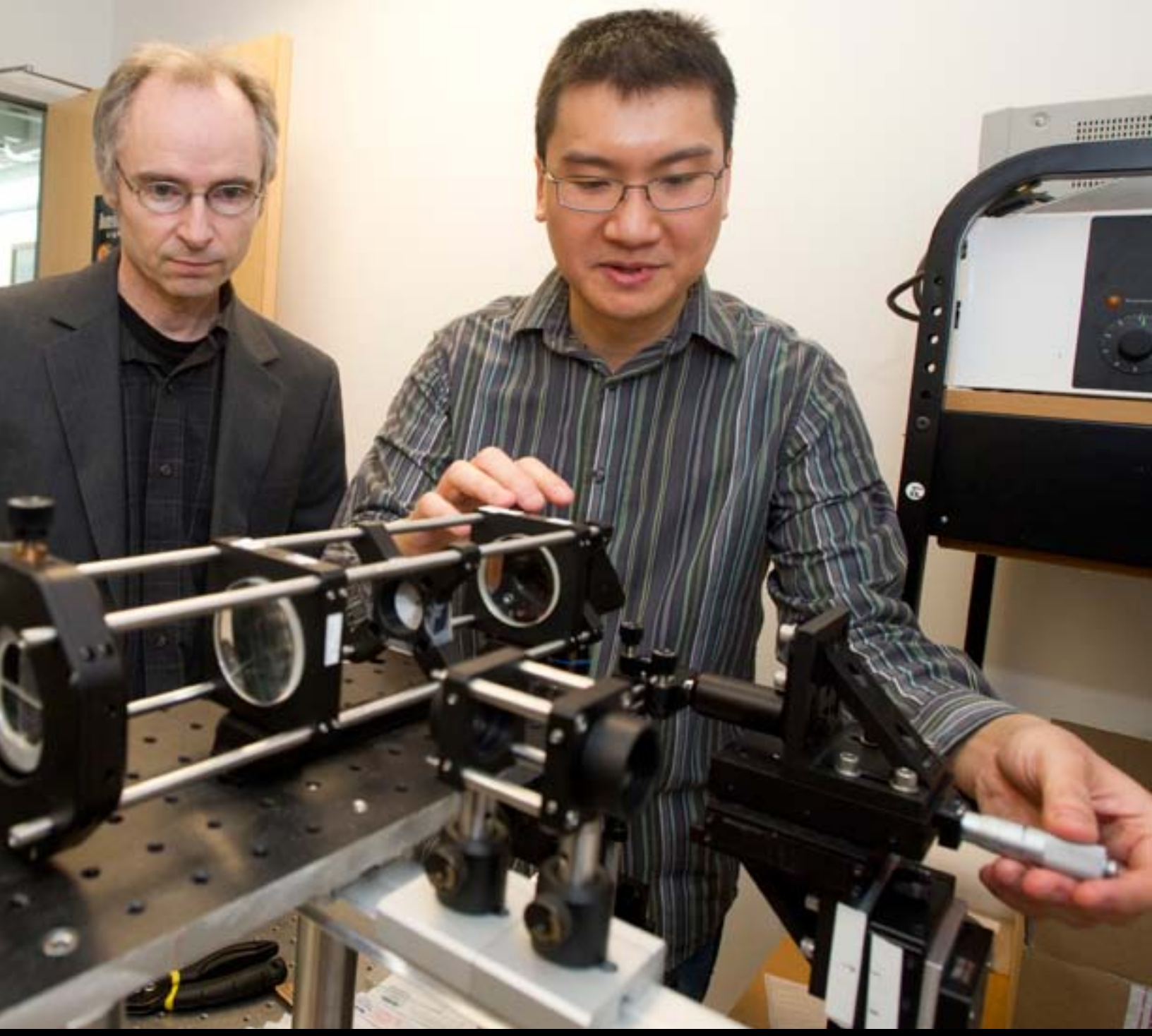

The Boston University photonics center

ANNUAL REPORT 2012-2013

LETTER FROM THE DIRECTOR

This annual report summarizes activities of the Boston University Photonics Center in the 2012-2013 academic year. In it, you will find quantitative and descriptive information regarding our photonics programs in education, interdisciplinary research, business innovation, and technology development.

Located at the heart of Boston University's large urban campus, the Photonics Center is an interdisciplinary hub for education, research, scholarship, innovation, and technology development associated with practical uses of light. Our iconic building houses world-class research facilities and shared laboratories dedicated to photonics research, and sustains the work of forty-six faculty members, nine staff members, and more than one hundred graduate students and postdoctoral fellows.

This has been an especially successful year for the Photonics Center. In the following pages, you will see that the Center's faculty received prodigious honors and awards, generated nearly 150 notable scholarly publications in the leading journals in our field, and attracted a record-breaking $21.8M in new research grants/contracts this year. Faculty and staff also expanded their efforts in education and training, though National Science Foundation sponsored sites for Research Experiences for Undergraduates and for Teachers. As a community, we hosted a compelling series of distinguished invited speakers, and emphasized the theme of 'Novel Applications of Photonics and Photonic Techniques' at our annual Future of Light Symposium. We took a leadership role in promoting the recommendations of a recent report by the National Academy of Sciences entitled 'Optics and Photonics: Essential Technologies for Our Nation,' and have joined a nationwide effort to establish a National Photonics Institute, in which we would be a key university member.

Highlights of our achievements for the year include an ambitious new NIH-sponsored Center grant for Innovation in Point-of-Care diagnostics led by Professor Catherine Klapperich, and the induction of Professor Theodore Moustakas into the National Academy of Inventors (Professor Moustakas was also acknowledged as Boston University's Innovator of the Year). Our community welcomed an auspicious cohort of new faculty members, including three newly hired Assistant Professors, one new senior Research Professor and one new Associate Professor. The Industry/University Collaborative Research Center that has become the centerpiece of our translational biophotonics program continues to focus on advancing the health care and medical device industries, and has entered its third year of operation with a strong record of achievement and with the support of an enthusiastic industrial membership base.

The Boston University Photonics Center has established itself as one of the nation's leading academic programs for photonics scholarship, education, and innovation. I welcome your interest in our activities.

Dr. Thomas Bifano
Director, Boston University Photonics Center

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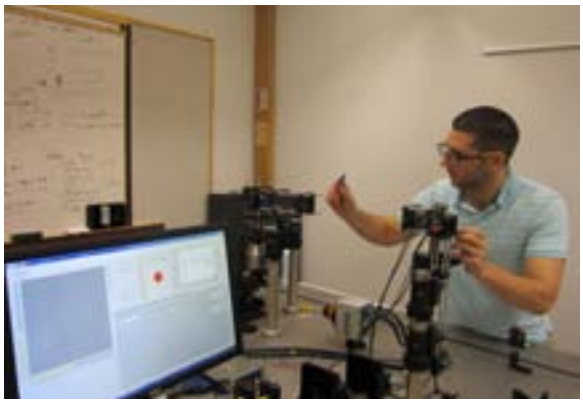
Cover Photo: Professor Jerome Mertz and Cliff Chan, a trainee in the National Science Foundation's Research Experiences for Veteran's program, demonstrating an optical system for quantitative phase imaging.

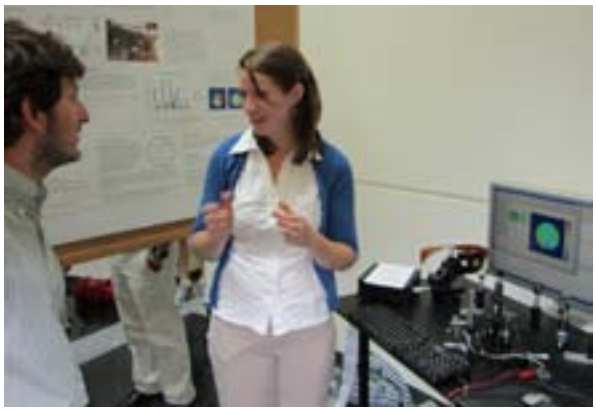
SUMMARY FY 2012-2013

This report summarizes activities of the Boston University Photonics Center during the period July 2012 through June 2013. These activities span the Center's complementary missions in education, research, technology development, and commercialization.



The Photonics Center continues to grow as an international leader in photonics research, while executing the Center's strategic plan and serving as a university-wide resource for several affiliate Centers. For more information about the strategic plan, read the Photonics Center Strategic Plan section on page 10.

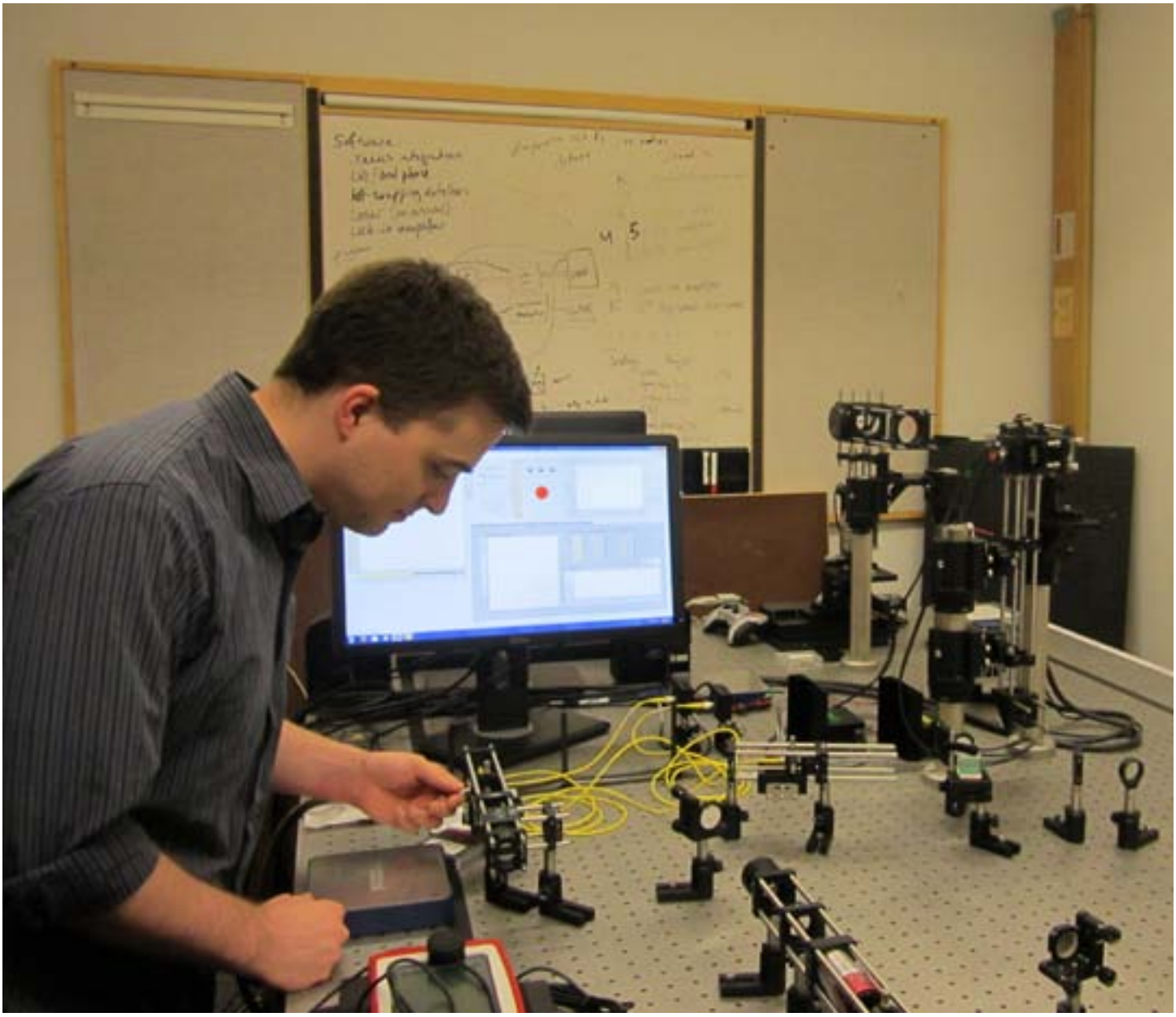
In research, Photonics Center faculty published nearly 150 journal papers spanning the field of photonics. A number of awards for outstanding achievement in education and research were presented to Photonics Center faculty members, including a Peter Paul Professorship for Professor Xue Han, an NSF Career Award for Professor Ajay Joshi, and the 2012 Innovator of the Year Award from Boston University for Professor Theodore Moustakas. New external grant funding for the 2012-2013 fiscal year totaled over $21.8M. For more information on our research activities, read the Research section on page 24.



In technology development, the Photonics Center has turned a chapter, by completing the transition from a focus on Defense/Security applications to a focus on the healthcare market sector. The commercial sector is expected to energize the technology development efforts for the foreseeable future, but the roots in defense/security are still important and the Center will continue to pursue new research grants in this area. For more information on our technology development program and on specific projects, read the Technology Development section on page 45.

In education, 20 Photonics Center graduate students received Ph.D. diplomas. Photonics Center faculty taught 32 photonics courses. The Center supported a Research Experiences for Teachers (RET) site in Biophotonic Sensors and Systems for 10 middle school and high school teachers. The Photonics Center sponsored the Herbert J. Berman "Future of Light" Prize at the University's Scholars Day. For more on our education programs, read the Education section on page 54.

In commercialization, Boston University's Business Innovation Center (BIC) currently hosts seven technology start-up companies. There is a healthy turnover in the Innovation Center space with a total of 19 companies residing at BIC over the past year. The mix of companies includes: life sciences, biotechnology, medical devices, photonics, and clean energy; and nine of the 19 companies originated from within BU. All the BIC tenants are engaged in the commercialization of new technologies of importance to society and all are active in the BU community in terms of offering internships, employment opportunities or research collaborations. For more information about Business Innovation Center activities, read the Business Innovation Center chapter in the Facilities and Equipment section on page 66.



Professor Tom Bifano's graduate student works in the lab.

Highlights for FY 2012-2013

External Grant Funding
External grant funding for FY 2012-2013 came in at over $21.8M, showing a balanced portfolio of funding sources. NSF accounted for 17% of total funding, while NIH and DoD each accounted for 15%. Over 15% of the total were from subcontracts from the Boston Medical Center and other universities. The Corporate and Private Foundation portion of total funding came in at 12% of the total.

Five New Photonics Center Faculty Members
This year, the Photonics Center welcomed Professors Jonathan Klamkin (ECE), Dimitris Pavlidis (ECE), Darren Roblyer (BME), Michelle Sander (ECE), and Joshua Semeter (ECE) to the community. The new faculty members' research is focused on integrated photonics, widebandgap semiconductor materials and devices, diffuse optics, femtosecond lasers, and image processing respectively.

Current Tenants of Business Innovation Center Include Key Companies
Current tenants include winners/finalist of prestigious Accelerator competitions such as the BU Ignition Awards (RayVio) and the Cleantech and MassChallenge Accelerator award winner NBD NanoTechnologies. At the other end of the innovation spectrum, BIC also houses a new product spinout from a multi-billion dollar international corporation. This company, Bioventus, is a leader in bio-material research and is expected to establish a new model for launching technology based commercial enterprises.

The 16th Annual Future of Light Symposium: Novel Applications of Photonics and Photonics Techniques
This year, the symposium focused on novel applications of photonics and photonics techniques. Almost 200 people from Boston University, other academic institutions and industry attended the event. At the conclusion of this year's conference, a reception was held where participants and speakers discussed their research in an informal setting.

Institute Activities
The Center has been conducting business as an institute leading on a number of activities such as leading the Business Innovation Center (BIC), equipping and running shared laboratories, administering/supporting block grants and supporting affiliated units.

Professor Siddharth Ramachandran delivers his talk at the annual Future of Light Symposium.

Photonics Center at a Glance

Faculty Members	46
Staff Members	9
Funded R&D Projects	103
Funding for R&D (New funds for current year)	$21.8M
Photonics Courses	32
Archival Publications	145
Shared Laboratory Facilities	4

The Photonics Center at Boston University.

Mission and Highlights

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 innovation and commercialization of photonics technology

The Photonics Center 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 on each of the four pillars supporting our mission.

Basic Research and Scholarship in Photonics

Photonics Center faculty are involved in research in diverse fields of study anchored by thematic areas of strength in biophotonics, nanophotonics, adaptive optics and photonic materials. Scholarship and research that has received prominent recognition and/or funding in the past year include:

- The emerging interdisciplinary field of optogenetics: the use of light-based tools to sense, actuate, or inhibit cellular functions.
- Techniques for fault isolation in back-side analysis of next-generation semiconductor circuits using aplanatic solid immersion lens microscopy.
- Adaptive wavefront shaping and thick tissue imaging.
- Narrow-gap and wide-band gap materials, plasmonics and photonic materials for cleantech applications and simulation tools for these materials.

Academic and Entrepreneurial Programs and Initiatives for Students

While the Photonics Center does not offer academic degrees, the faculty teach a broad array of graduate and undergraduate courses that cut across traditional departmental curricula. Beyond the classroom, students engage in diverse entrepreneurial activities, including internships with companies in the Business Innovation Center; access to office and lab space and mentoring for new business launch; opportunities for engagement/networking with industry, particularly members of the I/UCRC; and participation in the annual Photonics Symposium.

Technology Development for Defense, Security, and Healthcare Applications

The Photonics Center's technology development activities focus on emerging photonic applications in defense and healthcare. These activities include direct sponsored research collaboration with research labs at major corporations and the successful completion of the 2nd year of the NSF-sponsored, member-supported Industry/

University Cooperative Research Center on Biophotonic Sensors and Systems. That program and its corporate sponsored applied research projects have become a prime focus for Photonics Center efforts in technology translation.

Business Innovation and Commercialization of Photonics Technology

The Photonics Center remains as a leader in commercialization of photonics technology, an activity anchored by its Business Innovation Center (BIC). Individual tenant companies continue to demonstrate growth and commercial potential and to attract business financing. While several companies were launched with the support of the School of Management, this program cannot be continued in FY14 due to a loss of grant support and transfer of space to the Materials Science Division for new faculty. The smaller footprint provides an opportunity to be very selective in recruiting companies to BIC. Preferential selection of prospective tenants that work in areas aligned with the research and scholarship activities of Photonic Center faculty creates an environment rich with opportunities for collaboration and growth in sponsored research. Mentoring and access to shared laboratory and conference facilities will continue to be offered to promising student entrepreneurs.

Professor Xin Zhang's laboratory gathers after a Panera lunch celebrating their first prize win at Spring Cleaning Day for the most compliant lab.

PHOTONICS CENTER STRATEGIC PLAN

Central to the Photonics Center strategic plan is an operational model where the Center operates as a centralized resource – promoting, supporting, and sustaining allied research centers and programs across Boston University. Essentially, the Center has been conducting business as an institute leading on a number of activities such as the Business Innovation Center, equipping and running shared laboratories, administering/supporting block grants and supporting affiliated units.

Some of the affiliated units include the SMART Lighting Engineering Research Center, the Center for Nanoscience, the Industry/University Cooperative Research Center (I/UCRC) on Biophotonic Sensors and Systems (CBSS), the Center for Innovation in Point of Care Technologies for the Future of Cancer Care and the Materials Division. With respect to the Materials division, the Photonics Center has managed a substantial renovation for the Materials Division in space formerly allocated to the Business Innovation Center and will manage and maintain the Materials Science Division's new shared laboratory, and will oversee staff supporting that activity. One of these labs, dedicated to the Focused Ion Beam (FIB) tool came on-line during FY13, with a second facility supporting the Transmission Electron Microscope (TEM) coming on-line in the beginning of FY14. In addition to these facilities, the Photonics Center supports several other shared labs as described in the section on Facilities.

In support of its strategic goal of expanding core programs for research support, the Photonics Center has successfully completed the first two years of the I/UCRC on Biophotonic Sensors and Systems (CBSS) and the program formu-

lation for year three (concurrent with FY14). These efforts have yielded a well-functioning collaborative engagement between the two university sites and participating industry members and CBSS has become an active hub for industry-focused research on biophotonic research frontiers. Serving as the lead university of this I/UCRC, we have attracted the University of California at Davis as a partner site and ten corporate members. We expect to continue the growth of this I/UCRC with both additional university sites and additional corporate or government laboratories as members. With the support of the industry members, we have secured supplemental funding to the I/UCRC grant that has multiplied the initial NSF funding more than tenfold. One of the areas of supplemental funding related to a Fundamental Research Program (FRP) grant on "Characterization and Bioengineering of Optogenetic Rhodopsins," a key element of a strategic vision that focuses research in the transformative fields of Optogenetics and Photonic Biomaterials.

The resources and expertise of the Photonics Center staff are also employed to manage grants to several affiliated centers. These grants include: IARPA grant on back-side wafer analysis and training grants in conjunction with the affiliated Center for Nanoscience and Nanobiotechnology, faculty grants from NIH and NSF related to viral diagnostic technology, Research Experiences for Teachers, a substantial Research Experience for undergraduates/Veterans program and a grant on Multi-Scale Multi-Disciplinary Modeling of Electronic Materials (MSME). MSME is a major four-year grant that will involve close collaborations with the ARL's research scientist at the Sensors and Electronic Devices Directorate (SEDD) and interactions with ARL's Enterprise for Multiscale Research of Materials (EMRM), organizations that worked closely with the Photonics Center during the 10-year collaborative research agreement with ARL.

The same organizational and post award project management expertise of Photonics Center staff also will be employed on leading and supporting new major block grants. In FY13, the Photonics Center led or significantly contributed to proposals that include: National Nanomanufacturing Infrastructure Initiative (NNIN), Engineering Research Center on Exabit Networks, Research Experiences for Teachers, Scalable Nanomanufacturing, NIH Center on Translational Research, NSF Innovation Corps, several I/UCRC supplements and many other proposal that all support the Photonics Center strategic vision.

At the Business Innovation Center located on the 6th floor of the Photonics Center, Photonics Center staff have taken a leading role in setting the strategy and managing the operations. We are implementing strategic changes that align the business incubator more closely with ongoing Photonics Center member research and educational activities and with the activities of the I/UCRC and its member companies.

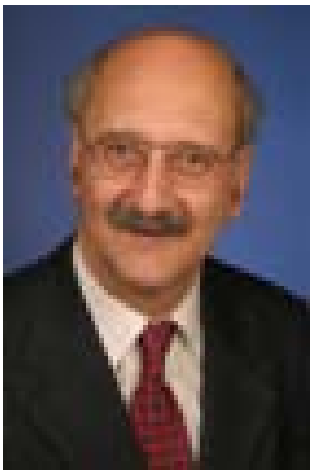
Photonics Center staff continued to pursue high value, multi-investigator grants in the areas of terahertz devices, quantum communications, energy conservation and adaptive optics for space or ground surveillance. Staff contributions to support proposal preparation and networking with government, academic and industrial partners have become increasingly important to the Photonics Center's strategic mission, and that role will continue to expand

FACULTY AND STAFF

New Faculty Members

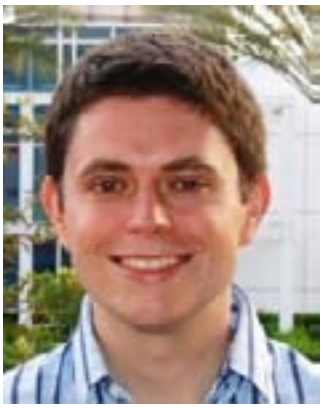
Assistant Professor Jonathan Klamkin

Dr. Jonathan Klamkin is an Assistant Professor in the Electrical and Computer Engineering department. He received a B.S. in Electrical and Computer Engineering (ECE) from Cornell University in 2002, and an M.S. in ECE and a Ph.D. in Electronic Materials from the University of California Santa Barbara in 2004 and 2008 respectively. From 2001-2002, he worked at BinOptics. From 2008-2011, he was a member of the Technical Staff in the Electro-Optical Materials and Devices Group at MIT Lincoln Laboratory. From 2011-2013, he was an Assistant Professor at the Institute of Communication, Information and Perception Technologies (TeCIP), Scuola Superiore Sant'Anna, in Pisa, Italy.



Research Professor Dimitris Pavlidis

Dr. Dimitris Pavlidis is a Research Professor of Electrical and Computer Engineering. He is also Adjunct Professor of Electrical Engineering and Computer Science at the University of Michigan, Ann Arbor, and Program Director in Electronics, Photonics and Magnetic Devices (EPMD) in the ECCS Division of the National Science Foundation. His research involves various types of semiconductor materials, devices, circuits, nanostructures, and sensors and has applications in the electronic and biological, biomedical fields. He received a B.Sc. in Physics from the University of Patras, Patras Greece in 1972, and a Ph.D. in Applied Science/Electronic Engineering from the University of Newcastle, Newcastle-upon-Tyne in 1976.



Assistant Professor Darren Roblyer

Dr. Darren Roblyer is an Assistant Professor in the department of Biomedical Engineering. His research focus is on the development of near-infrared diffuse optical techniques for basic and translational applications in oncology. After receiving a B.S. in Biomedical Engineering from Johns Hopkins University in 2004, Darren received his Ph.D. as a HHMI Med-Into-Grad Fellow in 2009 from the Bioengineering Department at Rice University where he studied under Professor Rebecca Richards-Kortum. There he explored the use of in vivo autofluorescence imaging for the detection and delineation of oral cancer lesions in collaboration with the M.D. Anderson Cancer Center.

Assistant Professor Michelle Sander

Dr. Michelle Sander is an Assistant Professor in the department of Electrical and Computer Engineering. Her research focuses on novel ultrafast laser systems from compact femtosecond fiber lasers to integrated waveguide lasers. Dr. Sander received her Ph.D. in Electrical Engineering from the Optics and Quantum Electronics Group with Professor Erich Ippen and Professor Franz Kaertner at the Massachusetts Institute of Technology in 2012. Previously, she received a Diploma degree in Electrical Engineering from the Technical University of Braunschweig, Germany, and a Master of Science degree from the Georgia Institute of Technology.

Associate Professor Joshua Semeter

Dr. Joshua Semeter is an Associate Professor of Electrical and Computer Engineering. His research involves interactions between the Earth's ionized outer atmosphere (the ionosphere) and the space environment. He began his career as a control systems engineer at Pratt and Whitney Aircraft. He received his Ph.D. in Electrical and Computer Engineering from Boston University in 1997, working in collaboration with the interdisciplinary BU Center for Space Physics. From 1997 to 1999, he was as a postdoctoral fellow at the Max Planck Institute for Extraterrestrial Physics in Garching, Germany. From 1999 to 2004 he was a Senior Research Engineer at SRI International.

Faculty Member Listing

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- Label-free biosensors

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- Terahertz spectroscopy
- Correlated electron materials

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- Semiconductor materials
- Parallel computing

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- Adaptive optics

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- Mechanical properties of materials at low temperatures
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- Environmental science

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- Virus/host interactions

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- Microfluidics for assay of DNA

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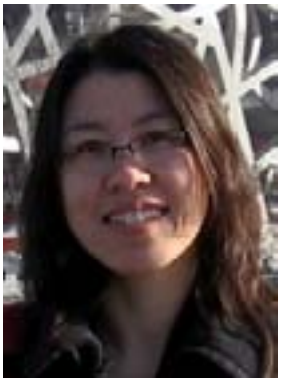
- Molecular aging disorders



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- Amorphous semiconductors

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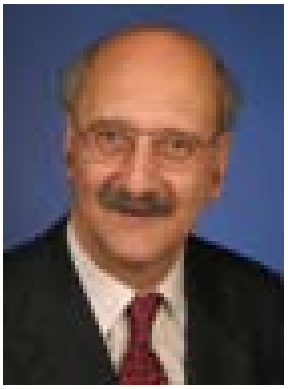
- Optoelectronic devices based on semiconductor quantum-confined systems and photonic nanostructures



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Research interests:
- Inospheric and space plasma physics
- Image processing

Alexander Sergienko
Professor, ECE

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

Anna Swan
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Research interests:
- Interactions of biomaterials with nanostructures
- Carbon nanotubes

Andre Sharon
Professor, ME

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

Malvin Teich
Professor Emeritus, ECE, BME & Physics

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Research interests:
- Quantum photonics
- Neural coding

Barry Unger
Associate Professor, MET

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Research interests:
- Entrepreneurship and venture capital investment
- Innovation and product development process

Selim Unlu
Professor, ECE

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Research interests:
- Nanophotonics
- Biophotonics
- High-resolution optical microscopy

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Professor, ME

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Research interests:
- Fundamental issues and applications of micro- and nanoelectromechanical systems (MEMS/NEMS or micro/nanosystems)

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Professor, Chemistry

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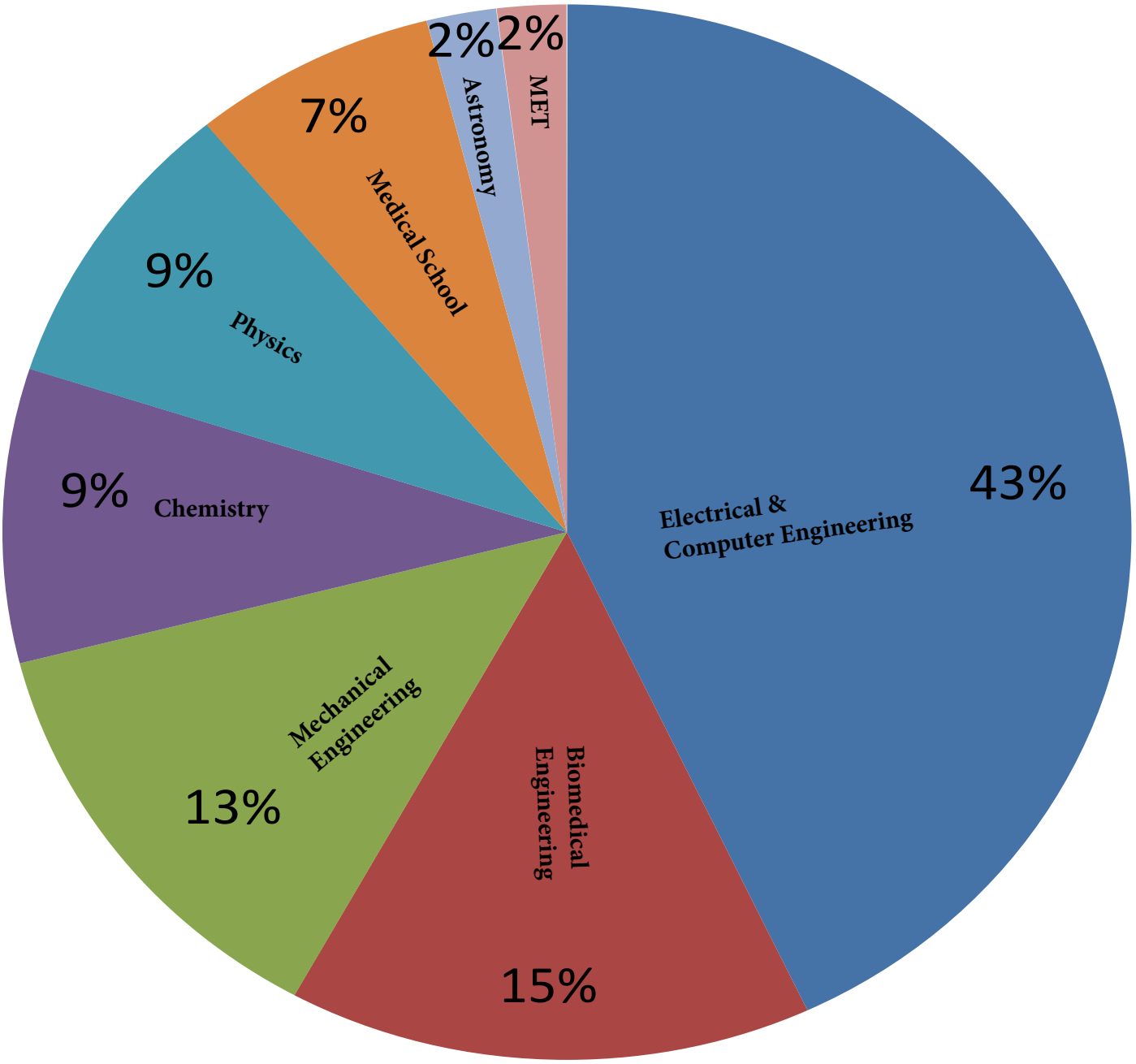
Research interests:
- Spontaneous resonance raman studies of photodissociative and biological chromophores

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 Photonics Center Director appoints committee chairs each year.

Photonics Center Guest Speakers:
Chair – Dr. Jerome Mertz
The Photonics Center Guest Speakers committee invited 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 – Open
The education committee investigated methods for applying and enriching education of photonics within the community and BU programs.

Equipment:
Chair – Dr. Bjoern Reinhard
The equipment committee recommended equipment upgrades or new equipment purchases that would enhance the research and development of faculty and students at the Center.

Executive Advisory:
Chair – Dr. Thomas Bifano
The executive advisory board advised the Director of the Photonics Center on educational and academic issues and was comprised of the chairs from the Center's affiliated departments.

Space Allocation:
Chair – Dr. Thomas Bifano
This committee chair generated policy guidelines for space management.

Symposium:
Chair – Dr. David Bishop
This committee chair organized the 16th annual "Future of Light" symposium that focuses on research and development of novel applications of photonics and photonics techniques, an area relevant to the Photonics Center community. The symposium includes external and internal faculty speakers.

Staff Member Listing

Dr. Thomas Bifano
Director

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Manager, Operations and Technical Programs

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Anlee Krupp
Laboratory Manager

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Robert Schaejbe
Assistant Director, Operations & Administration

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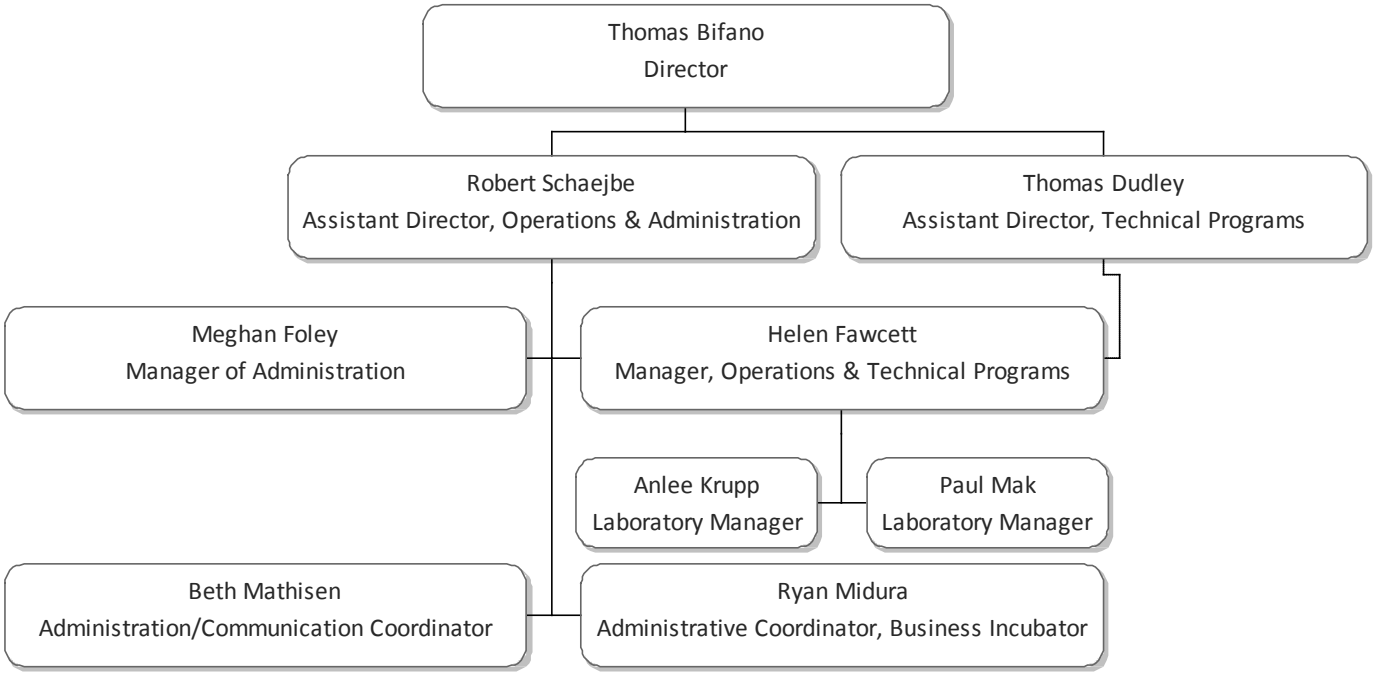
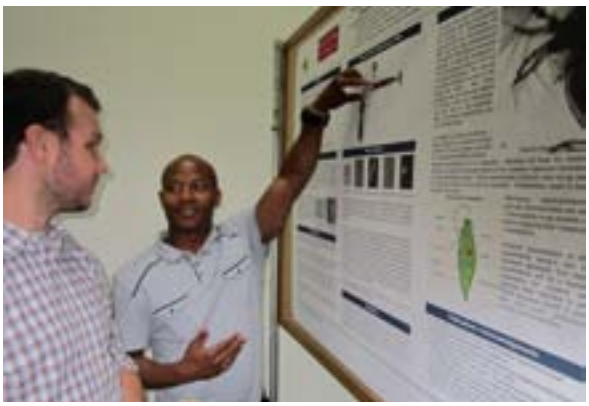
Photonics Center Organizational Chart



Research

The Photonics Center has a history of commitment to academic research. Its core shared laboratory facilities and multidisciplinary faculty laboratories provide fertile ground for seeding and cultivating discovery and innovation in photonics.

In the past year, Photonics faculty members received more than $21M in support from industry, academia and federal agencies including the National Science Foundation (NSF), Massachusetts General Hospital (MGH), the National Institute of Health (NIH) and the Department of Defense (DoD). One measurable outcome of our thriving research program was the collection of 145 archival publications authored by Photonics Center faculty and students.



Externally Funded Research

Photonics faculty members received more than $21.8M in external funding. The following table lists funds in the fiscal year (July 1, 2012-June 30, 2013), as reported by the Office of Sponsored Programs.

P.I.	Dept.	Title of Project	Agency	Period	Amount
Altug	ECE	High-Performance Nanoplasmonic Sensors for Biological Warfare Detection	Department of Defense/Navy	5/1/10-4/30/14	$52,677
Averitt	PHY	SISGR: Multifunctional Materials Research Using Ultrafast Optical Spectroscopy	Department of Energy	9/1/09-9/14/13	$194,000
Bellotti	ECE	CRA - Computationally-Guided Design of Energy Efficient Electronic Materials (CDE3M)	University of Utah	4/16/12-4/30/13	$515,000
Bellotti	ECE	CRA - Computationally-Guided Design of Energy Efficient Electronic Materials (CDE3M)	University of Utah	1/1/13-12/31/13	$292,618
Bellotti	ECE	CRA - Computationally-Guided Design of Energy Efficient Electronic Materials (CDE3M)	University of Utah	1/1/13-12/31/13	$305,074
Bellotti	ECE	Small Pitch III-V Barrier Detector Optical Modeling	DRS Sensors and Targeting System	9/25/12-12/31/13	$50,000
Bifano	ME	I/UCRC Collaborative Research	I/UCRC: Industry Memberships	7/1/11-6/30/13	$200,000
Bifano	ME	PFI-AIR: Nanoplasmonic Metamaterial Antennae for Efficient Wireless Power Transmission	National Science Foundation	7/15/12-6/30/14	$200,000
Bifano	ME	Photonics Research And Technology Insertion	Department of Defense/ARL	7/1/06-8/30/13	$99,067
Bifano	ME	IUCRC Collaborative Research : I/UCRC: Center for Biophotonic Sensors and Systems (CBSS)	National Science Foundation	3/1/11-2/29/16	$80,000
Bifano	ME	PFI-AIR: Nanoplasmonic Metamaterial Antennae for Efficient Wireless Power Transmission	Battelle Memorial Institute	10/1/12-9/30/14	$300,000
Bifano	ME	I/UCRC Collaborative Research : I/UCRC: Center for Biophotonic Sensors and Systems (CBSS)	National Science Foundation	3/1/11-2/29/16	$20,000
Bifano	ME	Photonics Research and Technology Insertion	Department of Defense/ARL	7/1/06-8/30/13	$206,020
Bifano	ME	RET-TRIPSS: Teachers' Research in Biophotonics - Sensors and Systems	National Science Foundation	6/1/10-6/30/14	$150,030
Bifano	ME	Using Adaptive Optics to Improve Imaging of the Inner Ear	Princeton University	4/1/13-6/30/13	$25,000

P.I.	Dept.	Title of Project	Agency	Period	Amount
Bifano	ME	Superpenetration Multi-Photon Microscope	Boston Micromachines Corporation	4/1/13-3/31/14	$59,652
Bigio	BME	Off Campus Funding for Kevin Shiuan	Beth Israel Deaconess Medical Center	9/1/11-6/17/12	$24,880
Bigio	BME	Optical Imaging of Chemotherapy For Brain Tumors	Columbia University	4/1/11-3/31/13	$17,226
Bigio	BME	Enhanced Intraarterial Delivery of Chemotherapeutic Drugs to The Brain	Columbia University	9/1/08-7/31/13	$91,672
Bigio	BME	Draper Laboratory Fellow - Carlos Segura	Draper Laboratory, Inc.	9/1/12-8/31/13	$40,954
Bigio	BME	Billing Agreement - Support for Hao Li	General Hospital Corp D/B/A Massachusetts General Hospital	9/1/12-8/31/13	$33,992
Bigio	BME	Margin Guidance for Oral Cancer Resection Using Light Scattering Spectroscopy	Boston Medical Center	12/14/12-11/30/13	$123,220
Connor	MED	Development of Near Real-Time, Multiplexed Diagnostics for Viral Hemorrhagic Fever	NIH/National Institute of Allergy & Infectious Diseases	8/1/11-7/31/13	$991,808
Dal Negro	ECE	Nano-Scale Optical Emitters for High Density Information Processing Using Photonics-Plasmnoic Coupling In Coaxial Nanopillars	Department of Defense/AFOSR	1/1/13-12/31/13	$199,996
Ehrlich	BME	High Throughput Biomems DNA Sequencing	NIH/National Human Genome Research Institute	9/1/10-6/30/13	$702,204
Fritz	AST	BUSAT2: The Boston University Student Satellite for Applications and Training	Department of Defense/AFOSR	1/1/11-6/30/13	$55,000
Fritz	AST	The Loss Cone Imager (LCI) for The DSX Program	Department of Defense/Air Force	4/1/10-12/31/13	$35,000
Fritz	AST	Implementation Of The Space Plug-And-Play (SPA) Architecture into The Boston University Student Satellite for Application and Training	Spaceworks, Inc.	11/1/12-10/31/13	$54,890
Fritz	AST	The Loss Cone Imager (LCI) for the DSX Program	Department of Defense/Air Force	4/1/10-12/31/13	$187,863

P.I.	Dept.	Title of Project	Agency	Period	Amount
Gabel	MED	C. Elegans Model for Mammalian Lesion-Conditioned Axon Regeneration	NIH/National Institute of Neurological Disorders and Stroke	9/1/12-8/31/13	$221,981
Gabel	MED	Molecular Determination of In Vivo Cellular Calcium Signaling During Nerve Damage	NIH/National Institute of Neurological Disorders and Stroke	5/1/13-4/30/14	$358,094
Goldberg	PHY	Boston University Cross-Disciplinary Training in Nanotechnology for Cancer	NIH/National Cancer Institute	9/1/10-7/31/13	$90,288
Goldberg	PHY	Boston University Cross-Disciplinary Training in Nanotechnology for Cancer	NIH/National Cancer Institute	9/1/10-7/31/13	$281,931
Goldberg	PHY	Next Generation Solid Immersion Microscopy for Fault Isolation In Back-Side Analysis	Department of Defense/Air Force	11/10/11-11/9/14	$504,000
Goldberg	PHY	Next Generation Solid Immersion Microscopy for Fault Isolation in Back-Side Analysis	Department of Defense/Aire Force	11/10/11-11/9/14	$450,000
Goldberg	PHY	Logic Analysis Tool	DCG Systems, Inc.	12/8/10-12/7/14	$250,940
Goldberg	PHY	Graphene Membranes as Micro-And Nano-Pressue Sensors	University of Texas	3/1/09-5/31/13	$14,558
Goldberg	PHY	Boston University Cross-Disciplinary Training in Nanotechnology for Cancer	NIH/National Cancer Institute	9/1/10-7/31/13	$56,365
Goldstein	MED	Effects of Space Radiation of Hippocampal-Dependent Learning And Neuropathology in Wild-Type And Alxheimer's Disease Trasngenic Mice	NASA	9/1/11-8/31/13	$449,999
Han	BME	Neural Circuit Mechanisms for Attention	The Pew Charitable Trusts	8/1/12-7/31/17	$240,000
Han	BME	Striatal Origin of Pathological Beta Oscillations in Parkinson's Disease	NIH/National Institute of Neurological Disorders and Stroke	9/1/12-8/31/13	$245,550
Han	BME	Light Controllable Nanorobot for Uncaging Arbitrary Bioactive Molecule	NIH/National Institute of Neurological Disorders and Stroke	9/30/12-8/31/17	$2,455,500
Han	BME	Thalamocortical Circuit Dysfunction in Schizophrenia	Brain & Behavior Research Foundation	1/15/13-1/14/14	$30,000

P.I.	Dept.	Title of Project	Agency	Period	Amount
Han	BME	MDR1/P-GP Overexpression and Negative Feedback Insensitivity in CRSWNP	Mass Eye and Eear Infirmary	7/1/12-6/30/13	$14,989
Han	BME	Non-Invasive Striatal Delivery of Glial Derived Neurotrophic Factor (GDNF) Via a Novel Heterotopic Mucosal Grafting Technique	Mass Eye and Ear Infirmary	8/1/12-7/31/13	$93,636
Joshi	ECE	Biologically-Inspired Hardware for Land/Aerial Robots (Student: Schuyler Eldridge)	NASA	8/1/12-7/31/16	$66,000
Joshi	ECE	Electro-Photonic Netowrk-On Chip Architecutres in 1000+ Core Systems (ENEAC)	Department of Defense/ Army/RDECOM Acquisition Center	7/1/12-6/30/14	$150,198
Joshi	ECE	Biologically-Inspired Hardware for Land/Aerial Robots (Student Schuyler Eldridge)	NASA	8/1/12-7/31/16	$68,000
Klamkin	ECE	Monolithic Microwave Photonics Integrated Circuit (MMPIC)	University of Massachusetts, Dartmouth	1/1/13-12/31/15	$10,000
Klapperich	BME	Center for Innovation in Point of Care Technologies for the Future of Cancer Care	NIH/National Institute of Biomedical Imaging and Bioengineering	7/1/12-6/30/14	$1,929,735
Klapperich	BME	Bacterial Drug Susceptibility Identification by Surface Enhanced Raman Microscopy	Fraunhofer USA	7/1/10-6/30/13	$85,000
Klapperich	BME	Integrated Molecular Diagnostic System for Point-of-Care	Biohelix Corporation	9/30/11-8/31/13	$104,073
Meller	BME	Single Molecule Sequncing by Nanopore Induced Photon Emission (SM-SNIPE)	NIH/National Human Genome Research Institute	7/20/10-6/30/14	$966,813
Mertz	BME	Billing Agreement - Off-Campus Funding for Hao Wang	Massachusetts General Hospital	9/1/12-2/28/13	$17,805
Mertz	BME	Billing Agreement - Off-Campus Funding for Whan Wook Chang	Massachusetts General Hospital	9/1/12-4/30/13	$23,835
Mertz	BME	Billing Agreement - Off-Campus Funding for Hao Wang (March-April)	Massachusetts General Hospital	3/1/13-4/30/13	$5,935
Mertz	BME	Billing Agreement - Off-Campus Funding for Hao Wang (May-August)	Massachusetts General Hospital	5/1/13-8/31/13	$11,881
Mertz	BME	Billing Agreement - Graduate Student Support - Raphael Turcotte	Massachusetts General Hospital	5/1/12-6/30/14	$32,028

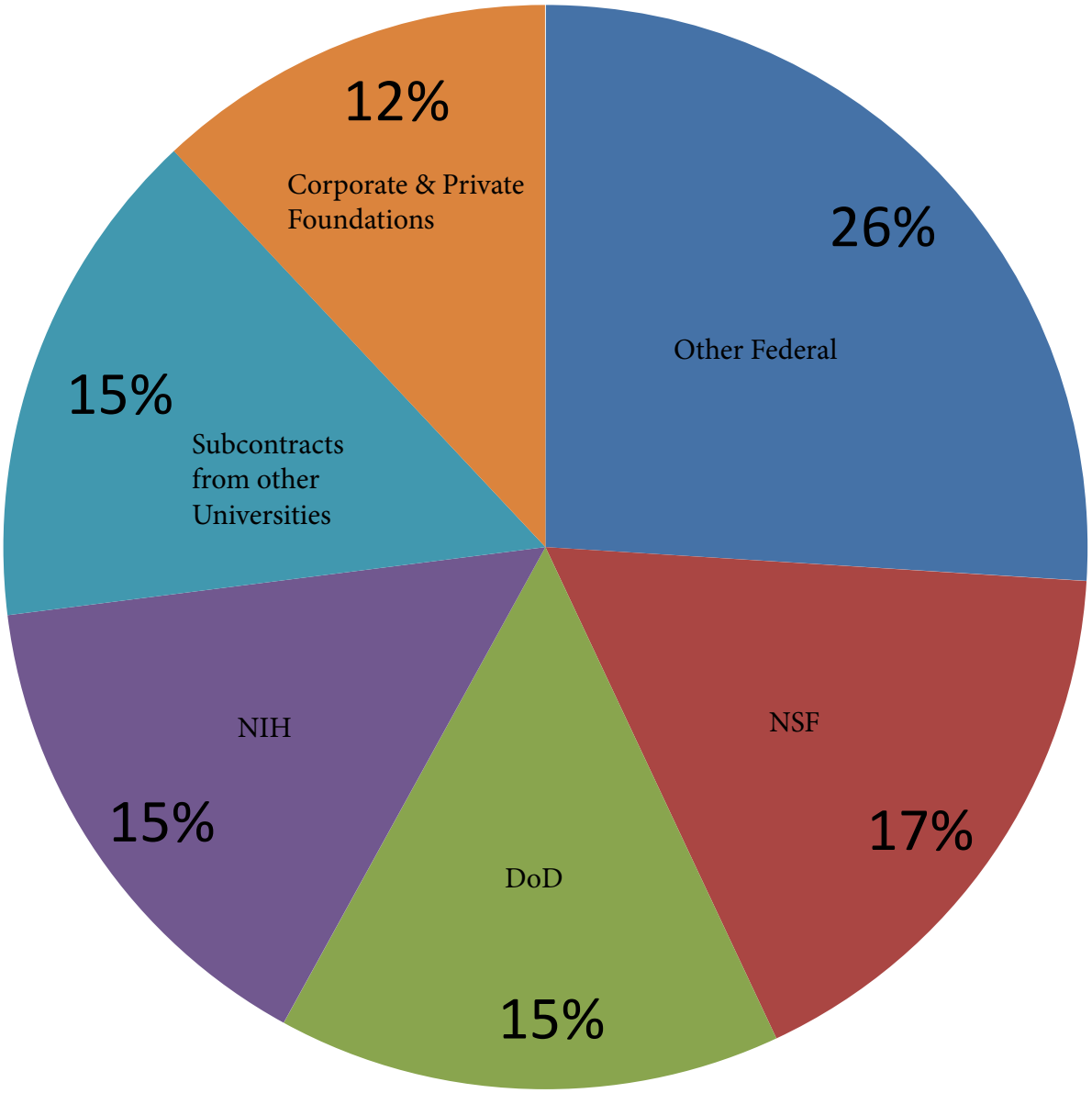
P.I.	Dept.	Title of Project	Agency	Period	Amount
Moustakas	ECE	Processing and Testing of Aigan Wafers and Surface Structuring of Phospors	Osram Sylvania, Inc.	9/1/12-9/30/13	$25,000
Moustakas	ECE	Joint Research and Development Work Between Boston University and Rayvio: Growth and Characterization of Deep UV-LEDS	Rayvio	7/1/12-12/31/13	$59,914
Moustakas	ECE	Joint Research and Development Work Between Boston University and Rayvio: Growth and Characterization of Deep UV-LEDS	Rayvio	7/1/12-12/31/13	$40,611
Moustakas	ECE	Highly Doped P-Type Distributed Bragg Reflectors Based on Aigan for Deep UV Optoelectronic Devices	National Science Foundation	6/15/13-5/31/14	$130,939
Paiella	ECE	Plasmonic Control of Radiation and Absorption Processes in Semiconductor Quantum Dots	Department of Energy	8/15/06-12/31/13	$148,000
Paiella	ECE	Plasmon-Enhanced Light Emission for Solid-State Lighting: A Feasibility Study	Sandia National Laboratories	5/23/13-1/31/14	$50,000
Paiella	ECE	Graphene on Nanoscale Gratings for Terahertz Light Emission	National Science Foundation	7/1/13-6/30/16	$480,000
Pavlidis	ECE	Deep UV Laser Diode Development for Medical and Precision Processing Applications	Electronics and Telecommunications Research Institute	4/1/12-10/31/13	$44,540
Ramachandran	ECE	Higher Dimensional Information Encoding with Vortex Fibers	Department of Defense/ Army/RDECOM Acquisition Center	7/20/12-7/19/14	$552,168
Ramachandran	ECE	High Power Blue Green Lasers for Communications	Department of Defense/ONR	11/1/10-4/30/14	$100,000
Ramachandran	ECE	Power Scalable Blue-Green Bessel Beams	Department of Defense/ONR	1/1/11-12/31/13	$52,960
Ramachandran	ECE	Photon Pair Generation with OA< States in Fiber	Department of Defense/ARO	4/15/13-4/14/14	$201,600
Ramachandran	ECE	High Power Blue Green Lasers for Communications	Department of Defense/ONR	11/1/10-4/30/14	$100,000
Ramachandran	ECE	Endoscopic Sted Nanscopy with Optical Fiber Vortices	National Science Foundation	6/15/13-5/31/16	$359,222
Reinhard	CHEM	Multiparamteric Optical Microbe Sensing with Engineered Photonic-Plasmonic Nanostructures	National Science Foundation	8/15/12-7/31/15	$300,000

P.I.	Dept.	Title of Project	Agency	Period	Amount
Reinhard	CHEM	Illuminating Dynamic Receptor Clustering in the Epidermal Growth Factor Receptor	NIH/National Cancer Institute	6/1/09-4/30/14	$76,863
Reinhard	CHEM	Illuminating Dynamic Receptor Clustering in the Epidermal Growth Factor Receptor	NIH/National Cancer Institute	6/1/09-4/30/14	$230,586
Reinhard	CHEM	Elucidating Non-Virus Encoded HIV Capture Through Artificial Virus Nanoparticles	NIH/National Institute of Allergy & Infectious Diseases	7/1/13-6/30/14	$384,696
Ritt	BME	Career Award at Scientific Interface	Burroughs Welcome Fund	1/1/10-6/30/13	$120,000
Rothschild	PHY	Analysis and Bioengineering of Optogenetic Rhodopsins	National Science Foundation	7/1/13-6/30/16	$598,026
Rothschild	PHY	Structure/Function of Micorbial Sensory Rhodopsins	University of Texas	4/1/13-3/31/14	$95,498
Semeter	ECE	Eager: High Speed Tomographic Imaging Facility for Studies of Auroral Fine Structure	National Science Foundation	9/1/12-8/31/14	$143,739
Semeter	ECE	URAD: Development of a Space Science Instrument Derived From Draper's SER Magnetometer	Draper Laboratory, Inc.	6/30/12-6/28/13	$65,000
Semeter	ECE	Collaborative Research: PINOT - PFISR Ion-Neutral Observations in the Thermosphere	National Science Foundation	10/1/12-9/30/15	$30,596
Semeter	ECE	Solar Maxiumum Studies at the Millstone Hill Observatory	Massachusetts Institute of Technology	11/1/10-12/31/12	$49,080
Semeter	ECE	Magnetrospheric Control of Density and Composition in the Polar Ionosphere	Department of Defense/AFOSR	4/1/12-3/31/15	$131,124
Semeter	ECE	The Millstone Hill Geospace Facility	Massachusetts Institute of Technology	12/15/12-11/30/17	$60,248
Sergienko	ECE	Quantum Communication Using Macroscopic Phase Entangled States	University of Maryland, Baltimore County	9/12/12-9/11/13	$86,235
Sergienko	ECE	High Information Capacity Quantum Imaging	University of Rochester	9/1/10-8/31/14	$41,667
Sergienko	ECE	Quantum Communication Using Macroscopic Phase Entangled States	University of Maryland, Baltimore County	9/12/12-9/11/13	$333,718
Sergienko	ECE	Attosecond-Resolution Quantum Interferometry - Quantum Measurement for Telecommunication and Science	National Science Foundation	9/1/13-8/31/16	$289,133

P.I.	Dept.	Title of Project	Agency	Period	Amount
Unlu	ECE	High Speed Diagnostic of Temperature and Intensity Variation of Diode-Laser Facets	Science Research Laboratory Inc.	8/1/10-6/30/13	$110,879
Unlu	ECE	Floating Light Activated Micro-Electrical Stimulators for Neural Prosthetics	New Jersey Institute of Technology	8/1/09-5/31/14	$104,529
Unlu	ECE	Multiplexed, Rapid, Point of Care Device to Quantify Speicifc IGE to Common Allergens	NIH/National Institute of Biomedical Imaging and Bioengineering	8/1/11-7/31/13	$204,625
Unlu	ECE	Rapid-Label-Free Single Virus Detection Platform for Multi-Pathogen Diagnostic	National Science Foundation	8/1/11-7/31/14	$16,000
Unlu	ECE	Point of Care Technology Research Center in Primary Care	General Hospital Corp D/B/A Massachusetts General Hospital	7/1/12-6/30/13	$312,767
Unlu	ECE	Graduate Assistance in Areas of National Need Fellowship in Nano-Bio Technology	Department of Edcuation	8/16/10-8/15/13	$133,266
Unlu	ECE	Rapid Label-Free Single Virus Detection Platform for Multi-Pathogen Diagnostic	National Science Foundation	8/1/11-7/31/14	$49,911
Zhang	ME	Draper Laboratory Fellow: Else Fohlich	Draper Laboratory, Inc.	9/1/12-8/31/13	$42,830
Zhang	ME	Coupled Evanescent Field Micro-Resonators for Downhole Data Relay	University of Texas	1/1/10-3/31/14	$258,690
Zhang	ME	Coupled Metamaterial Resonators for Real-Time Tunable Electromagnetic Materials	National Science Foundation	9/1/13-8/31/16	$348,922
Ziegler	CHEM	Ultrafast Dynamics of Supercritical Fluids	National Science Foundation	7/1/12-6/30/16	$177,830
Ziegler	CHEM	Bacterial Durg Susceptibility Identification by Surface Enahnce Raman Microscopy	Fraunhofer USA	7/1/10-6/30/13	$143,000
Ziegler	CHEM	Ultrafast Dynamics of Supercritical Fluids	National Science Foundation	7/1/12-6/30/16	$15,000
Ziegler	CHEM	Astrazeneca Graduate Fellowship in organic Chemistry	Astrazeneca	6/3/13-6/2/14	$10,000

TOTAL: $21,846,391

Breakdown by Granting Agency FY 2012-2013



External Grant Funding for the 2012-2013 fiscal year was over $21.8M. The Other Federal category represents a variety of grants including the Department of Energy, NASA, and subcontracts from Boston Medical Center. Other categories which showed large totals were NSF at 17% of funding, NIH, and DoD each accounted for 15% of funding.

Calendar Year 2012 Publications and Patents

Book Chapters

J. Zhang, Q. Cao, M. Mahalanabis, and **C. Klapperich**, "Integrated Microfluidic Sample Preparation for Chip Based Molecular Diagnostics," in *Microfluidic Applications for Human Health*, edited by World Scientific Publishing Co., 2012.

H. Wang, G. Rong, J. Wang, B. Yan, L. Skewis, and **B. Reinhard**, "Noble Metal Nanoparticles as Probes for Cancer Biomarker Detection and Dynamic Distance Measurements in Plasmon Coupling Microscopy," in *Biosensor and Biodetection Technologies for Cancer Detection, Diagnostic, and Research*, edited by K. Herold and A. Rasooly, CRC press, 2012.

Journal Articles

K. Iwaszczuk, A. Strikwerda, K. Fan, X. Zhang, **R. Averitt**, and P. Jepsen, "Flexible Metamaterial Absorbers for Stealth Applications at Terahertz Frequencies," *Optics Express* 20(635), 2012.

W. Chen, A. Totachawattana, K. Fan, J. Ponsetto, A. Strikwerda, X. Zhang, **R. Averitt**, and W. Padilla, "Single-Layer Metamaterials with Bulk Optical Constants," *Phys. Rev. B,* 85(035112), 2012.

H. Tao, M. Brenkle, M. Yang, J. Zhang, M. Liu, S. Siebert, **R. Averitt**, M. Mannoor, M. McAlpine, J. Rogers, D. Kaplan, and F. Omenetto, "Silk-Based Conformal, Adhesive, Edible Food Sensors," *Adv. Mat.* 24(1067), 2012.

C. Werley, K. Fan, A. Strikwerda, S. Teo, X. Zhang, **R. Averitt**, and K. Nelson, "Time-Resolved Imaging of Near-Fields in THz Antennas and Direct Quantitative Measurement of Field Enhancements," *Opt. Express,* 20 (8551), 2012.

M. Liu, H. Hwang, H. Tao, A. Strikwerda, K. Fan, G. Keiser, A. Sternbach, K. West, S. Kittiwatanakul, J. Liu, S. Wolf, F. Omenetto, X. Zhang, K. Nelson, and **R. Averitt**, "Terahertz-Field-Induced Insulator-to-Metal Transition in Vanadium Oxide Metamaterial," *Nature* 487(345), 2012.

E. Abreu, M. Liu, J. Liu, K. West, S. Kittiwatanakul, W. Yin, S. Wolf, and **R. Averitt**, "THz Spectroscopy of VO2 Epitaxial Films: Controlling the Anisotropic Properties Through Strain Engineering," *New. J. Physics,* 14 (083026), 2012.

J. Schuster, and **E. Bellotti**, "Analysis of Optical and Electrical Crosstalk in Small Pitch Photon Trapping HgCdTe Pixel Arrays," Applied Physics Letters, 101(26), Dec. 24, 2012.

R. Ganmukhi, M. Calciati, M. Goano, and **E. Bellotti**, "Theoretical Investigation of BeZnO-Based UV LEDs," *Semiconductor Science and Technology,* 27(12), Dec. 2012.

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G.Carlo, F. Damin, **M. S. Unlu**, P. Spuhler, and M. Chiari, "Synthesis and Conformational Characterization of Functional Di-block Copolymer Brushes for Microarray Technology," *Surface Science*, 258(1): 3750-3756, Feb. 2012.

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Patents

Theodore Moustakas (US Patent #8,237,175) Optical Devices Featuring Textured Semiconductor Layers.

Theodore Moustakas (US Patent #8,247,843) GaN-Based Permeable-Base Transistor and Method of Fabrication.

Theodore Moustakas (US Patent #8,257,987) Planarization of GaN by Photoresist Technique Using an Inductively Coupled Plasma.

Siddharth Ramachandran (US Patent #8,103,142) Preventing Dielectric Breakdown in Optical Fibers.

Siddharth Ramachandran (US Patent #8,175,435) Optical Fibers and Optical Fiber Devices with Total Dispersion Greater Than Material Dispersion.

Siddharth Ramachandran (US Patent #8,175,436) Optical Fibers and Optical Fiber Devices with Total Dispersion Greater than Material Dispersion.

Siddharth Ramachandran (US Patent #8,189,977) Optical Fibers and Optical Fiber Devices with Total Dispersion Greater than Material Dispersion.

Siddharth Ramachandran (US Patent #8,290,317) Production of Optical Pulses at a Desired Wavelength Utilizing Higher-Order-Mode (HOM) Fiber.

Siddharth Ramachandran (US Patent #8,358,888) Systems and Techniques for Generating Bessel Beams.

Kenneth Rothschild (US Patent #8,288,098) Bioreactive Agents.

Kenneth Rothschild (US Patent #8,278,045) Methods for the Detection, Analysis and Isolation of Nascent Proteins.

Kenneth Rothschild (US Patent #8,148,062) Detection of Disease Related Genes.

Kenneth Rothschild (US Patent #8,114,587) Methods for the Detection of Colorectal Cancer.

Professors and students participate in the Research Experiences for Teachers poster session.

Awards of Note

Dr. Tom Bifano received the Distinguished Scholar Award from Boston University's College of Engineering.

Dr. Bennett Goldberg was awarded the University Scholar/Teacher of the Year by Boston University.

Dr. Xue Han received the NIH New Innovator Award, the NARSAD Young Investigator Award, and the Boston University Peter Paul Professorship.

Dr. Ajay Joshi was awarded the NSF Career Award and a NASA Space Technology Research Fellowship.

Dr. Catherine Klapperich was named a Kern Faculty Fellow.

Dr. Ted Moustakas was elected as a Charter Fellow of the National Academy of Inventors and received the Boston University 2012 Innovator of the Year Award.

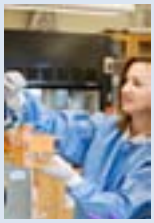
Dr. Xin Zhang won the Dean's Catalyst Award from Boston University.

Tom Bifano

Bennett Goldberg

Xue Han

Ajay Joshi



Catherine Klapperich

Theodore Moustakas

Xin Zhang

Technology Development

The Photonics Center has turned a chapter on technology development efforts, by completing the transition from a focus on Defense/Security applications to a focus on the healthcare market sector. The commercial sector is expected to energize the technology development efforts for the foreseeable future, but the roots in defense/security are still important and the Center will continue to pursue new research grants in this area. Some technology development highlights for FY13 are described in the following pages.

Leading Activities for FY 2012-2013

Biophotonics and Photonic Biomaterials:

The Photonics Center has led the I/UCRC on Biophotonic Sensors and Systems (CBSS) through two successful years and the program formulation for the third year. This Center has involved nearly half of the faculty researchers at the Photonics Center and at the partner University of California, Davis' Center for Biophotonic Science and Technology. The I/UCRC concept is a long-running NSF program designed to foster university and industry collaboration and is jointly supported by the foundation and industry. The mission of CBSS is:

- To create a national center of excellence for biosensor research with photonics as the enabling technology.
- To cultivate embryonic applications for biosensors.
- To advance biophotonic sensor technology, providing significant commercial benefits for disease diagnosis, patient monitoring, drug efficacy testing, and food and water safety.
- To develop effective methods for technology translation, accelerating innovative research to commercial benefit.
- To increase the quantity, quality and diversity of professionals prepared to work in this field.
- To involve the full technology and supply chain in a common focus of solving critical unmet needs in the healthcare sector using biophotonic sensing solutions.

The first two years of the program have yielded a well-functioning collaborative engagement between the two university sites and ten participating industry members. CBSS has become an active hub for industry-focused research on biophotonic research frontiers. The founding set of corporate sponsors included Agilent, General Electric's Applied Precision, Becton Dickinson, Fraunhofer, Lincoln Laboratory, and Thorlabs. Additional members that have joined since the center's inception include Potomac Photonics, Lawrence Livermore National Laboratory, BioTools, and IrisAO. BioTools and Iris AO were additions in FY13. Semi-annual meetings of the industrial advisory board have resulted in foundational documents including a common membership agreement and a set of bylaws, and have produced a well-functioning research project selection process. The main purpose of CBSS is to create a hub of innovative research activity in the area of Biophotonic systems. Primary among the research results to date has been the launch of 12 collaborative CBSS projects. In FY13, five projects were funded by the Industry members as follows:

Project	Project Lead	University Site
Monitoring Drug Dose Response of Single Cells using Micro-Raman Spectroscopy	J. Chan	UCD
Direct Molecular Detection via SERS and Aptamers	S.Wachsmann-Hogiu	UCD
POC Caner Detection from Serum	S. Unlu	BU
Snapshot 3D Flow Cyutometry	J. Mertz	BU
AO Hybrid Microscopy	R. Zawadzki	UCD

Notable results from these projects are discussed below.

Monitoring Drug Dose Response of Single Cells using Micro-Raman Spectroscopy. This project was led by Professor Chan at UCD under the mentorship of LLNL. The goal of this project was to apply single cell Raman spectroscopy/microscopy to study the drug response of single living cells. Raman spectroscopy enables continuous, label-free chemical analysis and imaging of single cells as they interact with their local environment. This makes the technology ideally suited for monitoring cell-drug interactions. The technology has the potential to be developed into a compact, cost-effective analytical tool for testing patient response to drugs for treatment monitoring, drug screening and discovery, and microdose testing. In this project, changes in specific Raman peak intensities of cells exposed to a drug (doxorubicin) as a function of exposure time were analyzed. This project demonstrated effective use of the technology (identifying changes in specific Raman peak intensities) by generating histograms depicting drug induced changes on cell DNS, protein and esterified fatty acids as a function of exposure time.

Direct Molecular Detection via SERS and Aptamers. This project was led by Professor Wachsmann-Hogiu at UCD under the mentorship of Agilent Technologies. Detection and tracking of molecules is invaluable in the field of medical diagnostics and also in drug development and analysis, environmental monitoring, forensic investigations and biodefense. Most commonly used methods make use of fluorescent labels as probe molecules, but this is not always advantageous as it can render the biomolecules inactive and these probes are subject to photobleaching. This project however aimed to develop a label free assay for direct detection of biomolecules using aptamers as molecular receptors and Surface Enhanced Raman Spectroscopy (SERS) as a detection method. This technique is specific, robust, cost effective and greatly reduces the amount of time normally involved in sandwich type assays. During the course of the project, the researchers developed new methods to fabricate flexible and tunable plasmonic nanostructures based on a combination of soft lithography and nanosphere lithography, and investigated the surface characteristics in the self-assembly of protein-metalic nanoparticle structures for label-free protein detection. A result of the project was the detection and measurements of the limit of detection of thrombin and thrombin-binding aptamer. Also demonstrated was that other proteins not binding to the aptamer do not change the SERS spectra of the aptamer.

POC Cancer Detection from Serum. This project was built from extensive prior research at BU and was led by Professor Unlu, with mentorship from BD. In the past decade many studies have shown that circulating RNA can serve as a biomarker for cancer. It has been shown that levels of non-coding RNA that can be either microRNA or long non-coding RNA are different between healthy and cancer patients. Functional studies have shown that these RNAs serve regulatory purposes and can be either tumor suppressive or oncogenic in human cancers. It has been shown that certain microRNA play a crucial role in tumor initiation, progression and metastasis. Therefore profiling RNA levels can serve as a diagnostic tool to detect, stage the cancer and monitor response to therapy.

Circulating RNA in serum serves as a great biomarker because of its stability. Unlike non-circulating RNA they are resistant to most RNases (enzymes that break down RNA) and are stable at room temperature for more than 24 hours. The aim of this project was to develop a diagnostic assay that would screen for melanoma based on the levels of four proven RNA targets. The diagnostic technology proposed is based on a proven Interferometric Reflectance Imaging Sensor (IRIS) technology which has shown very high sensitivity, eliminating the need for PCR amplification.

During the project, the team studied the effect of probe density and charge on assay performance. The study showed that binding increases with increasing probe density. The project was focused on testing the feasibility of detecting NRP-2 mRNA for cancer diagnostics. Stock concentrations were too high, so the extracted cDNA was diluted 10,000X and 100,000X and mixed with NRP-2 probe functionalized nanoparticles. After incubation, the chips were washed and imaged using IRIS. The technology showed that RNA extracted from Mel 1 melanoma cancer lines could be used to quantify NRP-2 mRNA levels with performance comparable with PCR without the

need for amplification.

Snapshot 3D flow cytometry. This project has generated significant commercial interest and the consensus support of the Industry Advisory Board, with mentoring and guidance from BD and Thorlabs. Professor Mertz is the project PI. Flow Cytometry (FCM) is a technique for counting and examining cells undergoing flow in a fluidic chamber. FCM is routinely used in the diagnosis of health disorders, especially blood cancers, but has many other applications in both basic research and the clinic. FCM can be based on scattering or fluorescence. The former is convenient because it requires no cell labeling. Forward-scatter FCM reveals larger scale cell morphology, such as size, whereas side-scatter reveals finer details, such as intracellular structure. This project involved the development of a hybrid forward/side scatter FCM that provides much more information than either technique. Standard scatter-based FCMs record only the amplitude of scattered light. This approach records both amplitude and phase (more precisely, phase gradient) of the scattered light. Using a technique called light-field imaging, a light-field camera records not only the amplitude of the light rays incident on the camera, but also the directions of these rays.

There is a direct correspondence between light-ray direction and wavefront phase gradient. Thus, light-field imaging provides a complete recording of an incident wavefront, both its amplitude and phase gradient. This description is so complete that one can numerically re-process the recorded image so as to re-adjust its focus a posteriori. That is, a single light–field snapshot provides an image whose focus can be arbitrarily adjusted after the image has been acquired. Light-field imaging is not new. Indeed, the company Lytro Inc. has recently popularized light-field imaging in the form of a general public camera. Light-field imaging has even been implemented in a microscope configuration, though only for demonstration purposes with reflected light imaging. It should be clarified that the recording of images at multiple foci is not the same as 3D imaging. To obtain 3D imaging from a multiple-focus stack, and extra numerical step must be taken that involves image deconvolution. To our knowledge, the combination of light-field imaging and deconvolution to obtain bona-fide 3D imaging has not yet been implemented in a same instrument, much less in a microscope, and much less still in a microscope designed for flow cytometry.

This project is unique in several aspects, light-field microscopy has not been used for FCM, nor has it been used to provide 3D imaging by deconvolution. However, the main difference is in the method of light-field imaging. This project involved the development of a light-field or wavefront-imaging microscope, demonstration of the capacity to numerically adjust focus a posteriori, demonstration of 3D imaging by deconvolution, and demonstration of applicability for high throughput FCM. As the development progressed, the development of an algorithm to generate 3D images was problematic. Although this aim has not been entirely abandoned, in the interest of producing results, the aim has been moderated to the development of an algorithm to extend the depth of focus of the PAW images. With respect to the modified aim, two algorithms to extend the depth of focus of PAW imaging have been developed. The first algorithm is fast, but susceptible to artifacts. The second algorithm is slower and can only be performed a posteriori. This second algorithm is robust and accurate.

AO Hybrid Microscopy. This project, which was initiated mid-year when a new sponsor (Iris AO) joined the I/UCRC, is being led by Professor Zawadzki at UCD. The goal of this project was to test the feasibility of Adaptive Optics enhanced hybrid imaging system that combines Optical Coherence Microscopy (OCM) with fluorescent confocal microscopy for in-vivo retinal imaging of small animals. An instrument was built and basic functionality tested. Multimodal imaging systems allow acquisition of different functional information captured by fluorescence and morphological information captured by OCM. The combined fluorescent and tissue scattering information offered by this system should be useful for pathological diagnosis and for studying cellular function in living animals.

The I/UCRC provides members with rights to a royalty free, non-exclusive license on inventions related to funded projects and also approval rights on publications related to funded research. This process works very well and in

the past year, the following publications were approved:

J. Chan, "Investigating the Effects of Doxorubicin Treatment on Living Jurkat Cells Using Line-Scanning Raman Spectroscopy," Manuscript submitted for publication, 2013.

A. Parthasarathy, K. Chu, T. Ford, and J. Mertz, "Quantitative Phase Imaging Using a Partitioned Detection Aperture," *Opt. Lett.* 37, 4062-4064, 2012.

M. Kahraman, B. Balz and S. Wachsmann-Hogiu, "Hydrophobicity-Driven Self-Assembly of Protein and Silver Nanoparticles for Protein Detection Using Surface-Enhanced Raman Scattering," Manuscript submitted for publication, 2013.

I. Schie, L. Alber, A. Gryshuk and J. Chan, "Comparing Local and Global Raman Spectra for Identifying Biochemical Changes in Single, Drug Exposed Lymphocytes," Manuscript submitted for publication, 2013.

Y. Jian, R. Zawadzki, and M. Sarunic, "Adaptive Optics Optical Coherence Tomography for In Vivo Mouse Retinal Imaging," *Journal of Biomedical Optics,* in press.

Y. Jian, J.Xu, R. Zawadzki, M. Sarunic,"Ultrahigh-Speed Ultrahigh-Resolution Adaptive Optics: Optical Coherence Tomography System for In-Vivo Small Animal Retinal Imaging," *SPIE BiOS*, 85711R-85711R-7.

E. Saint Clair, J. Ogren, S. Mamaev, D. Russano, J. Kralj, K. Rothschild, "Near-IR Resonance Raman Spectroscopy of Archaerhodopsin 3: Effects of Transmembrane Potential," *J Phys Chem B.* 116 (50), 2012.

J. Ogren, E. Saint Clair, S. Mamaev, D. Russano, J. Karlj, K. Rothschild, "Near-IR Resonance Raman and UV-Visible Absorption Kinetic Spectroscopy of Optogenetic Archaerhodopsin Neuronal Silencers: Effects of Membrane Potential," *Biophysical Journal*, 104(2), 2013.

Additional publications related to CBSS include:

C. Maedler, S. Erramilli, L. House, M. Hong, and P. Mohanty, "Tunable Nanowire Wheatstone Bridge for Improved Sensitivity in Molecular Recognition," *Applied Physics Letters*, 102, April 31, 2012.

The program formulation meeting for the FY14 projects was held in May 2013 after a formal solicitation process that resulted in 20 new proposals being submitted by faculty from BU and UCD. A screened set of these proposals along with the five running projects from FY13 were evaluated by the industry advisory board and the IAB recommended funding six projects. The Director and Site Directors approved all recommendations. The FY14 I/UCRC projects are the following:

Project	Project Type	Project Lead	University Site
Label-Free, Non-Genetic Method to Purify Stem Cell Derived Cardiomyocytes	New	J. Chan	UCD
Direct Molecular Detection via SERS and Aptamers	2nd Year Fudning	S. Wachsmann-Hogiu	UCD
Superpenetration Multiphoton Microscopy for Deep Tissue Imaging	New	T. Bifano	BU
Snapshot 3D Flow Cytometry	2nd Year Funding	J. Mertz	BU
AO Hybrid Microscopy	2nd Year Funding	R. Zawadzki	UCD
SERS Approach for Rapid Antibiotic	New	L. Ziegler	BU

The I/UCRC has spawned two supplemental projects that are both aligned with the I/UCRC and the strategic vision for the Photonics Center. These supplemental projects are Fundamental Research Program (FRP) on "Characterizations and Bioengineering of Optogenetic Rhodopsins" and a Partnerships for Innovation: Accelerating Innovation Research (PFI-AIR) project entitled "Nanoplasmonic Metamaterial Antennae for Efficient Wireless Power Transmission"

Characterization and Bioengineering of Optogenetic Rhodopsins. The FRP proposal had the strong endorsement of the IAB and is aligned with the Photonics Center strategic vision. The major goals of the project are to characterize the molecular basis for function of key optogenetic rhodopsins and to bioengineer improved versions for various neuroscience applications which will ultimately be tested in living cells and neural circuits. In the past year, extensive studies were conducted using both FTIR difference spectroscopy and resonance Raman confocal spectroscopy to study the structure and conformational changes of two major rhodopsins used in optogenetics (Archaerhodopsin 3 (AR3) and ChannelRhodopsin 1 and 2 (ChR1 and ChR2)) as well as mutants and other variants of these proteins. Procedures were also developed for expression of these proteins in both E.coli and yeast Pichia pastoris cells along with the purification and reconstitution.

The basic understanding of how the brain functions is widely believed to be one of the most important goals of science in the 21st century. In this regard, optogentics holds considerable promise in understanding the circuit-level functional organization of the brain. Such knowledge would not only impact the ability to cure disease of the brain but also many diverse fields ranging from computer to social science. As just one example, efforts to develop advanced prosthetic devices and restore lost sensing functions such as hearing and vision have focused largely until now on electrical device-body interfaces. The ChannelRhodopsins can be expressed in neuronal membranes and thus, this distinct family of microbial rhodopsins, have rapidly become important tools in neuroscience. And recent interest has focused on AR3 because of its ability to serve as a high-performance genetically targetable optical silencer of neuronal activity.

The research during the past year has set the state for deeper analysis of structural changes in key optogenetic rhodopsins by establishing key methods and procedures for studying these proteins using FTIR and Resonance Raman Spectroscopy as well as to provide basic information about the functioning of these proteins in the context of optogenetics. The methodology and spectroscopic techniques established in the study of the AR3 and ChR1/2 rhodopsins will be applied to mutants and other variants of these proteins. Additionally, advanced techniques for the study of these proteins developed in conjunction with Thorlabs and Agilent will be continued to be implemented including advanced methods of rhodopsin illumination using fiber optic LEDs and also advanced scan methods. Also, research will commence on expression of engineered rhodopsins characterized using spectroscopic methods in intact nerves and other cells.

Nanoplasmonic Metamaterial Antennae for Efficient Wireless Power Transmission. The main motivation for this project is the development of metamaterial nanoplasmonic rectennae for efficient wireless power transmission where millimeter wave metamaterials will be exploited to design miniature rectenna systems. The short wavelength and metamatial design allows for antenna systems with an electrical size that is much smaller than the wavelength, without sacrificing efficiency. For compactness, the frequency of operation should be as high as possible. But other factors, such as the availability of nonlinear circuit elements, maximum permissible exposure levels of microwave radiation, availability of sources, etc., put constraints on the frequency range. This project is developing nanoplasmonic rectennae in the 30GHz – 95GHz frequency range. In FY13, a 3mm x 3mm rectenna element was developed that meets power requirements for a silicon nanowire biosensor. In consultation with Battelle Memorial Institute, the corporate partner on this project, the initial devices were designed to operate at 35GHz. While the ultimate goal would be to power ingestible/implantable biosensors or other body-worn sensors, Battelle has targeted a more immediate market for heavy equipment maintenance sensors to prove-in the technology.

Battelle and BU made a joint presentation to NSF in May 2013 to review first year achievements against milestones and the market outlook for this technology. The review was well-received and NSF has decided to fund the second year of the project. Battelle is a technical collaborator on this research, and also is matching the NSF investment in this research. Both BU and Battelle have secured patent protections on inventions related to this project. The BU invention entitled "Phase Cascade Metamaterial Rectenna," relates to an arrangement of engineered phase shifts in rectenna elements that follow a defined mathematical sequence and results in enhanced efficiency in rectification. The device is tailored as a receiver for efficient wireless power transmission at ultrahigh frequency microwave and terahertz radiation. Applications include power chargers, embedded sensors and remote sensors which are not able to directly connect to an external power source.

Although not directly related to the I/UCRC, there was a second NSF AIR grant that involved a partnership with Becton, Dickinson, and Company (BD) and which had a technology basis aligned with the I/UCRC's primary focus. BD, a member of the I/UCRC on Biophotonic Sensors and Systems, is also one of the largest diagnostic companies in the world. This award relates to a viral diagnostic tool originally referred to as COBRA and developed with ARL funding and in collaboration with the US Army Medical Research Institute of Infectious Diseases. Additionally, on this same technology, the NIH awarded Professors Connor (PI) and Unlu (co-PI) a five-year ROI grant for a project entitled "Development of Near Real-Time, Multiplexed Diagnostics for Viral Hemorrhagic Fever." In collaboration with BD and several other faculty, the PI/co-PI will deliver a production ready instrument integrated with microfluidics and sample preparation and ready for use in a BL-4 laboratory before the end of the grant. The NSF AIR grant provided funding for "Rapid Label-Free Single Virus Detection Platform for Multi-Pathogen Diagnostics." At the completion of the grant, the team was well-positioned for a new business launch, and as this annual report goes to press, Dr. David Freedman, a recent graduate of the Unlu lab, was awarded an NSF ICORPS grant. This grant positions Dr. Freedman's company (Next Gen Array LLC) to compete for SBIR funding.

In another related research field, Professor Klapperich, a leader in the field of microfluidics, was awarded an NIH training grant (NIH U54) for a Center for Innovation in Point of Care Technologies for the Future of Cancer Care.

This Center is focusing on the identification, prototyping and early clinical assessment of innovative point-of-care technologies for the treatment, screening, diagnosis, and monitoring of cancers. This Center was launched in FY13 and the Photonics Center will provide administrative management of this grant. The Photonics Center is well-positioned in its role of administering this grant. And in the role of managing the I/UCRC, the staff will monitor opportunities that have overlapping research benefiting technology assessment for clinical use. Where possible, the Photonics Center will orchestrate the involvement of I/UCRC members in prototype and clinical device development in support of the POC efforts.

Photonic Materials:

Photonic Materials development has long been a key focus of the Photonic Center. The Photonics Center and the Moustakas labs have been leaders in the materials development required to produce efficient deep UV LEDs. UV light at under 260 nm acts on micro-biological contaminants in water and air through a process by which adjacent thymine nuclei acids on DNA are dimerized, preventing replication of the micro-organisms, a process shown to be effective on E.coli, giardia and even more resistant virus strains such as adenovirus. In FY12, RayVio, a startup company, spun out of BU with the assistance of the Office of Technology Development. Rayvio's core technology, a breakthrough crystal growth process for high efficiency deep UV LEDs was developed in Professor Moustakas' labs and licensed from BU. RayVio plans to commercialize this technology for a $1+ billion market for water, air and food disinfection. Rayvio moved into the Business Innovation Center at the beginning of FY13 and has subsequently initiated sponsored research agreements with the Moustakas labs.

BU was part of a team that proposed a comprehensive plan to address the U.S. Army's requirements for multi-scale, multi-disciplinary modeling of electronic materials (MSME). FY13 marked the "kick-off" year for the award, where BU participates on the team known as "Computationally-Guided Design of Energy Efficient Electronic Materials" (CDE3M). BU's efforts will focus on material simulations for III-Nitride based visible to UV light emitters, multi-spectral detector design, wide band gap power and RF devices, and devices for energy harvesting and power management. The research here needs to be responsive to the needs of the Army and focus on collaboration with the Army research scientist at the Sensors and Electronic Devices Directorate. The Photonic Center faculty (Professors Bellotti and Dal Negro) are major research contributors and leads on this project, and the team is also able to leverage the Photonics Center's extensive contacts and collaborative research track record with ARL to help make this project a success.

Other:

On an organizational level the experiences of program management on ARL projects has resulted in a disciplined administrative and financial management skill set in the Photonics Center. In addition to the Photonics Centers' involvement in the above projects, the staff has also assumed financial and administrative management for:

- NSF Research Experiences for Teachers site in Biophotonics Sensors and Systems. Dr. Fawcett along with Professors Ruane and Brossman successfully completed year two of this three-year program that trains teams of teachers in very intensive "hands on" training in biophotonics and cleanroom activities. (See the Education section for more information).
- IARPA: Intelligence Advanced Research Projects Activity. Professors Bennett Goldberg, Selim Unlu and Thomas Bifano were awarded two IARPA grants, one as the prime for a four-year grant entitled "Next Generation Solid Immersion Microscopy for Fault Isolation in Backside Analysis." The other as a subcontractor on the project entitled "Logic Analysis Tool." In both programs, the Photonics Center is providing financial and administrative management. Professor Helen Fawcett will assume the role of Program Manager for both of

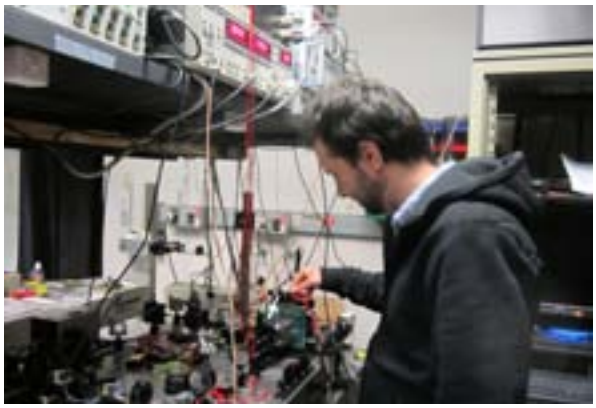
these IARPA awards.

- NIH XTNC: BU Cross-Disciplinary Training in Nanotechnology for Cancer. Boston University's cross-disciplinary training program in nanotechnology for cancer (XTNC), formed by the Center for Nanoscience and Nanobiotechnology as an offshoot of BU's nanomedicine initiative, is training a community of scientists, engineers and medical researchers capable of working across disciplines, at the interface between nanotechnology and cancer medicine. Now in its fourth year, XTNC has supported thirty-three pre- and post-doctoral fellows with backgrounds in medicine, biology, and other health sciences, as well as in the physical sciences and engineering -- all engaged in interdisciplinary mentored research to develop novel nanoscale therapeutic and diagnostic tools for the detection and treatment of cancer. Photonics staff members provide financial and administrative management on the Charles River Campus and coordinate with the corresponding Medical Campus portion of the program.

Professor Tom Bifano provides an introduction at a Town Hall event in February 2013.

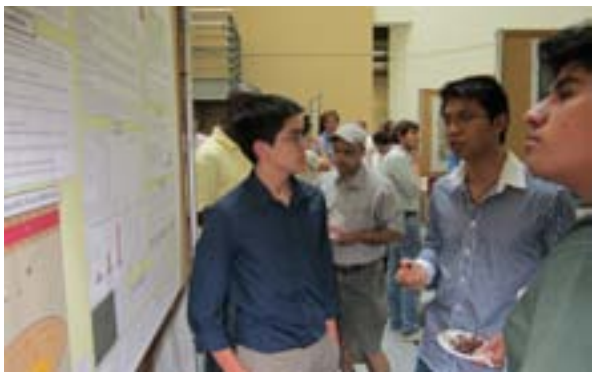
Education

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



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 Scholar's 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 a variety of student opportunities, the Center continued its support of the Research Experiences for Teachers and Research Experiences for Undergraduates in Photonics program.



Graduated Doctoral Students 2012-2013

PhD Graduate	Advisor	Primary Major
Ronen Adato	Hatice Altug	Electrical Engineering
Serap Aksu	Hatice Altug	Materials Science and Engineering
Alp Artar	Hatice Altug	Electrical Engineering
Nenad Bozinovic	Siddharth Ramachandran	Electrical Engineering
Thomas Butler	Joshua Semeter	Electrical Engineering
Katherine Calabro	Irving Bigio	Biomedical Engineering
Whan Chang	Jerome Mertz	Biomedical Engineering
Yushan Chen	Allyn Hubbard	Computer Engineering
Yuhao Chen	Siddharth Ramachandran	Electrical Engineering
Min Huang	Hatice Altug	Electrical Engineering
Jason Keller	Catherine Klapperich	Biomedical Engineering
Jing Li	Roberto Paiella	Biomedical Engineering
Margo Monroe	Selim Unlu	Biomedical Engineering
Srikant Sarangi	Lee Goldstein	Biomedical Engineering
Joseph Schroeder	Jason Ritt	Biomedical Engineering
Jonathan Schuster	Enrico Bellotti	Electrical Engineering
Haiding Sun	Theodore Moustakas	Electrical Engineering
Gary Walsh	Anna Swan	Electrical Engineering
Xirui Zhang	Selim Unlu	Biomedical Engineering

Selected Photonics Related Courses

ENG EC481 (Altug)/(Bishop)
Fundamentals of Nanomaterials and Nanotechnology
Nanotechnology encompasses the understanding and manipulation of matter with at least one characteristic dimension measured in nanometers with novel size-dependent physical properties as a result. This course explores the electronic and optical properties of material at the nanoscale and applications of nano-scale devices. The parallels between light and electron confinement are emphasized, e.g. in terms of normal modes, resonances and resonators, and the dispersion of light and electrons as affected by the periodicity of crystals and photonics crystals. Wave-mechanics and electromagnetics are reviewed and used to understand confinement and energy quantization. Nano-devices such as carbon nanotube transistors, nano-resonators, nanocavity lasers, nano-biosensor and their applications are discussed. Fabrication using top-down and bottom-up methods are discussed, as well as characterization using scanning probe methods, electron microscopy, and spectroscopic techniques.

ENG EC/MS574 (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 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.

KHC EK101 (Bifano)
Engineering Light
Students in this course will gain an appreciation for light and its use in three optical instruments: the eye, the microscope, and the telescope. They will study landmark discoveries concerning light, the development of various light sources, the scientific advances that led to our current understanding about the properties and characteristics of light waves and photons. The course includes weekly lectures and in-class laboratory exercises, several field trips, and a semester-long project. Students will engage in more than twenty hands-on experiments throughout the semester, to untwinkle the stars with adaptive telescopes, to measure the speed of light using parts hacked from a laser pointer, to make a light bulb like Thomas Edison's, to discover how engineers ruined -- and then fixed -- the world's first astronomical space telescope, and to use a high-resolution ophthalmoscope to see image photoreceptors and capillary blood flow in their own retinas.

ENG MS500 (Bishop)
Special Topics in Materials Science and Engineering
Coverage of a specific topic in materials science and engineering. Subject varies from year to year and is generally from an area of current or emerging research.

GRS CH 652 (Chen)
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.

ENG ME302 (Ekinci)
Engineering Mechanics II
Fundamentals of engineering dynamics. Kinetics of rigid bodies in two and three dimensions. Impulsive motion; impact. Energy and momentum methods. Mechanical vibrations of linear single-degree-of-freedom systems.

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.

CAS PY 521 (Erramilli)
Electromagnetic Theory 1
Vector and tensor analysis. Electrostatics, uniqueness, electrostatic energy, capacitance. Boundary value problems, conformal mapping, variable separation, Green's functions. Multipole expansion, electric polarization, atomic models, anisotropic media. Contour integration and application to frequency-dependent dielectric constant. Dielectrics, electrostatic energy, boundary value problems.

CAS PY522 (Erramilli)
Electromagnetic Theory II
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 BE 575 (Han)
Introduction to Neuroengineering
This course covers existing and future neurotechnologies for analyzing brain signals and for treating neurological and psychiatric diseases. It focuses on the biophysical, biochemical, anatomical principles governing the design of current neurotechnologies, with a goal of encouraging innovations of a new generation of therapies. Topics include basic microscopic and macroscopic architecture of the brain, the fundamental properties of individual neurons and ensemble neural networks, electrophysiology, DBS, TMS, various imaging methods, optical neural control technologies, optogenetics, neuropharmacology, gene therapy, and stem-cell therapy. Discussions of related literatures and design projects will be involved.

ENG EC 311 (Hubbard)
Introduction to Logic Design
Introduction to hardware building blocks used in digital computers. Boolean algebra, combinatorial and sequential circuits: analysis and design. Adders, multipliers, decoders, encoders, multiplexors. Programmable logic devices: read-only memory, programmable arrays, Verilog. Counters and registers.

ENG EC 772 (Hubbard)
VLSI Graduate Design Project
Students working in a group of one to four people design and simulate a microchip, and create a fabrication file. Students submit the design for fabrication. When the chip is returned, students test and if necessary redesign the circuitry. A project write-up is required. Students must take an I-grade until testing of the chip is completed.

ENG EC571 (Hubbard)/(Joshi)
Digital VLSI Circuit Design
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.

ENG EK131/2 (Joshi)/(Paiella)
Introduction to Engineering
Introduction to engineering analysis and/or design through a sequence of two modules or minicourses chosen from a selection of modules offered by participating engineering faculty. Each module presents students with key concepts and techniques relevant to an applied area of engineering.

ENG BE569 (Meller)
Next Generation Sequencing
The advent of high throughput sequencing is virtually changing biology and medicine. The technology enables us to catalog the entire functional parts list of living organisms from bacteria to human, develop and validate regulatory networks for controlling gene expression in systems biology models and develop novel biomarkers for personalized medicine that guide pharmacological treatments. In this course we will review the foundations of the field, starting from the biophysical foundations of current or emerging single molecule DNA sequencing techniques, through an introduction to the analytical tools to model and analyze NGS Data, and finally discussing clinical applications such as predicting drug response focusing on cancer. The course will involve bi-weekly homework assignments that include theoretical analysis and modeling, working with multiple analysis tools for NGS data including assembly, re-sequencing, alignments, RNA-seq, ChIP-seq, DNA methylation, mutation analysis and detection, copy number variation detection, and their applications to cancer.

ENG BE773 (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 BE 517 (Mertz)
Optical Microscopy of Biological Materials
In this course students will learn the practice and the underlying theory of imaging with a focus on state-of-the-art live cell microscopy. Students will have the opportunity to use laser scanning confocal as well as widefield and near-field imaging to address experimental questions related to ion fluxes in cells, protein dynamics and association, and will use phase and interference techniques to enhance the detection of low contrast biological material. Exploration and discussion of detector technology, signals and signal processing, spectral separation methods and physical mechanisms used to determine protein associations and protein diffusion in cells are integrated throughout the course. Students will be assigned weekly lab reports, a mid-term and a final project consisting of a paper and an oral presentation on a current research topic involving optical microscopy.

ENG EC/MS577 (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 471 (Moustakas)
Physics of Semiconductor Devices
Study of solid state electronic devices, including growth and structure of semiconductors, energy bands and charge carriers in semiconductors, junctions, diodes, bipolar junction transistors, field effect transistors and devices.

ENG EC 591 (Paiella)
Photonics Lab 1
Introduction to optical measurements. Laser safety issues. Laboratory experiments: introduction to lasers and optical alignment; interference; diffraction and Fourier optics; polarization components; fiber optics; optical communications; beam optics; longitudinal laser modes. Optical simulation software tools.

ENG EC568 (Ramachandran)
Optical Fibers and WaveGuides
Whether it be the FIOS™ internet connection at our homes, or fiber lasers powerful enough to cut metals (many automobile chassis are now made using fiber lasers), or the ability to perform endoscopic surgery and imaging, or doing frequency metrology with super-continuum sources (the basis of a few recent Nobel prizes)... the optical fiber has played a central, often dominant, role in many applications that impact the way we live. The main function of an optical fiber is to carry an electromagnetic (in the optical frequency) pulse over distances ranging from meters to greater than ten thousand kilometers without distortions. Fibers can also become smart light-pipes when they are intentionally designed to alter, temporally shape or amplify light pulses. Moreover, new developments in this field such as photonic bandgap fibers, fiber nanowires and higher-order mode fibers, are opening up new directions in science and technology. This course will introduce the optical fiber waveguide and its theory of operation. Specifically, the design and impact of the two most important properties in optical fibers -- dispersion and nonlinearity -- that govern the evolution of light in optical fibers, will be covered in detail. The latter part of the course will describe new fibers and fiber-structures that are active research topics today.

ENG EC 763 (Ramachandran)
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.

CAS CH 110 (Reinhard)
General and Quantitative Analytical Chemistry
Second of two-semester sequence for students concentrating in the sciences. Stoichiometry, acids, bases, liquids, solids, solutions, equilibria, thermodynamics, kinetics, electrochemistry, atomic structure, bonding, and selected chemical systems. Correlated laboratory experiments emphasizing quantitative analysis.

ENG BE401 (Ritt)
Signals and Systems in Biomedical Engineering
Signals and systems with an emphasis on application to biomedical problems. Laplace transforms, Fourier series, Fourier integral, convolution and the response of linear systems, frequency response, and Bode diagrams. Introduction to communication systems, multiplexing, amplitude modulation, and sampling theorem.

ENG BE 511 (Roblyer)
Biomedical Instrumentation
Physiological signals, origin of biopotentials (ECG, EMG, EEG), biomedical transducers and electrodes. Biomedical signal detection, amplifications and filtering. Analog front-ends of biomedical instruments. Electrical safety in medical environment.

ENG ME419 (Schmidt)
Heat Transfer
Fundamentals of heat exchange processes and applications to heat exchanger design. Principles of steady and unsteady conduction. Introduction to numerical analysis. Natural and forced convection heat transfer in internal and external flows. Radiant heat exchange. Introduction to boiling and condensation heat transfer.

ENG EK 301 (Schmidt)
Engineering Mechanics 1
Fundamental statics of particles, rigid bodies, trusses, frames, and virtual work. Distributed forces, uni-axial stress and strain, shear and bending moment diagrams. Application of vector analysis and introduction to engineering design.

ENG EC560 (Sergienko)
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.

ENG ME560 (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 semiconductor 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 ME460 (Sharon)
Electro-Mechanical Systems Design
This course melds traditional machine component design with the design, instrumentation, and control of high precision, computer-controlled automation systems, 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 Pro-Engineer, Solid Works, or other comparable CAD system, culminating in a group presentation at the end of the semester.

ENG ME 305 (Zhang)
Mechanics of Materials
Definitions of stress and strain. Stress and strain transformations. Stress-strain-temperature equations. Yield criteria for ductile metals. Fatigue failure. Torsion of shafts and thin-walled tubes. Bending of beams. Combined loadings. Elastic stability and column buckling.

Professor David Bishop and several teachers discuss their research during the RET poster session.

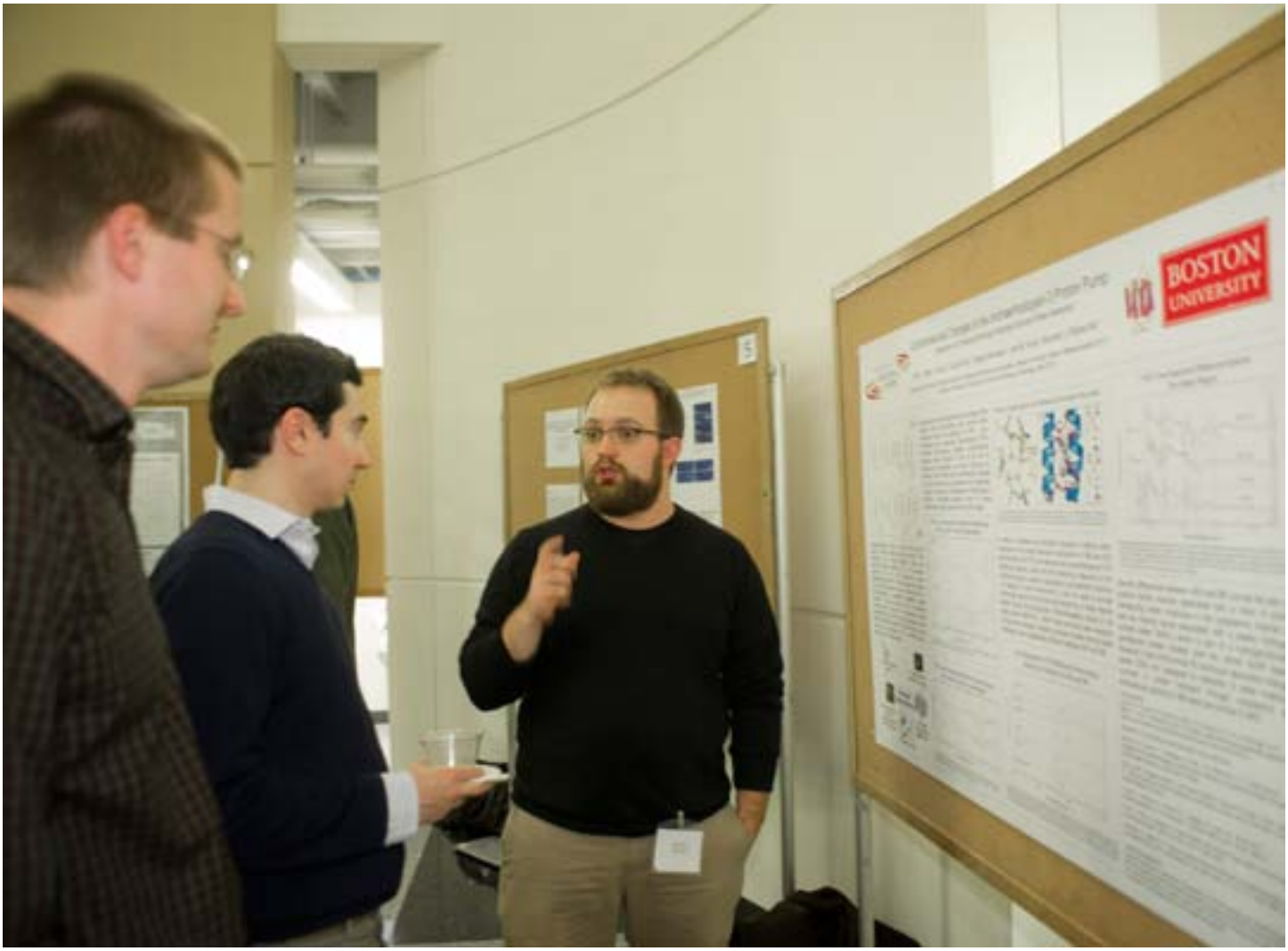
Scholars Day

On April 2, 2013, Boston University hosted its annual Scholars Day event (formerly Science and Engineering Day). This event is held annually in the George Sherman Union and gives students from all science and engineering disciplines the opportunity to share their current research. Each year, the Photonics Center sponsors a prize for this event, the Photonics Center Berman Future of Light Award.

The Photonics Center would like to congratulate the following individuals who won awards at this year's event:

Photonics Center Berman Future of Light Award
Winner: Xiaoning Wang
Advisor: Professor Xin Zhang
Title: Size and Shape Specific Contrast Agents for Biomedical Imaging: Design, Fabrication, and Characterization

College of Engineering Dean's Award
Winner: Allison Squires
Advisor: Professor Amit Meller
Title: Nanopore Mapping of Transcription Factors on Single DNA Molecules



Students discuss their research during Scholars Day.

Research Experiences for Teachers (RET) in Biophotonic Sensors and Systems

Professor Emeritus Michael Ruane (PI), Cynthia Brossman (co-PI), and Helen Fawcett (co-PI) completed the third year of a three-year NSF Research Experiences for Teachers (RET) in Biophotonics Sensors and Systems. In addition, through the NSF RET, two NSF Research Experiences for Undergraduates (REU) supplement students were awarded along with two more NSF REU supplements from the NSF I/UCRC Center for Biophotonic Sensors and Systems and one NSF Research Experiences for Veterans (REV) supplement from the I/UCRC. Through these programs, the undergraduates, master's student and the teacher interacted on cleanroom activities as well as seminars and presentations.

For the third year, five teacher teams were paired (middle school with a high school teacher, or pre-service with a high school teacher) and worked in the laboratories. The faculty members who mentored these teachers included Professors Thomas Bifano, David Bishop, Theodore Fritz, Jerome Mertz and Selim Unlu. In addition to working in the laboratories, the 10 teachers participated in weekly pedagogy sessions, including one through the Smart Lighting Engineering Research Center. The teachers concluded their six-week session with a combined posters session in the 7th floor atrium of the Photonics Center.

The NSF REU and REV supplement students engaged in many activities with the teachers. Brown bag seminars were shared by all groups. When the NSF RET participants arrived in late June, the REU and REV participants presented to the teacher in an overview of what their last four weeks of immersion into the research laboratories was like. The teachers and the other participants worked along with some RISE high school students in the cleanroom activities. The participants split into two groups, a mix of teachers and students, where they created their own masks and then worked on photolithography equipment in the Class 100 cleanroom to spin wafers, expose them with their own mask, and develop the final wafers. They then learned about metal deposition and lift off, taking their wafers home with a sense of shared accomplishment.

The following table indicates the teacher teams that worked in BU Photonics Center laboratories during the summer.

2012 Faculty Projects	2012 RET Teams	School
Dr. Thomas Bifano	Maureen Chase	Quabbin Regional High School
	Michelle McMillan	Sanborn Regional Middle School
Dr. David Bishop	Joel Bradford	Natick High School
	Julia Dekermendjian	Pre-Service Teacher
Dr. Theodore Fritz	Jason DeFuria	Pioneer Valley Regional School
	Fjodor Dukaj	Somerville High School
Dr. Jerome Mertz	James Louis	TechBoston Academy
	Elizabeth Mundy	Pre-Service Teacher
Dr. Selim Unlu	Stephanie Giglio	St. John's Preparatory School
	Valerie Ordway	Sharon Middle School

More information about the projects and the teachers can be found at: http://www.bu.edu/photonics/research/nsf-research-experiences-for-teachers-ret-program/.

OSA and SPIE Student Chapters

During Fall 2012 and Spring 2013, the OSA/SPIE chapter was led by the following officers:

President: Alket Mertiri
Vice President: Xirui Zhang
Secretary: Durba Chaudhuri
Treasurer: Ronen Adato
Additional Officers: Katherine Calabro

The OSA/SPIE chapter organized and held four events. The President of the Boston University chapter of OSA, participated in a Congressional visit day in Washington D.C.

1) General Meeting and Elections (October 2012): All students (predominantly graduate students) in the Photonics Center were invited to attend a general meeting and election for the chapter. At the meeting, events from the previous year were discussed, officers were elected for the coming year, and potential future events were presented.

2) Professional Development Series (November 2012): A breakfast seminar was held entitled "Technology Commercialization in a Startup and Quantum Cascade Lasers." This was a seminar talk by Dr. Christian Pfluegl, co-founder and head of R&D at EOS Photonics. He discussed some of the challenges and opportunities in technology commercialization in a startup setting based on his experiences co-founding EOS Photonics as well as their breakthrough Quantum Cascade Laser (QCL) technology.

3) Industry Networking Night (March 2013): The New England section of the Optical Society of America NES/OSA in association with the OSA Student Chapter at Boston University, the OSA Student Chapter at the Massachusetts Institute of Technology, the OSA Student Chapter at Harvard University, the IEEE Photonics Society and the Optical Society of America held the annual forum on Optics Jobs in New England. The optics industry joined area students to talk about what graduates can look forward to when they have completed their formal education. The program included speakers sharing their insights and experience making the transition from student to industry.

4) Congressional Visit Day in Washington D.C. (March 2013): As President of the Boston University chapter of the Optical Society of America (OSA), Photonics Center Ph.D. student Alket Mertiri met with members of Congress in Washington D.C. to talk about support of sustained funding for science. On March 12-13, he participated in training programs and briefings from Congressional staff and Administrative and American Association for the Advancement of Science (AAAS) staff. Among the speakers was Kei Koizumi, a Boston University alumni who now is an adviser to President Barack Obama. During the meetings, Alket described the importance of funding science and engineering and discussed the impact those fields have on the economy, job creation and research advancements. He hopes that his visit brings awareness to the lawmakers on Capitol Hill about the importance of sustained funding in science and engineering. More information is available at: http://setcvd.org/.

5) Cambridge Science Festival (April 2013): BU student chapter members participated in one of the biggest science fairs in the state of Massachusetts. Along with the NES/OSA, they participated at the science carnival and robot zoo exhibit. They presented a few demos, explained some of the principals of optics and explained how optics is used in everyday activities. They demonstrated various optical principles behind everyday devices from flat panel televisions to magnifying glasses to fiber based telecommunications. They had their giant Kaleidoscope, jello optics and other hands on demonstrations.

Boston University Satellite for Applications and Student Training (BUSAT2) and ANDESITE: The Excitement Grows

The University Nanosat Program operated by the US Air Force (USAF) AFRL has a two-year cycle in which approximately 10 university teams compete in the design and fabrication of small satellites. Boston University has participated in UNP Cycle #7 from 2011 to 2013 with the design and fabrication of the BUSAT2 satellite. The scientific mission BUSAT2 performs measurements of the precipitating energetic electron fluxes from low Earth orbit over the high latitude auroral zones and to simultaneously image the auroral emissions caused by these electrons. The satellite is built around the concept of pre-defined interfaces which will permit easy integration and therefore fast access to space for spaceflight payloads. Each payload will utilize a cubical structure having a dimension of 10 cm on a side (= a unit or U). BUSAT2 is composed of the equivalent of 27 cubes which are held in compression in a 3x3x3 array. At the Final Qualification Review held in Albuquerque in January 2013, the USAF expressed strong interest in the BUSAT2 mission and authorized a second cycle of funding over a two-year period. The BUSAT2 team continues to function this summer with Mr. Calvin Patmont as Project Manager leading a team of approximately 20 students. With the interest from a part of the Air Force different from the UNP, it is anticipated that BUSAT could be launched within two years.

The UNP Cycle #8 kick-off was also in January 2013 at the FCR for cycle #7. BU submitted a completely different payload concept for Cycle #8 and this satellite concept was selected to compete in this next cycle. This project is known as ANDESITE (or BUSAT3) and is described below.

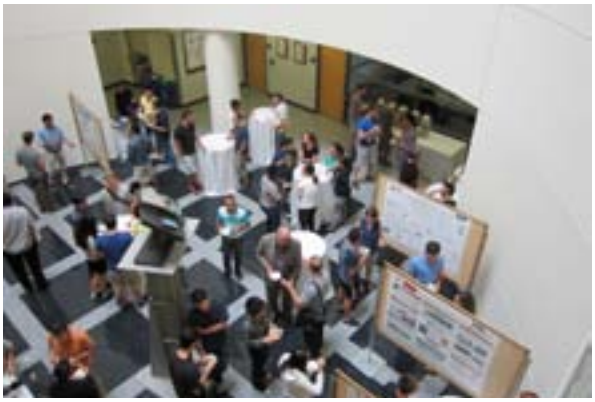
As part of the BUSAT2 test program a Test Rig configuration consisting of a 27 unit-based satellite structure with two deployable solar panels was developed in order to test the functionality of the design for the deployment of the solar panels. This test was performed in April 2013 with five students participating in a series of microgravity flights sponsored by the NASA Flight Opportunities Program (FOP). This microgravity team formulated a proposal to the FOP and this proposal was accepted. The FOP provides the ride but no funding for fabrication of the test item or for travel. Special funding was provided by the Dean of Engineering and the Chair of Engineering in Electrical and Computer Engineering. For deployment, the test rig utilized two Frangibolt® non-explosive actuators and mechanisms, as well as two electromagnetic locks.

Ad-Hoc Network Demonstration for Extended Satellite-Based Inquiry and Other Team Endeavors (ANDESITE) was proposed in response to the AFOSR University Nanosat Program (AFOSR-BAA-2012-6) for cycle #8 and involves the Center for Space Physics, the Departments of Electrical and Computer Engineering and Mechanical Engineering at BU and the School of Earth and Atmospheric Sciences and the Georgia Tech Research Institute at Georgia Institute of Technology in Atlanta, GA. The Project Manager is Mr. Steven Yee, a BU student, and the Project Engineer is Mr. Josh Mendez, a student at Georgia Tech. A separate team of 13 students has been hard at work on this new satellite project this summer.

ANDESITE is a broad, high-impact constellation project which aims to develop an easy-to-use, rapidly-deployable architecture for dense, low-cost wireless sensor networks in space and planetary science applications. Over the next two years the objectives of the project are threefold: 1) Demonstrate viability of satellite based sensor networks by deploying a 16-node miniature CubeSAT network to study current filamentation in the auroral zones of the Earth's magnetosphere. 2) Test the scalability of proposed protocols, including localization techniques, tracking, data aggregation, and routing, for a three-dimensional wireless sensor network using a "flock" of buoyant motes in storm systems. 3) Construct a 1 unit Cube-Sat running the Android OS as an integrated constellation manager and data mule. With the ability to integrate tens to several hundreds of nodes, ANDESITE networks will provide unprecedented resolution for many sensing applications at lower cost per unit mass, and will drastically redefine the concept-to-deployment timescale.

Facilities and Equipment

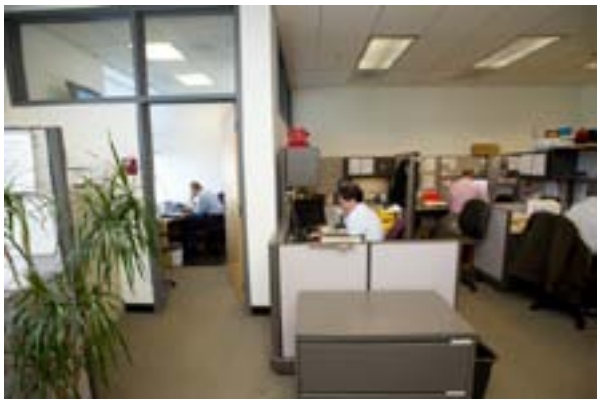
The Boston University Photonics Center opened in June 1997 and consists of ten floors of 235,000 net square feet of space including: classrooms, conference rooms, faculty offices, educational laboratories, faculty research laboratories and four shared laboratories managed by the Photonics Center.



The Center's faculty, students, and incubator companies utilize these core-shared facilities. The Photonics Center also offers collaborators from industry and other universities use of the facilities when time is available. Upgrades are routinely made to the four shared laboratories to ensure faculty and student research is being supported and maintained.

The Photonics Center also features a Business Innovation Center located on the 6th floor. The Innovation Center consists of 15,000 square feet of flexible space that can sponsor up to 14 start-up companies. The space provides state-of-the-art facilities and a collaborative environment with faculty and students.

New and existing Photonics Center faculty members are provided with Photonics staff assistance in laboratory design. This year, Professors Michelle Sander moved into her newly designed laboratory in the Photonics Center.



Shared Laboratory Facilities

The Optoelectronic Processing Facility (OPF) includes a Class 100 photolithography cleanroom and a 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 adjacent standard laboratory space for spectroscopy measurements. The Precision Measurement laboratory (PML) consists of two laboratory spaces with scanning electronic and atomic force microscopy among other analytical surface characterization tools. The newest shared laboratory at the Photonics Center, the Focused Ion Beam/Transmission Electron Microscope Facility (FTF), also located in the basement, currently houses a FIB instrument and installation of a TEM is expected in the first semester of 2013.

Optoelectronic Processing Facility (OPF)

OPF is a multi-user 2500 sq. ft. facility located on the 8th floor of the Photonics Center. The facility contains equipment for semiconductor and optoelectronic fabrication from bare chip to fully populated components. The facility includes both a Class 100 and 1000 cleanroom and equipment facilitating photolithography, wet chemical processing, thin film depositions, plasma etching and cleaning, thermal oxidation, thermal annealing, wire bonding, and electrical characterization.

The Class 100 cleanroom has capabilities for photolithography, mask fabrication and nanoscale replication. 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 5mmx5mm 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 well as larger wafers. The laboratory conveniently provides ovens and a hood for bakes to facilitate development. Chip and wafer exposure is achieved through two UV exposure tools; the MJB3 (for three inch masks or smaller) and the MA6 (up to a 6 inch square masks). A high-powered optical Nikon microscope provides higher resolution imaging for surface inspection. The newest addition to OPF is the Nanonex NBX200, purchased by this year's Capital Equipment Committee. It allows thermo and UV replication processes for nanoscale structures given a mold that can be up to a 3 inch diameter.

Cleaning, etching or characterization tools are found in the Class 1000 cleanroom. With a KLA Tencor surface profilometer, students learn how to measure the step height of features that they make on wafers. The high powered optical Nikon microscope allows users to captures still or video images from the sample or wafer.

Dry etching processes are readily available and used in the OPF cleanroom, including plasma etching, reactive ion etching and a deep reactive ion etching. In addition to dry etching, both acid and separate solvent hoods are available to complete wet chemical etching or cleaning and lift-off. In addition, the HF vapor etch system has addressed safety issues for students or 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 four and six-inch full wafers.

Many of the research laboratories at Boston University use thin film deposition systems. Thermal oxide furnaces, evaporators and sputtering systems all provide students with the ability to learn about different coating processing methodologies and how to measure the films deposited after processing. This year's Capital Equipment Committee purchased new sputter targets for the Denton Sputtering System, a well-used piece of equipment in the cleanroom. Wire bonding, wedge bonding, or testing can also be done inside the cleanroom in OPF. The Current Voltage/Capacitance Voltage characterization test set up is used to evaluate devices post wire bonding and pre-integration into test set ups on the lab bench.

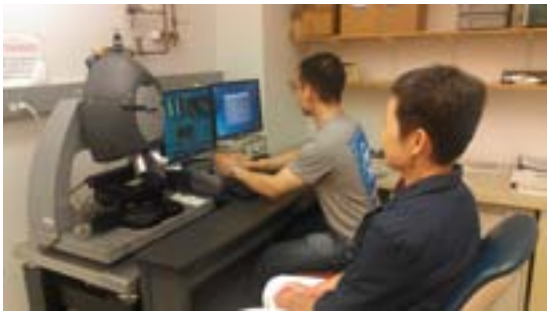
Integrated Optics Laboratory (IOL)

The IOL houses a Class 100 cleanroom and a standard laboratory space within its 900 sq. ft. It is a multi-user facility on the 5th floor of the Center and is stocked with state-of-the-art equipment for bonding and spectroscopic analysis of components.

The Class 100 cleanroom employs a Suss Microtech FC-150 flip chip bonder that is used to seal and create eutectic bonds either through thermocompression or soldering processes. This is a precise system that uses fiducials to aid in placement accuracy. Several researchers in device packaging (LED's) use this piece of equipment and 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 Varian Cary 5000 UV-VIS-NR spectrometer covers wavelength ranges from 175-3300 nm. In addition to measuring reflectance and transmission at a particular wavelength, it can also measure absorption. The Bruker FTIR was upgraded this year as part of the Capital Equipment Committee. The older FTIR was traded in to make space for the Vertex 70V, the latest FTIR technology that is also compatible with the accessories purchased over the years for this shared tool.

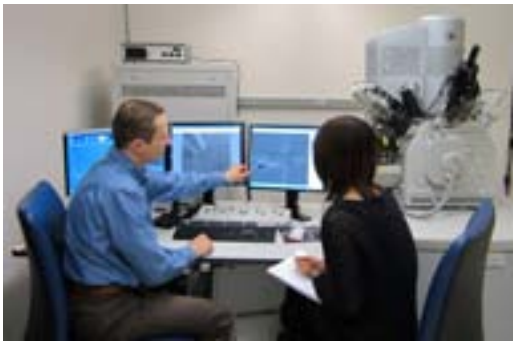
Precision Measurement Laboratory (PML)



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, Cathodoluminescence (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 Cathodoluminescence (CL) monochromator 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. CL spectra provide information about wavelength of the emitted light at areas of interests (dislocations, grain boundaries, lattice imperfections). CL maps provide information about spatial distribution of light and defects in the specimen.

The second laboratory space includes: a Veeco (formerly Digital Instruments) Atomic Force Microscope (AFM) a Pico-Force AFM System, a Zeiss Supra 40VP Field Emission Scanning Electron Microscope (FESEM), a Zygo NewView 6300 and a Zeiss Supra 55VP FESEM. The Pico-Force AFM System enables accurate force measurements and manipulation of biological or material samples at the pico-Newton level, including inter- and intramolecular forces, for applications ranging from drug discovery to basic molecular-scale research. The Zeiss Supra 40VP FESEM allows polymers and plastics to be viewed without conductive coatings, thus a non-destructive way to view a sample. The Zeiss Supra 55VP FESEM, in addition to imaging using secondary electron detectors, this SEM is also capable of imaging thin TEM samples using a STEM detector, providing atomic contrast information using a backscattered electron detector and chemical composition using Energy Dispersive Spectrometer (EDS). It is also equipped with an Electron Backscatter Diffraction (EBSD) detector which gives information on the crystalline structure and grain boundary orientations on polished materials. A hot and cold stage is also available for in-situ work in the SEM chamber. Both the Supra 40VP and 55VP have ebeam blankers to allow for e-beam writing of nanoscale structures. The ZYGO NewView 6300, an interferometric microscope with dynamic MEM's capability has a heating and cooling stage that allows testing under controlled temperature and the viewing and measurement in-situ. Surface roughness, morphology, and displacement can all be measured using this instrument.

The Focused Ion Beam/Transmission Electron Microscope Facility (FTF)

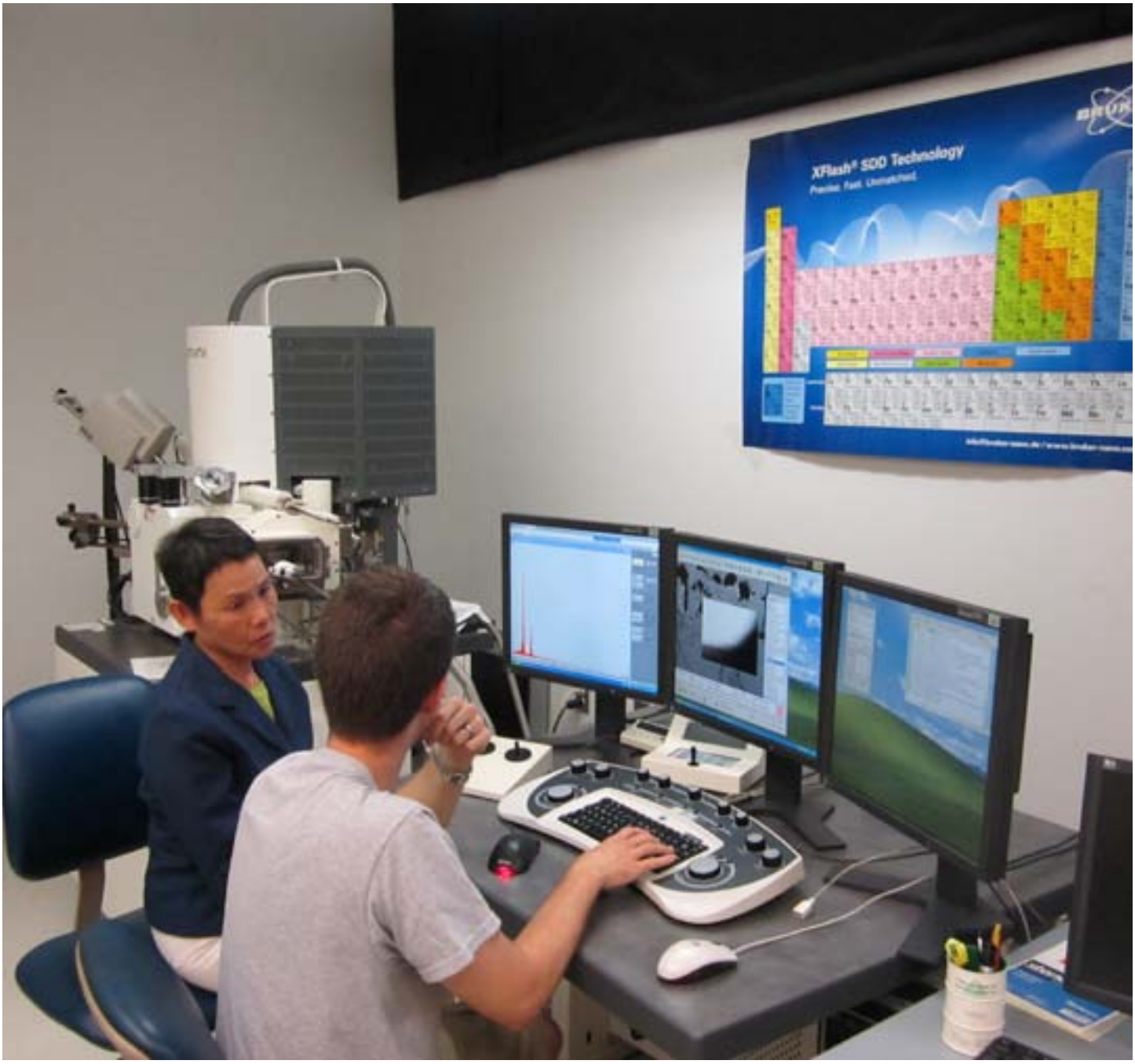


The FIB/TEM Facility is comprised of two laboratories consisting of 600 square feet with capabilities to measure material composition, image surface morphology and micro/nano machined materials. This laboratory houses a FEI Quanta 3D Field Emission Gun Focused Ion Beam (FEG GIB) system and a FEI Tecnai Osiris 200kV S/TEM.

The FEI Quanta 3D FEG FIB is a powerful tool with a resolution of 1.2 nm in the HiVac mode, 2.9 nm in LoVac mode, 7 nm with the FIB column. The tool has a wide variety of detectors including: Everhart Thornley Detector (EDT), continuous dynode multiplier (CDEM), ion induced secondary electron (SE) imaging, backscattered electron detector (BSED), low vacuum secondary electron detector (LVSED), gaseous analytical solid-state back scattered electron detector (ESEM GAD), high contrast detector (vCD), annular STEM detector (bright field (BF), dark-field (DF), and high-angle annular dark field (HAADF) modes), and Oxford Instruments Energy

Dispersive Spectrometry (EDS). The system also includes gas injector modules (GIS) and an Omniprobe micromanipulator can be used for TEM sample preparation and lift-out. For research applications and to study in situ dynamic behavior of materials at different humidity (up to 100% RH) and temperatures (-10 °C to 1000 °C), an additional Peltier/Heating Stage Control Kit was included in the purchase.

During the first semester of 2013, the FEI Tecnai Osiris TEM will be installed in the back portion of the facility. The system specifications state a TEM point resolution of 0.25 nm, line 0.102 nm, extended to 0.16 nm with TrueImage™ software, and STEM HAADF 0.18 nm. The system includes Super-X EDX detection system, SDD technology, windowless, shutter-protected, X-FEG Electron Source and also includes EFTEM with EELS and a Gatan Orius CCD.



Lab Manager Anlee Krupp guides a student in the Precision Measurement Laboratory.

Equipment Committee

This year's capital equipment committee was led by Professor Bjoern Reinhard. The purchases fulfilled a continuing need, identified in a poll of faculty members, to enable further research in nanofabrication. There was overwhelming support for the addition of a Nanonex NXB200, Bruker FTIR Vertex 70V, and additional targets for the Denton Sputterer.

The following criterion was considered in making the decision to support the new equipment purchase:

- 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.
- The instrument is near full usage and more users are coming on-line.

Using these guidelines for identification and ranking of equipment improvements, the majority of Photonics Faculty users supported these purchases. The Nanonex NXB200 has capabilities of both UV and thermal replication. Samples can be up to three inches in diameter and the chuck also accommodates small non-standard sized parts as well. This tool will help in providing a way to validate a process of nanoscaled structures without having to fabricate them individually on the FIB or Ebeam. The Bruker FTIR was also upgraded this year as part of the equipment committee. A new Vertex 70V FTIR was purchased. This system is under vacuum and provide more capabilities and options that our older model. The Hyperion microscope is still part of the system as well as the Silicon Bolometer. All accessories are compatible with the new system. The final purchase was a new set of sputter targets for the Denton Sputter System. This system is fully utilized and new targets will assist in more uniform coating and to help prevent extensive down time if the targets degrade.

The Denton Sputter System.

Innovation Center Facilities

Located on the 6th floor of the Photonics Center building, Boston University's Business Innovation Center (BIC) currently hosts seven technology start-up companies. There is a healthy turnover in the Innovation Center space with a total of 19 companies residing at BIC over the past year. The mix of companies includes: life sciences, biotechnology, medical devices, photonics, and clean energy; and nine of the 19 companies originated from within BU. All the BIC tenants are engaged in the commercialization of new technologies of importance to society and all are active in the BU community in terms of offering internships, employment opportunities or research collaborations.

BIC attempts to recruit companies that are commercializing transformative and innovative technologies. These companies are typically staffed with seasoned executives and subject matter experts and have attracted significant financial backing. They represent the benchmark by which BU internal spinout companies may be compared and act as exemplary living case studies for the teaching of entrepreneurship to our students.

After having a record number of BU student/alumni companies launched by a collaborative program with the Institute of Technology Entrepreneurship and Commercialization (ITEC) in the Graduate School of Management, this program has lost its grant support. Since this program offers exciting opportunities for the teaching of technology entrepreneurship, the Photonics Center intends to offer conference facilities, mailbox services, and shared lab usage to student led companies pursuing photonics related technology business launches. While incubation of new businesses has become less of a core directive, innovation continues to be of prime importance.

Current tenants include winners/finalist of prestigious Accelerator competitions such as the BU Ignition Awards (RayVio) and Cleantech and MassChallenge Accelerator award winner NBD NanoTechnologies. At the other end of the innovation spectrum, BIC also houses a new product spinout from a multi-billion dollar international corporation. This company, Bioventus, is a leader in bio-material research and is expected to establish a new model for launching technology based commercial enterprises. This partnership will involve corporate scientist working with faculty, hiring student interns and meeting business growth needs with a pipeline of trained students. As these businesses succeed and grow beyond the capabilities of BIC, a succession of other new product and business launches are expected to fill the innovation pipeline. BIC is always active in finding innovators that have overlapping research interests with Photonics Center faculty.

BIC provides innovators with the tools necessary to accelerate their growth and enter new markets. To attract the leading innovators in the region BIC has recently become a "Silver" sponsor of the Mass Challenge Accelerator, a

global competition that attracts over 1,200 companies annually. BIC will offer space and shared lab access to the top photonics innovators in the annual competition, which will allow these leading start-ups to focus resources on developing product and business growth.

Company plaques in the 6th floor Innovation Center.

Building Projects

PHO B11C

Construction in the basement of the Photonics Center began in the Fall of 2012 in preparation for the FEI Quanta 3D FEG Focused Ion Beam system installation. The construction included dividing the space in half with a solid wall to allow the back side to be a future TEM facility while the front operates as a FIB area.

PHO 503B

Construction in PHO 503B was completed in March 2013. PHO 503B has been converted into several sections, including the shared laboratory space, an alpha prototyping space and research area for research faculty member Mario Cabodi. The alpha prototyping space for a NIH U54 Center for innovation in Point of Care Technologies for the Future of Cancer Care, led by Professor Catherine Klapperich, takes about 1/3 of the space of the lab. The prototyping area allows students and faculty conducting research in cancer care to utilize the equipment available for developing first generation prototypes to evaluate if fixtures or methods will work. The shared laboratory space consists of the CARY 5000 UV/VIS/NIR Spectrophotometer and the Bruker FTIR Vertex 70V and Professor Cabodi's space consists of two laboratory benches for completing research.

PHO 507A

Professor Michelle Sander, a recent hire to ECE has a newly renovated laboratory space in PHO 507A. The laboratory was completed in June 2013 and consists of an inner wet laboratory space and several optical laser bays for Class IIIb and IV laser work.

PHO 507B

Professor Bjoern Reinhard, from the Chemistry Department, was in need of additional space at the Photonics Center. PHO 507B was renovated to include wet lab and student office space. This construction was completed in June 2013.

PHO 737

Professor Theodore Fritz from the Astronomy and ECE Departments has been located on the 6th floor for several years. With the expansion of the Materials Science Division to the 6th floor, his laboratory space was needed for incubator companies interested in the Photonics Center. Laboratory space (737) is being renovated for Professor Fritz.

PHO 735

Construction for Professor Jonathan Klamkin, a recent hire in ECE, is expected to be completed in Fall 2013.

PHO 601, 627, 628, 629

As faculty members are being hired in the Materials Science Division, laboratories are being constructed on the 6th floor. Expected renovations that will initiate sometime during the Fall of 2013, include Professor Allison Dennis (601) and Professor Jillian Goldfarb (629). Two other faculty members will be joining them, Professor Alice White (627) and Scott Bunch (628), but their laboratory design is not expected to commence until later in 2014.

Construction is complete in room 737.

Community Events

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 important to further the center's collaborative mission.

The Photonics Center collaborates each year with 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.

Photonics Cafes and Forums

The Photonics Center hosted two monthly events: The Photonics Cafe and the Photonics Forum. The Cafes bring together the faculty, students, staff and incubator company employees in an informal setting for conversation and collaboration. The Cafes 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 Spring of 2013, give the community opportunities to participate in technical discussions in an open forum over lunch. A Photonics faculty member is selected to discuss their current research endeavors and the real-world applications of their research.

2013 Forum Schedule

Date	Speaker	Presentation
January	Mr. William Kallinich, Environmental Health and Safety, Boston University	Annual Laboratory Safety Training
February	Mr. John Kurkomelis, Boston University Radiation Specialist	Annual Laser Safety Training
March	Professor Darren Roblyer, Boston University	Diffuse Optical Spectroscopy for Basic Science and Translational Applications in Oncology
April	Professor Michelle Sander, Boston University	Femtosecond Lasers: From Compact High-Repetition Rate Fiber Sources Towards Integrated Waveguide Lasers
May	Professor Jonathan Klamkin, Boston University	Micro and Nano Photonic Integrated Circuits

Professors and students enjoy a Photonics Cafe.

16th Annual Future of Light Symposium: Novel Applications of Photonics & Photonics Techniques

This year, the 16th Annual Future of Light Symposium focused on novel applications of Photonics and Photonics techniques. Almost 200 people from Boston University, outside academic institutions and industry attended the event.

The agenda for this year's symposium featured presentations by Photonics faculty members and researchers from leading photonics research institutions. The conference explored leading edge research in the field of novel applications of Photonics.

Our speakers included:

Dr. Andrew Chraplyvy, Bell Labs/Alcatel-Lucent
Dr. Jonathan Klamkin, Boston University
Dr. Thomas Koch, University of Arizona
Dr. W.E. Moerner, Stanford University
Dr. Theodore Moustakas, Boston University
Dr. Siddharth Ramachandran, Boston University
Dr. Michelle Sander, Boston University

The symposium also included a lunch speaker, Dr. Rod Alferness from the University of California at Santa Barbara. At the conclusion of this year's conference, a reception was held where participants and speakers discussed their research in an informal setting.

Professors Klamkin and Moustakas discuss their research at the Future of Light Symposium.

Town Hall on Essential Technologies for our Future

The Boston University Photonics Center hosted a town hall meeting on February 22, 2013 in collaboration with the Optical Society (OSA) devoted to the National Academy of Sciences (NAS) report, "Optics and Photonics: Essential Technologies for Our Nation."

In the report, NAS identified technological opportunities and applications in optics today from solid-state lighting, photovoltaics, manufacturing, fiber optic telecommunications, defense, displays, to diagnostic medicine. The report assessed the current state of optics worldwide from a market perspective, prioritizes a set of "grand challenge" questions to fill technological gaps, and recommends actions for development and maintenance of the field.

The findings were discussed, as well as current and future global innovations and technological opportunities enabled by optical science. Audience members had the opportunity to ask questions of the panelists. Panelists included:

Elizabeth Rogan, The Optical Society

Larry Goldberg, National Science Foundation

Tom Baer, Stanford Photonics Research Center, NRC Committee

Ed White, Edward White Consulting, NRC Committee

Steve Fantone, Optikos

The crowd enjoys the Town Hall on Essential Technologies for our Future.

Spring Cleaning Day 2013

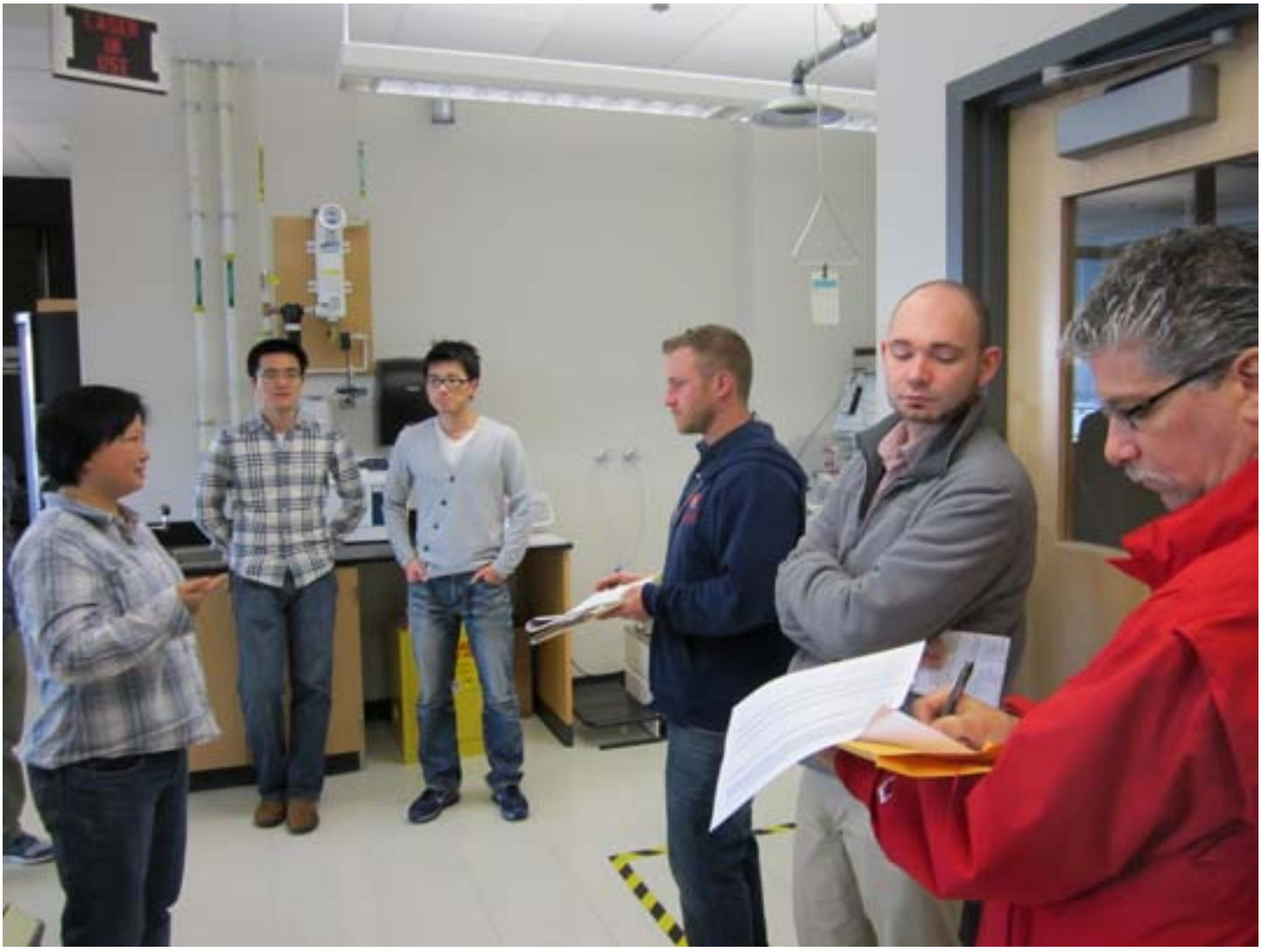
The Boston University Photonics Center, Electrical and Computer Engineering Department and the Environmental Health and Safety Department hosted Laboratory Spring Cleaning Day on March 28, 2013.

In addition to learning about safety and compliance, the students, faculty, researchers, and staff enjoyed breakfast and an ice cream party. Photonics Center mugs were handed out as a give-away. Professor Xin Zhang's lab was awarded the grand prize of a Panera lunch for their adherence to lab compliance procedures. Other award winners included:

Most Improved – Dal Negro Laboratory

Most Team Work – Bishop Laboratory

Most Sparkling – Unlu Laboratory



Professor Xin Zhang and her graduate students meet with Environmental Health and Safety during Spring Cleaning Day.

Photonics Center Guest Speakers

Over the year, the Boston University Photonics Center hosted several seminars by photonics experts. The following list includes the seminars for 2012–2013.

Date	Speaker	Title of Presentation
8-3-12	Professor Hakan Urey Koc University	Optical MEMS Sensors and Actuators for Dispalys, Spectrscopy, and Biosensing
9-21-13	Professor Francesco Pavone University of Florence	Imaging of Electrical Activity and Morphology in Intact Tissues
10-9-12	Dr. Karlene Hoo The National Science Foundation	NSF Innovation Programs: Partnerships with a Focus on Translation and Transfer of Basic Research Discoveries
4-3-13	Dr. Minbiao Ji Harvard University	Rapid Label-Free Detection of Brain Tumors with Stimulated Raman Scattering Microscopy
5-15-13	Professor Andy Weiner Purdue University	Ultrafast and Broadband Photonic Signal Processing: Microdevices, Combs, and Control of RF Propogation
5-22-13	Professor Govind Agrawal The University of Rochester	Dynamic Optical Resonators
6-5-13	Dr. Eric Betzig Howard Hughes Medical Institute	Pushing the Envelope in Biological Fluorescence Microscopy

Professor Andrew Weiner from Purdue University delivers a Photonics Seminar.

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