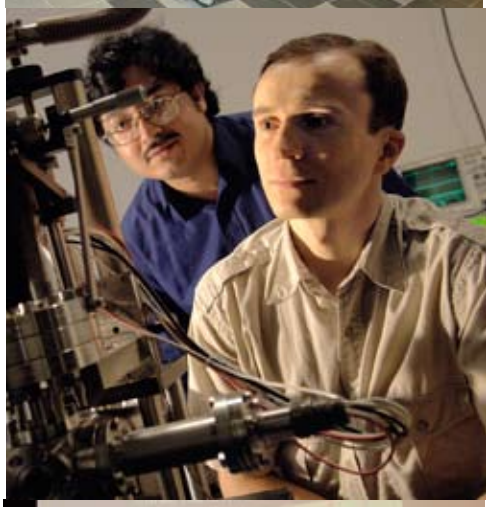
Business Incubation and Commercialization of Photonics Technology

Zoiray Technologies, Inc., led by Dr. David Bergstein, a former BU post-doctoral fellow, continued its efforts in viral antibody detection. This BU spin-off company is based upon the research and technology developed in Professor Selim Unlu's laboratory. The technology features on-board, efficient processing for multiplexed, label-free virus detection and diagnosis of serum from a symptomatic patient. The technology developed by Professor Unlu and Zoiray is one of the technology transition projects exiting this year from the BUPC Prototype Development Pipeline. This technology has been further refined with collaboration from Professor John Connor (MED) and Dr. Thomas Geisbert.

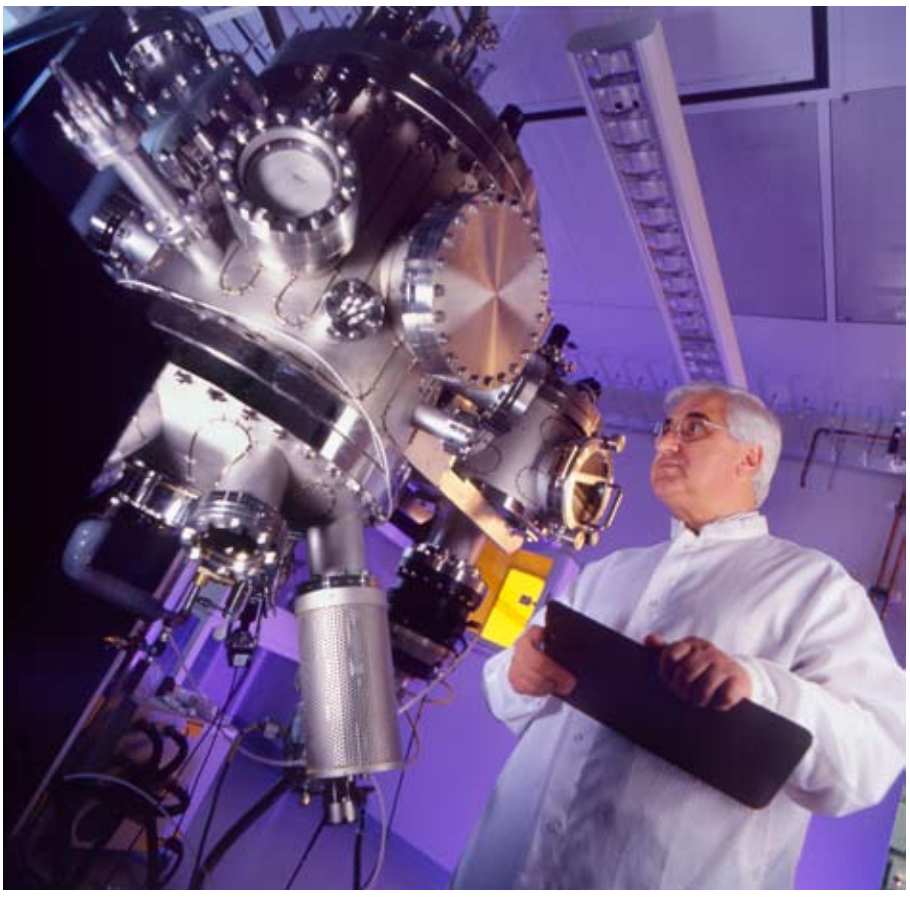
Sand 9, a BU spinout company founded in part by Professor Pritiraj Mohanty (PHY), graduated from the business incubator this year. Sand 9 has since received $12M is funding from Commonwealth Capital Ventures to further develop technologies for GPS and mobile wireless devices. The company recently relocated to Kendall Square in Cambridge, Massachusetts.

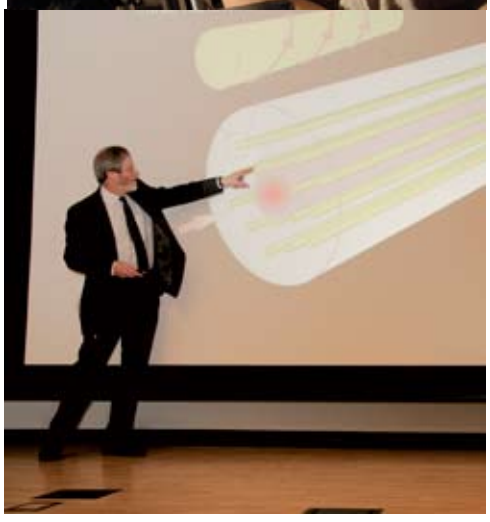
BUPC Strategic Plan

BUPC strategic plan



In the Spring of 2010, the University began a comprehensive review of centers and institutes on the Charles River Campus. To prepare for this review, the BUPC drafted a five-year strategic plan for the Center. This plan will help the Center remain a leader in photonics research and technology transfer while expanding its four pillar mission. In this section, you will find highlights from our strategic plan.





BUPC Strategic Plan

The Photonics Center strategic plan was developed with input from constituencies that included: our core faculty, staff and students; our Academic Advisory Board comprised of the Chairs of our cognate departments; our Scientific Advisory Board comprised of Directors of optics and/or photonics centers at other institutions; and the Vice President for Research at Boston University. Below are the nine major strategic goals for the Center:

- Become an Institute. We define an institute to be an officially-chartered, permanent fixture of the University's research mission that is recognized as a premier national resource for interdisciplinary scholarship and education, and that offers the community support for space, facilities and technical support in an area of sustained national need.

- Achieve a consistent level of funding totaling approximately twenty million dollars annually, spread between faculty grants, Army Research Laboratory Cooperative Research Agreement, the Industry/University Cooperative Research Center program and other Center-based grants. BUPC staff will increase their fractional effort and participation in grant and large proposal preparation. This will help BUPC secure a major competitive research center grant by 2014.

- Build an educational program around the photonics theme. BUPC will expand the influence of its MS in Photonics degree program and will encourage entrepreneurial education. Furthermore, BUPC will develop an undergraduate course suitable for all engineering students to enhance the BU Engineering curriculum.

- Strengthen and expand connections with domestic and international partners to enhance BUPC's impact as a world leader in biophotonics, nanophotonics for medical applications and photonics biosensing.

- Reconnect the business incubator with its programs and missions. The student connection to the incubator companies, focusing on science, engineering and entrepreneurship will be expanded. BUPC will take an active role in the selection of incubator companies and will ensure support for industrially relevant academic programs.

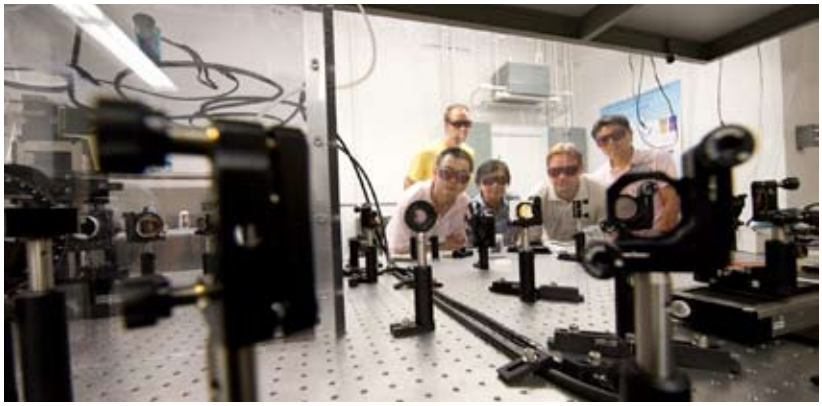
- Support the creation and success of topical centers of excellence within the BUPC institute. This could include collaborative support for programs in existing research centers, such as the NSF Smart Lighting Engineering Research Center and the Center for Nanoscience and Nanobiotechnology, or it could include support for entirely new activities, such as a new center for neurophotonics research to support emerging needs in defense and health care.

- Continue to pursue research in the biophotonics area. The BUPC will work to pursue other federally funded sources on this topic, engage the Center for Integration of Medicine and Innovative Technologies at Massachusetts General Hospital for technology transition opportunities and offer a cross department certificate program in biophotonics for students engaged in biopohotonic research.

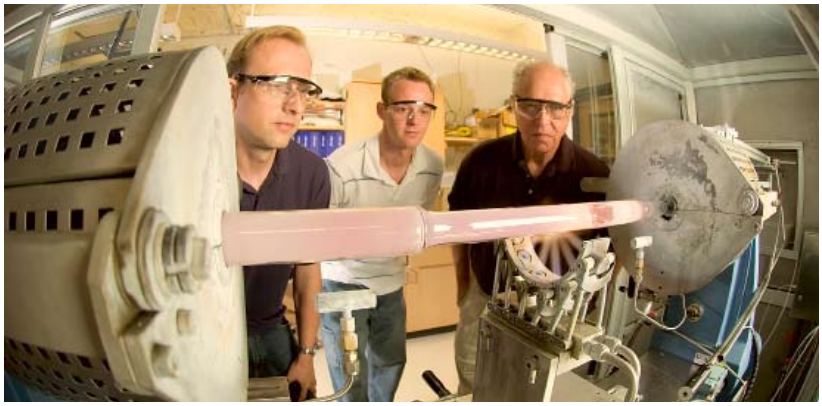
- Pursue high value, multi-investigator grants in the areas of terahertz devices, quantum communications, energy conservation and adaptive optics for space or ground surveillance. These grants will be leveraged by support from the staff in proposal preparation and networking with government, academic and industrial partners.

- Expand successful technology transfer process beyond Department of Defense applications. The Center will emphasize the recruitment of photonics related companies to the business incubator and become more proactive in licensing photonics technologies.

Faculty and Staff
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 collaboration. 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, industrial partners and U. S. Department of Defense partners.



New Faculty Members

Professor John Connor

Dr. John H. Connor is an Assistant Professor of Microbiology at the BU School of Medicine. He is also a faculty member of the Immunology Training Program within the BU School of Medicine. Dr. Connor earned his B.A. from Swarthmore College and his Ph.D. in Pharmacology from Duke University. Dr. Connor was awarded a Peter Paul Career Development Professorship in 2007. Dr. Connor's research interests include protein synthesis for virus replication and using the vesicular stomatitis virus as a means to target hypoxic tumor cells for destruction.

Professor Helen Fawcett

Dr. Helen Fawcett is a Research Assistant Professor in the College of Engineering, Mechanical Engineering Department. Professor Fawcett earned her B.S. and Ph.D. in Mechanical Engineering at Boston University. In her professional career, Dr. Fawcett has worked for several start up compaies including: MicroE Systems, Axsun Technologies and EM4, Inc. Currently, Dr. Fawcett is an Operations and Technical Program Manager at the Photonics Center, where she oversees operations and laboratory design. Dr Fawcett has been the Technical Program Manager for many of the ARL Pipeline programs at the Photonics Center. Her main areas of focus are: biosensing, nano-scale structures, and prototype development.

Professor Christopher Gabel

Dr. Christopher Gabel is an Assistant Professor in the Department of Physiology and Biophysics at the BU School of Medicine. Professor Gabel received his B.A. in Physics from Princeton University and his Ph.D. in Physics from Harvard University. Before joining BU, Dr. Gabel was a Postdoctoral Fellow at Harvard University. His current research program is focused on the study of neural regeneration through the application of femtosecond laser surgery and optical neurophysiology.

Professor Ajay Joshi

Dr. Ajay Joshi is an Assistant Professor in the Electrical and Computer Engineering Department. Professor Joshi received his B.S. in Engineering from the University of Mumbai and his M.S. and Ph.D. in Electrical and Computer Engineering from Georgia Institute of Technology. Before joining BU, Dr. Joshi worked as a postdoctoral researcher in the EECS department at MIT as part of the Integrated Systems Group. Dr. Joshi also interned with Intel, where he was part of the system validation team in the Post-Silicon Validation Department for the IA-64 processor family. His research interests include: interconnect modeling, networking-chip design, high-speed low-power digital design, and physical design.

Professor Catherine Klapperich

Dr. Catherine Klapperich joined the faculty of the Boston University College of Engineering in 2003. She earned her B.S. in Materials Science and Engineering at Northwestern, her M.S. in Engineering from Harvard University and her Ph.D. in Mechanical Engineering from the University of California, Berkeley. She is the director of the Biomedical Microdevices and Microenvironments Laboratory in the Departments of Biomedical and Mechanical Engineering. Before coming to Boston, Dr. Klapperich was a Visiting Postdoctoral Fellow at Lawrence Berkeley Laboratory in the lab of Dr. Carolyn Bertozzi, and was a Senior Research Scientist at Aclara Biosciences in Mountain View, CA. Dr. Klapperich's research is focused on engineering disposable microfluidic diagnostic devices that incorporate on-board sample preparation.

Professor Siddharth Ramachandran

Dr. Siddharth Ramachandran, a noted scholar in the field of photonics, joined the Electrical and Computer Engineering Department as an Associate Professor with tenure. Dr. Ramachandran obtained his Ph.D. in Electrical Engineering from the University of Illinois, Urbana, in 1998. His graduate work focused on spectroscopic investigations of rare-earth doped chalcogenide glasses. In November, 1998, he joined Bell Laboratories, Lucent Technologies, as a member of the technical staff and subsequently continued with its spin-off, OFS Laboratories. In March 2003, he was promoted to the position of Distinguished Member of Technical Staff. Dr. Ramachandran's research focuses on fiber and fiber-grating devices in specialty fibers, with applications in biomedical imaging, lasers, sensors, as well as telecommunications. His work on higher order mode fibers has been highlighted several times in popular trade magazines such as Laser Focus World and Photonics Spectra.

Professor Jason Ritt

Dr. Jason Ritt is an Assistant Professor in the Biomedical Engineering Department. Professor Ritt received his M.A. in Mathematics and his Ph.D. in Neuroscience from Boston University. Before joining BU, Dr. Ritt was a Postdoctoral Fellow at MIT. His research interests include: neuroscience of sensorimotor behaviors; biological active sensing; functional role of embodiment in neural computation; brain machine interfaces; neural prosthetics.

Faculty Member Listing

Steven Ahlen
Professor, Physics

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590 Commonwealth Ave., 275

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Research interests:
- Atlas experiment at CERN
- High flux netron detectors
- High energy physics

Hatice Altug
Assistant Professor, ECE

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

Richard Averitt
Professor, Physics

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Research interests:
- Metamaterials & plasmonics
- Terahertz spectroscopy
- Correlated electron materials

Enrico Bellotti
Associate Professor, Physics

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Research interests:
- Computational electronics
- Semiconductor materials
- Parallel computing

Thomas Bifano
Professor, ME

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Research interests:
- Microelectromechanical systems (MEMS)
- Adaptive optics

Irving Bigio
Professor, BME

Office Address:
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Research interests:
- Biomedical optics
- Medical applications of optics, lasers and spectroscopy

John Connor
Professor, MED

Office Address:
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Research interests:
- Protein synthesis in virus replication
- Vesicular stomatitis virus

Luca Dal Negro
Assistant Professor, ECE

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Research interests:
- Optical amplification phenomena
- Photonics crystals
- Nanophotonics and plasmonics

Kamil Ekinci

Assistant Professor, ME

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

Shyamsunder Erramilli

Professor, Physics

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Research interests:
- Infrared and raman microscopy
- Quantum cascade laser sources
- Ultrafast infrared spectroscopy

Helen Fawcett

Professor, ME

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Research interests:
- Biodetection, optics, nanoscale lithography and imaging
- Photonics applications

Theodore Fritz

Professor, Astronomy

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Research interests:
- Space plasma physics
- Magnetosphere physics
- Rocket and satellite experiments

Christopher Gabel

Assistant Professor, Physiology & Biophysics, MED

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Research interests:
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- Femtosecond laser surgery

Bennett Goldberg

Professor, Physics

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Research interests:
- Biological sensors
- Single-made waveguide devices
- Nanotubes and nano-optics

Lee Goldstein

Associate Professor, Psychiatry

Office Address:
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Research interests:
- Alzheimers disease
- Biometals & metallomics
- Molecular aging disorders

Allyn Hubbard

Assistant Professor, ECE

Office Address:
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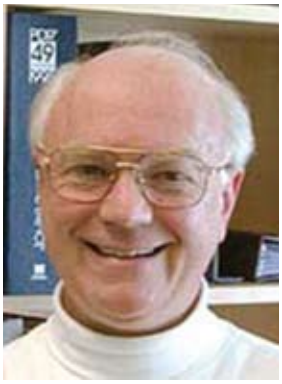
Research interests:
- Auditory physiology
- Neurocomputing and biosensors
- VLSI design of smart senor chips



Guilford Jones

Professor, Chemistry

Office Address:
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Research interests:
- Photochemistry
- Dye probes

Ajay Joshi

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Research interests:
- On-chip and off-chip interconnect design
- Computer architecture

Catherine Klapperich

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Phone: 617-353-0253
e-mail: catherin@bu.edu

Research interests:
- Nanomechanics of hydrated biomaterials
- Microfluidic device design

Amit Meller

Associate Professor, BME

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e-mail: ameller@bu.edu

Research interests:
- Ultrafast DNA sequencing
- Optical methods for single molecule detection

Michael Mendillo

Professor, Astronomy

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Research interests:
- Planetary atmospheres
- Space physics
- Observations and models

Jerome Mertz

Professor, BME

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

Theodore Morse

Professor, ECE

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Research interests:
- Photonic material processing
- Optical fiber fabrication, lasers, and sensors

Theordore Moustakas

Professor, ECE

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Research interests:
- MEMS
- III-Nitrides
- Amorphous semiconductors

Roberto Paiella

Assistant Professor, ECE

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Research interests:
- Terahetz photonics
- Surface-plasmon-enhanced light emitting devices

Siddharth Ramachandran

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Research interests:
- Micro & nano optical fibers

Bjoern Reinhard

Assistant Professor, Chemistry

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Research interests:
- Design, implementation of new tools for manipulation of biological & inorganic materials

Jason Ritt

Assistant Professor, BME

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Research interests:
- Active sensing by organisms
- Electrophysiological analysis of rodent whisker systems

Kenneth Rothschild

Professor, Physics

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Research interests:
- Biomembrane technology and biomolecular photonics
- Ion transport

Michael Ruane

Professor, ECE

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Research interests:
- Resonant cavity biosensors
- Optical design
- K-12 outreach and education

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Professor, ECE

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Research interests:
- Ultrafast quantum optics
- Quantum metrology
- Quantum biophotonics

Andre Sharon

Professor, ME

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Research interests:
- Electomechanical machines
- Fiber optic manufacture
- Biomedical devices

Anna Swan

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Research interests:
- Interanctions of biomaterials with nanostructures
- Carbon nanotubes

Malvin Teich

Professor, ECE

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

Barry Unger

Associate Professor, MET

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Research interests:
- Venture capital investment
- Product design process
- MIT Tech. Enterprise Forum

Selim Unlu

Professor, ECE

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Research interests:
- Optical characterization
- Nanophotonics
- Nanoscale biological imaging

Xin Zhang

Assistant Professor, ME

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Research interests:
- Nano and microsystems
- Microelectromechanical sys.
- Nanoelectromechanical sys.

Lawrence Ziegler

Professor, Chemistry

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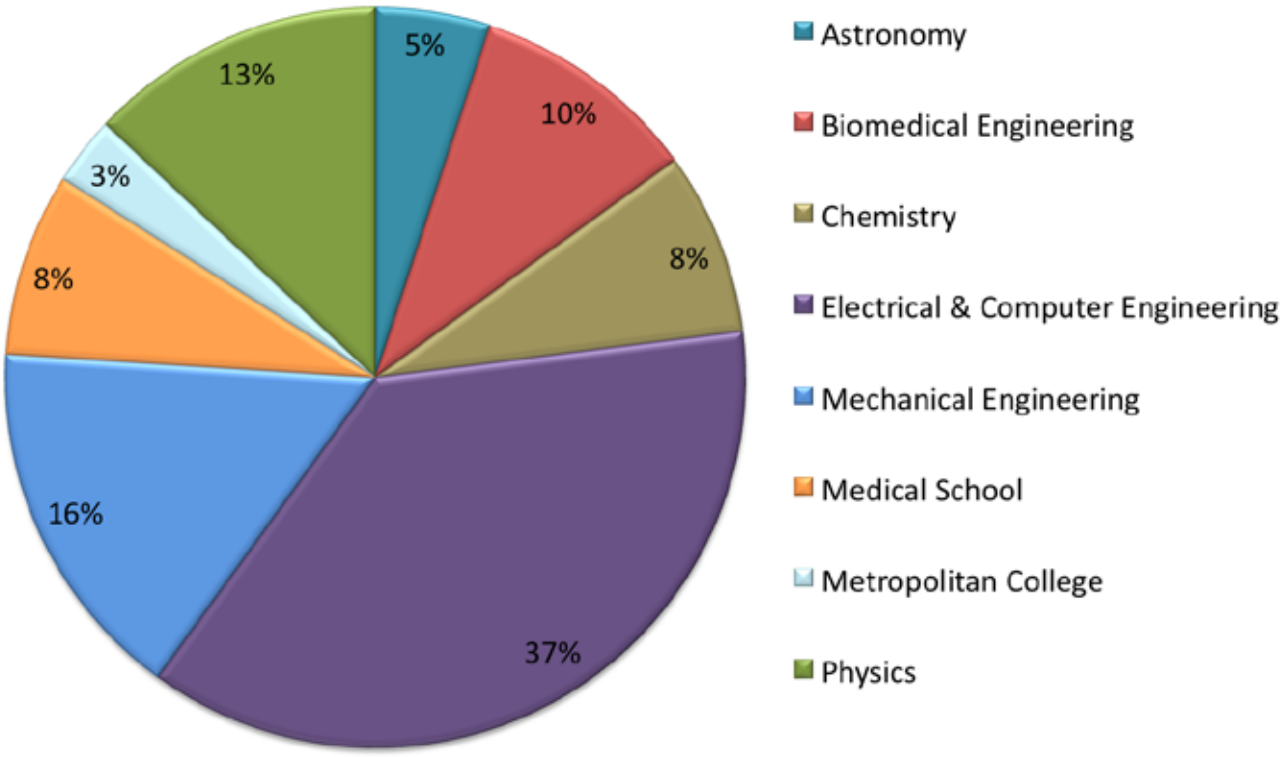
Research interests:
- Spontaneous resonance raman studies of photodissociative and biological chromophores

Primary Faculty Departments



Faculty Committees

The Photonics Center has six committees that support and serve its faculty and staff. In the spirit of continuous improvement and community involvement, the BUPC Director appoints committee chairs each year.

Distinguished Lecturer Series:
Chair – Luca Dal Negro
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 – Francesco Cerrina, Bennett Goldberg
Recommends equipment upgrades or new equipment purchases that will enhance the research and development of faculty and students at the Center.

Executive Advisory:
Chair – John Straub
Advises the Director on educational and academic issues and is comprised of the chairs from the Center's affiliated departments.

Space Allocation:
Chair – Thomas Bifano
Generates policy guidelines for space management.

Symposium:
Chair – Irving Bigio
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 external 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 Member Listing

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Leah Ziph-Schatzberg
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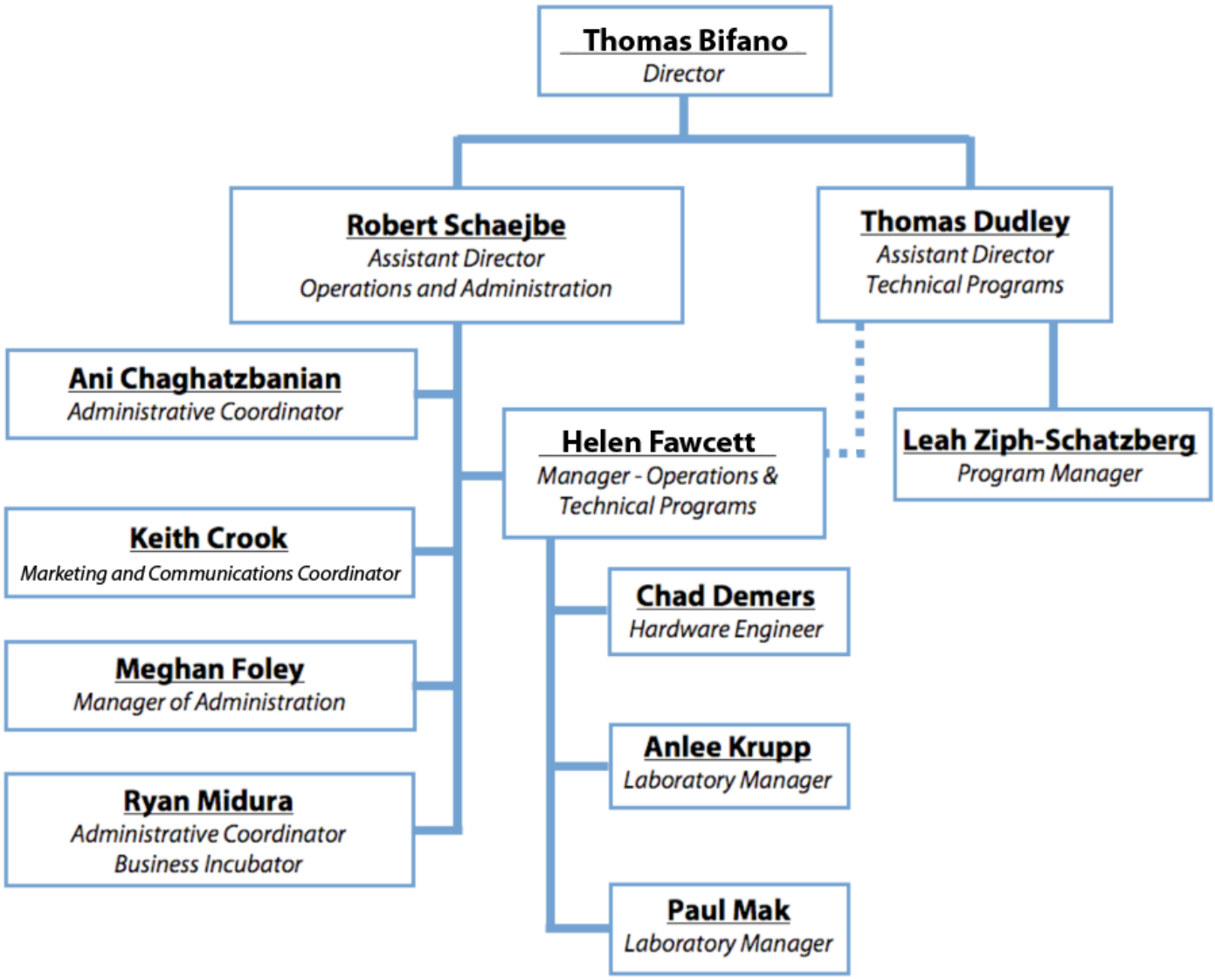
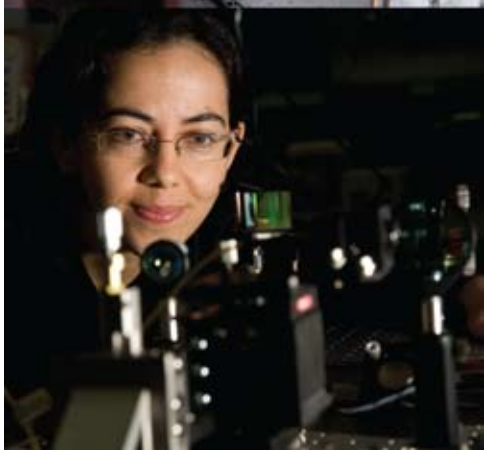
Staff Organizational Chart



Reseach research



Basic research and scholarship in photonics is a core mission for the Boston University Photonics Center. This committment to academic research provides the foundation for further innovation in technology development. Scholarly research conducted at the Photonics Center originates from the traditional disciplines of the faculty members' host departments: Astronomy, Biology, Chemistry, Physics, Mechanical Engineering, Biomedical Engineering, Electrical and Computer Engineering, and the School of Medicine.

The BUPC individual faculty laboratories have pioneered breakthrough photonic devices that include UV LED's, quantum cryptography systems, deformable mirrors, high-speed photodetectors, and metamaterial devices. Photonics faculty members 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). In addition, faculty and students associated with the Photonics Center published more than 180 journal papers.

Externally Funded Research

Photonics faculty members received more than $21.1M in external funding. The following table lists funds in the fiscal year (July 1, 2009 through June 30, 2010), as reported by the Office of Sponsored Programs.

P.I.	Dept.	Title of Project	Agency	Period	Amount
Ahlen	PHY	ARI-SA: Development and Testing of a Direction-Sensitive Neutron Detector (Year 3)	Dept. of Homeland Security	9/1/08 8/31/10	$95,435
Ahlen Butler Heintz Shank	PHY	Research in Particle Physics/Task A2: Atlas	Dept. of Energy	2/1/09 1/31/10	$35,000
Altug	ECE	Development of Multiplexed, Ultra-Sensitive, Label-Free and Rapid Biosensing Technologies for Proteomics and Virus Detection Applications	Comm. Of Mass./Life Sciences Center	9/1/09 8/31/10	$91,082
Altug	ECE	CAREER: Nano-Plasmonic Resonances for Bio-Detection Systems	NSF	2/15/10 1/31/15	$399,869
Altug	ECE	High-Performance NanoPlasmonic Sensors for Biological Warfare Detection	DoD/Navy	5/1/10 4/30/13	$60,780
Averitt	PHY	SISGR: Multifunctional Materials Research Using Ultrafast Optical Spectrocopy (In conjunction with Photonics Center)	Dept. of Energy	9/1/09 9/14/10	$149,999
Averitt	PHY	THz Spectroscopy with Schlumberger-Doll Research (In conjunction with Photonics Center)	Schlumberger Technology Corporation	11/1/09 7/1/11	$240,000
Bellotti	ECE	Photon-Trap Structures for Quantum Advanced Detectors (PT-SQUAD) (Subcontract via BAE Systems)	DoD/DARPA	8/18/09 9/30/10	$82,820
Bifano	PHO	Photonics Research and Technology Insertion (Leah Schatzberg)	DoD/Army	7/1/09 6/30/10	$34,000

P.I.	Dept.	Title of Project	Agency	Period	Amount
Bifano	PHO	Photonics Research and Technology Insertion (Richard Averitt and Xin Zhang)	DoD/Army	7/1/09 6/30/10	$60,000
Bifano	ME	Photonics Research and Technology Insertion	DoD/Army	7/1/10 6/30/11	$4,010,000
Bigio	BME	Instrumentation for Optical Monitoring of Apoptosis in Unlabeled Cell Cultures (in conjunction with Photonics Center)	HHS/NIH/ NIBIB	7/1/09 6/30/10	$243,750
Bigio	BME	Spatially Modulated Near-Infrared Light for Image-Guided Cancer Surgery (Sylvain Gioux) (Subcontract via Beth Israel Deaconess Medical Center)	HHS/NIH/NCI	9/1/09 10/31/09	$6,854
Bigio	BME	Enhanced Intraarterial Delivery of Chemotherapeutic Drugs to the Brain (Subcontract via Columbia University)	HHS/NIH/NCI	8/1/09 7/31/10	$87,750
Bigio	BME	Instrumentation for Optical Monitoring of Apoptosis in Unlabeled Cell Cultures (In conjunction with Photonics Center)	HHS/NIH/ NIBIB	7/1/10 6/30/11	$203,125
Butler Ahlen	PHY	U.S. ATLAS Research Program: Empowering U.S. Universities for Discoveries at the Energy Frontier (Subcontract via Columbia University)	NSF	3/1/07 1/31/11	$68,000
Castanon Roy Teich Barbone	ECE	CenSSIS Program - Year 10 (Subcontract via Northeastern University)	NSF	9/1/09 8/31/10	$314,518
Cerrina	ECE	Table Top EUV Holography: A New Approach for Versatile Nanolithography (Subcontract via Colorado State University)	NSF	7/1/09 6/30/12	$138,435

P.I.	Dept.	Title of Project	Agency	Period		Amount
Cerrina Benson Collins Galagan	ECE	MRI-RS: Acquisition of a Pacific Biosciences S.M.R.T. DNA Sequencing Instrument (additional co-p.i.: Martin Herbordt)	NSF	1/1/10	12/31/12	$727,565
Dal Negro	ECE	CAREER: Combined Light and Carrier Localization in High-Refractive Index Silicon Nanocrystal Structures - A Novel Approach for Si-based Lasers	NSF	8/1/09	7/31/14	$400,000
Dal Negro	ECE	Aperiodic Photonic-Plasmonic Structures with Broadband Field Enhancement for Optical Limiting Applications (Subcontract via Batelle Columbus Operations)	DoD/Army	5/29/09	5/28/10	$88,474
Dal Negro	ECE	Deterministic Aperiodic Structures for On-Chip Nanophotonics and Nanoplasmonics Device Applications	DoD/Air Force	10/1/09	11/30/09	$26,500
Dal Negro	ECE	Deterministic Aperiodic Structures for On-Chip Nanophotonics and Nanoplasmonics Device Applications	DoD/Air Force	12/1/09	11/30/10	$159,999
Dal Negro	ECE	MURI: Electrically-Pumped, Silicon-Based Lasers for Chip-Scale Nanophotonic Systems (subcontract via MIT)	DoD/Air Force	7/1/06	11/30/10	$100,000
Dal Negro	ECE	Biodegradable Communications System (Subcontract via Tufts University)	DoD/DARPA	1/1/08	1/31/11	$149,539
Dal Negro	ECE	DURIP - 1.54 mm Optical Gain in Si and Ge-Based Structures for Optical Amplification and Electrically Pumped Lasers	Dod/AFOSR	6/1/10	5/31/11	$237,995

P.I.	Dept.	Title of Project	Agency	Period	Amount
Dal Negro	ECE	Silk Based Optical Food Sensors (Subcontract via Tufts University)	DoD/AFOSR	3/1/10 2/28/11	$100,000
Ekinci	ME	CAREER: Photonic Integration of Silicon Nanoelectromechanical Systems (In conjunction with Center for Nanoscience and Nanobiotechnology)	NSF	3/1/10 2/28/11	$82,717
Ekinci	ECE	CAREER: Photonic Integration of Silicon Nanoelectromechanical Systems (REU Supplement)	NSF	5/1/08 2/28/11	$6,000
Ekinci Yachot	ECE	Tailor-Made Superhydrophobic Surfaces for MEMS and NEMS	NSF	5/1/10 4/30/13	$280,143
Erramilli	PHY	Nanoplasmonic Infrared QCL/SEIRA System for Biochemical Detection (Subcontract via MIT/Lincoln Laboratory)	DoD/Air Force	4/1/10 9/30/10	$50,000
Erramilli Mohanty	PHY	Gate-Controlled Silicon Based Nanoscale Processor for Multiple Analyte Assay	Ninth Sense, Inc.	6/13/08 6/30/09	$1,908
Fritz	CSP	Virtual Observations (Subcontract via University of Maryland, Baltimore County	NASA	9/1/09 12/31/09	$8,068
Fritz	AST	The Cluster RAPID Investigation 2008-2011	NASA	7/1/08 7/16/11	$100,000
Fritz	AST	The Loss Cone Imager (LCI) for the DSX Program (Task 1)	DoD/Air Force	4/1/10 9/30/11	$233,000
Fritz	AST	The Cluster RAPID Investigation 2008-2011	NASA	7/1/08 7/16/11	$40,000
Goldberg	PHY	Multi-Photon Solar Cell (In conjunction with Center for Nanoscience and Nanobiotechnology and Photonics Center) (Subcontract via Photonic Glass Corporation)	DoD/Air Force	4/1/10 12/31/10	$40,000

P.I.	Dept.	Title of Project	Agency	Period		Amount
Goldberg DeRosa Snyder Meller	PHY	PROSTARS: Program in STEM Academic Retention and Success (in conjunction with Center for Nanoscience and Nanobiotechnology)	NSF	1/1/09	12/31/09	$215,261
Goldberg DeRosa Snyder Meller	PHY	ProSTARS: Program in STEM Academic Retention and Success (Participant Support) (in conjunction with Center for Nanoscience and Nanobiotechnology)	NSF	1/1/09	12/31/09	$103,556
Goldberg DeRosa Snyder Meller	PHY	PROSTARS: Program in STEM Academic Retention and Success (in conjunction with Center for Nanoscience and Nanobiotechnology)	NSF	1/1/07	12/31/11	$444,710
Goldberg DeRosa Snyder Meller	PHY	PROSTARS: Program in STEM Academic Retention and Success (Participant Support (In conjunction with Center for Nanoscience and Nanobiotechnology)	NSF	1/1/07	12/31/11	$224,828
Goldberg Stanley	PHY	GK12 Track II: Boston University Urban Fellows Project (Participant Support Account)	NSF	6/1/06	5/31/11	$152,650
Goldberg Stanley	PHY	GK12 Track II: Boston University Urban Fellows Project	NSF	6/1/06	5/31/11	$76,071
Goldberg Stevens	PHY	Summer Immersion Institutes	Stephen Bechtel Fund	12/4/09	10/1/10	$100,000
Goldstein	MED	AD Lens Pathology: Biochemistry and Diagnostic Imaging	HHS/NIH/ NIGMS	6/1/09	5/31/10	$261,935
Goldstein	MED	Novel Regenerative Nanoparticle-based Microsensor for the Detection of Reactive Oxygen Species in Biological Systems (Subcontract via University of Florida)	NSF	8/15/09	7/31/10	$99,420

P.I.	Dept.	Title of Project	Agency	Period		Amount
Goldstein	MED	Label-Free Protein Array for Alzheimer's Disease Detection and Monitoring (Subcontract via Zoiray Technologies, Inc.)	HHS/NIH/NIA	8/15/09	7/31/10	$50,521
Goldstein	MED	Non-Invasive Detection and Molecular Analysis of Early Low X-Ray Dose Effects to the Lens	Dept. of Energy	9/1/09	4/30/10	$214,975
Goldstein	MED	AD Lens Pathology: Biochemistry and Diagnostic Imaging	HHS/NIH/ NIGMS	1/28/10	12/31/10	$103,704
Goldstein	MED	Non-Invasive Detection and Molecular Analysis of Early Low X-Ray Dose Effects to the Lens	Department of Energy	9/1/10	4/30/11	$263,520
Goldstein	MED	Novel Regenerative Nanoparticle - based Microsensor for the Detection of Reactive Oxygen Species in Biological Systems (Subcontract via University of Florida)	NSF	8/15/10	7/31/11	$76,165
Goldstein	MED	Femtosecond Infrared Laser Ablatin Platform	HHS/NIH/ NCRR	7/1/10	6/30/11	$418,549
Klapperich	ME	Disposable Microfluidic Devices for Point of Care Diagnostics (in conjunction with Center for Nanoscience and Nanobiotechnology)	HHS/NIH/ NIAID	7/1/09	6/30/10	$262,625
Klapperich	ME	Microchip to Detect Influenza Infection and Type in Nasopharyngeal Swabs (in conjunction with Center for Nanoscience and Nanobiotechnology)	HHS/NIH/ NIBIB	9/1/09	8/31/11	$173,711
Klapperich	ME	A Microfluidic System for Monitoring Sepsis at the Point of Care (Subcontract via CMIT/Mass General Hospital)	DoD/Army/ Medical Research Acquisition Activity	12/16/09	9/30/10	$140,000

P.I.	Dept.	Title of Project	Agency	Period		Amount
Klapperich	ME	Microchip to Detect Influenza Infection and Type in Nasopharyngeal Swabs (In conjunction with Center of Nanoscience and Nanobiotechnology)	HHS/NIH/ NIBIB	7/1/10	6/30/11	$343,117
Klapperich	ME	Micro Solid Phase Extraction Module Development for EO-NAT-HIV Rapid Point-of-Care Diagnostic Device for Resource-Limited Settings (Subcontract via Wave 80 Biosciences, Inc.)	HHS/NIH/ NIAID	9/30/09	9/29/14	$627,485
Klapperich	ME	Disposable Microfluidic Devices for Point of Care Diagnostics (In conjunction with Center for Nanoscience and Nanobiotechnology)	HHS/NIH/ NIAID	7/1/10	6/30/11	$206,375
Klapperich Sharon	BME	Portable Low Power Nucleic Acid Extraction Module (In conjunction with Center for Nanoscience and Nanobiotechnology) (Subcontract via Program for Appropriate Technology in Health)	HHS/NIH/ NIBIB	9/1/09	8/31/10	$140,343
Meller Weng	ME	High Throughput DNA Sequencing Using Design Polymers and Nanopore Arrays	HHS/NIH/ NHGRI	9/1/09	8/31/10	$931,269
Mendillo	CSP	Comparison of Cassini Observations with the Saturn-Thermosphere-Ionosphere-Model (STIM)	NASA	7/1/09	6/30/10	$152,354
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	$102,993
Mendillo	CSP	Imaging Science and Modeling Investigations of the Upper Atmosphere	NSF	12/1/08	11/30/09	$20,911

P.I.	Dept.	Title of Project	Agency	Period		Amount
Mendillo	CSP	Inter-Hemisphere Studies of Ionospheric Irregularities	DoD/Navy	12/12/08	12/31/11	$158,638
Mendillo	CSP	Imaging Science and Modeling Investigations of the Upper Atmosphere	NSF	12/1/09	11/30/10	$285,000
Mendillo	AST	A Comprehensive Multi-Process Saturn-Thermosphere-Ionosphere-Model (STIM)	NASA	3/1/09	2/29/12	$100,000
Mendillo Martinis	CSP	Altitude-Latitude Ion-Neutral Coupling Using CINDI and C/NOFS and Conjugate Ground-Based Optical Diagnostics	NASA	6/30/09	6/29/12	$96,803
Mendillo Martinis	ECE	Altitude-Latitude Ion-Neutral Coupling Using CINDI and C/NOFS and Conjugate Ground-Based Optical Diagnostics	NASA	6/30/09	6/29/12	$100,202
Mertz	BME	Novel Techniques in Microscopy Conference	HHS/NIH/ NIBIB	4/1/09	3/31/10	$10,000
Mertz	BME	Dynamic Calcium Clamp: Design and Application (E. Idoux) (Subcontract via Universite Paris Descartes)	European Commission/ Marie Curie Fellowship Program	10/1/08	9/30/10	$14,410
Mertz Singh	BME	The Development of Hybrid Widefield Imaging for Out-of-Focus Background Rejection	HHS/NIH/ NIBIB	9/30/09	6/30/10	$349,988
Mertz Singh	BME	The Development of Hybrid Widefield Imaging for Out-of-Focus Background Rejection	HHS/NIH/ NIBIB	7/1/10	6/30/11	$364,865
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	Double Clad Fiber with Single Mode Core (Subcontract via Massachusetts General Hospital)	HHS/NIH/NCI	12/1/09	7/31/10	$12,462

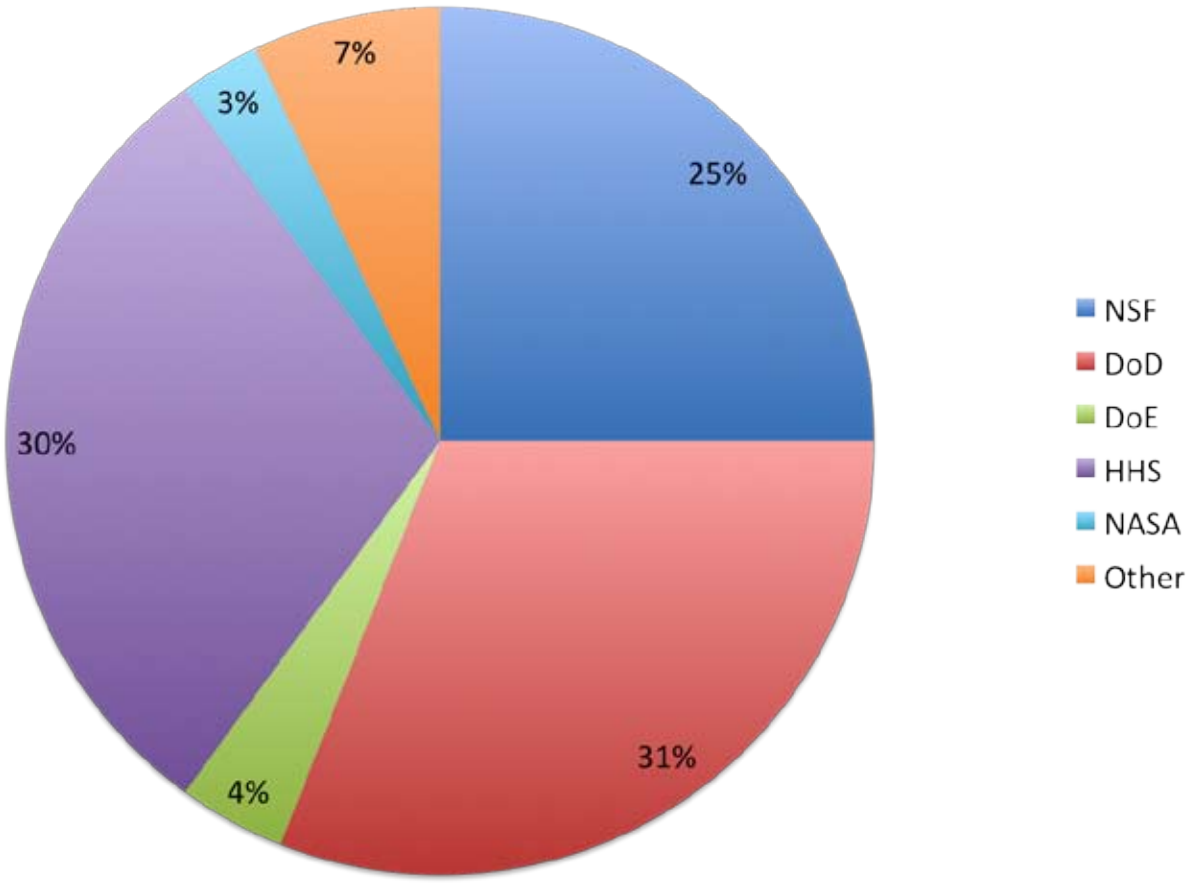
P.I.	Dept.	Title of Project	Agency	Period	Amount
Morse	ECE	Double Clad Fiber with Single Mode Core (Subcontract via Massachusetts General Hospital)	HHS/NIH/ NHLBI	12/1/09 7/31/10	$12,462
Morse	ECE	Higher Order Mode (HOM) Fibers for Blue Laser Application	DoD/Navy	3/1/10 10/1/10	$11,764
Morse	ECE	Higher Order Mode (HOM) Fibers for Blue Laser Application (Modification No. 1)	DoD/Navy	3/1/10 10/1/10	$36,505
Mountain Hubbard Cotanche Barbone	ECE	Active Filtering in the Cochlea (In conjunction with Hearing Research Center)	HHS/NIH/ NIDCD	6/30/09 8/31/10	$717,322
Moustakas	ECE	Development of an Electron Beam Injected Laser Structure at 235nm Based on AlGaN/AlN Multiple Quantum Wells on SiC Substrates (In conjunction with Photonics Center) (Subcontract via Photon Systems, Inc.)	NASA	1/15/10 1/15/12	$150,000
Paiella	ECE	Collaborative Research: Quantum-Cascade-Laser Active Materials Based on Silicon-Germanium Nanomembranes	NSF	7/1/10 6/30/11	$78,270
Paiella	ECE	Plasmonic Nanostructures Integrated with Semiconductor Light Emitting Materials for Enhanced Efficiency and Functionality	DoE	1/1/10 6/30/11	$155,000
Reinhard	CHEM	Plasmon Coupling Microscopy for the in Vivo Detection and Tracking of Cytoplasmic RNA	HHS/NIH/ NIBIB	7/1/09 6/30/10	$203,125
Reinhard	CHEM	Bioavailability and Toxicity of Engineered Nanomaterials (Lynell Skewis)	HHS/NIH/ NIMH	8/1/09 7/31/10	$28,091
Reinhard	ECE	CAREER: Frequency Domain Plasmon Fluctuation Spectroscopy for Single Polymer Mechanical Sensing (In conjunction with Center for Nanoscience and Nanobiotechnology)	NSF	3/15/10 2/28/15	$400,000

P.I.	Dept.	Title of Project	Agency	Period	Amount
Reinhard	ECE	Illuminating Dynamic Receptor Clustering in the Epidermal Growth Factor Receptor (In conjunction with Center for Nanoscience and Nanobiotechnology)	HHS/NIH/NCI	5/1/10 4/30/11	$337,188
Reinhard Dal Negro	ECE	Rationally Designed Plasmonic Nanostructures for Rapid Bacteria Detection and Identification (In conjuntion with CNN)	NSF	6/1/09 5/31/11	$180,700
Rothschild	PHY	FTIR Study of Signal Transdcution in Sensory Rhodopsins	HHS/NIH/ NIGMS	9/30/09 8/31/10	$284,375
Ruane Swan	ECE	REU Site: Research Experience for Undergraduates in Photonics	NSF	5/1/09 10/31/09	$12,681
Shane Goldberg	PHY	Upward Bound Math/Science - Year 2	Dept. of Education	9/1/09 8/31/10	$250,000
Swan Altug Smith Andersson	ECE	NUE: Undergraduate Laboratory Experiences in Nanotechnology Devices and Systems (U-LENS) (additional co-p.i.: Tyrone Porter) (in conjunction with Center for Nanoscience and Nanobiotechnology and Photonics Center)	NSF	9/1/09 8/31/11	$200,000
Teich	ECE	Quantum Optical Coherence Tomography (CenSSIS Supplement) (Subcontract via Northeastern University)	NSF	2/1/03 8/31/10	$35,000
Teich Saleh Sergienko	ECE	Quantum Imaging: New Methods and Applications (MURI) (In conjunction with Photonics Center) (Subcontract via University of Rochester)	DoD/Army	5/1/05 9/30/10	$40,000
Teich Saleh Serginko	ECE	Quantum Imaging: New Methods and Application (MURI) (In conjunction with Photonics Center) (Subcontract via University of Rochester)	DoD/Army	5/1/05 9/30/10	$19,086

P.I.	Dept.	Title of Project	Agency	Period		Amount
Unlu	ECE	Label-Free Multiplexed Immunoassay Platform for Diagnosing Liver Disease (Subcontract via Zoiray Technologies Inc.)	HHS/NIH/ NIDDK	7/1/09	3/31/10	$51,127
Unlu	ECE	Research Agreement (In conjunction with Center for Nanoscience and Nanobiotechnology and Photonics Center)	Mitre Corporation	10/1/09	9/30/10	$80,000
Unlu	ECE	Floating Light-Activated Micro-Electrical Stimulators for Neutral Prosthetics (Subcontract via New Jersey Institute of Technology)	HHS/NIH/ NIBIB	8/1/09	5/31/10	$152,971
Unlu	COE	BU/CIMIT Applied Healthcare Engineering Fellowship (Subcontract via Massachusetts General Hospital/CIMIT)	DoD/Army/ Medical Research Acquisition Activity	1/1/09	12/31/09	$117,450
Unlu DeLisi Goldberg Irani	ECE	High Throughput Qualification of Conformation and Kinetics of DNA-Protein Complexes (In conjunction with Center for Nanoscience and Nanobiotechnology)	NSF	9/15/09	8/31/10	$110,000
Unlu Goldberg	ECE	Research Agreement	The Mitre Corporation	6/1/09	9/30/09	$5,500
Unlu Ruane Goldberg Zaman Porter	ECE	GAANN: Fellowships in Nanobiotechnology	Dept. of Education	8/16/10	8/15/11	$131,265
Zhang	ME	An Impedance-Based Assay Microsystem for Real-Time High Throughput Study of Single Cells (in conjunction with Photonics Center)	NSF	10/1/09	9/30/10	$86,435

P.I.	Dept.	Title of Project	Agency	Period		Amount
Zhang	ME	Mechanical Behavior of Amorphous Plasma-Enhanced Chemical Vapor Deposited Silicon Oxide Films for MEMS Applications (REU Supplement) (in conjunction with Photonics Center)	NSF	6/1/09	5/31/10	$6,000
Zhang	ME	Collaborative Research: Elastic and Viscoelastic Characterization and Modeling of Polymer Based Structures for Biological Applications (REU Supplement)	NSF	6/1/10	8/31/11	$6,000
Zhang Averitt	ME	Materials and Mechanics of Metamaterial Enhanced MEMS for Terahertz Technology (In conjunction with Photonics Center)	DoD/Air Force	9/30/09	3/31/10	$65,000
Zhang Averitt	PHY	Coupled Evanescent Field Micro-Resonators for Downhole Data Relay (In conjunction with Photonics Center) (Subcontract via University of Texas, Austin)	Advanced Energy Consortium	1/1/10	12/31/10	$200,000
Zhang Averitt	PHY	Materials and Mechanics of Metamaterial Enhanced MEMS for Terahertz Technology (In conjunction with Photonics Center)	DoD/AFOSR	4/1/10	3/31/11	$130,000
					TOTAL:	$21,096,058

Breakdown by Granting Agency FY 2009-2010



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T. D. Moustakas, "Semiconductor Device Having Group-III Nitride Buffer Layer and Growth Layers," U. S. patent no. 7,663,157, February 16, 2010.

Yitao Liao and **T. D. Moustakas**, "Method of Growing an AlGaN layer with Band Structure Potential Fluctuations and Manufacturing Ultraviolet Light Emitting Devices Containing the Same," U. S. Patent no. 61/329,947, April 30, 2010.

S. Ramachandran, "Measuring Modal Content of Multi-Moded Fibers," U. S. Patent no. 20090185171, July 23, 2009.

S. Ramachandran, "Systems and Techniques for Generating Cylindrical Vector Beams," U. S. Patent no. 20090202191, August 13, 2009.

S. Ramachandran, "Systems and Techniques for Generating Bessel Beams," U. S. Patent no. 20090257711, October 15, 2009.

S. Ramachandran, "Pumping In A Higher-Order Mode That Is Different From A Signal Mode," U. S. Patent no. 20100002992, January 7, 2010.

S. Ramachandran, "Segmented Gain-Doping Of An Optical Fiber," U. S. Patent no. 20100008633, January 14, 2010.

S. Ramachandran, "Preventing Dielectric Breakdown In Optical Fibers," U. S. Patent no. 20100008664, January 14, 2010.

S. Ramachandran, "Optical Fibers and Optical Fiber Devices with Total Dispersion Greater than Material Dispersion," U. S. Patent no. 20100014820, January 21, 2010.

S. Ramachandran, "Sequentially Increasing Effective Area In Higher-Order Mode (HOM) Signal Propagation," U. S. Patent no. 20100034500, February 11, 2010.

S. Ramachandran, "Production of Optical Pulses at a Desired Wavelength Utilizing Higher-Order-Mode (HOM) Fiber," U. S. Patent no. 20100054661, March 4, 2010.

S. Ramachandran, "Selectively Pumping A Gain-Doped Region Of An Optical Fiber," U. S. Patent no. 20100103959, April 29, 2010.

W. R. Premasiri, D. M. Moir, **L. D. Ziegler** "Analyzer for Nanostructured Substrate for Surface Enhanced Raman Scattering", Provisional Patent Application (2009)

Awards of Note

BUPC faculty members are honored each year by numerous organizations for their exceptional educational and research activities. Below is a select list of notable awards received by our faculty.

- BUPC continued its Cooperative Agreement with the Army Research Laboratory. Between July 2009 and June 2010, BUPC received $4M that supports a variety of photonics based technology prototype development with defense and security objectives.

- NSF Faculty Career Development Awards:

Hatice Altug

- In February 2010, Professor Hatice Altug received the National Science Foundation's prestigious Faculty Early Career Development (CAREER) award in recognition of her outstanding research and teaching capabilities. The five-year, $400,000 award funds high-impact projects that effectively combine research and educational objectives. Professor Altug was awarded for her work in new bio-detection platforms for the large-scale study of proteins, from their detection and quantification to the determination of their functions and interactions.

Luca Dal Negro

- The National Science Foundation (NSF) awarded Professor Luca Dal Negro a Faculty Early Career Development (CAREER) Award in December 2009. Spread over five years, the CAREER Award supports junior faculty who exemplify the role of teacher-scholars through outstanding research, excellent education, and the integration of education and research within the context of their institution's mission. Professor Dal Negro's CAREER award supports his project, "Combined Light and Carrier Localization in High-refractive Index Silicon Nanocrystal Structures: a Novel Approach for Si-based Lasers."

Bjoern Reinhard

- The National Science Foundation (NSF) awarded Professor Bjoern Reinhard a Faculty Early Career Development (CAREER) Award in February 2010. Professor Reinhard's CAREER award supports his project, "Frequency Domain Plasmon Fluctuation Spectroscopy for Single Polymer Mechanical Sensing."

- Educational Grants:

Bennett Goldberg

- The National Science Foundation awarded Professor Bennett Goldberg with a grant to continue his work with the Boston Urban Fellows Project. The Boston University Urban Fellows Project is a 10-year NSF supported program to institute a sustainable model of immersing K-12 teaching partnerships within urban school systems for graduate fellows in sciences and engineering.

- Professor Goldberg was also awarded a NSF grant to continue the Programs in STEM Academic Retention and Success (PROSTARS). PROSTARS designs and implements programs geared toward increasing retention and graduation rates of Science, Technology, Engineering and Mathematics (STEM) students from Boston University. Activities are largely focused on underserved STEM students, including students from urban schools, women in physical sciences and engineering disciplines, and students who matriculate with test scores and other indicators that lead to higher than average STEM program attrition.

Michael Ruane

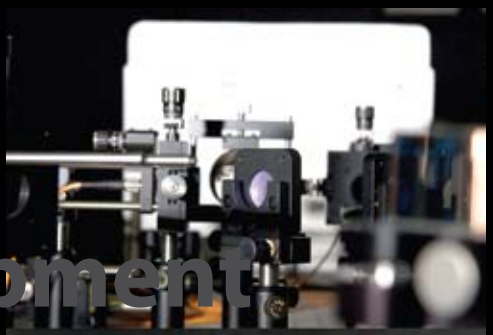
- Professor Michael Ruane was awarded a grant from the National Science Foundation to establish a Research Experiences for Teachers (RET) in Photonics program. The experiences are designed to give middle and high school teachers an opportunity to develop interactive experiments for implementation into their science curriculum.

Anna Swan

- Professor Anna Swan was awarded a grant from the National Science Foundation to continue her work with the Four Schools for Women in Engineering. This program is a group of four university Science, Technology, Engineering and Mathematics (STEM) teams who develop innovative practices for integrating engineering with science, technology, and math into middle school classrooms using gender-inclusive approaches.

Technology Development

technology development



The basic research conducted by our faculty provide a continuous flow for the technology development pipeline.

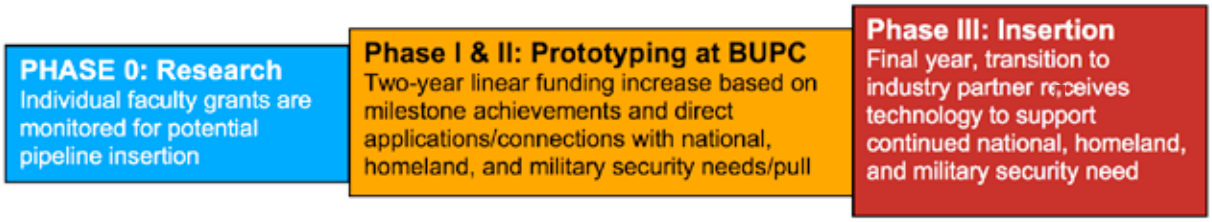
BUPC has become well known for its program of defense-related technology transfer through targeted prototype development. In the past year, BUPC has continued to develop prototypes for military applications while expanding coverage into the healthcare sectors. These programs are highlighted and summarized along with the programs chosen for support during the next program year of the ARL Cooperative Agreement.

This section also outlines new funding opportunities that BUPC is pursuing in collaboration with BUPC faculty members, industrial partners, and other Photonics-based universities in an effort to further develop research applications in bio-sensing, systems, and applications.

Prototype Development Pipeline

The Photonics Center has become well known for its program of defense related technology transfer through targeted prototype development. The Boston University Photonics Center continues to develop prototypes for military applications while expanding coverage into the healthcare sectors.

The BUPC prototype development pipeline is a three phased program for technology transfer. Beginning with fundamental research, the pipeline is designed to fund projects that have strategic importance for our governmental and industrial partners. The first two phases, each a year long, lay out a series of developmental milestones for researchers to achieve. By the end of phase two, the developed prototype is transferred or inserted into a military or commercial setting for use in the field. BUPC staff work with researchers during all phases of the pipeline process and work with our governmental and industrial partners for a successful transition.



The diagram above highlights the phases for the prototype development pipeline at BUPC

BUPC, working through a Cooperative Agreement with the U.S. Army Research Laboratory (ARL), has been at the forefront of ground breaking research and technology development and demonstration. The MEMS-based Secure Communicating Optical Ultra-light Transponder (SCOUT) and the Compact Optical Biothreat Rapid Analysis (COBRA) Portable Raman Microscope System for bacterial detection are two such examples of this effort.

The Secure Communicating Optical Ultra-light Transponder (SCOUT) exited the pipeline earlier this year. Communications have continued with various agencies within the Department of Defense. The Naval Research Laboratory (NRL) has provided funding for further collaboration between NRL and BUPC.

The Compact Optical Biothreat Rapid Analysis (COBRA) Portable Raman Microscope System exited the pipeline with an identified military customer. The team collaborated with Delta Nu to develop a first generation prototype and a smaller, lower cost model. The first unit produced by Delta Nu has been fully calibrated. Training has been provided to researchers at the United States Army Medical Research Institute for Infectious Diseases (USAMRIID). In January 2010, COBRA III was deployed to USAMRIID and BUPC researchers assisted in follow-up training and set up. Further collaboration is expected as the system transitions into BL3 and BL4 laboratories.

In the upcoming year, it is expected that several programs in the pipeline will be deployed to various agencies for insertion and testing. They include: the Resonant Optical Virus Reader (ROVR), the Neutron Detector and the Photonic Sniffer.

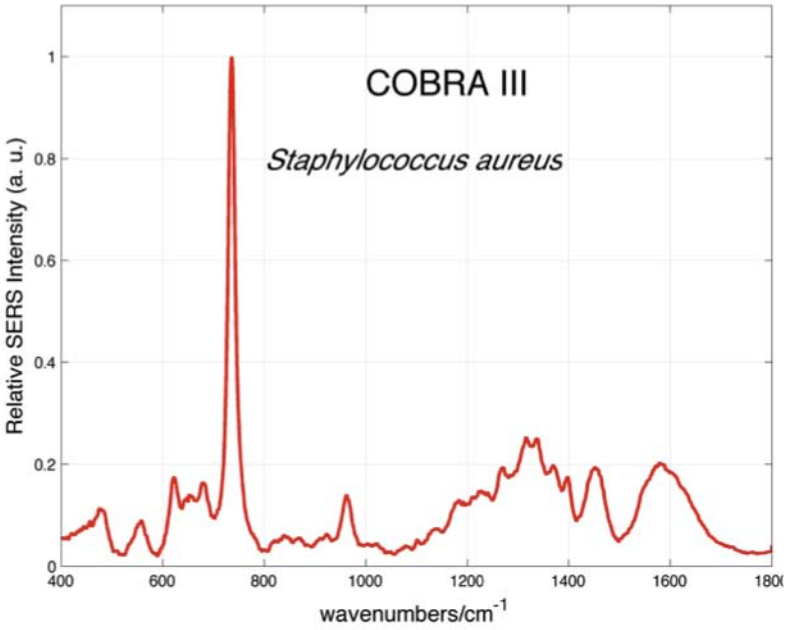
This section outlines the ARL funded programs for this past year.

Phase III Pipeline Project: Optimization and Manufacturability of Surfaced Enhanced Raman Spectroscopy (SERS) Substrates for Biological Detection

Task Manager: Professor Lawrence Ziegler/Dr. Helen Fawcett

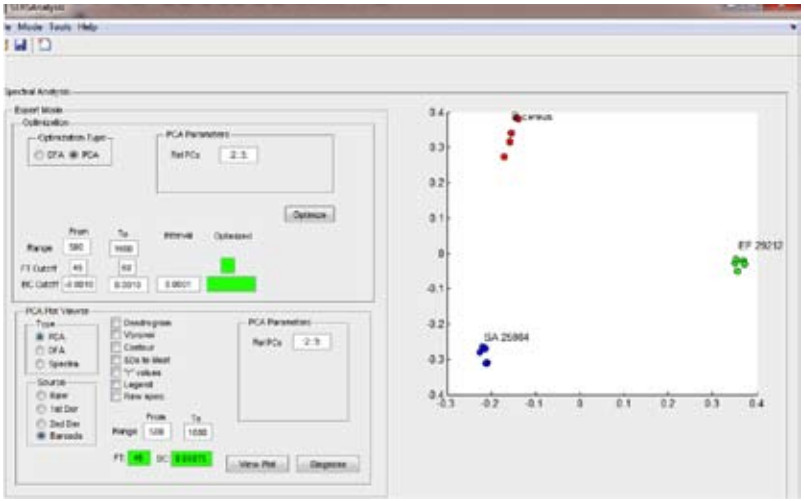
Objective: Final data collection and determination of performance and identification of engineered substrates when compared to the sol-gel chemically manufactured nanostructured metal substrates. Based on this data, the team developed a manufacturing protocol that can transferred to a manufacturing partner.

Approach: Three methodologies were considered for possible substrates developed through rational engineered design. The first was e-beam fabricated structures that were coated with either gold or silver. These substrates were very repeatable; however, the signal to noise ratio (SNR) was not comparable to the sol-gel substrates. The second methodology, taking the e-beam fabricated structures and running them through the reduction process used for sol-gel substrates, provided comparable SNR; however, repeatability and reproducibility became deficiencies in this development. The final strategy, nano-cluster arrays (NCA's), demonstrated consistent performance and SNR comparable to sol-gel substrates.



SERS spectrum Staphylococcus aureus (ATCC 25904); 50x objective, 785 nm, 2.4 mW, 10 sec data collection

A final task of head-to-head identification of closely related species and another bacteria standard used for testing was completed. The data was not conclusive and the sol-gel substrates continued to demonstrate reproducibility and were being fabricated by more than one individual. Based upon this data and testing, the team determined that the final path was to pursue a manufacturing methodology for producing the substrates in a batch process that maintained the repeatability and reproducibility.



Screen capture showing PCA clustering of: S. aureus, Enterococcus faecalis and B. cereus SERS spectra acquired on COBRA III

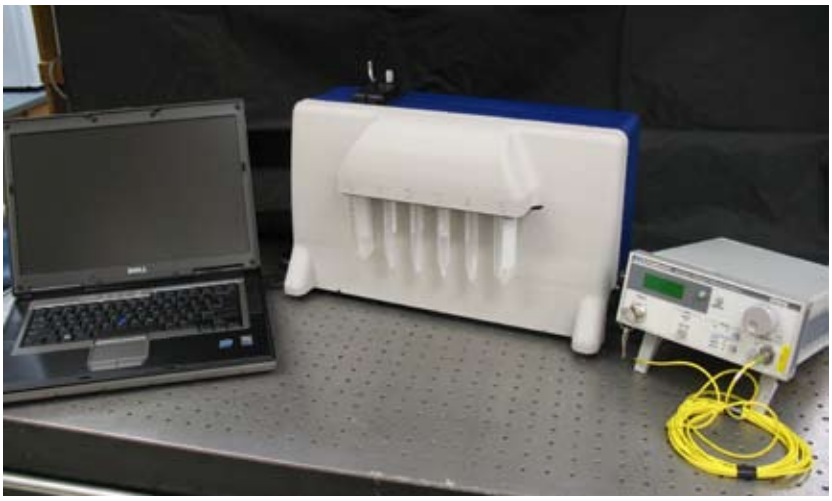
Pipeline Exit: As this project exits the pipeline, funding opportunities from the National Institutes of Health and an external defense company have been established.

Phase III Pipeline Project: Spectral Reflectance Imaging Biosensor (SRIB)

Task Manager: Professor Selim Unlu/Dr. Helen Fawcett

Objective: Develop a label-free antigen detection platform for virus biothreats. The team was challenged with developing a detection platform for antigen as opposed to antibody detection to fulfill the general concept of detection prior to infection.

Approach: SRIB, a label free process, can be used to diagnose and detect numerous distinct molecular biomarkers in a multiplexed format when compared to individual single Enzyme-Linked Immunsorbent Assay (ELISA) test protocols. Throughout the year, the team worked to develop an antigen based capture technology. The main purpose was detection of clinically relevant quantities (10^6 PFU) of a virus within the sample. After many test configurations, the final sensitivity with reproducibility was above the clinically relevant amount. The team determined that this program was not going to fulfill the needs of the military and completed the year with testing and verification for further programs, including the whole virus detection program ROVR.



The Spectral Reflectance Imaging Biosensor System

The SRIB team had previously demonstrated successful antibody detection with the SRIB process. Zoiray Technologies, Inc., a spin off company, has developed a successful business model based upon antibody detection. The team made the decision in the final year to develop a chip and process for antigen detection to minimize the need to wait for a patient to become infected and develop antibodies. This was desired in the case of many pathogens, since the body's development of antibodies can yield to systemic infection, person-to-person transfer, and eventual outbreak or death.

Pipeline Exit: As the project exits the pipeline, Zoiray Technologies is pursuing anitbody based detection as well as an external defense company that is funding a variation of the program.

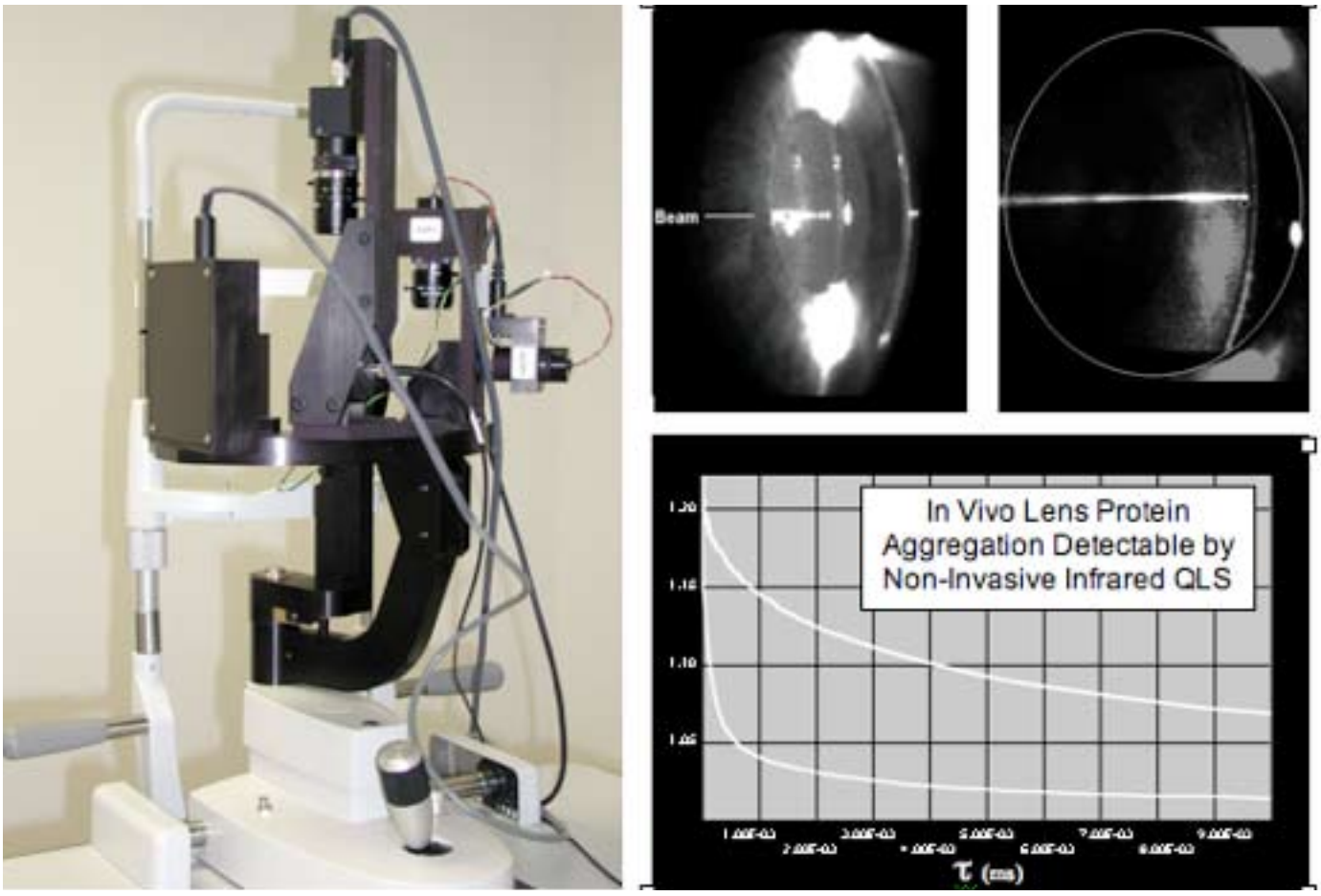
Phase III Pipeline Project: RADSCAN Platform Development and Enhancement

Task Manager: Professor Lee Goldstein/Leah Ziph-Schatzberg

Objective: Perform data analysis involving on-going bio-dosimetry research at Armed Forces Radiology Research Institute (AFRRI) and Lawrence Berkley National Laboratory (LBNL). Refine and enhance instrument operation and post-acquisition analytical algorithms. Characterize and validate RADSCAN instrument.

Approach: The BU team invested significant effort to improve the analytical algorithms and allow data analysis. The LBNL data is still being analyzed, as the research project at LBNL is on-going. The system was refined and tested extensively to demonstrate performance as designed. The system is now ready to be duplicated and deployed at several sites for both bio-dosimetry research as well as Alzheimer Disease (AD) research.

Further Development: The team continues working with LBNL on bio-dosimetry research. In addition, the instrument is being used for AD research.



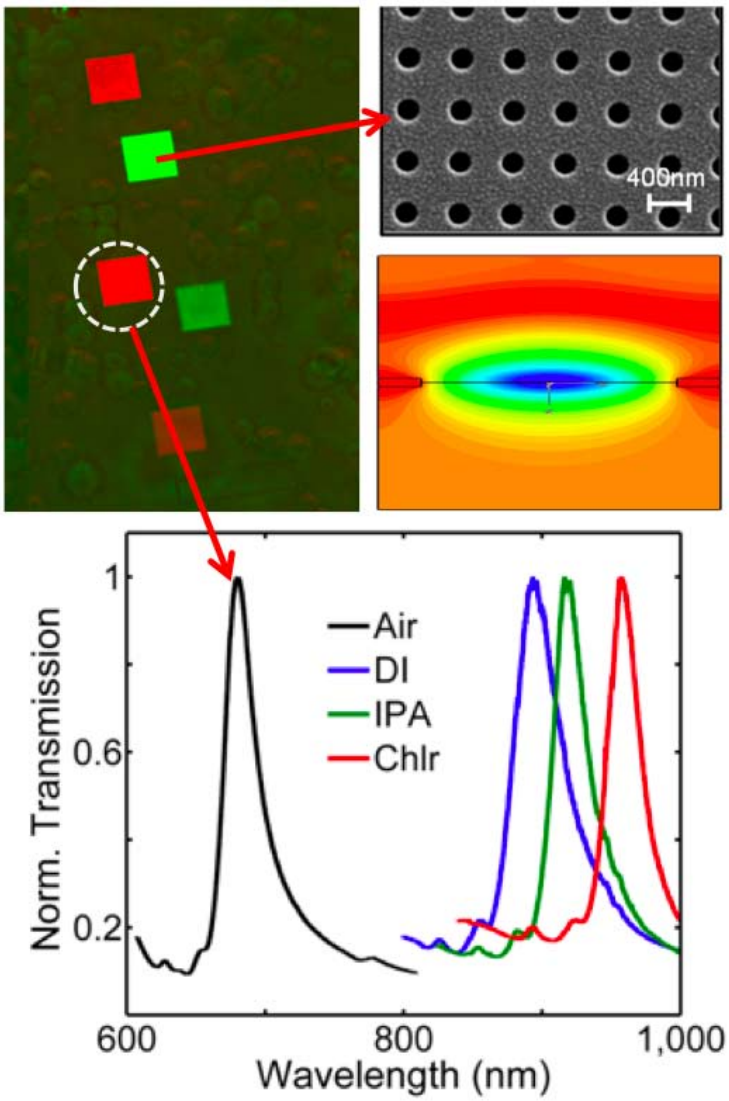
The device (above left) is a prototype for the RADSCAN platform. Using this device researchers can examine cataracts behind the lens of the subject's eye (top right) to determine the detectable protein (bottom right).

Phase I Pipeline Project: Resonant Optical Virus Reader (ROVR)

Task Manager: Professors Hatice Altug and John Connor/Dr. Helen Fawcett

Objective: Validate detection of clinically relevant concentrations of whole virus in serum using Vesicular Stomatitis Virus (VSV) and well developed antibodies against VSV.

Approach: Optical resonances are among the most sensitive optical phenomena to small refractive index modulations in their near-environment. Consequently, it is of great interest to pursue control of resonance effects in photonic structures. One can use photonic crystal (PhC) structures to manipulate light on a chip. By changing the size of one or more holes, one can create nano-scale optical resonators (also known as photonic crystal nanocavities or defects) that can localize light in these defect regions. The exceptional property of PhC nanocavity is that it can localize the light in a very small area (called mode volume) and for a long period of time (related to the Q-factor of the cavity). Employing enhanced resonance effects, namely small mode volume and high Q, dramatically reduces the detection limit of optical resonance based biosensors while increasing their multiplexing capability.



Plasmonic Nanoholes in Sensing.

Further Development: The team demonstrated virus detection (clinically relevant amounts in serum). The strength of the results led to a Phase II pipeline award. This program is a primary example of the synergy with the Medical Campus without whose input into proper clinical preparation and relevance in terms of samples, the engineering team would not be making forward progress in the clinical aspect. The goal for this coming year's program is to develop a virus reader system that can be sent to collaborators for evaluation of technology benefits to current virus detection methodologies.

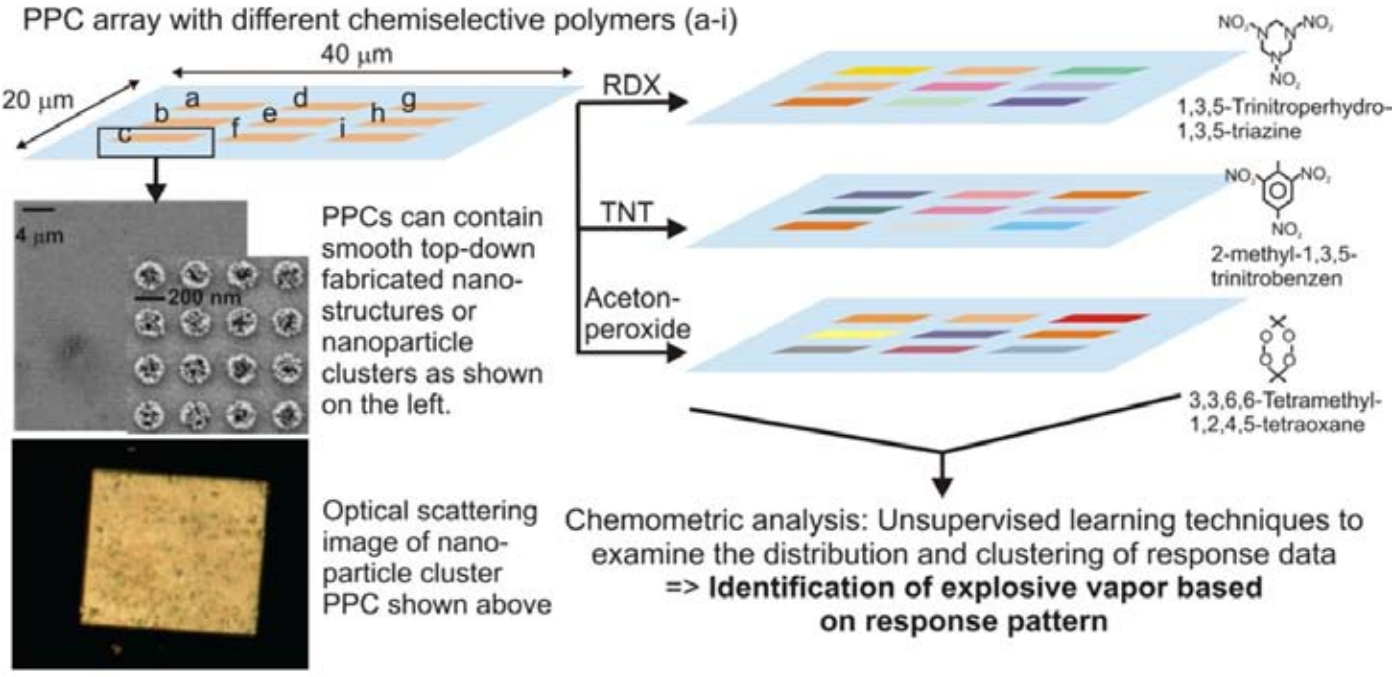
Phase I Pipeline Project: Chemically Enhanced Photonic-Plasmonic Crystals for Explosive Vapor Detection (Photonic Sniffer)

Task Manager: Professor Bjoern Reinhard/Dr. Helen Fawcett

Objective: The goal of this application is to develop a lightweight "photonic nose" that is capable of detecting traces of explosive vapor.

Approach: At the heart of this technology are two-dimensional arrays of gold nanoparticles that support photonic-plasmonic resonances with extremely narrow line shapes in extinction and scattering. The gold particle arrays form two-dimensional photonic-plasmonic crystals (PPCs) whose resonances are tunable through the array morphology. For a fixed geometry, the resonance wavelength depends sensitively on the dielectric permittivity of its environment. The sharpness of the optical resonances facilitates the detection of even small shifts in ε that arise from changes in the chemical environment of the PPCs. We propose to utilize the extraordinary sensitivity of the PPCs for the specific detection of explosives vapors.

Further Development: The team demonstrated chemical detection comparable to state of the art explosive detection limits along with repeatability data to demonstrate consistency. As a result, the team was awarded a Phase II pipeline program in which an industry collaborator will be identified and integrated into the team before the end of Phase II. Plans for this phase also include testing in a mixed environment and with the same protocol as standard chemical detection equipment.

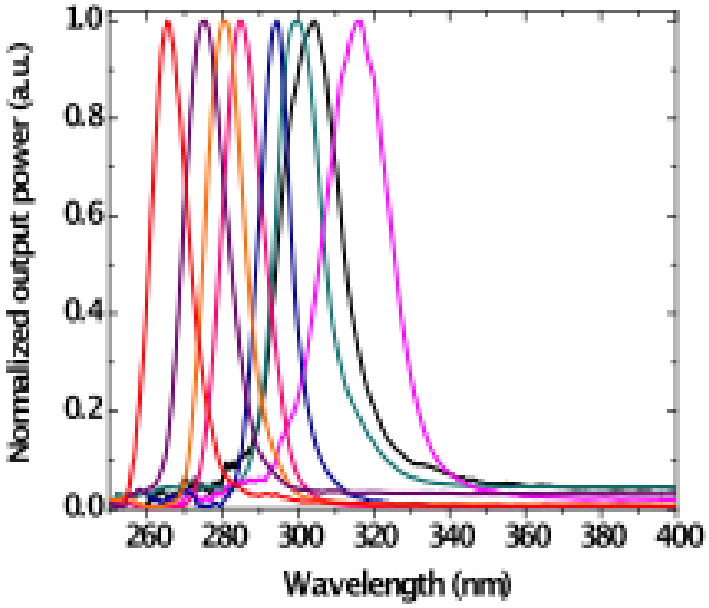


The figure above highlights the physical form of the Photonic-Plasmonic Crystals used in the Photonics Sniffer and the results of a reaction with explosive vapors.

Phase I Pipeline Project: Development of UV LEDs Emitting at 250-260 nm for Water-Air Purification and Surface Sterilization

Task Manager: Professors Enrico Bellotti, Theodore Moustakas and Roberto Paiella/Leah Ziph-Schatzberg

Objective: The team set out to develop electrically pumped UV LEDs emitting at 250-260 nm for water-air purification and surface sterilization applications. UV light at these wavelengths acts on microbiological contaminants in water and air through a process by which adjacent thymine nucleic acids on DNA are dimerized, preventing replication of the microorganisms. This process has been shown to be effective for E. coli, Giardia and even more resistant virus strains such as Adenovirus. The developed robust and non-toxic solid state devices are intended to replace the present low-pressure mercury lamp emitting at 254nm.



The figure above highlights the variety of UV LEDs the Boston University team has developed in recent ARL funded projects.

Approach: The BUPC team is a leader in UV LED material and device development. Throughout the year, the team concentrated on developing high quality AlN templates, heavily doped contact layers and high IQE quantum wells. Throughout the development, the team performed modeling and simulations to predict and understand device performance. Toward the end of the year, the group demonstrated state of the art devices emitting at 273 nm and then initial devices emitting a 265 nm.

Further Development: The team continues to optimize the UV LEDs at the 260 nm range. This year, the team will concentrate on optimizing these devices as well as developing packaging methods to further improve the extraction efficiency of the devices.

Phase I Pipeline Project: Construction of a Field Testable Direction-Sensitive Neutron Detector

Task Manager: Professor Steven Ahlen/Leah Ziph-Schatzberg

Objective: The team's goal was to design and build a portable, field-testable prototype of a direction sensitive neutron detector. This team has developed a new type of detector that can be used to determine neutron flux, energy distribution, and direction of neutron motion. The detector is free of background from x-rays, gamma rays, beta particles, relativistic singly charged particles and cosmic ray neutrons. It is sensitive to thermal neutrons, fission spectrum neutrons, and high-energy neutrons, with detection features distinctive for each energy range. It is capable of determining the location of a source of fission neutrons based on characteristics of elastic scattering of neutrons by helium nuclei.

Approach: The team developed automated image analysis software. The analysis software was used to look at thousands of events and optimize the use of the detector. At the same time, the new portable detector was being designed, built and tested. At the end of the project, the new portable detector was built and is operational. It had been demonstrated at the Photonics Center and will be tested by outside users.

The Direction-Sensitive Neutron Detector

Further Development: The neutron detector will be tested for several Homeland Security and military applications. In parallel, the team will develop technology to replace the current devices that use Helium-3.

FTDAs Selected for ARL Support in FY 2010

The Photonics Center continued its Faculty Technology Development Awards Program (FTDA) selection process for programs starting July 1, 2010. After a general solicitation, proposals were rated by peers from industry, academia, and government agencies . The committee provided written evaluations to the Director of the Center. 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 awards varied depending upon PI request and committee recommendations to the Center Director.

Program	Faculty PI Co-Investigators	Program Manager	FY2010 Pipeline Status
Plasmon-enhanced Stimulated Coherent Raman Spectroscopy	Lawrence Ziegler & Bjoern Reinhard	Helen Fawcett	Phase II
Resonant Optical Virus Reader (ROVR)	Hatice Altug, John Connor & Selim Unlu	Helen Fawcett	Phase II
Photonic Sniffer: Chemically-Enhanced Photonic-Plasmonic Crystals for Explosive Vapor Detection	Bjoern Reinhard & Luca Dal Negro	Helen Fawcett	Phase II
A Thermal Neutron Detector Using Lithium Film in an Optical Time Projection Chamber	Steven Ahlen	Leah Ziph-Schatzberg	Phase I
Nanoplasmonic Infrared Chemical Imaging Spectrometer	Shyam Erramilli, Hatice Altug & Kenneth Rothschild	Leah Ziph-Schatzberg	Phase I
Development of UV LEDs Emitting at 266 nm for Water-Air Purification and Surface Sterilization	Theodore Moustakas	Leah Ziph-Schatzberg	Phase I
A Flexible, Lightweight, Remotely-Accessible THz Source and Detector	Siddharth Ramachandran & Richard Averitt	Leah Ziph-Schatzberg	Phase I
Quantified High-throughput Biomarker Discovery by Mass Spectrometry on Label-Free Arrays	Bennett Goldberg & Mark McComb (BU Medical)	Helen Fawcett	Phase 0

Secure Communicating Optical Ultra-light Transponder (SCOUT)

Task Manager: Leah Ziph-Schatzberg

Objective: The project's goal was to test the SCOUT system retro reflector unit in an underwater communication application. The team was comprised of BUPC and NRL. The testing was done at NRL facilities.

Approach: The SCOUT system was developed at BUPC and demonstrated voice communication at distances of over 200m with 1550nm interrogation detector. NRL wanted to test the system with a green laser (532nm) in an underwater application. BUPC made two retro reflector assemblies for NRL testing. NRL performed the testing and reported on the success of it. The BU retro reflector assemblies performed better than other tested devices. The test determined that the assemblies are suitable for underwater communication application at higher modulation frequencies.

Further Development: NRL is looking for additional funding to continue working on this project. The additional funding will support an electronics redesign to allow the system to perform at higher modulation frequencies.

Retro-Communicator (above)

Transceiver (above)

Students Supported by ARL Cooperative Agreement

Richard Averitt (PHY)
Drew Strikwerda

Luca Dal Negro (ECE)
Ashwin Gopinath
Alyssa Pasquale

Allyn Hubbard (ECE)
Sarah Kelsall
Yirong Pu

Theodore Moustakas (ECE)
Chen-Kai Kao
Yitao Liao

Selim Ünlü (ECE)
Sunmin Ahn
Abdulkadir Yurt
Xirui Zhang

Thomas Bifano (ME)
Alioune Diouf

Shyamsunder Erramilli (PHY)
Alket Mertiri

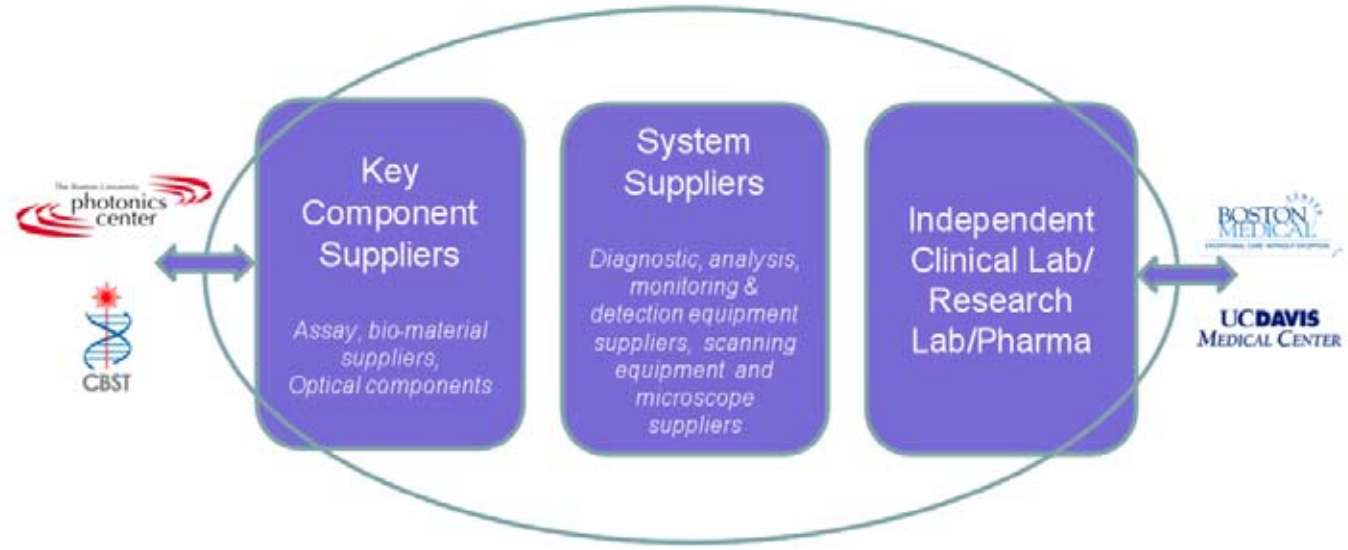
Theodore Morse (ECE)
Andrea Rosales Garcia
Jing Li

Bjoern Reinhard (Phy)
Bo Yan

Dr. Lawrence Ziegler (Chem)
Logan Chieffo
Jude Schneck
Jeffrey Shattuck

Cooperative University/Industry Research and Development

At the beginning of this fiscal year, the Photonics Center was awarded a planning grant by the National Science Foundation (NSF) to establish a national center for biophotonic sensors and systems research. This proposal was submitted under the NSF program: Industry/University Collaborative Research Centers (I/UCRC). The proposed center would be called the Center for Biophotonic Sensors and Systems (CBSS). The Photonics Center is collaborating with the University of California at Davis (UCD) on this proposal. UCD's involvement enhances the Center's mission to create a national resource for biophotonic sensors research. The Photonics Center, BU Medical Campus and the corresponding elements at UCD would anchor this new center. Industrial members would primarily support CBSS across the industrial value chain (Components, Equipment / Instrumentation, and End Users) as depicted below:



The engagement with potential industrial partners has provided the Photonics Center with an opportunity to formulate a cohesive research strategy and strengthen its focus on biophotonic research. While not yet achieving critical mass to kick-off the I/UCRC planning workshop, the industrial engagements have resulted in tremendous financial benefits to the Photonic Center with respect to directed research programs under two-party Sponsored Research Agreements.

Additionally, there has been significant interest among women or minority owned businesses desiring to take advantage of the Supplemental Opportunity for SBIR/STTR Membership offered by NSF. While these companies may not currently qualify, they are excited about the prospects of participating in CBSS and plan to become more active participants in the NSF SBIR/STTR process in order to qualify for subsequent I/UCRC funding opportunities. The Business Incubator at the Photonics Center could also prove to play a key role in advancing the readiness of these small companies for participation in the proposed I/UCRC.

After negotiating the date of the workshop with NSF our kick-off workshop was held in August, 2010 with approximately twenty different industrial firms participating.

Education
education

One of the most important missions of the Boston University Photonics Center is education. Center faculty members teach many photonics related courses in addition to their core area of expertise. BUPC faculty members also mentor undergraduate, graduate, and post-doctoral student and fellows working in their research laboratories.

The Center encourages collaboration and mentorship through its Fellowship program. The program recruits top incoming graduate students to the university while helping support those graduate students currently immersed in Photonics Center faculty laboratories. Through these programs, students participate in Photonics Center activities and work with the community in our shared laboratories. In the laboratories, students help train users and also assist lab managers with equipment troubleshooting and maintenance.

Each year, Center students participate in a variety of educational opportunities supported by Photonics Center staff. Students present during research poster sessions at the university-wide Science and Engineering Day and the Boston University Photonics Center Future of Light Symposium. These events give students the opportunity to highlight their cutting edge research and collaborations with the various departments. To further highlight the Center's commitment to supporting a variety of student opportunities, the Center continued its support of the Research Experiences for Undergraduates (REU) in Photonics program. The Center also supported the formation of student SPIE and OSA chapters.

Graduated Doctoral Students

Summer 2009

Student	*Program of Study*	*Advisor*
David Voss	PhD in Electrical Engineering	Fritz

Fall 2009

Student	*Program of Study*	*Advisor*
Danilo D'Orsogna	PhD in Electrical Engineering	Bellotti
Sylvain Gioux	PhD in Biomedical Engineering	Bigio
David Freedman	PhD in Electrical Engineering	Hubbard
Nishant Mohan	PhD in Biomedical Engineering	Teich

Spring 2010

Student	*Program of Study*	*Advisor*
Alioune Diouf	PhD in Mechanical Engineering	Bifano
Kurt Schoener	PhD in Biomedical Engineering	Bigio
Ashwin Gopinath	PhD in Electrical Engineering	Dal Negro
Rui Li	PhD in Electrical Engineering	Dal Negro
Jonathan Niehof	PhD in Astronomy	Fritz
Brian Walsh	PhD in Astronomy	Fritz
Douglas Carssow	PhD in Electrical Engineering	Hubbard
Marianne Nourzad	PhD in Electrical Engineering	Hubbard
Majd Matta	PhD in Astronomy	Mendillo
Carl Schmidt	PhD in Astronomy	Mendillo
Guoxin Rong	PhD in Chemistry	Reinhard
Anupama Thubagere Jagadeesh	PhD in Chemistry	Reinhard
Hongyun Wang	PhD in Chemistry	Reinhard
Bo Yan	PhD in Chemistry	Reinhard
Fatih Koklu	PhD in Electrical Engineering	Unlu
Yiling Qiu	PhD in Mechanical Engineering	Zhang
Hu Tao	PhD in Mechanical Engineering	Zhang

Selected Photonics Related Courses

CAS PY 522 (Averitt)
Electromagnetic Theory II
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 EC 574 (Bellotti)
Physics of Semiconductor Materials
This course teaches the relevant notions of quantum mechanics and solid state physics necessary to understand the operation and the design of modern semiconductor devices. Specifically, this course focuses on the engineering aspects of solid state physics that are important to study the electrical and optical properties of semiconductor materials and devices. Particular emphasis is placed on the analysis of the electronic structure of semiconductor bulk systems and low-dimensional structures, the study of the carrier transport properties and the calculation of the optical response that are relevant to the design and optimization of electronics and photonics semiconductor devices. The students will learn to apply the quantum mechanical formalism to the solution of basic engineering device problems (quantum wells, wires, and dots, 2D electron gas) and to perform numerical calculation on more complex systems (band structure calculation of bulk and low dimensional systems).

ENG EC 771 (Bellotti)
Physics of Compound Semiconductor Devices
Physics of present-day compound devices, and emerging devices based on quantum mechanical phenomena. MESFETs, Transferred Electron Devices, avalanche diodes, photodetectors, and light emitters. Quantum mechanical devices based on low dimensionality confinement through the formation of heterojunctions, quantum wells, and superlattices. High electron mobility transistors, resonant tunneling diodes, quantum detectors, and lasers. Materials growth and characterization are integral to the course.

ENG EC 575 (Bellotti)
Semiconductor Devices
Fundamentals of carrier generation, transport, recombination, and storage in semiconductors. Physical principles of operation of the PN junction, metal-semiconductor contact, bipolar junction transistor, 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.

ENG EK 720 (Bifano)
Biophotonic System Design and Prototyping
Theory and practice of biophotonic instrument design with application to biomedical devices. Students will work on problems introduced and defined by physicians and clinical researchers, to develop new medical products from concept to prototype design and development. Students in physics, chemistry, and engineering will learn fundamentals of biophotonics sensors and systems development and prototyping for three end uses: in vivo platforms, exploring innovative techniques for sub-cellular imaging of biomolecular structure and interactions in living tissue; resonant and interferometric biosensors, exploring resonance-enhanced photonic pathogen detection or disease diagnosis with

high sensitivity and specificity; and point-of-care diagnosis, exploring rapid, low-cost spectroscopic and imaging techniques that will add to our understanding biological behavior at the molecular level and will lead to important new tools for biomedicine, particularly in areas where there are currently few means of diagnosis. The course provides foundational instruction with respect to core photonic and biomedical design principles, and a case-study based instructional approach to technology transfer and prototyping. Semester-long projects conducted by interdisciplinary teams involve design and prototyping based on problems introduced by practitioners and researchers identified by a regional health care consortium.

ENG BE 466 (Bigio)
Biomedical Engineering Senior Project
Completion of project in an area of biomedical engineering, such as biomedical instrumentation and electronics, biological signal processing, biological modeling and simulation, or clinical informational systems. Training in technical project presentation techniques. Includes progress reports, abstracts, final reports, and oral presentation. The faculty must approve written final report.

ENG EC 560 (Dal Negro)
Introduction to Photonics
Introduction to ray optics; matrix optics; wave optics; Fourier optics; electromagnetic optics including absorption and dispersion. Polarization, reflection and refraction, anisotropic media, liquid crystals, and polarization devices. Guided-wave and fiber optics. Nanophotonics. Laboratory experiments: interference; diffraction and Fourier optics; polarization; fiber optics.

ENG EC 770 (Dal Negro)
Guided-wave Optoelectronics
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.

ENG ME 516 (Ekinci)
Statistical Mechanical Concepts in Engineering
Specific prerequisites vary according to topic, but do not extend beyond what is covered in the core courses in the undergraduate curriculum in mechanical engineering. Elementary introduction to selected fundamental concepts in probability, random processes, signal processing, and statistical mechanics with strong emphasis on their applications to aerospace and mechanical engineering. Examples taken from acoustics, mechanics, thermodynamics, and fluid dynamics.

GRS PY 897 (Erramilli)
Seminar: Special Topics in Experimental Physics
Surface physics; intermediate energy nuclear physics experiments; low temperature techniques, liquid and solid helium, and magnetism at low temperatures. Raman effect, gels, and biophysics. High-energy physics experimental techniques.

GRS AS 703 (Fritz)
Introduction to Space Physics
Survey of physical phenomena in the sun, solar wind, magnetospheres, ionospheres, and upper atmospheres of objects in the solar system. Introduction to the physical processes governing space plasmas, solar-terrestrial interactions, and ionized and neutral media surrounding the Earth and other solar system bodies.

ENG EC 571 (Hubbard)
VLSI Principles and Applications
Very-large-scale integrated circuit design. Review of FET basics. Functional module design, including BiCMOS, combinational and sequential logic, programmable logic arrays, finite-state machines, ROM, and RAM. Fabrication techniques, layout strategies, scalable design rules, design-rule checking, and guidelines for testing and testability. Analysis of factors affecting speed of charge transfer, power requirements, control and minimization of parasitic effects, survey of VLSI applications. Extensive CAD laboratory accompanies course.

ENG ME 523 (Klapperich)
Mechanics of Biomaterials
Covers the chemical composition, physical structure, and mechanical behavior of engineering polymers. Study of types of polymers; rubber elasticity; fundamentals of viscoelastic phenomena such as creep, stress relaxation, stress rupture, mechanical damping, impact; effects of chemical composition and structure on viscoelastic and strength properties; methods of chemical property evaluation. Fracture and fatigue of polymer materials. Influences of plastics fabrication methods on mechanical properties. Emphasis on recent research techniques and results. Students will complete a semester-long project.

ENG ME 504 (Klapperich)
Polymers and Soft Materials
An introduction to soft matter for students with background in materials science, chemistry, and physics. This course covers general aspects of structures, properties, and applications of soft materials such as polymers, colloids, liquid crystals, amphiphiles, gels, and biomaterials. Emphasis on chemistry and forces related to molecular self-assembly. Topics include forces, energies, kinetics in material synthesis, growth and transformation; methods for preparing synthetic materials; formation, assembly, phase behavior, and molecular ordering of synthetic soft materials; structure, function, and phase transition of natural materials such as nucleic acids, proteins, polysaccharides, and lipids; techniques for characterizing the structure, phase, and dynamics of soft materials; application of soft materials in nanotechnology.

ENG EC 773 (Mertz)
Advanced Optical Microscopy and Biological Imaging
This course will present a rigorous and detailed overview of the theory of optical microscopy starting from basic notions in light propagation and covering advanced concepts in imaging theory such as Fourier optics and partial coherence. Topics will include basic geometric optics, photometry, diffraction, optical transfer functions, phase contrast microscopy, 3D imaging theory, basic scattering and fluorescence theory, imaging in turbid media, confocal microscopy, optical coherence tomography (OCT), holographic microscopy, fluorescence correlation spectroscopy (FCS), fluorescence resonant energy transfer (FRET), and nonlinear-optics based techniques such as two-photon excited fluorescence (TPEF) and second-harmonic generation (SHG) microscopy. Biological applications such as calcium and membrane-potential imaging will be discussed. A background in optics is preferable. A background in signals and analysis is indispensable. In particular, the student should be comfortable with Fourier transforms, complex analysis, and transfer functions.

ENG EC 563 (Morse)
Fiber-Optic Communication Systems
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 splices, 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.

ENG EC 577 (Moustakas)

Electronic Optical and Magnetic Properties of Materials

This course in intended to develop an in depth knowledge of solid state concepts that are important for students in the areas of material science and electrical engineering. Specifically, this course focuses on the study of different apsect of solid state physics necessary to study technologically relevant crytalline and amorphous systems. Particular enphasis is placed on the study of the crystal structure, crystal diffraction and the related techniques used as diagnostic tools; the electronic, thermal, optical and magnetic properties of material systems important for electronics and photonics device applications. Furthermore the course will also consider the theory of superconductivity, the chemistry aspcts of solid state materials and will provide an introduction to solid state biophysics.

ENG EC 560 (Paiella)

Introduction to Photonics

Introduction to ray optics; matrix optics; wave optics; Fourier optics; electromagnetic optics including absorption and dispersion. Polarization, reflection and refraction, anisotropic media, liquid crystals, and polarization devices. Guided-wave and fiber optics. Nanophotonics. Laboratory experiments: interference; diffraction and Fourier optics; polarization; fiber optics.

ENG EC 591 (Paiella)

Photonics Lab I

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.

GRS CH 655 (Reinhard)

Statistical Mechanics I

Introduction to statistical mechanical fundamentals; ensemble theory, Fermi-Dirac, Bose-Einstein, Gibbs-Boltzmann statistics; computational methods, Monte Carlo, Molecular Dynamics, many-body quantum mechanical simulations, normal mode analysis; ergodic hypothesis, modern theories of liquids and biomolecules, thermodynamic perturbation theory, integral equations, Debye-Huckel theory.

ENG BE 567 (Ritt)

Nonlinear Systems in Biomedical Engineering

Introduction to nonlinear dynamical systems in biomedical engineering. Qualitative, analytical and computational techniques. Stability, bifurcations, oscillations, multistability, hysteresis, multiple time-scales, chaos. Introduction to experimental data analysis and control techniques. Applications discussed include population dynamics, biochemical systems, genetic circuits, neural oscillators, etc.

GRS PY 771 (Rothschild)

Biophysics

Introduction to biomolecular forces, energy flow, and thermodynamics in biological systems. Hydrophobic interactions and membrane structure. Feedback and control mechanisms; allosteric enzymes. Mechanisms of transport in biological membranes. Emphasis on the physical principles underlying biological structure and function.

ENG ME 560 (Sharon)

Precision Machine Design and Instrumentation

This interdisciplinary course teaches the student how to design, instrument, and control high-precision, computer-controlled automation equipment, using concrete examples drawn from the photonics, biotech, and semi-conductor industries. Topics covered include design strategy, high-precision mechanical components, sensors and measurement, servo control, design for controllability, control software development, controller hardware, as well as automated error detection and recovery. Students will work in teams, both in-classroom and out-of-classroom, to integrate and apply the material covered in class to a term-long multi-part design project in PTC Pro-Engineer or other comparable CAD system, culminating in a group presentation at the end of the class.

ENG EC 764 (Swan)

Optical Measurement

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 EC 570 (Teich)

Lasers

Review of wave optics. Gaussian, Hermite-Gaussian, Laguerre-Gaussian, and Bessel optical beams. Planar- and spherical-mirror resonators; microresonators. Photons and photon streams. Energy levels; absorption, spontaneous emission, and simulated emission. Thermal and scattered light. Laser amplification and gain saturation. Laser oscillation. Common lasers and introduction to pulsed lasers. Photon interactions in semiconductors. LEDs, laser diodes, quantum-confined lasers, and microcavity lasers. Introductoin to photon detectors. Laboratory experiments: beam optics; longitudinal laser modes; laser-diode output characteristics.

ENG EC 763 (Teich)

Nonlinear and Ultrafast Optics

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.

MET AD 667 (Unger)

Innovation, Global Competitiveness, and National Economic Development

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 740 (Unger)
Planning and Operating New Ventures
Includes opportunity assessment and feasibility analysis, concept development, budgeting and financial operations, financial and human resource management, legal and organizational issues, role of boards and external advisors that lead to the writing of a business plan.

MET AD 741 (Unger)
The Innovation Process: Developing New Products and Services
Addresses the specifics of new product and service development and fostering innovation and technology to increase performance. Topics include generating and screening initial ideas; assessing user needs and interests; forecasting results; launching, and improving products and programs; bringing innovation to commercial reality.

ENG MS 555 (Zhang)
MEMS: Fabrication and Materials
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 ENGME555. Students may not receive credit for both.

GRS CH 652 (Ziegler)
Molecular Quantum Mechanics II
The chemical bond; Huckel, molecular orbital, and valence bond theories; ab initio methods, density functional theory; Born-Oppenheimer approximation/breakdown; time-dependent processes; Fermi's golden rule; non-adiabaticity; time-dependent perturbation theory; computational methods.

Photonics Center Fellowship Program

Since 2006, the Photonics Center Fellowship Program has been divided into two categories: Junior and Senior Fellowships. Junior Fellowships were intended for newly matriculating graduate students. Senior Fellowships were intended to support continuing students in BU PhD programs who were advised by BUPC faculty.

This past year, Senior Fellowship recipients completed internships in shared laboratory facilities that closely aligned with their research programs. Some of the fellows were previously trained as "super-users" of equipment, while others were new to shared laboratories. Fellows unaccustomed to the labs were aligned with newer pieces of equipment in order to participate in the installation and subsequent training to all shared laboratory users. Two Senior Fellowship recipients were awarded a full year (12 months) of support and two were awarded an academic year (8 months) of support. In addition to the shared laboratory responsibilities, Senior Fellowship recipients were active members in assisting with the annual Future of Light Symposium as well as student poster participants in both the Symposium and the Science and Engineering Day.

One Junior Fellowship recipient was recruited for admission to the Department of Electrical and Computer Engineering. This fellow assisted in organizing and hosting the monthly Photonics Forums. The student worked with the Photonics staff to select faculty and student speakers. This student was given the opportunity to meet a variety of faculty members, leading to a possible research collaboration and mentoring. In addition, the Junior Fellow worked in Precision Measurement Laboratory.

Academic Year 2009-2010 Photonics Fellowship Recipients

Student	***Dept.***	***Advisor***	***Staff Contact***	***Service***
Ronen Adato	ECE	Altug	Anlee Krupp	Zeiss/E-beam
Arif Cetin	ECE	Altug	Anlee Krupp/ Keith Crook	AFM /Zeiss/E-beam Photonics Forums
Kebin Fan	ME	Zhang	Paul Mak	Heidelberg/Photolithography
Alexander Kitt	Physics	Goldberg	Paul Mak	Coatings
Daryl Lim	BME	Mertz	Keith Crook	Seminars

New Photonics Center Dean's Fellowship Program

For the 2010-2011 academic year, we have changed the Photonics Fellowship Program. As a result, the Photonics Center Dean's Fellowship process now aligns with the standard Dean's Fellowship program supported by the Graduate Schools of Arts and Sciences (GRS) and Engineering. Below is a summary of the requirements for fellowship candidates:

Fellowship Candidates must be from Photonics Center Affiliated Departments:

- College of Arts and Sciences (CAS):
    - Physics
    - Chemistry
    - Astronomy/Space Physics
- College of Engineering (ENG):
    - Biomedical Engineering
    - Electrical and Computer Engineering
    - Mechanical Engineering
- School of Medicine:
    - Microbiology
    - Psychiatry

Photonics Center Dean's Fellowships require research alignment with Photonics Center faculty members. Graduate applications must identify:

- Interest in working with a Photonics Center faculty member or group
- Interest in specific graduate research topics in photonics

Responsibilities of Photonics Center Dean's Fellowship recipients include:

- Completing at least one rotation or research program in a Photonics Center faculty laboratory
- Participating in Photonics Center community activities

The recipients for the 2010-2011 academic year are Jinwang Tan in Mechanical Engineering, Linxi Wu in Chemistry and Lingyue Cao in Physics. Jinwang Tan is joining BU from the University of Missouri at Columbia with a Masters in Biomedical Engineering. He will work with Professors Xin Zhang and Catherine Klapperich. Linxi Wu is joining BU from Peking University in Beijing, China with a BS in Chemistry. She will work with Professor Bjoern Reinhard's group. Lingyue Cao is joining BU from Nanjing University with a BS in Physics. He will work with Professor Averitt's group.

Science and Engineering Day

On March 30, 2010, the University hosted its annual Science and Engineering Day. This event is held each year in the George Sherman Union and gives students from all science and engineering disciplines the opportunity to share their current research endeavors. Each year, the Photonics Center sponsors a prize for this event, the Herbert J. Berman "Future of Light" Prize.

The Photonics Center would like to congratulate the Photonics Center graduate students who won prizes at this year's event:

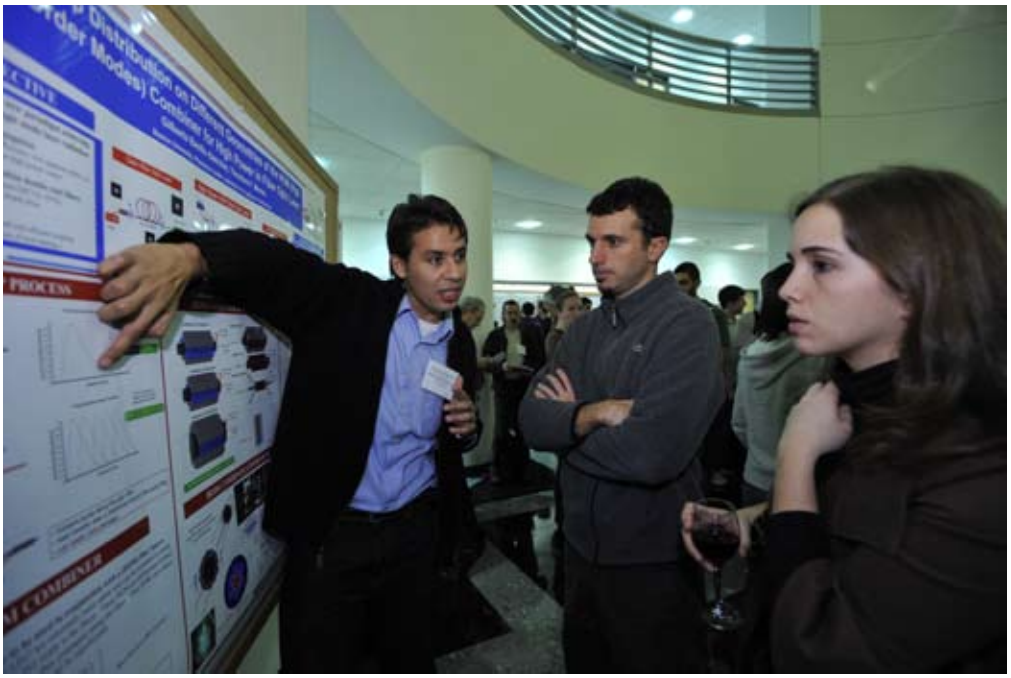
College of Engineering Dean's Award
Winner: Gilberto Basilio-Sanchez
Advisor: Theodore Morse

Center for Nanoscience and Nanobiotechnology Award
Winner: Ronan Adato
Advisor: Hatice Altug

Office of Technology Development Award
Winner: Gilberto Basilio-Sanchez
Advisor: Theodore Morse

Center for Subsurface Sensing and Imaging Systems Award
Winner: Margo Monroe
Advisor: Selim Unlu

Gordon CenSSIS and Smart Lighting Center Award
Winner: George Daaboul
Advisor: Selim Unlu

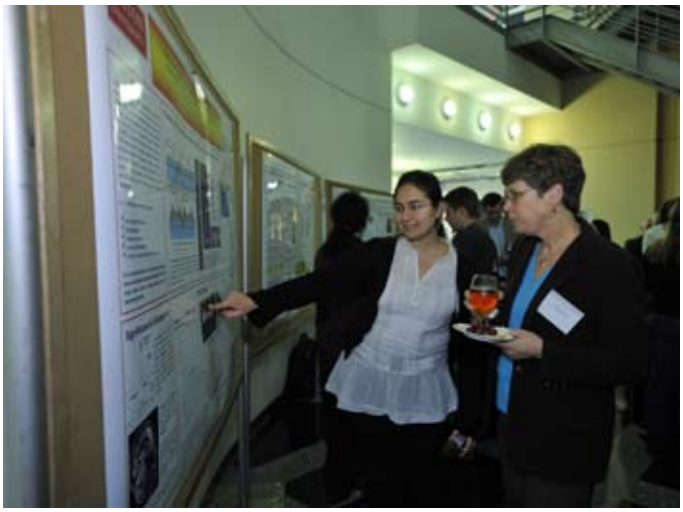


Gilberto Basilio-Sanchez (left) presenting his poster to fellow graduate students

Future of Light Symposium Poster Session

As part of this year's Future of Light Symposium, the Photonics Center held its annual student poster session. Over 30 graduate and post-doctoral researchers participated in this year's poster session. The poster session provides researchers with the opportunity to discuss their work with symposium attendees and speakers from a variety of academic and industrial institutions.

Daryl Lim and Nenad Bozinovic discuss their work with Professor Singh



BUPC Staff member, Leah Ziph-Schatzberg, listens to a graduate student's presentation

Professor Sergienko and Dr. Lev Perelman discuss the work of Olga Minaeva

Dr. Mahadevan-Jansen discusses her work at Vanderbilt University with symposium guests

Research Experiences for Undergraduates in Photonics Program

Three students participated in the 2009 Research Experience for Undergraduates (REU) in Photonics program at Boston University. The National Science Foundation (NSF) directly funded two positions while the College of Engineering and the Photonics Center contributed additional support for the remaining student.

The program goals are to:

- Educate science, math, and engineering undergraduates in the emerging technology of photonics
- Mentor students in the planning and conduct of independent research in photonics and related application fields
- Attract promising undergraduate students from diverse groups and from across the nation into graduate study in photonics
- Encourage women and under-represented minorities to pursue advanced study in this technologically critical area
- Prepare students for the responsible conduct of research based on an innovative campus program for undergraduate research students

In this fourth and final year of the program, students worked in laboratories associated with the Boston University Photonics Center and with faculty pursuing photonics-related research in their home department. REU students were integrated into faculty labs and were assigned the challenge of solving a problem from an existing research project. This approach provides students an opportunity to work on an interesting research topic and see its impact on the larger program.

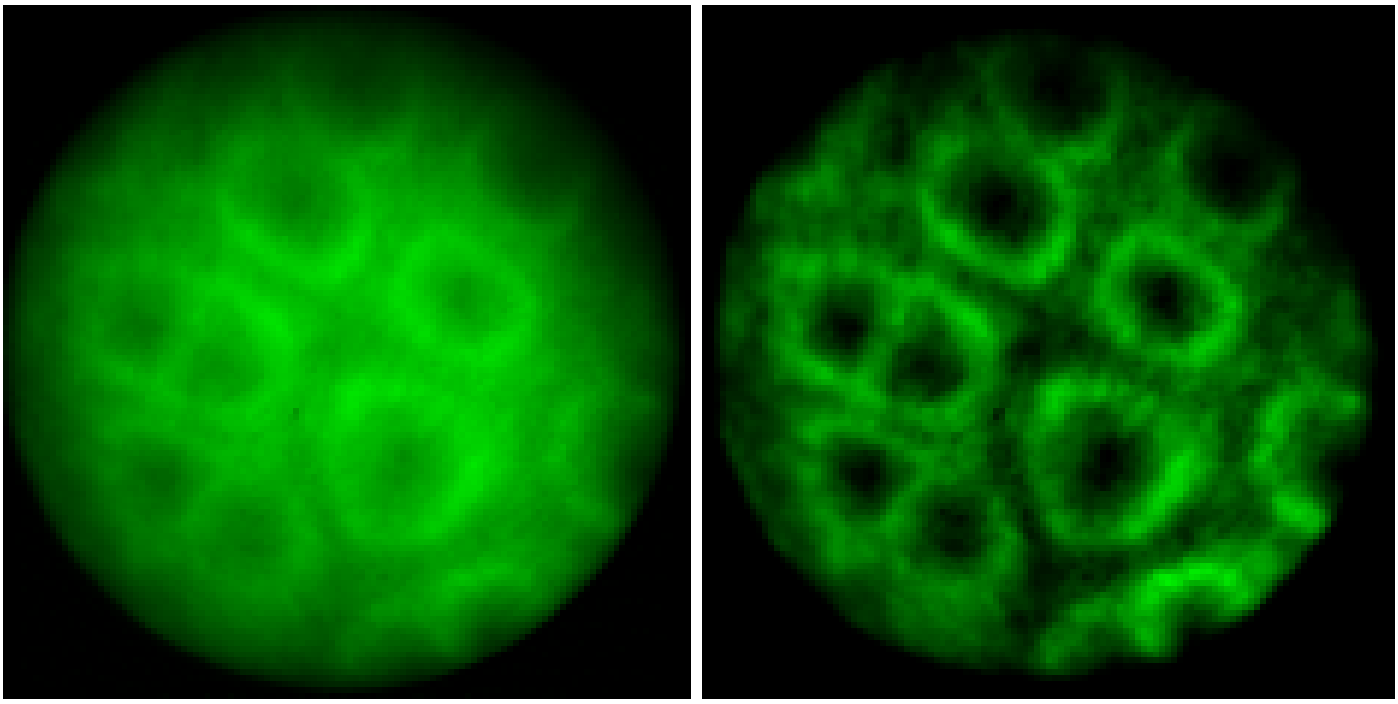
Undergraduate Students working during their 8-week Research Experience

Research Experiences for Teachers in Photonics Program

In June 2010, Professor Michael Ruane received a NSF funded award for a three-year summer Research Experiences for Teachers (RET) program in Biophotonics. The program is hosted by the Boston University Photonics Center in order to connect area teachers with researchers conducting a wide breadth of photonics research and technology development.

This Research Experiences for Teachers (RET) in biophotonic sensors and systems concentrates on three intertwined pillars of worldwide biophotonics research to create a cohesive research experience for the teacher participants. The award allocates funding for two-person teacher teams, comprising of one science subject teacher and one elementary or pre-service teacher. Each team focuses on one of three broad areas: in-vivo biophotonic imaging, resonant and interferometric biosensors, and point-of-care biophotonic systems. A graduate student mentor or post-doctoral researcher will support each team.

Each year, potential projects are identified and shared with applicants during the recruiting process. Project teams will depend on the pool of accepted teachers and available projects. Teams will receive weekly research training and pedagogical support for developing classroom materials. Labs will receive $500 per teacher for materials and expendables. This is the first BU RET in Engineering site supported by NSF and will continue in 2011 and 2012 with 5-teacher teams. The projects and teacher teams were recruited in early June and the program will run from June 28 – August 6, 2010.



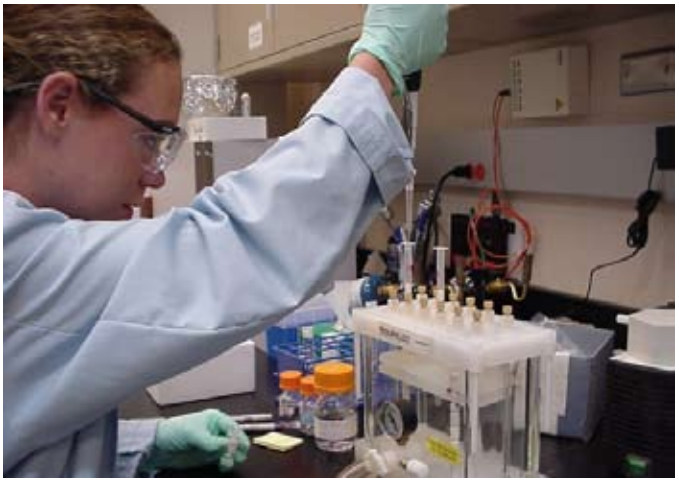
Biophotonic imaging project – these photographs represent endo-microscopic images of fluorescently labeled mouse colon tissue with standard wide field imaging (left) and HiLo imaging (right) through an optical fiber bundle. Note out-of-focus background rejection in HiLo imaging. Field of view is 250μm.

Four Schools for Women in Engineering

Professor Anna Swan, along with several professors from area universities, received a grant to continue their work with their university Science, Technology, Engineering and Mathematics (STEM) teams. The STEM teams are a part of a three-year NSF supported program called Four Schools for Women in Engineering.

The mission of the program is to develop innovative practices for integrating engineering with science, technology, and mathematics into middle school classrooms using gender-inclusive approaches. The practices and lessons developed are designed to provide a model for national dissemination of engineering into K-12 with emphasis on serving girls and women. The program consists of four STEM Teams. Each team is associated with one university.

The teams consists of faculty, staff, and students from Northeastern University, Tufts University, Boston University and Worcester Polytechnic Institute. This collaborative effort also involves engineers from Raytheon, Intel, Verizon, and EMC as well as teachers from Boston, Worcester, Malden, Brookline, and Cambridge middle schools. The STEM team members are typically female faculty, engineers, college students, and teachers providing a strong role model for girls in middle schools. Assessment of the program was conducted by the Wellesley Center for Women.



Middle school students participating in STEM curriculum developed by the Four Schools for Women in Engineering teams.

Boston Urban Fellows Project

Professor Bennett Goldberg continued work as principal investigator this year with the Boston Urban Fellows Project. The Boston University Urban Fellows Project is a 10-year NSF supported program to institute a sustainable model of immersing K-12 teaching partnerships within urban school systems for graduate fellows in sciences and engineering.

This project has further strengthened the existing relationships between Boston University and the Chelsea, Quincy, and Boston urban school districts. The Boston Urban Fellows Project has trained 67 K-12 fellows in urban schools and worked with more than 200 classrooms since it was established 6 years ago. The project's support staff provides content support, curriculum materials, and role models for more than 5,000 children. The project's graduate student 2-credit seminar course in science education is in its 4th year and provides for fellow training on how to teach concepts in the classroom.

Teaching fellows learn new curriculum techniques from their Boston Urban Fellow Mentors.

Formation of New OSA and SPIE Student Chapters

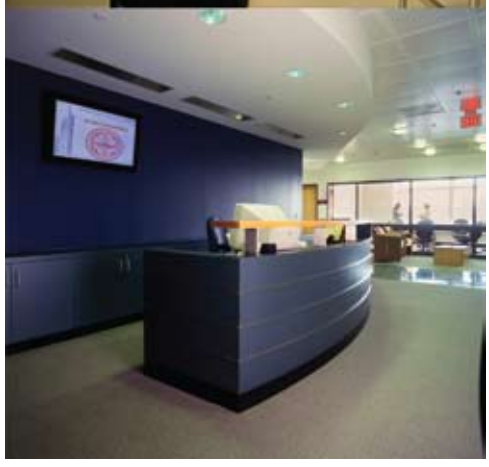
This year the Photonics Center supported and facilitated the initiation of two new optics and photonics related student chapters at Boston University. The student chapters are affiliated with the Optical Society of America (OSA) and with SPIE. SPIE is an international society advancing an interdisciplinary approach to the science and application of light. Both organizations provide student chapter members with networking opportunities for students with an interest in optics and photonics. They also provide start-up funds and travel grants for chapter members to attend conferences.

Since forming in October, 2009, the chapters have organized two student lunches for networking and community building as well as a photography contest with an award ceremony. The chapters co-hosted a lecture at the Photonics Center with the New England section of OSA on imaging inside the coronary arteries with Optical Coherence Tomography. The student chapter also sponsored a student industry forum with speakers from companies such as: Optikos Corporation, InfraReDx, BAE Systems, and Karl Storz Endoskope. This gave members an opportunity to meet and network with people from industry. This event was held with the New England section of OSA.

Hu "Tiger" Tao (left) standing next to his first place winning photo entry for the SPIE/OSA Photonics Photography Competition (right)

Facilities and Equipment

facilities and equipment



The Boston University Photonics Center first opened in June 1997 as a unique national resource for academic research in photonics. The facility has ten floors consisting of 235,000 net square feet of space including: classrooms, conference rooms, faculty offices, educational laboratories, faculty research laboratories and three shared laboratories managed by the Photonics Center.

The Center's faculty, students, and incubator companies utilize these core-shared facilities. Every year upgrades are made to the three-shared laboratories to ensure faculty and student research is being supported and maintained at exceptional levels.

The business incubator is another unique aspect of the Photonics Center. Located on the 6th floor, the incubator provides 23,000 square feet of flexible space that can be configured to house up to 14 start-up companies. This space offers start-up companies state-of-the-art facilities and a collaborative environment with faculty and students.

As an added benefit to Center membership, new faculty members joining the Photonics Center are provided with Photonics staff assistance in laboratory design. This year, Professors Kamil Ekinci Bjoern Reinhard and Siddharth Ramachandran moved their laboratories into the Photonics Center.

Shared Laboratories

The Photonics Center operates three shared facilities that are utilized by Boston University faculty, staff, students, and incubator companies. The Optoelectronic Processing Facility (OPF) includes a Class 100 photolithography cleanroom and an exterior Class 1000 cleanroom with processing and test equipment for die and wafer level processing. The Integrated Optics Laboratory (IOL) includes a flip chip bonding system in the Class 100 cleanroom and a standard laboratory space next door for spectroscopy measurements. The Precision Measurement Laboratory (PML) spans two laboratory spaces with scanning electron and atomic force microscopy among other analytical surface characterization tools.

Optoelectronic Processing Facility (OPF)

OPF is a multi-user facility located on the 8th floor of the Photonics Center. Within its 2500 square feet, this lab has equipment for semiconductor and optoelectronic fabrication from bare chip to fully populated components. The facility includes both Class 100 and 1000 cleanrooms and equipment facilitating photolithography, wet chemical processing, thin film deposition, plasma etching and cleaning, thermal oxidation, thermal annealing, and electrical characterization.

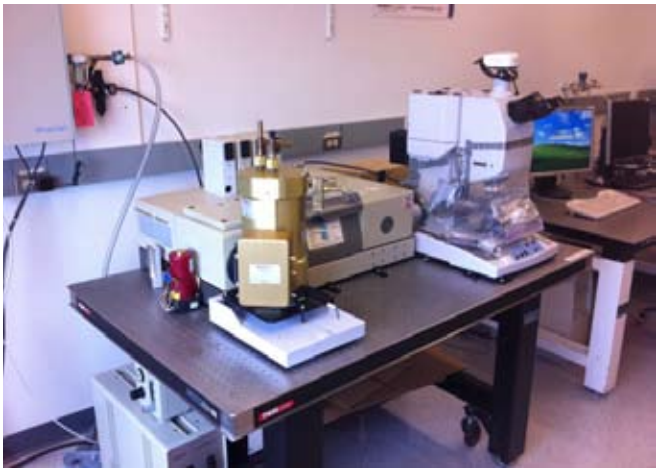
The Class 100 cleanroom is a photolithography and mask-making laboratory. Two types of photoresist spinners are available for use by all self-users in OPF. The standard Headway Research spinner is designed to accommodate small chip level to six-inch wafers, while the Suss Microtech Delta 80 is used to spin chrome on glass masters that can be written using the Heidelberg Direct Write Laser System. As part of recent Equipment Committee additions, the laser diode exposure source in the mask writer was replaced and re-calibrated for mask writing. Ovens and a hood for bakes and development are readily available. Two UV exposure tools, the MJB3 (for three inch masks or smaller) and the MA6 (up to a 6 inch square mask) are fully utilized for chip and wafer exposure. A new high-powered optical microscope was also purchased by the Equipment Committee to provide higher resolution imaging.

In the Class 1000 cleanroom, wafer processing from the photolithography room can include cleaning, etching, or characterization. With a Tencor surface profilometer, students learn how to measure the step height of features that they make on wafers. This contact profilometer requires students to either create measurement fiducials on their structure or work with large features into which the stylus can drop down, reach base surface, and then run back up to the top of the structure. The high-powered microscope has alleviated congestion in OPF's photolithography room and allows users to capture still or video images from the sample.

Dry etching processes are readily available and used in the OPF cleanroom, including but not limited to plasma ashing, reactive ion etching, and deep reactive ion etching. As an upgrade, the piping system has been completely renovated and an end-point detection system installed onto the RIE system. Although not a full solution to over-etching or a replacement for inductively coupled plasma etching, this tool will

assist in process variations to the system caused by such a variety of users and materials. In addition to dry etching, both acid and separate solvent hoods are available to complete wet chemical etching. The HF vapor etch system alleviates safety issues for students and faculty so that they do not have to handle liquid HF, but rather use the vapor system to release oxide films. This system accommodates small pieces of wafers as well as 4 and 6-inch full wafers.

A majority of the research laboratories at Boston University use thin film deposition systems. Thermal oxide furnace, ion assisted deposition, evaporators and sputtering systems all provide students with the capability to learn about different coating process methodologies and how to measure the films deposited after processing. The CHA thermal and e-beam evaporators has been instrumental in complementing the standard Sharon vacuum and Edward's thermal, ion-assisted, and the e-beam evaporators. The Equipment Committee upgraded the CHA this year with a thermally controlled sample stage as well as a throttle valve and piping from the hydrogen generator for silicon film deposition. The J. A. Woollam Co., Inc V-VASE spectroscopic ellipsometer has allowed students to evaluate coatings for uniformity and composition as well as index of refraction information. The Equipment Committee also replaced the dicing saw this year with a new Disco dicing saw with programmable features. The scriber is also utilized by faculty and students processing larger scale repeated patterns on wafers or chips that they then want to make into smaller foot-prints to complete a series of experiments with the same base substrate. Wirebonding, wedgebonding, or testing can also be done inside the cleanroom in OPF. The current voltage (I-V) characterization test set up is used to evaluate devices post wirebonding and pre-integration into test set-ups on the lab bench.



Integrated Optics Laboratory (IOL)

Within its 900 square feet, the IOL houses a Class 100 cleanroom and a standard laboratory space. It is a multi-user facility on the 5th floor of the Photonics Center and is equipped with state-of-the-art equipment for bonding and spectroscopic analysis of components.

In the Class 100 cleanroom, a Suss Microtech FC-150 flip chip bonder is used to seal and create eutectic bonds either through thermocompression or soldering processes. This is a precise pick and place system that uses fiducials to aid in placement accuracy. Several researchers in device packaging (LED's) use this piece of equipment and many outside collaborators also use the system for alignment and bonding of devices. The IOL standard laboratory space includes a soft lithography area and spectroscopic tools. The soft lithography station uses PDMS to make replicas from masters created through photolithography or e-beam writing. The Equipment Committee decided to upgrade the Bruker FTIR Hyperion microscope this year. The upgrade allows users to evaluate the role of polarization in response to excitation through the FTIR. The Varian Cary 5000 UV-VIS-NIR spectrophotometer covers wavelength ranges from 175 – 3300 nm. In addition to measuring reflectance and transmission at a particular wavelength, it can also measure absorption.

Precision Measurement Laboratory (PML)

PML is comprised of two laboratories located in the basement of the Photonics Center. The PML allows the measurement of features and surface morphology. In one of the lab spaces, a JEOL SEM with imaging, Cathode Luminescence (CL), and Energy Dispersive Spectrometer (EDS) is available for use. The EDS allows validation of elemental composition and surface contaminants in selected locations over the surface of the sample. The JEOL, with Gatan Cathode Luminescence (CL), 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 also be determined and emission spectrum can be evaluated.

Also available in the PML are: a Veeco (formerly Digital Instruments) Atomic Force Microscope (AFM) a Pico-Force System, a Zeiss Field Emission Scanning Electron Microscope (FESEM) and a Zygo NewView 6300. The AFM was upgraded this year with a closed-loop scanner. This will assist in nanoscale structural measurements. 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) 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, thus a non-destructive way to view a sample. The beam blanker added to the Zeiss FESEM for the exclusive use of Photonics members allows e-beam writing of nanoscale structures. The heating and cooling stage combined with the ZYGO NewView 6300 with dynamic MEM's capability allows testing under controlled temperature and the viewing and measurement in-situ. Surface roughness, morphology, and displacement can all be measured using this instrument.

Incubator Facilities

Located on the sixth floor of the Photonics Center building, Boston University's Business Incubator is near capacity and host to eleven technology start-up companies. This past year, two incubator companies successfully graduated from the incubation program and moved to commercial space off campus. As these companies were launched, one new company joined the incubator and two current companies increased their floor space. The mix of companies includes: life sciences, biotechnology, medical devices, photonics, clean energy and engineering. Currently three of the companies originate from within BU and eight from outside of BU. All companies are engaged in the commercialization of new technologies of importance to society and all are engaged in BU's educational mission to train students in entrepreneurial management.

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 spinout companies are compared and act as exemplary living case studies for the teaching of entrepreneurship to our students. All are professionally managed by seasoned CEOs and founders and are funded by reputable institutional investors. They have undergone external professional due diligence by their investors. All are commercializing revolutionary technologies developed at many of the region's leading research institutions such as: Dana-Farber Cancer Institute, Massachusetts General Hospital, Draper Laboratories, MIT, and other universities and government agencies.

Total financing for all the companies in the Business Incubation Program is approximately $35 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, we began partnering students with incubator companies. Since that time, approximately sixty-five 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. To date, incubator companies have hired two graduated BUPC Ph.D. students full time.

Current Incubator Companies

Company	*Origin*	*Technology*	*Market Sector*	*Funding*
Block MEMS	Company Spin-Out Block Engineering	Optical MEMS Micro Chemical Sensors	Military, Industrial	DoD, Corporate
Cyber Materials	BU, ME	Process Control	Industrial	SBIR, Sales
Entra	MIT	Thin Film Deposition Microelectronics	Manufacturing Drug Delivery	Venture Capital
Pharmaceuticals First Founders Ltd	MIT	Venture Mentoring Service	Not for Profit	N/A
Good Start Genetics	Harvard	DNA Sequencing	Pre-pregnancy Genetic Testing	MLSC/Venture Capital
LumenZ	MIT	Opto-electronic Materials	Blue /UV LEDs	Venture Capital
Mass Medical Devices Journal	De novo start-up	N/A	Medical Device Journalism	Sales/Advertising
MTPV	Draper Laboratories	Microgap Thermo PhotoVoltaics	Clean Energy	Angel
Nano Surfaces	Cornell University	Nano Structured Surfaces	Antifouling Coatings	Angel
Ninth Sense	BU, BME/Physics	Protein Biomarkers	Medical Diagnostics	Launch Award
Zoiray Technologies	BU, BME/ECE	Immunoassay Instrumentation	Medical Diagnostics	OTD Photonics Tech. Award

Building Projects

Laboratory Upgrades

PHO706/708

Construction in PHO706 – 708 was completed in August, 2009. Professor Bjoern Reinhard's laboratory successfully moved from the Metcalf Science Building to the Photonics Center in an organized way to avoid extensive downtime. The laboratory, PHO706, now identified as the Bio-Interface Laboratory, houses a BL2 cell culture room, BL2 laser laboratory, wet chemistry and optical area along with student offices. Photonics staff, working with Professor Reinhard and Office of Environmental Health and Safety, were able to create the separate office space within the chemistry laboratory. The remaining portion of this large laboratory suite, PHO708, remains under the supervision of Professor Guilford Jones.

PHO B18

Construction on PHO B18 was completed in September, 2009. Professor Kamil Ekinci's laboratory moved from the Metcalf Science Building to the Photonics Center. The move required some critical components to be held under high vaccum over a two day period. With help from the Photonics Center facilities employees and BU Trucking, this move occurred on schedule and without compromising the SPM system. The lab consists of separate SPM and Class IIIb/IV laser laboratories as well as a curtained laser area in the outer laboratory.

PHO505/507

A new faculty member, Professor Siddharth Ramachandran, joined the Boston University Electrical and Computer Engineering department and became a Photonics Center faculty member in January 2010. His research is complementary to the work of Professor Theodore Morse. In order to locate Professor Ramachandran in the Photonics Center, we subdivided Professor Morse's laboratory. The office suite and front lab area were re-designed into laboratory space. The space was designed to hold several class IIIb/IV lasers as well as a fiber grating fabrication system.

Equipment Committee

This year's Equipment Committee was chaired by Professor Franco Cerrina and co-chaired by Professor Bennett Goldberg. Photonics Staff members: Chad Demers, Helen Fawcett, Anlee Krupp, Paul Mak and Leah Ziph-Schatzberg assisted in facilitating equipment requests. Before decisions were made, an open forum was held for all Photonics faculty members to have their requests heard. Faculty members were polled on several equipment purchases to ensure support from the majority of faculty.

The 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 these guidelines for identification and ranking of equipment improvements, the committee determined that the best use of capital equipment funds were to upgrade or replace existing equipment in the shared laboratories. These upgrades ensure the instruments will run at peak perfomance and will provide for the latest technology available.

The following table shows the upgrades and replacement equipment that was purchased.

Equipment	***Lab***
Denton Vacuum Upgrade Package: Throttle Valve & Heated Stage	OPF
Digital Instruments: AFM Closed Loop Scanner	PML
Nikon: High Magnification Inspection Microscope	OPF
Plasma Therm: RIE Gas Piping Upgrade	OPF
Plasma Therm: In-situ End Point Detection and Etch Rate	OPF
DISCO: Dicing Saw	OPF
Heidelberg Direct Write: Laser Diode Replacement	OPF
Denton Vacuum: RF Matching Network	OPF
LYTRON: Recirculation Chiller	OPF

Community Outreach

community outreach

The community within the Photonics Center spans several colleges and schools on both Boston University campuses. As the community expands, the role of community events and outreach becomes even more essential to further the Center's collaborative mission.

The Photonics Center opens its doors each year to outside academic institutions, industrial partners and to the greater BU community through symposia, seminars and building activities. These events foster interdisciplinary discussion and encourage faculty and students to collaborate with a variety of professionals on fundamental research.

Community Events

The Photonics Center hosts two monthly events: The Photonics Café and the Photonics Forum. The cafés bring together the faculty, students and incubator company employees in an informal setting for conversation and collaboration. The cafés are hosted on the second Friday of each month from September through April in the West End Lounge.

The Photonics Forum, held on the fourth Wednesday of each month throughout the academic year, gives the community an opportunity to experience and participate in technical discussions in an open forum over lunch. A Photonics Faculty member along with one of their graduate students is selected to discuss their current research endeavors and the real-world applications of their research.

2009-2010 Photonics Forum Schedule

September
Presenter: Dr. Bjoern Reinhard
Presentation: Active Plasmonic Nanostructures in Biosensing and Imaging

December
Presenter: Dr. Jerome Mertz
Presentation: Pushing the Limits of Two-photon Microscopy

January
Presenter: Michael Penn
Presentation: Laboratory Safety and Hazardous Waste Management Training

February
Presenter: Dr. Barry Unger with Jonathan Dorsheimer
Presentation: The Business Side of Photonics: Light Emitting Diodes and Their Rapidly Evolving Markets

March
Presenter: Dr. Siddharth Ramachandran
Presentation: Rings of Light: Properties and Applications

April
Presenter: Dr. John Connor
Presentation: Detecting and Dissecting Viruses

Annual Events

Laboratory Spring Cleaning Day

Each year the Photonics Center partners with the Office of Environmental Health and Safety (EHS) and the Electrical and Computer Engineering Department to host Spring Cleaning and Laboratory Safety Training Day. This year, the event focused on personal protective gear. This event features several training sessions open to all members of the building and the University.

To ensure each lab had an opportunity to get ready for cleaning day, a week before the event, each lab received cleaning supplies. Triumvirate Environmental along with EHS completed satellite accumulation area (SAA) inspections, general chemical waste pickup, and general lab "cleanliness" inspections.

Kentek Corporation, MedTech Gases, Fisher Scientific and Triumvirate Envrionmental all set up booths and sponsored student gifts and prizes. 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 eco-friendly and the best shared lab clean-up team.

- Safest: Bio-Raman Laboratory
  Principal Investigator: Professor Lawrence Ziegler

- Most Sparkling: Molecular Aging & Development Laboratory
  Principle Investigator: Professor Lee Goldstein

- Most Eco-Friendly: Nano-Bio-Interface Laboratory
  Principal Investigator: Bjoern Reinhard

- Best Shared Lab Clean-up Team: Precision Measurement Laboratory

Nano-Bio-Interface Laboratory (left)

13th Annual Future of Light Symposium: Biophotonics Sensors and Systems, Point of Care Diagnostics

This year, the 13th Annual Future of Light Symposium focused on point of care diagnostics research and technology development. Nearly 200 people from Boston University as well as outside academic institutions and companies attended the event.

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

To conclude this year's conference, Dr. Thomas Bifano, Director of BUPC, gave a speech highlighting the advances in biohotonics research conducted at the Photonics Center and the future of the Industry/ University Cooperative Research Center effort between Boston University and the University of California at Davis.

Our external, guest speakers included:

- Vadim Backman - Northwestern University
- Heather Clark – Draper Laboratory
- Sergio Fantini – Tufts University
- Anita Mahadevan-Jansen – Vanderbilt University
- Lev Perelman – Beth Israel Deaconess Medical Center
- Brian Pogue – Dartmouth University
- Gary Tearney – Center for Integration of Medicine and Innovative Technology
- Bruce Tromberg – University of California, Irvine

Nearly 25 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 opportunity to share their results.

Bruce Tromberg - University of California, Irvine

Sergio Fantini - Tufts University

Distinguished Lecturer Series

Dr. Susumu Noda

On October 28, 2009, the Photonics Center hosted Dr. Susumu Noda from Kyoto University as part of our Distinguished Lecturer Series. Dr. Noda presented his work: the Manipulation of Photons by Photonic Crystals. Dr. Noda's biography and his presentation abstract follows:

Biography:
Professor Susumu Noda received his M.S. and Ph.D. degrees in electronics from Kyoto University, Japan, in 1984 and 1991, respectively. He worked for Mitsubishi Electric Corporation from 1984 to 1988 where he was engaged in research on optoelectronic devices such as AlGaAs/GaAs distributed feedback (DFB) lasers, multiple quantum well (MQW) DFB lasers, and grating-coupled surface-emitting lasers. His Ph.D. thesis summarizes the work performed at Mitsubishi Electronic Corporation.

In 1988, Dr. Noda joined Kyoto University as a research associate and became an associate professor in the Department of Electronic Science and Engineering in 1992. His research interests cover the quantum optoelectronics field including photonic and quantum nanostructures. He actively studies ultrafast optical devices using intersubband-transition in quantum wells, growth and characterization of InAs quantum dots on GaAs substrate, and semiconductor based 3D and 2D photonic crystals. He is the author of more than 200 scientific journals articles. He received the Ando Incentive Prize, Marubun Incentive Prize, IBM Science Award, and Sakurai Award of Optoelectronic Industry and Technology Development Association (OITDA) in 1991, 1999, 2000, and 2002, respectively. Since 2003, he has served as an IEEE/LEOS Distinguished Lecturer. Dr. Noda is a member of IEEE, IEICE, and JAPS.

Abstract:
Photonic crystals, in which the refractive index changes periodically, provide an exciting tool for the manipulation of photons and have made substantial progresses in recent years. In his presentation, Professor Noda discussed the recent progresses in photonic-crystal researches including two-dimensional photonic-crystal cavities and waveguides, three-dimensional photonic crystals, and two-dimensional photonic-crystal lasers.

Dr. David Payne

The Photonics Center hosted Dr. David Payne from the University of Southampton on February 1, 2010, as the spring term Distinguished Lecturer. Dr. Payne presented: Problems Solved and Unsolved in Photonics. Dr. Payne's biography and presentation abstract follows:

Biography:
Professor David Payne is the Director of the Optoelectronics Research Centre at the University of Southampton. He led the team that first reported the silica optical fiber laser and the erbium-doped fiber amplifier (EDFA) and is credited with many other key advances in optical fiber technology over the last forty years. His career has spanned both the academic and the commercial, where his activities have led to a cluster of ten companies in the local area.

Payne has won the John Tyndall Award (USA), the Rank Prize for Optics, the Japanese Computers and Communications Prize, the prestigious Benjamin Franklin Medal (USA), the Basic Research Award by the Eduard Rhein Foundation, and the Mountbatten Medal of the IEE.

For his unique contributions to both science and engineering, in 2004, the combined UK Societies awarded him the Kelvin medal. In 2007, he received the IEEE Photonics Award for Outstanding Achievements in Photonics. In 2008, he became a Millennium Prize Laureate.

Abstract:
Powering the optical fiber internet with its huge global reach, photonics has changed our lives. Optical fibers snake across continents and oceans carrying terabits per second of data in a vast information network that brings untold human connectivity. How did this happen and is that the end of it?

Capacity demand continues to grow at a startling rate, doubling every two years, while the internet is estimated as burning 4% of world energy usage. The solution to both of these unexpected consequences of success is more photonics, reaching further into the network with optics to overcome the existing bottlenecks and employing next-generation optical components.

The great success of optical fibers and planar circuits in telecommunications has generated numerous applications in a number of related fields, such as sensing, bio- and nano-photonics and high-power lasers. Incredibly, the same fibers that carry tiny internet signals can also generate kilowatts of power, sufficient to cut through inch-thick steel.

The talk explored prospects for building new technologies and applications through harnessing the properties of new optical materials, devices and structures.