

Boston University  
Photonics Center

Annual Report

2014





# Letter from the Director

**THIS ANNUAL REPORT** summarizes activities of the Boston University Photonics Center in the 2013–2014 academic year. In it, you will find quantitative and descriptive information regarding our photonics programs. The Photonics Center, located at the heart of Boston University's large urban campus, is an interdisciplinary hub for education, research, scholarship, business 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 46 faculty members, 10 staff members, and more than 100 graduate students and postdoctoral fellows.

This has been a good year for the Photonics Center. In the following pages, you will see that the center's faculty received prodigious honors and awards, generated more than 100 notable scholarly publications in the leading journals in our field, and attracted \$14.5M in new research grants and contracts this year. Faculty and staff also expanded their efforts in education and training, through 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 **Innovations at the Intersections of Micro/Nanofabrication Technology, Biology, and Biomedicine** at our annual Future of Light Symposium. We took a leadership role in running national workshops on emerging photonic fields, including an **OSA Incubator on Controlled Light Propagation through Complex Media**, and an **NSF Workshop on Noninvasive Imaging of Brain Function**.

Highlights of our research achievements for the year include a distinctive **Presidential Early Career Award for Scientists and Engineers (PECASE)** for Assistant Professor Xue Han, an ambitious new DoD-sponsored grant for **Multi-Scale Multi-Disciplinary Modeling of Electronic Materials** led by Professor Enrico Bellotti, launch of our NIH-sponsored **Center for Innovation in Point of Care Technologies for the Future of Cancer Care** led by Professor Cathy Klapperich, and successful completion of the ambitious IARPA-funded contract for **Next Generation Solid Immersion Microscopy for Fault Isolation in Back-Side Circuit Analysis** led by Professor Bennett Goldberg. These three programs, which represent more than \$20M in research funding for the University, are indicative of the breadth of Photonics Center research interests: from fundamental modeling of optoelectronic materials to practical development of cancer diagnostics, from exciting new discoveries in optogenetics for understanding brain function to the achievement of world-record resolution in semiconductor circuit microscopy.

Our community welcomed an auspicious cohort of new faculty members, including a newly hired assistant professor and a newly hired professor (and Chair of the Mechanical Engineering Department). The Industry/University Cooperative Research Center—the centerpiece of our translational biophotonics program—continues to focus on advancing the health care and medical device industries, and has entered its fourth 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



The center's faculty received prodigious honors and awards, generated more than 100 notable scholarly publications in leading journals, and attracted \$14.5M in new research grants and contracts.

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# Mission Statement

**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 health care, defense, and security applications
- Business innovation and commercialization of photonics technology

The Photonics Center community of faculty, students, and staff engages 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 members are involved in research in diverse fields of study anchored by thematic areas of strength in biophotonics, nanophotonics, adaptive optics, and photonic materials. It is noteworthy that Professors Bifano and Mertz hosted an Optical Society of America (OSA) Incubator Meeting on Controlled Light Propagation through Complex Media in March 2014. They led researchers, engineers, and business leaders on discussions regarding advances, challenges, and opportunities in photonics research.

## **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; they have access to office and lab space and mentoring for new business launch; they experience opportunities for engagement/networking with industry, particularly with members of the Industry/University Cooperative Research Center; and they participate in the annual Photonics Symposium.

## **Technology Development for Health Care, Defense, and Security Applications**

The Photonics Center's technology development activities focus on emerging photonic applications in health care. These activities include direct sponsored research collaboration with research labs at major corporations and the successful completion of the third year of the NSF-sponsored, member-supported Industry/University Cooperative Research Center on Biophotonic Sensors & Systems. That program and its corporate-sponsored applied research projects have become a prime focus for Photonics Center efforts in technology translation. Additionally, our Center for Innovation in Point of Care Technologies for the Future of Cancer Care promotes technology translation in an area of critical national need.

## **Business Innovation and Commercialization of Photonics Technology**

The Photonics Center remains 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. There has been an 80% turnover of BIC-based companies and a marked improvement in the number of internships and research collaborations since rebranding to the Business Innovation Center two years ago. Preferential selection of prospective tenants that work in areas aligned with the research and scholarship activities of Photonics Center faculty creates an environment rich with opportunities for collaboration and growth in sponsored research. Mentoring and access to shared laboratory and conference facilities are also offered to promising student entrepreneurs. ■



# Highlights of FY2014

## External Grant Funding

External grant funding for FY2014 totaled over \$14.5M, showing funding from a variety of sources. Highlights of our research achievements for the year include a new grant for Multi-Scale Multi-Disciplinary Modeling of Electronic Materials, continued support for our Center for Innovation in Point of Care Technologies for the Future of Cancer Care, our Center for Biophotonic Sensors & Systems, our Center for Smart Lighting, a Presidential Early Career Award for Scientists and Engineers (PECASE), and the launch of a new research program supported by ARAMCO Services Company, which recently established a research base in Cambridge.

## Three New Photonics Center Faculty Members

This year, the Photonics Center welcomed Professor Soumendra Basu (ME), who has a research focus in processing/structure/property relationships in thin films for energy, electronic, photonic, and superconducting applications; Assistant Professor Scott Bunch (ME), who is involved in research on experimental nanomechanics of 2D materials such as graphene; and Professor Alice White, chair of the Mechanical Engineering Department, with research interests in optical materials and optoelectronic integration and packaging.

## Business Innovation Center Includes Key Companies

Current tenants of the Business Innovation Center (BIC) include winners/finalist of prestigious accelerator competitions such as the BU Ignition Award, Cleantech Accelerator, and the MassChallenge Accelerator, as well as companies named among the 50 Most Influential Companies in their industry. BIC has a mission to cultivate innovation—whether in larger companies or in start-ups. As an example, BIC houses a new product spinout from a joint venture (Bioventus) formed by a multi-billion-dollar international corporation and a leading private equity firm. The center looks for innovation throughout the Boston area, and in the past year the non-BU spinouts hit a peak of 70% of the BIC tenants. These tenants are active in the BU community and have hired record numbers of interns over the past year.

## The 17th Annual Future of Light Symposium: Innovations at the Intersections of Micro/Nanofabrication Technology, Biology, and Biomedicine

This year, the symposium focused on innovative activities occurring at the intersection of life sciences and micro/nanofabrication technologies. Professor Xin Zhang chaired the conference, which drew nearly 180 attendees. Faculty from Boston University, Harvard University, and MIT delivered talks, as well industry representatives from the Charles Stark Draper Laboratory, MC10, and Cardio MEMS. Attendees participated in a lively reception where participants and speakers discussed their research.

## Institute Activities

The Photonics Center has been conducting business as an institute providing leadership on a number of activities such as: direction of the BIC, managing and equipping shared laboratories, and administering/supporting block grants and supporting affiliated units.

## PHOTONICS CENTER AT A GLANCE

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46

Faculty Members

---

10

Staff Members

---

90

Funded R&D Projects

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\$14.5M

Funding for R&D  
(New funds for current year)

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38

Photonics Courses

---

104

Archival Publications

---

4

Shared Laboratory Facilities



# Photonics Center Strategic Plan

## CENTRAL TO THE PHOTONICS

**CENTER'S 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, managing and equipping shared laboratories, and administering/supporting block grants and supporting affiliated units.

Some of the affiliated units include: the Center for Nanoscience & Nanobiotechnology (CNN), the Industry/University Cooperative Research Center (I/UCRC) on Biophotonic Sensors & Systems (CBSS), the Center for Innovation in Point of Care Technologies for the Future of Cancer Care, the Materials Science & Engineering Division, and the SMART Lighting Engineering Research Center. The Photonics Center has managed substantial renovations for the Materials Division to provide space formerly allocated to the Business Innovation Center. One of the Materials Division labs that came online in FY2014 supports the Transmission Electron Microscope (TEM). 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 three years of the I/UCRC on Biophotonic Sensors & Systems (CBSS) and the program formulation for year four (concurrent with FY2015). 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 11 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 nearly tenfold.

The resources and expertise of the Photonics Center staff are employed to manage grants for several affiliated centers. These grants include: an IARPA grant on backside wafer analysis and training grants in conjunction with the affiliated Center for Nanoscience & 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 new DoD 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 research scientist at the Sensors and Electronic Devices Directorate (SEDD) of the US Army Research Laboratory (ARL), 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 will also be employed on leading and supporting new major block grants. In FY2014, the Photonics Center led or significantly contributed to proposals that included: NSF's Partnerships for Innovation Research, Research Experiences for Teachers, Research Experiences for Undergraduates, the DOE's Energy Frontiers Research Center, and several I/UCRC supplements and other proposals that support the Photonics Center's strategic vision.

At the Business Innovation Center, located on the 6th floor, Photonics Center staff are implementing strategic changes that align the center 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. ■

The center operates as a centralized resource—promoting, supporting, and sustaining allied research centers and programs across Boston University.



# Photonics in the World

## ■ FROM BATTLEFIELD TO LAB BENCH

NSF RESEARCH PROGRAM HELPS ENG VETS  
SHAPE CAREERS

By Rachel Harrington

**US MILITARY PERSONNEL** return from active duty with highly marketable knowledge and skills, but many find it difficult to quickly translate their experience into well-paying jobs. To help rectify the situation, the National Science Foundation (NSF) funds the Veteran's Research Supplement (VRS) program, which allows veterans at selected colleges and universities to participate in industrially relevant research in science, technology, engineering, and mathematics (STEM) fields—where job openings far outpace the supply of qualified US applicants.

Since the inception of VRS in 2011, the College of Engineering's NSF Industry/University Collaborative Research Center for Biophotonic Sensors & Systems has welcomed the opportunity to engage veterans in research through this program.

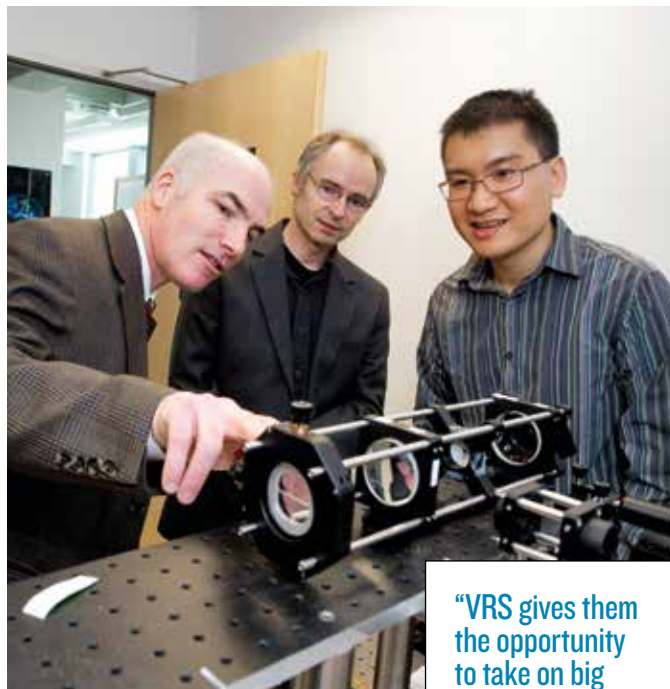
"Vets come to us with an unusually strong work ethic and high confidence but often lack the experience to be comfortable in taking on a big research project," says BU Photonics Center Director and Professor Thomas Bifano (ME). "VRS gives them the opportunity to take on such projects and pursue careers in research, which is the main engine of our economy."

So far, two veterans have thrived in faculty-supervised summer projects funded by VRS, emerging not only with new research skills but also a more well-defined career path.

### CLIFF CHAN: FROM TECHNICIAN TO ENGINEER

Cliff Chan, who deployed four times in the Middle East and Southeast Asia as an Air Force Guidance and Control Specialist, came to BU seeking to take his skillset to the next level. With a BS in mathematics and computer science from the University of California, San Diego, two years developing software for an electronic health records company, and four years maintaining aircraft control systems for the Air Force under his belt, Chan aspired to learn how to design the kinds of technologies he came across during his military service.

To transform himself from a technician to an engineer, he sought a way to earn a master's degree in electrical engineering in a reasonable timeframe without having to start from scratch. He found it in his College of Engineering's Late Entry Accelerated Program (LEAP). Like all LEAP students, Chan spent his first year taking undergraduate engineering courses to get up to speed, but got his first taste of engineering design the following summer (2011), thanks to the VRS program. Working for three months in Professor Jerome Mertz's (BME) Biomicroscopy Lab within BU's Center for Biophotonic Sensors & Systems, he developed software



Photonics Center Director and Professor Thomas Bifano (ME), Professor Jerome Mertz (BME) and Cliff Chan in Mertz's Biomicroscopy Lab. Photo by BU Photo

**"VRS gives them the opportunity to take on big projects and pursue careers in research, which is the main engine of our economy."**

**Thomas Bifano (ME)**

that enables microscopes to provide high-contrast images of biological samples in real time.

"The project was a real transition for me, as I had to solve a problem by first figuring out what I needed to learn, and then how to apply it," says Chan, who was used to getting more explicit instructions in the Air Force and had never worked in a research lab. "It opened up my eyes to another world."

Subsequently hired to work full-time in the Biomicroscopy Lab while completing his Master of Engineering in electrical engineering, Chan has continued to advance microscopy techniques aimed at improving medical diagnostic imaging. The experience has led him to consider working in research and development for defense and other industries, conducting experiments and designing devices with real-world applications.

It has also prepared him to work through the inevitable unexpected challenges that arise in advancing new technologies.

"What I like about Cliff is that he's undaunted," says Mertz. "He wants to learn everything that's out there to tackle his work. The problems we faced were much more complex than I had anticipated, but Cliff's efforts definitely kept us on track, and kept us progressing."



## CHRIS STOCKBRIDGE: FROM DEFUSING ROADSIDE BOMBS TO PROTECTING FUTURE SOLDIERS

Chris Stockbridge returned to civilian life after five years as an officer and combat engineer in the Army that included two tours of duty in Iraq. During each deployment, he came to appreciate the engineering behind technologies used to protect soldiers, including devices used to search for and destroy roadside bombs. Equipped with those experiences and a BS in mechanical engineering from the US Military Academy at West Point, he applied to the PhD program in mechanical engineering at BU with the goal of working as a civilian engineer at a national military research lab.

"I came to BU to study micro-electro-mechanical systems (MEMS), particularly those which could be of great value in military applications, and because I knew that the Photonics Center has a strong relationship with the US Army Research Laboratory," says Stockbridge.

Supported in summer 2013 by the VRS program to serve as the lead student in an NSF-funded project in Bifano's Precision Optics Research Lab, he began fabricating MEMS for a new deformable mirror design for use in the Keck and other very large telescopes. Aimed at supplying the telescopes with mirrors that have more pixels for finer imaging control, his work could enable astronomers to make observations that could shed light on the origin of the universe and the existence of life on extra-solar planets.

"The primary benefit to me from this project was spending more time doing hands-on MEMS fabrication work," says Stockbridge, who had already spent two years working on the design of deformable mirrors in Bifano's lab. "While I would prefer to work more in design after graduation, the hands-on skills are important for getting an appreciation of each process step that goes into building a MEMS mirror."

During each deployment, he came to appreciate the engineering behind technologies used to protect soldiers.



Christopher Stockbridge in Bifano's Precision Optics Research Lab

As he has cultivated those skills, Stockbridge has proven to be an invaluable asset in Bifano's lab.

"Chris is a consummate engineer who seems to thrive on tackling problems that are both thorny and hard, and I can see in his work the experience and training that he gained while serving in the Army," says Bifano. "He is a natural collaborator, and all of the other students in my lab and in the labs of my close colleagues have come to rely on him for his strong sense of mechanical design and for his eagerness to help those around him. Chris will make a great professional engineer." ■

## BU INNOVATOR OF THE YEAR: ENG'S THEODORE MOUSTAKAS

RECOGNIZED FOR SCIENTIFIC CONTRIBUTIONS WITH COMMERCIAL POTENTIAL

By Kira Jastive

**PROFESSOR THEODORE MOUSTAKAS** (ECE, MSE, Physics) won BU's 2013 Innovator of the Year Award, recognizing a faculty member whose research and ideas have led to the formation of companies that benefit society at large.

Jean Morrison, BU provost and chief academic officer, presented the award to Moustakas on July 16, 2013, at Tech, Drugs and Rock & Roll—the University's annual networking event for those involved in university technology transfer in the Boston area.

Moustakas is the coinventor of the blue light-emitting diode (LED). His lab develops semiconductors for photonics and other applications. Moustakas is also the founder of RayVio Corp., a venture-backed company that makes ultraviolet LEDs, a compact, energy-efficient, durable, and environmentally friendly substitute for mercury lamps used in water purification and disinfection systems.

"Professor Moustakas is an entrepreneurial scientist, whose inventions have been licensed to a number of companies, including major manufacturers of blue LEDs and lasers—Cree and Philips-Lumileds in the United States and Nichia in Japan," says Morrison. "His accomplishments in FY 2013 include nine peer-reviewed papers published and five patent filings."

The Innovator of the Year Award recognizes faculty members who have conducted peer-recognized, world-class research and whose research projects show potential for commercialization.

Moustakas says he is honored to receive the award. "In a research university like ours there are many gifted and talented individuals who deserve such an award," he says. "Through working in an interdisciplinary field like materials and device physics, I have had the privilege to collaborate and benefit from many colleagues at BU as well as at other institutions. And I have been blessed to have mentored so many bright and talented young people over the last 26 years." >>



Jean Morrison, University provost and chief academic officer, presents the Innovator of the Year Award to Theodore Moustakas. Photo by Cydney Scott

The Innovator of the Year Award recognizes faculty members who have conducted peer-recognized, world-class research and whose research projects show potential for commercialization.

Moustakas's contributions cover a broad spectrum of topics in optoelectronic materials and devices. He is the coeditor of eight books and the author of chapters in nine books and more than 300 papers in technical journals and conference proceedings. He has been granted 25 US patents and several are pending in the fields of nitride semiconductors, amorphous silicon, and diamond materials. He was elected a Fellow of the American Physical Society in 1994 and of the Electrochemical Society in 1997. In 2003, he received an honorary degree from Aristotle University for outstanding contributions to research and teaching. In 2010, he was awarded the MBE Innovator Award and in 2011 was chosen for ENG's Distinguished Scholar Award. He is also a fellow of the National Academy of Inventors.

"Ted has been a prolific academic entrepreneur, but 2013 was especially productive with the launch of RayVio," says Vinit Nijhawan, managing director of the office of Technology Development, which sponsors the award. ■

## ■ NEW BU INITIATIVE TO BOOST STEM EDUCATION

GOLDBERG, WONG NAMED TO COORDINATE TEACHING, RECRUITMENT

By Susan Seligson

**IT'S A FITTING ACRONYM:** STEM is the basis for budding careers, for the growing of cutting-edge research, and for increased competence across a range of disciplines. While Boston University has long shown a strong commitment to education in science, technology, engineering, and mathematics (STEM) fields, it recently launched an initiative to improve that commitment by boosting interdisciplinary cooperation, recruiting more students in underrepresented populations, and arming the University with even more of a competitive edge in seeking outside funding.

Jean Morrison, University provost and chief academic officer, named two BU faculty members to take STEM to the next level. Bennett Goldberg, a College of Arts & Sciences professor of physics and a College of Engineering professor of electrical & computer engineering and of biomedical engineering, has been appointed director of BU's STEM Education Initiatives. Joyce Y. Wong, an ENG professor of biomedical engineering and of materials science & engineering, has been named director of a new University effort to advance women in STEM fields.

Goldberg will be responsible for oversight and coordination of efforts to "increase effectiveness of instruction" in STEM subjects, says Morrison in announcing the appointment. "A world-class scientist, innovator, and teacher who has devoted his career to impactful interdisciplinary scholarship, Professor Goldberg is exceptionally equipped for this responsibility," she says. The new post includes four major areas of oversight: leading an effort to "articulate the aspirations" of BU faculty for undergraduate STEM education; working with schools and colleges and the Center for Excellence & Innovation in Teaching to advance the "sharing of best practices"; working to boost recruitment of students, including women and minorities, underrepresented in STEM programs;



Bennett Goldberg

Goldberg will coordinate the establishment of more interactive learning studios, more peer learning, more small seminars like those used in some engineering courses, and more roundtable teaching.

and directing the development, writing, and submission of grants supporting STEM education at the University.

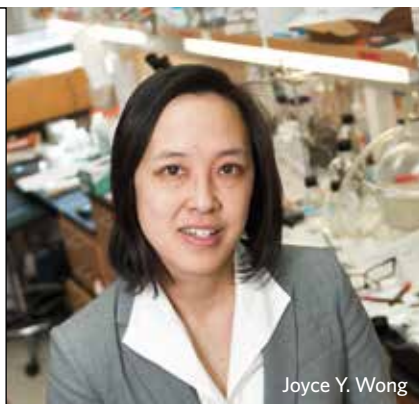
"STEM education at BU has a fair amount of innovation, but we don't have a really coordinated effort or strategic plan," says Goldberg. "If you look at what's happening in higher education in the United States, there are a lot of pressures, and our model for the future must include high-engagement

learning—moving away from the traditional talking head at the front of the class." In STEM education, in particular, the talking head model reaches "a very small fraction of our students," he says.

STEM education at BU is already embracing this move away from the traditional lecture model, but Goldberg will coordinate the establishment of more interactive learning studios, more peer learning, more small seminars like those used in some engineering courses, and more roundtable teaching. "My job is really to figure out what kind of support is necessary and how we can create a collective vision," he says. "It's planning, it's discussing, it's developing, and it's implementing."

Goldberg, who was named BU's 2013 United Methodist Scholar-Teacher of the Year, has long held an active interest in improving education in math and the sciences. Director of the Center for Nanoscience & Nanobiotechnology since 2004, he earned a bachelor's from Harvard University and a master's and a doctorate from Brown University. Of Goldberg's work cultivating clean energy sources, developing new drug delivery systems, and diagnostic methods, Morrison says that he "has committed himself

Wong is “uniquely positioned to help BU emerge as a leader in addressing the underrepresentation of women” in STEM fields.



Joyce Y. Wong

to breaking boundaries, working across fields of scientific research in a way that pushes the limits of our capabilities.”

Wong is “uniquely positioned to help BU emerge as a leader in addressing the underrepresentation of women” in STEM fields, according to Morrison. She notes that while BU attracts outstanding female students and faculty in these fields, “there is more work to be done both in recruitment and retention and in our endeavors to support their success.” Wong’s undergraduate and doctoral degrees are from the Massachusetts Institute of Technology. Her research focuses on the development of biological materials that could aid in detecting cancer and cardiovascular disease.

“I look forward to engaging all members of the BU community and to reaching out to the many people on campus who are running excellent programs at all levels, precollege, undergraduate, graduate, postdoctoral, and faculty, to advance STEM in an equitable manner,” says Wong. ■

## ■ WHITE HOUSE LAUDS BU PROF

ENG RESEARCHER RECEIVES PRESIDENTIAL EARLY CAREER AWARD

By Amy Laskowski

**IN 2014, ENG’S XUE HAN** was recognized for her important and creative research.

She travelled to Washington, DC, in April to accept the Presidential Early Career Award for Scientists and Engineers (PECASE), one of the highest honors for young science and engineering professionals.

Xue Han, a College of Engineering assistant professor of biomedical engineering, was among 102 awardees whose distinction comes with research grants lasting up to five years.

Han develops high-precision genetic, molecular, optical, and electrical tools and other nanotechnologies that make it possible to study the workings of the brain’s ultrafast neural pathways. Her research could ultimately be used to create new drugs and other therapeutic approaches for a wide spectrum of ailments, including

attention deficit disorders, depression, Parkinson’s disease, and schizophrenia.

“PECASE awards are extraordinarily competitive and provided only to those rare early career faculty who are judged likely to transform society through their research,” says Kenneth Lutchten, ENG dean and a professor of biomedical engineering. “Professor Han is an exceptionally innovative and creative bioengineer. Her ideas to advance optogenetic approaches are ingenious, especially since she is considering the most important and exciting questions in brain neuroscience.”

In the past few years, Han has received the National Institutes of Health (NIH) Director’s New Innovator Award, and been named a Pew Scholar in the Biomedical Sciences, a Sloan Research Fellow, and a Peter Paul Professor. “I’ll be using this award to recruit some talented grad students and postdocs,” she says, “and also to buy materials and instruments for our experiments.”

This marked Han’s second trip to the White House; in spring 2013, she traveled to Washington for President Barack Obama’s announcement of the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative, a \$100 million program to invent and hone technologies to understand the human brain. ■

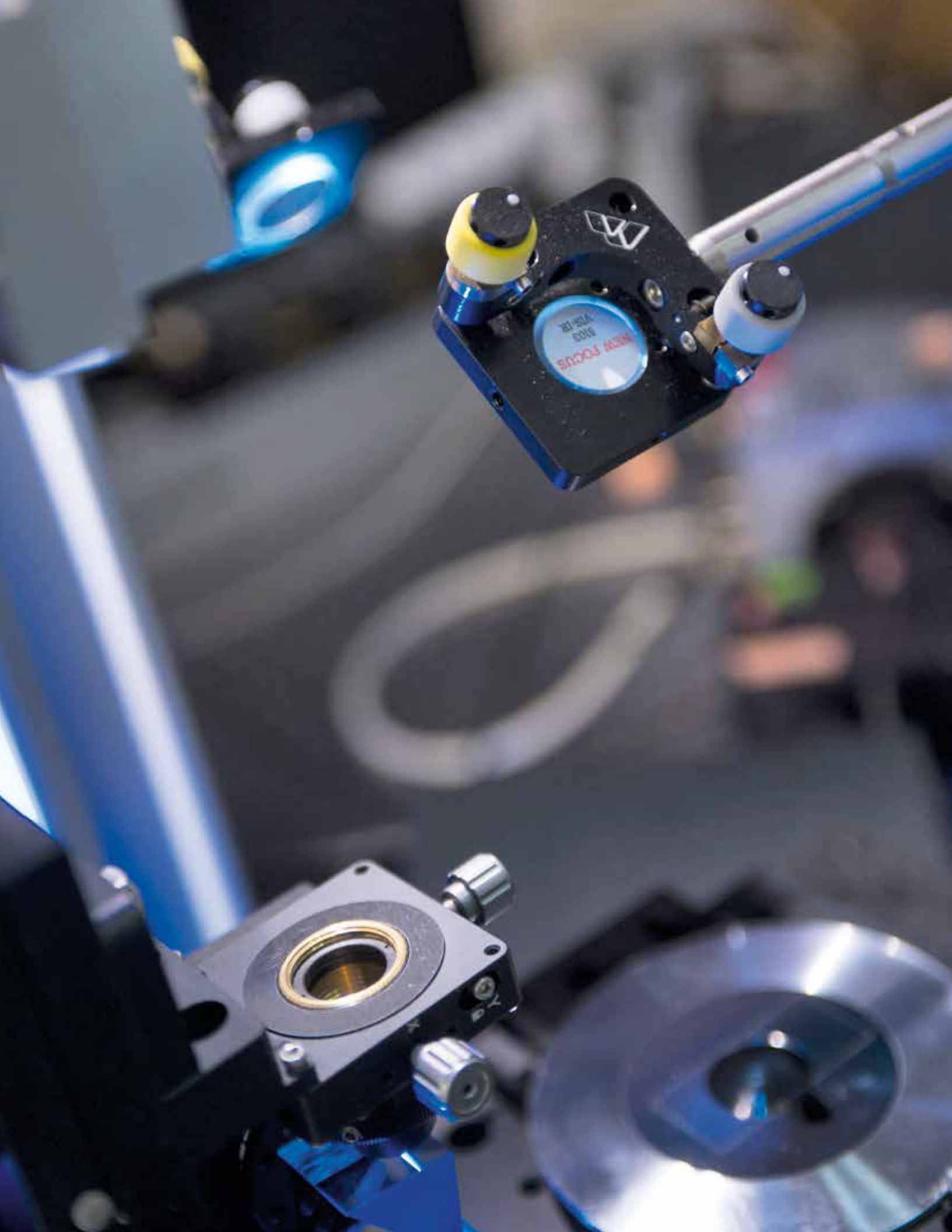
Her research could ultimately be used to create new drugs and other therapeutic approaches for a wide spectrum of ailments, including attention deficit disorders, depression, Parkinson’s disease, and schizophrenia.



Xue Han









# Faculty & Staff



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*Research interests:*

- New instrumentation and methods for cell-based assays
- Deep-UV microscopy
- Microfluidics for assay of DNA



**Kamil Ekinci**  
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*Research interests:*

- Nanophotonics, nano-opto-mechanics, and optical metrology
- Nanofluidics
- Nanomechanics and NEMS



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- Infrared and Raman microscopy
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*Research interests:*

- Biodetection, optics, nanoscale lithography, and imaging
- Photonics applications

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- Rocket and satellite experiments

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*Research interests:*

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- Femtosecond laser surgery

**Bennett Goldberg**

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*Research interests:*

- Biological sensors
- Semiconductor IC optical failure analysis
- Nanotubes and nano-optics

**Lee Goldstein**

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- Biometals and metallomics
- Molecular aging disorders

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*Research interests:*

- Neurotechnology
- Optical neural modulation
- Optogenetics

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*Research interests:*

- Auditory physiology
- Neurocomputing and biosensors
- VLSI design of smart sensor chips

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*Research interests:*

- Photochemistry
- Dye probes

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- Computer architecture

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*Research interests:*

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- Silicon photonics
- Optical communications

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*Research interests:*

- Nanomechanics of hydrated biomaterials
- Microfluidic device design

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*Research interests:*

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- High resolution imaging

**Theodore Morse**

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*Research interests:*

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- Optical fiber fabrication, lasers, and sensors

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*Research interests:*

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- Amorphous semiconductors



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- Terahertz photonics
- Plasmonics and related optoelectronic device applications



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*Research interests:*

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- Circuits for high frequency



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*Research interests:*

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- Optical physics of guided waves



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- New optical materials



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- Optical functional imaging



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*Research interests:*

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- Laser-material interaction



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- Quantum biophotonics



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*Research interests:*

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- Biomedical devices



**Anna Swan**  
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- Interactions of biomaterials with nanostructures
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- Venture capital businesses



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*Research interests:*

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- Nanoscale imaging of biological samples
- Biosensors



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*Research interests:*

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- Optoelectronic integration and packaging



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*Research interests:*

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- Micro nanomechanics



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*Research interests:*

- Spontaneous resonance Raman studies of photodissociative and biological chromophores
- IR and SERS based approaches

## **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 Committee Chair, Dr. Jerome Mertz**

The Photonics Center Guest Speakers Committee invites distinguished leaders in the field of photonics to visit the Photonics Center and give seminars on subjects of importance in the field. The lecturers also meet with individual faculty members and students.

### **Education Committee Chair, Open**

The Education Committee investigates methods for applying and enriching education of photonics within the community and BU programs.

### **Equipment Committee Chair, Dr. Jonathan Klamkin**

The Equipment Committee recommends equipment upgrades or new equipment purchases that would enhance the research and development of faculty and students at the center.

### **Executive Advisory Committee Chair, Dr. Thomas Bifano**

The Executive Advisory Committee advises the Director of the Photonics Center on educational and academic issues and is comprised of the chairs from the center's affiliated departments.

### **Space Allocation Committee Chair, Dr. Thomas Bifano**

The Space Allocation Committee generates policy guidelines for space management.

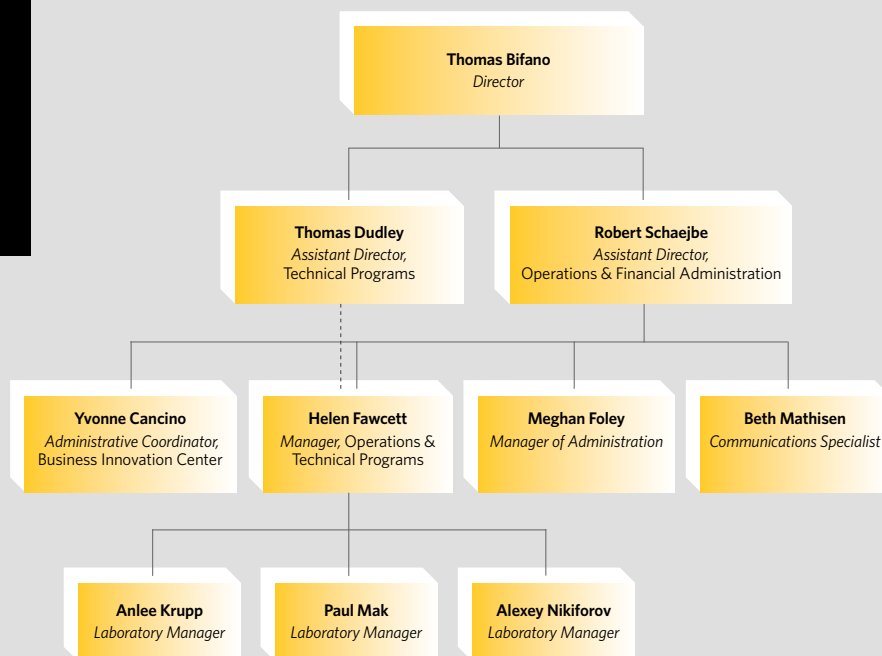
### **Symposium Committee Chair, Dr. Xin Zhang**

The Symposium Committee chair organized the 17th annual Photonics Center Symposium that focused on research and development of novel applications of photonics and photonics techniques, an area relevant to the Photonics Center community. The symposium included external and internal faculty speakers.



# Leadership & Administrative Staff

## Photonics Center Organizational Chart



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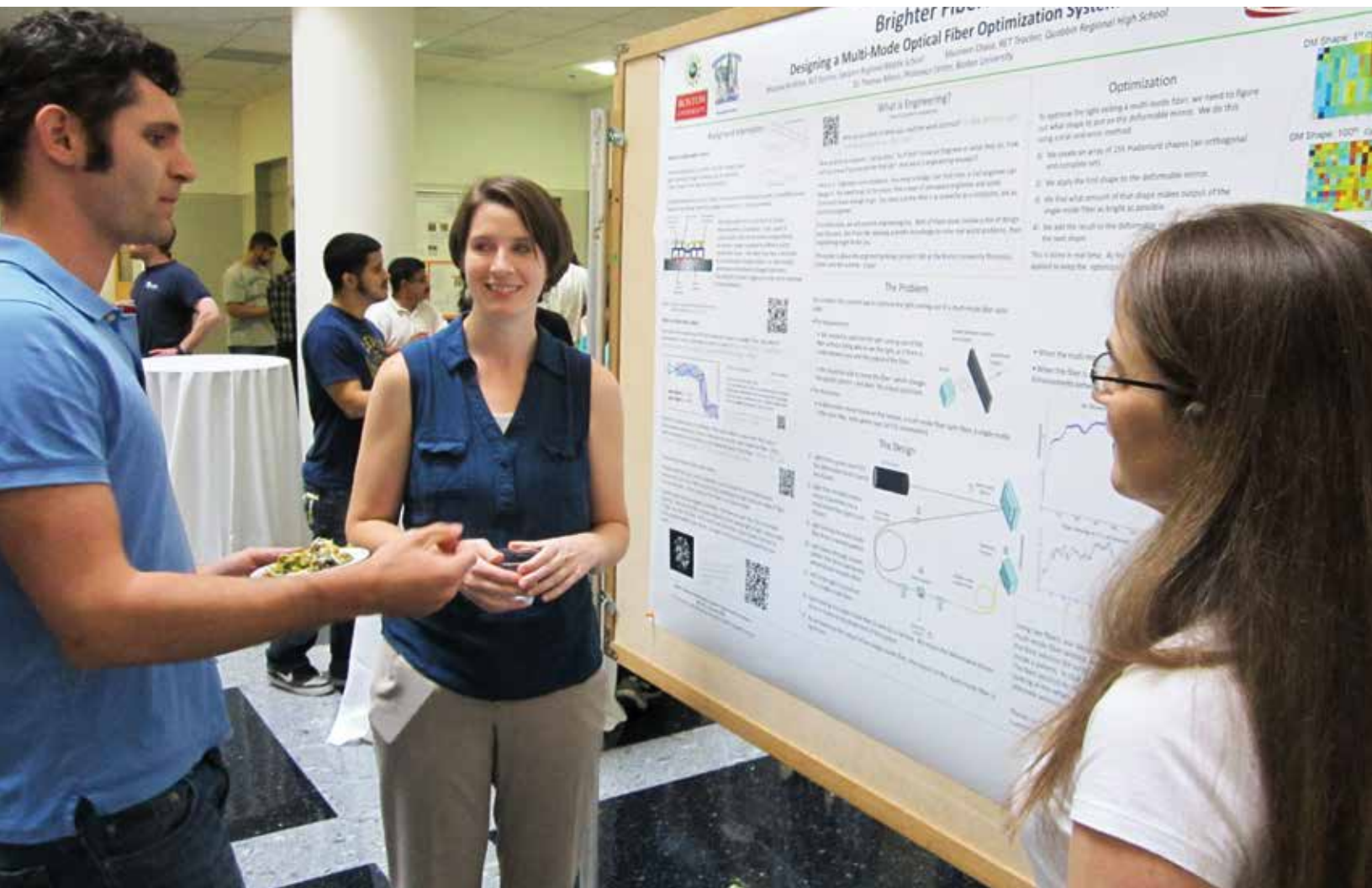
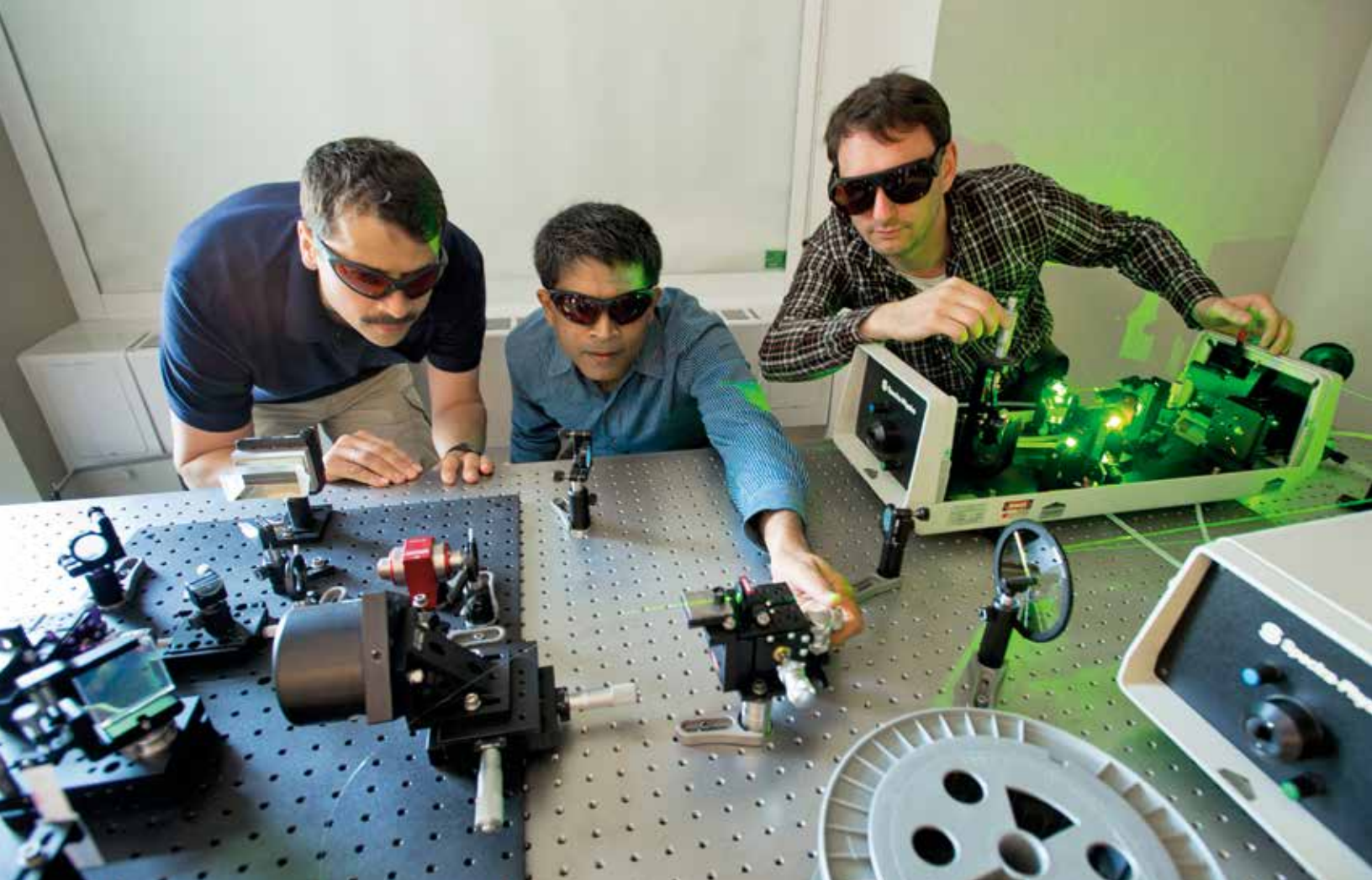
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# Research Projects & Technology Development

## FACULTY MEMBERS AND STAFF OF THE PHOTONICS CENTER

continue to be involved in a number of leading-edge research activities either through support of affiliated units in the Materials Science & Engineering Division, the Center for Nanoscience & Nanobiotechnology (CNN), the Industry/University Cooperative Research Center (I/UCRC) on Biophotonic Sensors & Systems (CBSS), and the Smart Lighting Engineering Research Center, or through the administration of block grants from the National Institutes of Health, National Science Foundation, and Department of the Army and others.

## I/UCRC ON BIOPHOTONIC SENSORS & SYSTEMS

The initial five-year grant to establish and execute the Center for Biophotonic Sensors & Systems (CBSS) has involved all of the staff and nearly half of the faculty researchers at the Photonics Center and at the partner University of California Davis's Center for Biophotonics. 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,
- Cultivate embryonic applications for biosensors,
- Advance biophotonic sensor technology, providing significant commercial benefits for disease diagnosis, patient monitoring, drug efficacy testing, and food and water safety,
- Develop effective methods for technology translation, accelerating innovative research to commercial benefit,
- Increase the quantity, quality, and diversity of professionals prepared to work in this field, and
- Involve the full technology and supply chain in a common focus of solving critical unmet needs in the health care sector using biophotonic sensing solutions.

CBSS has completed three successful years and the program formulation process for year four. The center has established a mechanism for an organized and

functioning collaborative engagement between the two university sites and 11 participating industry members and is positioned for future growth. Industry members that have been part of the center over the first three years include: Agilent, General Electric Healthcare's Applied Precision, Becton Dickinson, BioTools, Fraunhofer IPT, Iris AO, Lawrence Livermore National Laboratory, Lincoln Laboratory, Optofluidics, Potomac Photonics, and Thorlabs. Recruiting for new members is ongoing, and Purdue University submitted a Letter of Intent to NSF to join as a third university site.

Since the center's inception, 13 projects have been launched and 10 of these projects have been completed. FY2014 was a busy year for CBSS, as seven of the projects were active (six were selected at the prior program formulation meeting and the seventh project was added with a new member at the mid-year point). A summary of these projects appears in the table below, with a more detailed discussion of results on page 18.

The Industry/University Cooperative Research Center on Biophotonic Sensors & Systems had a busy year, with seven active projects.

Project	Project Lead	University Site
Integration of Raman Spectroscopy with NanoTweezer System	J. Chan	UCD
Superpenetration Multiphoton Microscope for Deep Tissue Imaging	T. Bifano	BU
SERS Approach for Rapid Antibiotic Specific UTI Diagnosis	L. Ziegler	BU
Label-Free, Non-Genetic Method to Purify Stem Cell Derived Cardiomyocytes	J. Chan	UCD
Snapshot 3D Flow Cytometry	J. Mertz	BU
Direct Molecular Detection via SERS and Aptamers	S. Wachsmann-Hogiu	UCD
AO Hybrid Microscopy	R. Zawadzki	UCD

### **Integration of Raman Spectroscopy with NanoTweezer System for Analyzing Dynamics of Single Trapped Bacteria Cells.**

This project was led by Professor Chan at UCD under the mentorship of Optofluidics. The goal of this project was to develop a laser trap Raman spectroscopy system by integrating micro-Raman spectroscopy capabilities with Optofluidics's NanoTweezer system for label-free biochemical analysis of single cells and nanoparticles. The patented Optofluidics technology based on a chip-based photonic resonance trapping approach allows for the manipulation of objects much smaller than traditional optical tweezers including metallic nanoparticles, bacteria, and protein aggregates. This project was started mid-year when Optofluidics joined the center and the project will continue into FY2015.

### **Superpenetration Multiphoton Microscope (S-MPM) for Deep Tissue Imaging.**

This project was led by Professor Bifano with considerable equipment and engineering support from Thorlabs, the IAB mentor for this project. This project took advantage of recent breakthroughs in controlled optical propagation and focusing through scattering media, along with the availability of fast MEMS spatial light modulators (SLM) developed at BU to extend the depth for visualizing cell-scale structures in the brain. Algorithms were developed to optimize SLM performance and real-time S-MPM imaging through thick skull and brain tissue were evaluated and compared with images made on existing MPM commercial instruments. The success of the evaluation led to positive feedback from Thorlabs Imaging Systems for follow-up in their life sciences and biomedical product line.

### **SERS Approach for Rapid Antibiotic Specific UTI Diagnosis.**

This project was led by Professor Ziegler under the mentorship of BioTools. The goal of this project was to develop a Raman spectroscopy (SERS) based platform for the rapid (~ 30 minute), reliable, easy-to-use, inexpensive diagnosis of bacterial pathogens with antibiotic spec-

ificity in patients presenting with urinary tract infection (UTI) symptoms for use in clinical settings. In the past year, a SERS library with 10 relevant species/strains with known drug resistance susceptibilities was developed and minimal bacterial sensitivity goals and diagnostic sensitivity goals >95% were demonstrated.

**CBSS has completed three successful years and the program formulation process for year four.**

### **Label-Free, Non-Genetic Method to Purify Stem Cell Derived Cardiomyocytes.**

The goal of this project, which was led by Professor Chan and mentored by Becton Dickinson (BD), was to develop a

new label-free, non-genetic approach for sorting stem cell cardiomyocytes based on nonlinear optical signals. At the end of the current fiscal year, system development has been completed. System testing will continue into the new fiscal year.

**Snapshot 3D Flow Cytometry.** This project generated significant commercial interest and the consensus support of the Industry Advisory Board (IAB). This was originally funded by the IAB in FY2013 and support was continued for a second year (FY2014) due to the research progress and potential for a commercial

product such as a microscope add-on to existing cytometry techniques used for cell identification. In the initial year of this project, which was led by Professor Mertz and mentored by BD, a phase-contrast imaging flow microscopy system (PAWS) was developed. In FY2014, the PAWS system was integrated into a full flow cytometry system. Numerical methods as well as hardware-based methods, utilizing a "layer-cake" aperture for extended depth of focus images, were developed.

### **Direct Molecular Detection via SERS and Aptamers.**

This project, led by Professor Wachsmann-Hogiu at UCD and mentored by Agilent, has demonstrated a new methodology for direct detection of molecules that makes use of subtle Raman peak shifts rather than changes in Raman peak intensities.

**AO Hybrid Microscopy.** This project, led by Professor Zawadzki at UCD, also had a second year of IAB support largely led by Iris AO, which sees commercial potential and mentored this project. The motivation behind this project was to test feasibility of adaptive optics enhanced in-vivo small animal retinal imaging system for longitudinal studies in animal models of human blinding diseases.





A second and third year of R&D support for the two top-ranked I/UCRC projects approved for FY2015, shown in the table below, reflects the industry perspective that they have commercial potential.

Project	Project Type	Project Lead	University Site
Adaptive Optics Enhanced Hybrid Fluorescence and OCT System	3rd-Year Funding	R. Zawadzki	UCD
Superpenetration Multiphoton Microscopy for Deep Tissue Imaging	2nd-Year Funding	T. Bifano	BU
Rapid, Multiplexed Sample-to-Answer Diagnostic for High Consequence Pathogens	New	J. Connor	BU
Improving the Speed of Hyperspectral Raman Imaging Using a Modulated, Multifocal Detection Scheme	New	J. Chan	UCD

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 eight publications were approved and two patent applications were made on I/UCRC-funded projects.

The program formulation meeting for FY2015 was held in May 2014 after a formal solicitation process that resulted in 27 new proposals being submitted by faculty from Boston University and University of California Davis. A screened set of these proposals was presented at the program formulation meeting and the IAB rank-ordered the projects for funding. The director of the center and the site directors approved the ranking as submitted by the IAB and authorized funding for four projects, as shown in the table.

The I/UCRC has also spawned several supplemental projects that are aligned with the I/UCRC and the strategic vision for the Photonics Center. In FY2014, the supplemental grants largely took the form of training grants to support undergraduate and graduate students and secondary school teachers, as well as veterans.

The second year of a Partners for Innovation: Accelerating Innovation Research (PFI:AIR) led to notable results on a grant entitled "Nanoplasmonic Metamaterial Antennae for Efficient Wireless Power Transmission." In this proposal,

the implementation of nanoplasmonics augments biosensor research by defining a path for remote powering of portable devices including implantable biosensors. This project also generated substantial commercial interest, and was backed up by a one-for-one match on NSF funds by Battelle Memorial Institute, which has also contributed significantly in testing and applications development. In the past year, protocols and procedures for device fabrication have been developed and device testing in various configurations (single loop, and stacked or diamond pattern arrays) has begun. Further characterization and testing is planned and demonstrations powering silicon nanowire sensors for biosensing will be prepared. Early in FY2015, a final design review will be held at Battelle and discussions for commercial integration and technology transfer will be pursued.

CBSS was also awarded a second I/UCRC supplement on the Fundamental Research Program (FRP) on a project entitled "Dynamic Imaging of Cancer Stem Cell Proliferation Using SERS Labels." The award is a positive reflection on the strength of the technology development activities and the cohesive vision cultivated by CBSS.

#### MAJOR PROJECTS MANAGED BY THE CENTER

**NIH U54: Center for Innovation in Point of Care Technologies for the Future of Cancer Care**

Professor Catherine Klapperich was awarded a five-year U54 cooperative agreement that started on July 1, 2012. The focus of the program is on identification, prototyping, and early clinical assessment of innovative point of care technologies for treating, screening, diagnosing, and monitoring of cancers. Helen Fawcett is the program manager of this grant. The Photonics Center also provides financial and administrative management of this five-year grant. The second year of the grant has been completed and a new set of projects will initiate in Year 3. Project solicitation will commence for Year 4 in late summer. For more details and information on this dynamic center, please visit [www.bu.edu/cftcc/](http://www.bu.edu/cftcc/).

#### NIH R01: Development of Near Real-Time, Multiplexed Diagnostics for Viral Hemorrhagic Fever

Professors John Connor (PI) and Selim Unlu (co-PI) were awarded a NIH R01 program on August 1, 2011. This is a five-year grant and is entitled "Development of Near Real-Time, Multiplexed Diagnostics for Viral Hemorrhagic Fever." This grant has a component that includes partnership with a commercial entity that has been identified and engaged from the start of the program, with the focus to be generating a production-ready instrument for use in a BSL-4 laboratory. Faculty members participating in the grant besides the PI and Co-PI include: Professors Helen Fawcett, Catherine Klapperich, and Mario Cabodi. The focus of the grant is on development of a photonics-based technology platform,



including integration with microfluidics and sample preparation techniques. The team is currently preparing, alongside two commercial partners, a launch of an instrument into a BSL-4 laboratory. Year 4 (August 2014) will be an exciting year for this team as an instrument with photonics technology will be evaluated for practical use with bona fide biohazards. In addition to assisting in the writing of the grant and program management, the Photonics Center also provides financial and administrative management of this five-year program.

#### **NIH XTNC: Cross-Disciplinary Training in Nanotechnology for Cancer**

This training program, formed by the Center for Nanoscience & 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 fifth and final year, XTNC has supported 42 pre- and post-doctoral fellows engaged in interdisciplinary mentored research to develop novel nanoscale therapeutic and diagnostic tools for the detec-

tion and treatment of cancer. Photonics Center staff members provide financial and administrative management on the Charles River Campus and coordinate with the corresponding Medical Campus portion of the program.

#### **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." Professor Goldberg also has a subcontract on a second IARPA program, "Logic Analysis Tool." In both programs, the Photonics Center is providing financial and administrative management. Helen Fawcett has assumed the role of program manager for both of these IARPA awards. As the final year will be coming to a close on the IARPA awards, the team is transitioning the advanced technology onto a commercial unit that will then be installed in a government facility for further testing and development of a first-generation technology platform.

#### **NSF AIR: Rapid Label-Free Single Virus Detection Platform for Multi-Pathogen Diagnostics**

Professors Selim Unlu (PI) and Helen Fawcett (Co-PI) were awarded a supplemental award for the Option 1, NSF AIR: Accelerating Innovative Research grant for the project entitled "Rapid Label-Free Single Virus Detection Platform for Multi-Pathogen Diagnostics." The program was originally awarded in July 2011 and with the supplement was extended through June 2014. This supplement added an additional \$50K to upgrade the prototype unit and add an enclosed chamber for sample insertion and detection. Dr. David Freedman, a former postdoctoral researcher in Professor Unlu's laboratory, has successfully spun-out a company, NexGen Arrays, LLC, to further develop commercialization of the prototype and a business plan. The team was awarded the supplement after participating in the NSF Technology Showcase last May. Another exciting outcome of the NSF AIR project was a funded NSF I-CORPS proposal led by Dr. Freedman and current postdoctoral researcher George Daaboul. ■

## LIST OF CURRENT GRANTS

Photonics faculty members received more than \$14.5M in external funding. The following table lists funds in the fiscal year (July 1, 2013–June 30, 2014), as reported by the Sponsored Programs Office.

PI	Dept.	Title of Project	Agency	Period	Amount
Averitt	PHY	● SISGR: Multifunctional Materials Research Using Ultrafast Optical Spectroscopy	Department of Energy	9/1/09-9/14/14	\$194,000
		● SISGR: Multifunctional Materials Research Using Ultrafast Optical Spectroscopy		9/1/09-9/14/15	\$194,000
Bellotti	ECE	● CRA: Computationally-Guided Design of Energy Efficient Electronic Materials (CDE3M)	University of Utah	1/1/13-12/31/13	\$76,250
		● CRA: Computationally-Guided Design of Energy Efficient Electronic Materials (CDE3M)		1/1/14-12/31/15	\$278,850
		● Theoretical Foundations of Advanced III-Nitrides Power	National Science Foundation	7/1/14-6/30/17	\$336,902
Bifano	ME	● I/UCRC Collaborative Research	I/UCRC: Industry Memberships	7/1/11-6/30/14	\$200,000
		● I/UCRC Collaborative Research: I/UCRC: Center for Biophotonic Sensors & Systems (CBSS)	National Science Foundation	3/1/11-2/29/16	\$7,956
		● I/UCRC Collaborative Research: I/UCRC: Center for Biophotonic Sensors & Systems (CBSS)		3/1/11-2/29/16	\$19,971
		● PFI-AIR: Nanoplasmonic Meta-material Antennae for Efficient Wireless Power Transmission		7/15/12-6/30/14	\$200,000
		● Scalable, Cost-Effective, High Actuator-Count Deformable Mirrors for Astronomical Adaptive Optics		7/1/11-6/30/14	\$115,805
		● I/UCRC Collaborative Research: I/UCRC: Center for Biophotonic Sensors & Systems (CBSS)		3/1/11-2/29/16	\$80,000
		● High-Precision Phased Array Beam Steering Using Enhanced MEMS Mirrors	The Optical Sciences Company	3/20/14-10/19/14	\$35,000
Bigio	BME	● Training Program in Quantitative Biology and Physiology	National Institutes of Health	7/1/12-6/30/17	\$312,582
		● Draper Laboratory Fellow—Carlos Segura	Draper Laboratory, Inc.	9/1/13-8/31/14	\$41,278
		● Clinical Study to Assess Reliability of ESS for Distinguishing Parathyroid from Nearby Tissue During a Surgical Procedure	Invuity, Inc.	1/31/14-1/30/15	\$40,000

PI	Dept.	Title of Project	Agency	Period	Amount
Bigio	BME	● Optical Imaging of Chemotherapy for Brain Tumors	Columbia University	4/1/11-3/31/14	\$45,602
		● Optical Imaging of Chemotherapy for Brain Tumors		4/1/11-3/31/14	\$49,655
		● Margin Guidance for Oral Cancer Resection Using Light Scattering Spectroscopy	Boston Medical Center	12/14/12-11/30/14	\$99,742
		● Training Program in Quantitative Biology and Physiology	National Institutes of Health	7/1/12-6/30/17	\$315,939
Bishop	ECE	● Nanoscale Additive Manufacturing of Photonic Devices	Bell Labs/Alcatel Lucent	7/1/13-6/30/16	\$69,900
		● ACE Program for Advanced Components	LGS Innovations, LLC	7/1/13-12/31/14	\$25,578
		● Building a MEMS-Based Fab on a Chip as a Technique for Nanomanufacturing	National Science Foundation	6/1/14-5/31/17	\$393,747
Connor	MED	● Development of Near Real-Time, Multiplexed Diagnostics for Viral Hemorrhagic Fever	National Institutes of Health	8/1/11-7/31/16	\$836,193
Dal Negro	ECE	● Nano-Scale Optical Emitters for High Density Information Processing Using Photonic-Plasmonic Coupling in Coaxial Nanopillars	Department of Defense/AFOSR	1/1/13-12/31/14	\$179,993
Fritz	AST	● UNP8/BUSAT3: ANDESITE: Ad-hoc Network Demonstration for Spatially Extended Satellite-Based Inquiry and Other Team Endeavors		9/1/13-10/30/15	\$55,000
Gabel	MED	● <i>C. Elegans</i> Model for Mammalian Lesion-Conditioned Axon Regeneration	National Institutes of Health	9/1/12-8/31/14	\$197,463
		● Molecular Determination of In Vivo Cellular Calcium Signaling During Nerve Damage		5/1/13-4/30/18	\$354,514
Goldberg	PHY	● High-Resolution Imaging of Oil/Water and Nanoparticle Flow in Rock	ARAMCO Services Company	12/17/13-12/31/14	\$400,000
		● Next Generation Solid Immersion Microscopy for Fault Isolation in Back-Side Analysis	Department of Defense/Air Force	11/10/10-11/9/14	\$427,000
		● Next Generation Solid Immersion Microscopy for Fault Isolation in Back-Side Analysis		11/10/10-11/9/14	\$70,303
		● Boston University Cross-Disciplinary Training in Nanotechnology for Cancer	National Institutes of Health/National Cancer Institute	9/1/10-7/31/15	\$45,144



PI	Dept.	Title of Project	Agency	Period	Amount
Goldberg	PHY	● Boston University Cross-Disciplinary Training in Nanotechnology for Cancer	National Institutes of Health/National Cancer Institute	9/1/10-7/31/15	\$287,212
		● Logic Analysis Tool	DCG Systems, Inc.	12/8/10-12/7/14	\$146,892
		● Graphene Membranes as Micro- and Nano-Pressure Sensors	University of Texas	3/1/09-12/31/15	\$300,373
		● MOOC-Sponsored Learning Communities for Future STEM Faculty: Multiple Paths to Advanced Evidence-Based Teaching Across the Nation	Michigan State University	10/1/13-9/30/16	\$30,651
		● The CIRT Network: 25 Universities Preparing a National Faculty to Advance STEM Undergraduate Learning	University of Wisconsin	8/15/13-7/31/14	\$53,381
Goldstein	MED	● Effects of Blast Neurotrauma on Alzheimer's Disease Pathogenesis	Department of Defense	9/16/13-9/15/15	\$363,389
		● Effects of Space Radiation on Hippocampal-Dependent Learning and Neuropathy in Wild-Type and Alzheimer's Disease Transgenic Mice	NASA	9/1/11-8/31/14	\$225,000
		● Progesterone Therapy for CTE	BHR Pharma, LLC	1/15/13-1/14/15	\$299,999
		● Effects of Space Radiation on Hippocampal-Dependent Learning and Neuropathy in Wild-Type and Alzheimer's Disease Transgenic Mice	NASA	9/1/11-8/31/14	\$225,000
Han	BME	● Striatal Origin of Pathological Beta Oscillations in Parkinson's Disease	National Institutes of Health	9/1/12-8/31/14	\$197,463
		● Causal Analysis of Electrically Connected Neural Networks		9/30/13-8/31/17	\$339,475
		● Non-Invasive Striatal Delivery of Glial Derived Neurotrophic Factor (GDNF) via a Novel Heterotopic Mucosal Grafting Technique	Massachusetts Eye and Ear Infirmary	8/1/12-7/31/14	\$7,000
		● Thalamocortical Circuit Dysfunction in Schizophrenia	Brain & Behavior Research Foundation	1/15/13-1/14/15	\$30,000
		● Biologically-Inspired Hardware for Land/Aerial Robots (Student: Schuyler Eldridge)	NASA	8/1/12-7/31/16	\$60,616

PI	Dept.	Title of Project	Agency	Period	Amount
Klamkin	ECE	<ul style="list-style-type: none"> <li>Monolithic Microwave Photonics Integrated Circuit (MMPIC)</li> </ul>	University of Massachusetts, Dartmouth	1/1/13-12/31/15	\$6,000
Klapperich	BME	<ul style="list-style-type: none"> <li>Center for Innovation in Point of Care Technologies for the Future of Cancer Care</li> </ul>	National Institutes of Health	7/1/12-6/30/17	\$1,644,981
		<ul style="list-style-type: none"> <li>A Rapid Instrument Free Molecular Diagnostic for <i>B. Pertussis</i></li> </ul>		2/21/14-2/20/16	\$57,902
		<ul style="list-style-type: none"> <li>A Rapid Instrument Free Molecular Diagnostic for <i>B. Pertussis</i></li> </ul>		2/21/14-2/20/16	\$1,152
		<ul style="list-style-type: none"> <li>Bacterial Drug Susceptibility Identification by Surface Enhanced Raman Microscopy</li> </ul>	Fraunhofer USA	7/1/10-6/30/14	\$77,500
		<ul style="list-style-type: none"> <li>Helicase Dependent Amplification for Simpler Diagnosis of Human African Trypanosomiasis</li> </ul>	Makerere University College of Health	4/1/13-9/30/14	\$29,451
		<ul style="list-style-type: none"> <li>A Portable, Self-Contained Nucleic Acid Extraction and Storage System for POC Tests</li> </ul>	AI Biosciences, Inc.	4/1/14-12/31/14	\$60,000
Meller	BME	<ul style="list-style-type: none"> <li>Tunable Nanofiber Mesh Coatings for Improved Nanopore Sensing</li> </ul>	National Institutes of Health	7/5/13-6/30/15	\$245,550
		<ul style="list-style-type: none"> <li>Tunable Nanofiber Mesh Coatings for Improved Nanopore Sensing</li> </ul>		7/5/13-6/30/15	\$198,486
Mertz	BME	<ul style="list-style-type: none"> <li>Billing Agreement for Hao Wang</li> </ul>	Massachusetts General Hospital	9/1/13-4/30/14	\$24,024
		<ul style="list-style-type: none"> <li>High Resolution Phase Contrast Endoscopy</li> </ul>	National Institutes of Health/National Cancer Institute	12/15/13-11/30/17	\$354,523
		<ul style="list-style-type: none"> <li>Billing Agreement for Hao Wang</li> </ul>	Massachusetts General Hospital	5/1/14-8/31/14	\$12,029
Moustakas	ECE	<ul style="list-style-type: none"> <li>Joint Research and Development Work Between Boston University and Rayvio: Growth and Characterization of Deep UV-LEDs</li> </ul>	Rayvio	7/1/12-12/31/13	\$43,178
		<ul style="list-style-type: none"> <li>Surface Structuring for Monolithic Phosphors</li> </ul>	Osram Sylvania, Inc.	9/1/12-12/31/13	\$25,000
Paiella	ECE	<ul style="list-style-type: none"> <li>Collaborative Research: Strain-Tunable Ge Nanomembrane Lasers</li> </ul>	National Science Foundation	8/15/13-7/31/16	\$281,677
		<ul style="list-style-type: none"> <li>Plasmonic Control of Radiation and Absorption Processes in Semiconductor Quantum Dots</li> </ul>	Department of Energy	8/15/06-12/31/15	\$170,000

PI	Dept.	Title of Project	Agency	Period	Amount
Pavlidis	ECE	<ul style="list-style-type: none"> <li>Deep UV Laser Diode Development for Medical and Precision Processing Applications</li> </ul>	Electronics and Telecommunications Research	4/1/12-10/31/14	\$43,606
Ramachandran	ECE	<ul style="list-style-type: none"> <li>Power Scalable Blue-Green Bessel Beams</li> </ul>	Department of Defense/ONR	1/1/11-12/31/13	\$36,605
		<ul style="list-style-type: none"> <li>High Power Blue Green Lasers for Communications</li> </ul>		11/1/10-4/30/14	\$71,161
		<ul style="list-style-type: none"> <li>Fundamental Research on Wavelength-Agile High-Rate Quantum Key Distribution (QKD) in a Marine Environment</li> </ul>	University of Illinois, Urbana-Champaign	8/1/13-7/31/16	\$41,886
		<ul style="list-style-type: none"> <li>Fundamental Research on Wavelength-Agile High-Rate Quantum Key Distribution (QKD) in a Marine Environment</li> </ul>		8/1/13-7/31/16	\$106,110
Reinhard	CHEM	<ul style="list-style-type: none"> <li>New Optoplasmonic Materials for Next Generation Energy Systems</li> </ul>	Department of Energy	9/1/13-8/31/16	\$160,000
		<ul style="list-style-type: none"> <li>Illuminating Dynamic Receptor Clustering in the Epidermal Growth Factor Receptor</li> </ul>	National Institutes of Health/National Cancer Institute	5/1/14-4/30/19	\$293,649
		<ul style="list-style-type: none"> <li>New Optoplasmonic Materials for Next Generation Energy Systems</li> </ul>	Department of Energy	9/1/13-8/31/16	\$160,000
		<ul style="list-style-type: none"> <li>Illuminating Dynamic Receptor Clustering in the Epidermal Growth Factor Receptor</li> </ul>	National Institutes of Health/National Cancer Institute	5/1/14-4/30/19	\$55,566
Ritt	BME	<ul style="list-style-type: none"> <li>Career Award at Scientific Interface</li> </ul>	Burroughs Wellcome Fund	1/1/10-6/30/14	\$100,000
Schmidt	ME	<ul style="list-style-type: none"> <li>The EM-Tech Polymer Project</li> </ul>	EM-Tech	1/1/14-12/31/14	\$35,000
		<ul style="list-style-type: none"> <li>The Dutch Project</li> </ul>	The University of Twente	4/30/14-12/31/14	\$10,000
Semeter	ECE	<ul style="list-style-type: none"> <li>IR&amp;D: Development of a Prototype CPT Magnetometer</li> </ul>	Draper Laboratory, Inc.	9/1/13-6/27/14	\$30,000
		<ul style="list-style-type: none"> <li>EAGER: High Speed Tomographic Imaging Facility for Studies of Auroral Fine Structure</li> </ul>	National Science Foundation	9/1/12-8/31/14	\$117,519
		<ul style="list-style-type: none"> <li>Collaborative Research: RINGS-RISR Investigation of the Geospace System</li> </ul>		8/15/13-7/31/16	\$110,954
		<ul style="list-style-type: none"> <li>Inspire Track 1: Mahali Space Weather Monitoring Everywhere</li> </ul>	Massachusetts Institute of Technology	12/1/13-11/30/16	\$29,779
		<ul style="list-style-type: none"> <li>Magnetospheric Control of Density and Composition in the Polar Ionosphere</li> </ul>	Department of Defense/AFOSR	4/1/12-3/31/15	\$134,759



PI	Dept.	Title of Project	Agency	Period	Amount
Semeter	ECE	● Collaborative Research: PINOT-PFISR Ion-Neutral Observations in the Thermosphere	National Science Foundation	10/1/12-9/30/15	\$31,443
		● The Millstone Hill Geospace Facility	Massachusetts Institute of Technology	12/15/12-11/30/17	\$62,054
Sergienko	ECE	● Developing Ultra-High Precision Light Pulse Atom Interferometers (Draper Fellow: Mackenzie Van Camp)	Draper Laboratory, Inc.	6/1/13-8/31/13	\$10,198
		● Quantum Communication Using Macroscopic Phase Entangled States	University of Maryland, Baltimore County	9/12/12-9/11/14	\$203,811
		● Quantum Communication Using Macroscopic Phase Entangled States		9/12/12-9/11/14	\$154,887
		● Quantum Communication Using Macroscopic Phase Entangled States		9/12/12-9/11/14	\$309,779
Unlu	ECE	● Multiplexed, Rapid, Point of Care Device to Quantify Specific IGE to Common Allergens	National Institutes of Health	8/1/11-7/31/14	\$192,961
Zhang	ME	● Mercury Sensor Development for Application in the Oil and Gas Industry	Schlumberger-Doll Research Center	7/1/11-6/30/14	\$58,893
		● Draper Lab Fellow: Else Frohlich	Draper Laboratory, Inc.	9/1/13-8/31/14	\$45,405
Ziegler	CHEM	● Bacterial Drug Susceptibility Identification by Surface Enhanced Raman Microscopy	Fraunhofer USA	7/1/10-6/30/15	\$144,000
		● Ultrafast Dynamics of Supercritical Fluids	National Science Foundation	7/1/12-6/30/16	\$135,000
		● Ultrafast Dynamics of Supercritical Fluids		7/1/12-6/30/16	\$135,000
				TOTAL:	\$14,516,295

# Publications, Patents & Awards

## BOOK CHAPTERS

**S. Basu** and V. Sarin, "Thermal and Environmental Barrier Coatings," in *Comprehensive Hard Materials*, edited by V.K. Sarin, Elsevier Ltd., 2013.

C. Batten, **A. Joshi**, V. Stojanovi, and K. Asanovi, "Designing Nanophotonic Interconnection Networks," in *Integrated Optical Interconnect Architectures and Applications in Embedded Systems*, Springer, 2013.

A. Fan, S. Byrnes, and **C. Klapperich**, "Purification of DNA/RNA in a Microfluidic Device," in *Microfluidic Diagnostics*, edited by G. Jenkins and C. D. Mansfield, Humana Press: New York, 2013.

**A. Schmidt**, "Pump-Probe Thermoreflectance," in *Annual Review of Heat Transfer*, 16(1):159181, 2013.

**J. Semeter** and M. Zettergren, "Model-Based Inversion of Auroral Processes," in *Modeling the Ionosphere-Thermosphere System*, edited by J. Huba, R. Schunk, and G. Khazanov, John Wiley & Sons, Ltd, 2014.

D. Simon, G. Jaeger, and **A. Sergienko**, "Quantum Information in Communication and Imaging," in *International Series on Modern Physics*, edited by World Scientific, 2013.

S. Ahn, D. Freedman, X. Zhang, and **M. Unlu**, "High-throughput Label-free Detection of DNA Hybridization and Mismatch Discrimination Using Interferometric Reflectance Imaging Sensor," in *Nucleic Acid Detection: Methods in Molecular Biology*, Vol. 1039, September 2013.

X. Zhang, P. Spuhler, D. Freedman, and **M. Unlu**, "Spectral Self-Interference Fluorescence Microscopy to Study Conformation of Biomolecules with Nanometer

Accuracy," in *Nanoscale Spectroscopy with Applications*, November 2013.

## JOURNAL ARTICLES

J. Xu, B. Lo, Y. Jiang, U. Pal, and **S. Basu**, "Stability of Yttria Stabilized Zirconia in Molten Oxy-Fluorite Flux for the Production of Silicon with the Solid Oxide Membrane Process," *Journal of the European Ceramic Society*, 2013.

J. Milshtein, E. Gratz, **S. Basu**, S. Gopalan, and U. Pal, "Study of the Two-Step W/WO<sub>3</sub> Solar to Fuel Conversion Cycle for Syngas Production," *Journal of Power Sources*, 236, 95-102, 2013.

C. Heveran, J. Xu, V. Sarin, and **S. Basu**, "Simulation of Stresses in TBC-EBC Coating Systems for Ceramic Components in Gas Turbines," *Surface & Coatings Technology*, 235, 354-360, 2013.

Y. Lu, **T. Bifano**, **M. Unlu**, and **B. Goldberg**, "Aberration Compensation in Aplanatic Solid Immersion Lens Microscopy," *Optics Express*, Vol. 21, pp. 28189-28197, November 2013.

O. A'amar, L. Liou, E. Rodriguez-Diaz, T. King, A. De las Morenas, and **I. Bigio**, "Comparison of Elastic Scattering Spectroscopy with Histology in Ex-vivo Prostate Glands: Potential Application for Optically-Guided Biopsy and Directed Treatment," *Lasers in Medical Science*, 28:1323-1329, 2013.

J. Rosen, H. Suh, N. Giordano, O. A'amar, E. Rodriguez-Diaz, **I. Bigio**, and S. Lee, "Preoperative Discrimination of Benign from Malignant Disease in Thyroid Nodules with Indeterminate Cytology Using Elastic Light-Scattering Spectroscopy," *IEEE Trans. Biomed. Eng.*, PMID: 23771305, 2013.

J. Briggs, O. A'amar, **I. Bigio**, J. Rosen, S. Lee, A. Sharon, and A. Sauer-Budge, "Integrated Device for in vivo Fine Needle Aspiration Biopsy and Elastic Scattering Spectroscopy in Pre-Operative Thyroid Nodules," *J. of Medical Devices*, 8, 021003-1 – 021003-6, 2014.

M. Imboden, H. Han, F. Pardo, C. Bolle, E. Lowell, and **D. Bishop**, "Atomic Calligraphy: The Direct Writing of Nanoscale Structures Using a Microelectromechanical System," *ACS Nano Letters*, 13 (7), 3379-3384, 2013.

M. Imboden, H. Han, J. Morrison, E. Lowell, and **D. Bishop**, "Controlling Levitation and Enhancing Displacement in Electrostatic Comb Drives of MEMS Actuators," *J. MEMS*, 2014.

M. Imboden, H. Han, T. Stark, E. Lowell, J. Chang, C. Bolle, F. Pardo, and **D. Bishop**, "Building a Fab on a Chip," *Nanoscale*, 2014.

N. Boddeti, X. Liu, R. Long, J. Xiao, **J. Bunch**, and M. Dunn, "Graphene Blisters with Switchable Shapes Controlled by Pressure and Adhesion," *Nano Letters*, 13, 6216-6221, 2013.

N. Boddeti, S. Koenig, R. Long, J. Xiao, **J. Bunch**, and M. Dunn, "Mechanics of Adhered, Pressurized Graphene Blisters," *Journal of Applied Mechanics*, 80, 040909, 2013.

X. Liu, N. Boddeti, M. Szpunar, L. Wang, M. Rodriguez, R. Long, J. Xiao, M. Dunn, and **J. Bunch**, "Observation of Pull-in Instability in Graphene Membranes under Interfacial Forces," *Nano Letters*, 13, 2309-2313, 2013.

D. Chung, C. Jonsson, N. Tower, Y. Chu, E. Sahin, J. Golden, J. Noah, C. Schroeder, J. Sotsky, M. Sosa, D. Cramer, S. McKellip,



L. Rasmussen, E. White, C. Schmaljohn, J. Julander, J. Smith, C. Filone, **J. Connor**, Y. Sakurai, and R. Davey, "Discovery of a Novel Compound with Anti-Venezuelan Equine Encephalitis Virus Activity That Targets the Nonstructural Protein," *2.PLoS Pathog*, 10(6):e1004213, 2014.

D. Gammon, S. Duraffour, D. Rozelle, H. Hehnly, R. Sharma, M. Sparks, C. West, Y. Chen, J. Moresco, G. Andrei, **J. Connor**, D. Conte, D. Gundersen-Rindal, W. Marshal, J. Yates, N. Silverman, and C. Mello, "A single vertebrate DNA virus protein disarms invertebrate immunity to RNA virus infection," *eLife*, 10.7554/eLife.02910n, 2014.

D. Rozelle, C. Filone, K. Dower, and **J. Connor**, "Vaccinia Reporter Viruses for Quantifying Viral Function at All Stages of Gene Expression," *JoVE*, 2014.

D. Rozelle, C. Filone, N. Kedersha, and **J. Connor**, "Activation of Stress Response Pathways Promotes Formation of Antiviral Granules and Restricts Virus Replication," *Mol Cell Biol*, 34:2003-16. PMID: 24662051, 2014.

A. Reddington, J. Trueb, D. Freedman, A. Tuysuzoglu, G. Daaboul, C. Lopez, W. Karl, **J. Connor**, **H. Fawcett**, and **M. Unlu**, "An Interferometric Reflectance Imaging Sensor for Point of Care Viral Diagnostics," *IEEE Trans Biomed Eng*, 60:3276-83. PMID: 24271115, 2014.

C. Filone, I. Caballero, K. Dower, M. Mendillo, G. Cowley, S. Santagata, D. Rozelle, J. Yen, K. Rubins, N. Hacohen, D. Root, L. Hensley, and **J. Connor**, "The Master Regulator of the Cellular Stress Response (HSF1) Is Critical for Orthopoxvirus Infection," *PLOS Pathogens*, 2014.

S. Malhotra, J. Yen, A. Honko, S. Haramszegi, I. Caballero, J. Johnson, E. Mucker, J. Trefry, L. Hensley, and **J. Connor**, "Transcriptional Profiling of the Circulating Immune Response to Lassa Virus in an Aerosol Model of Exposure," *PLoS Neg. Trop. Dis.*, 7(4):e2171. PMID: 23638192, 2014.

A. Reddington, J. Trueb, D. Freedman, A. Tuysuzoglu, G. Daaboul, C. Lopez, W. Karl, **J. Connor**, **H. Fawcett**, and **M. Unlu**,

"An Interferometric Reflectance Imaging Sensor for Point of Care Viral Diagnostics," *IEEE Transactions on Biomedical Engineering*, Vol. 60, No. 12, pp. 3276-3283, December 2013.

G. Walsh, **L. Dal Negro**, "Engineering Plasmon-enhanced Au Light Emission with Planar Arrays of Nanoparticles," *Nano Lett.*, 13, 786, Jan. 15, 2013.

S. Lee, G. Walsh, and **L. Dal Negro**, "Microfluidics Integration of Aperiodic Plasmonic Arrays for Spatial-spectral Optical Detection," *Opt. Express*, 21, 4945, Feb. 25, 2013.

D. Simon, N. Lawrence, J. Trevino, **L. Dal Negro**, and **A. Sergienko**, "High Capacity Quantum Fibonacci Coding for Key Distribution," *Phys. Rev. A*, 87, 032312, March 11, 2013.

E. Pecora, A. Capretti, G. Miano, and **L. Dal Negro**, "Generation of Second Harmonic Radiation from Sub-stoichiometric Silicon Nitride Thin Films," *Appl. Phys. Lett.*, 102, 141114, April 12, 2013.

G. Walsh and **L. Dal Negro**, “Enhanced Second Harmonic Generation by Photonic-Plasmonic Fano-type Coupling in Nanoplasmonic Arrays,” *Nano Lett.*, 13, 3111, June 25, 2013.

N. Lawrence and **L. Dal Negro**, “Radiation Rate Enhancement in Sub-wavelength Plasmonic Ring Nanocavities,” *Nano Lett.*, 13, 3709, June 27, 2013.

G. Walsh and **L. Dal Negro**, “Enhanced Second Harmonic Generation from Au Nanoparticle Arrays by Femtosecond Laser Irradiation,” *Nanoscale*, 5, 7795, July 16, 2013.

N. Caselli, N. Lawrence, J. Trevino, D. S. Wiersma, F. Intonti, and **L. Dal Negro**, “Near-field Distribution and Propagation of Scattering Resonances in Vogel Spiral Arrays of Dielectric Nanopillars,” *New Journal of Physics*, 15, 085023, Aug. 22, 2013.

E. Pecora, G. F. Walsh, C. Forestiere, A. Handin, E. Russo-Averchi, A. Dalmau-Mallorqui, I. Canales-Mundet, A. Fontcuberta, I. Morral, and **L. Dal Negro**, “Enhanced Second Harmonic Generation from InAs nano-wing Structures on Silicon,” *Nanoscale*, 5, 10163, Aug. 27, 2013.

C. Forestiere, **L. Dal Negro**, G. Miano, “Theory of Coupled Plasmon Modes and Fano-like Resonances in Subwavelength Metal Structures,” *Phys. Rev. B*, 88, 155411, Oct. 10, 2013.

J. Trevino, G. Walsh, S.V. Boriskina, and **L. Dal Negro**, “Photonic-Plasmonic Coupled Nanoantennas for Polarization-controlled Multispectral Nanofocusing,” *Optics Lett.*, 38, 4861, Nov. 15, 2013.

H. Sun, J. Woodward, J. Yin, A. Moldawer, E. Pecora, A. Yu. Nikiforov, **L. Dal Negro**, **R. Paiella**, K. Ludwig, Jr., D. J. Smith, and T. Moustakas, “Development of AlGaIn-Based Graded-Index-Separate-Confinement-Heterostructure Deep UV Emitters by Molecular Beam Epitaxy,” *J. Vac. Sci. Technol. B*, vol. 31, art. no. 03C117, March 2013.

O. Basarir and **K. Ekinici**, “Dynamic Interactions between Oscillating Cantile-

vers: Nanomechanical Modulation Using Surface Forces,” *Appl. Phys. Lett.*, 103, 083505, 2013.

O. Ozsun, V. Yakhot, and **K. Ekinici**, “Non-invasive Measurement of the Pressure Distribution in a Deformable Micro-channel,” *J. Fluid Mech.*, 734, R1, 2013.

T. Kouh, U. Kemiktarak, O. Basarir, C. Lissandrello, and **K. Ekinici**, “Measuring Gaussian Noise Using a Lock-in Amplifier,” *Am. J. Phys.*, 2013.

R. Adato, A. Artar, **S. Erramilli**, and H. Altug, “Engineering Absorption Enhancement and Induced Transparency in Coupled Molecular and Plasmonic Resonator Systems,” *Nanoletters*, 13, 2584-2591, 2013.

C. Mädler, **S. Erramilli**, L. House, M. Hong, and P. Mohanty, “Tunable nanowire: Wheatstone bridge for improved sensitivity in molecular recognition,” *Applied Physics Letters*, 102, 043112, 2013.

J. Shattuck, J. Schneck, L. Chieffo, **S. Erramilli**, and **L. Ziegler**, “Dispersed Three-Pulse Infrared Photon Echoes of Nitrous Oxide in Water and Octanol,” *Journal of Physical Chemistry, B*, 117: 15774-15785, 2013.

A. E. Cetin, A. Mertiri, M. Huang, **S. Erramilli**, and H. Altug, “Thermal Tuning of Surface Plasmon Polaritons Using Liquid Crystals,” *Advanced Optical Materials*, 1, 915-920, 2013.

C. Parker, D. Voss, and **T. Fritz**, “Electron and Proton Beam Testing of Pixelated Solid State Detectors,” *Nuclear Instruments and Methods*, Volume 741, 21, Pages 37-41, March 2014.

M. Klida and **T. Fritz**, “Characterising Electron Butterfly Pitch Angle Distributions in the Magnetosphere through Observations and Simulations,” *Ann. Geophys.*, 31, 305-314, 2013.

G. Daaboul, C. Lopez, J. Chinnala, **B. Goldberg**, **J. Connor**, and **M. Unlu**, “Digital Sensing and Sizing of Vesicular

Stomatitis Virus Pseudotypes in Complex Media; A Model for Ebola and Marburg Detection,” *ACS Nano*, 8:6047-55. PMID: 24840765, 2014.

S. Remi, **B. Goldberg**, and **A. Swan**, “Charge Tuning of Nonresonant Magnetoexciton Phonon Interactions in Graphene,” *Physical Review Letters*, Vol. 112, pp. 056803 2014.

B. Bleier, R. Kohman, R. Feldman, S. Ramanlal, and **X. Han**, “Permeabilization of the Blood-Brain Barrier via Mucosal Engrafting: Implications for Drug Delivery to the Brain,” *Plos One*, PMID: PMC3634848, 2013.

X. Zhang, C. LaManna, R. Kohman, T. McIntosh, **X. Han**, and M. Grinstaff, “Lipid-mediated DNA and siRNA transfection efficiency depends on peptide headgroup,” *Soft Matter*, 2013.

B. Bleier, A. Nocera, H. Iqbal, J. Hoang, R. Feldman, and **X. Han**, “P-glycoprotein Functions as an Immunomodulator in Healthy Human Primary Nasal Epithelial Cells,” *Int Forum Allergy Rhinol.*, 2013.

B. Bleier, A. Nocera, H. Iqbal, J. Hoang, R. Feldman, and **X. Han**, “P-glycoprotein promotes epithelial T helper 2-associated cytokine secretion in chronic sinusitis with nasal polyps,” *Int Forum*.

S. Dai, X. Cao, T. Yi, **A. Hubbard**, and Z. Hong, “A 1-V Low-power Programmable Rail-to-Rail Operational Amplifier With Improved Trans-conductance Feedback Technique,” *IEEE Transactions on Very Large Scale Integration*, Vol. 21, Issue 10, pp. 1928-1935, 2013.

D. Freedman, H. Cohen, S. Deligeorgis, C. Karl, and **A. Hubbard**, “An Analog VLSI Implementation of the Inner Hair Cell and Auditory Nerve Using a Dual AGC Model,” *IEEE Trans. Biomedical Circuits and Systems*, May 2014.

S. Joshi, R. Singh-Moon, M. Wang, **I. Bigio**, and A. Mayevsky, “Real-time Hemodynamic Response and Mitochondrial Function Changes with Intracarotid Mannitol Injection,” *Brain Research*, 2013.



S. Joshi, R. Singh-Moon, M. Wang, D. Chaudhuri, M. Holcomb, N. Straubinger, J. Bruce, **I. Bigio**, and R. Straubinger, "Transient Cerebral Hypoperfusion Assisted Intraarterial Cationic Liposome Delivery to Brain Tissue," *J. Neuro-Oncology*, 2013.

C. Chen and **A. Joshi**, "Runtime Management of Laser Power in Silicon-Photonic Multibus NoC Architecture," *Selected Topics in Quantum Electronics, IEEE Journal*, vol.19, no.2, pp.338-350, March-April 2013.

S. Byrnes, A. Fan, J. Trueb, F. Jareczek, M. Mazzochette, A. Sharon, A. Sauer-Budge, and **C. Klapperich**, "A Portable, Pressure Driven, Room Temperature Nucleic Acid Extraction and Storage System for Point of Care Molecular Diagnostics," *Anal. Methods*, 5, 3177-3184, 2013.

S. Huang, J. Do, M. Mahalanabis, A. Fan, L. Zhao, L. Jepeal, S. Singh, and **C. Klapperich**, "Low Cost Extraction and Isothermal Amplification of DNA for Infectious Diarrhea Diagnosis," *PLoS ONE*, 8(3): e60059, 2013.

J. Zhang, M. Mahalanabis, L. Liu, J. Chang, N. Pollock, and **C. Klapperich**, "A Disposable Microfluidic Virus Concentration Device Based on Evaporation and Interfacial Tension," *Diagnostics*, 3, 155-169, 2013.

A. Mertiri, H. Altug, M. Hong, P. Mehta, **J. Mertz**, **L. Ziegler**, and **S. Erramilli**, "Pitchfork Bifurcation and Zharov Splitting in Nonlinear Mid-infrared Photothermal Spectroscopy," *Phys. Rev. Lett.*, 2013.

R. Barankov and **J. Mertz**, "Single-exposure Profilometry Using Partitioned Aperture Wavefront Imaging," *Opt. Lett.*, 38, 3961-3963, 2013.

H. Paudel, C. Stockbridge, **J. Mertz**, and **T. Bifano**, "Focusing Light through Strongly Scattering Media," *Opt. Express*, 21, 17299-308, 2013.

T. Ford and **J. Mertz**, "Video-rate Imaging of Microcirculation with Single-exposure Oblique Back-Illumination Microscopy," *J. Biomed Opt.*, 18, 066007, 2013.

**T. Moustakas**, "The Role of Extended Defects on the Performance of Optoelectronic Devices in Nitride Semiconductors," *Physica Status Solidi A*, 210, No.1, 169-174, 2013.

G. Staszczak, I. Gorczyca, T. Suzki, X. Wang, N. Christensen, A. Svane, E. Dimakis, and **T. Moustakas**, "Photoluminescence and Pressure Effects in Short Period InN/nGaN superlattices," *J. Appl. Phys.*, 113, 123101, March 2013.

L. Zhou, D. Smith, M. McCartney, E. Dimakis, and **T. Moustakas**, "Measurement and Effects of Polarization Fields on One-monolayer-thick InN/GaN Multiple Quantum Wells," *Phys. Rev. B*, 88, 125310, September 2013.

I. Gorczyca, T. Suski, G. Staszczak, N. Christensen, A. Svane, X. Wang, E. Dimakis, and **T. Moustakas**, "InN/GaN Superlattices: Band Structures and Their Pressure Dependence," *Japanese Journal of Applied Physics*, Vol. 52, 08JL06, August 2013.

N. Di Fiori, A. Squires, D. Bar, **T. Moustakas**, and A. Meller, "Optoelectronic Control of DNA Translocation Speed through Solid-state Nanopores," *Nature Nanotechnology*, 2013.

J. DiMaria, E. Dimakis, **T. Moustakas**, and **R. Paiella**, "Plasmonic Off-Axis Unidirectional Beaming of Quantum-Well Luminescence," *Appl. Phys. Lett.*, vol. 103, art. no. 251108, Dec. 2013.

C. Boztug, J. Sánchez Pérez, J. Yin, M. Lagally, and **R. Paiella**, "Grating-Coupled Mid-Infrared Light Emission from Tensilely Strained Germanium Nanomembranes," *Appl. Phys. Lett.*, vol. 103, art. no. 201114, Nov. 2013.

K. Tantiwanichapan, J. DiMaria, S. Melo, and **R. Paiella**, "Graphene Electronics for Terahertz Electron-Beam Radiation," *Nanotechnology*, vol. 24, art. no. 375205, July 2013.

The Boston University Photonics Center has established itself as one of the nation's leading academic programs for photonics scholarship, education, and innovation.

E. Pecora, W. Zhang, A. Nikiforov, J. Yin, **R. Paiella**, **L. Dal Negro**, and **T. Moustakas**, "Sub-250nm Light Emission and Optical Gain in AlGaIn materials," *J. Appl. Phys.* 113, 013106, Jan. 4, 2013.

P. Sookchoo, F. Sudradjat, A. Kiefer, H. Durmaz, **R. Paiella**, and M. Lagally, "Strain-Engineered SiGe Multiple-Quantum-Well

Nanomembranes for Far-Infrared Inter-subband Device Applications," *ACS Nano*, vol. 7, pp. 2326-2334, Feb 2013.

C. Boztug, J. R. Sánchez Pérez, F. Sudradjat, R. Jacobson, D. Paskiewicz, M. Lagally, and **R. Paiella**, "Tensilely Strained Germanium Nanomembranes as Infrared Optical Gain Media," *Small*, vol. 9, pp. 622-630, 2013.

H. Ostendorff, A. Awad, K. Braunschweiger, Z. Liu, Z. Wan, **K. Rothschild**, and M. Lim, "Multiplexed VeraCode Bead-based Serological Immunoassay for Colorectal Cancer," *Journal of Immunological Methods*, 400-401, 58-69, 2013.

M. Lim, Z. Liu, K. Braunschweiger, A. Awad, and **K. Rothschild**, "Correlated MALDI-MS and Fluorescent Imaging of Photocleavable Peptide-Coded Random Bead-Arrays," *Rapid Communications in Mass Spectrometry*, 2014.

S. Nabanja, L. Kolodziejski, G. Petrich, **M. Sander**, J. Morse, K. Shtyrkova, E. Ippen, and F. Kärtner, "Large-Area Broad Band Saturable Bragg Reflectors Using Oxidized AlAs in the Circular and Inverted Mesa Geometries," *Journal of Applied Physics*, 113, 163102, 2013.

J. Yang, C. Maragliano, and **A. Schmidt**, "Thermal Property Microscopy with Frequency Domain Thermorefectance," *Review of Scientific Instruments*, 84(10), 104904 1-9, 2013.

S. Park, **A. Schmidt**, M. Bedewy, and A. Hart, "Measurement of Carbon Nanotube Microstructure Relative Density

by Optical Attenuation and Observation of Size-dependent Variations,” *Physical Chemistry Chemical Physics*, PCCP, 15(27), 11511–9, 2013.

J. Liu, J. Zhu, M. Tian, X. Gu, **A. Schmidt**, and R. Yang, “Simultaneous Measurement of Thermal Conductivity and Heat Capacity of Bulk and Thin Film Materials using Frequency-dependent Transient Thermoreflectance Method,” *The Review of Scientific Instruments*, 84(3), 034902, 2013.

R. Nakamura, T. Karlsson, M. Hamrin, H. Nilsson, O. Marghitu, O. Amm, C. Bunesco, V. Constantinescu, H. Frey, A. Keiling, **J. Semeter**, E. Sorbalo, J. Vogt, C. Forsyth, and M. Kubyskhina, “Low-altitude Electron Acceleration Due to Multiple Flow Bursts in the Magnetotail,” *Geophys. Res. Lett.*, 41, 777–784, 2014.

H. Dahlgren, **J. Semeter**, R. Marshall, and M. Zettergren, “The Optical Manifestation of Field-Aligned Bursts in the Aurora,” *J. Geophys. Res.*, 118, 2013.

H. Akbari, **J. Semeter**, and M. Nicolls, “On the Localization of Auroral Langmuir Turbulence in Thin Layers,” *J. Geophys. Res.*, 118, 2013.

C. Goenka, **J. Semeter**, J. Noto, H. Dahlgren, R. Marshall, J. Baumgardner, J. Riccobono, and M. Migliozzi, “Tunable Optical Instrument for Multispectral Imaging of Aeronautical Features,” *Adv. Space Res.*, 52, 1366–1377, 2013.

A. Keiling, O. Marghitu, J. Vogt, O. Amm, C. Bunesco, V. Constantinescu, H. Frey, M. Hamrin, T. Karlsson, R. Nakamura, H. Nilsson, **J. Semeter**, and E. Sorbalo, “Magnetosphere-ionosphere Coupling of Global Pi2 Pulsations,” *J. Geophys. Res.*, 2013.

N. Uribe-Patarroyo, A. Fraine, D.S. Simon, O. Minaeva, and **A. Sergienko**, “Object Identification Using Correlated Orbital Angular Momentum States,” *Physical Review Letters*, v.110, 043601 2013.

G. Jaeger, D. Simon, and **A. Sergienko**, “Implications of Disentanglement and Locality Induction for Quantum Infor-

mation Processing and Cryptography,” *Quantum Matter*, v. 2, 427–435, 2013.

C. Schuck, W. Pernice, O. Minaeva, M. Li, G. Gol’tsman, **A. Sergienko**, and H. Tang, “Matrix of Integrated Superconducting Single-photon Detectors with High Timing Resolution,” *IEEE Transactions on Applied Superconductivity*, v. 23, No 3, 2201007, 2013.

M. Minozzi, S. Bonora, **A. Sergienko**, G. Vallone, and P. Villorosi, “Optimization of Two-Photon Wavefunction in Parametric Down Conversion by Adaptive Optics Control of the Pump Radiation,” *Optics Letters*, v. 38, No. 4, pp. 489–491, 2013.

L. Mazzarella, F. Ticozzi, **A. Sergienko**, G. Vallone, and P. Villorosi, “Asymmetric Architecture for Heralded Single Photon Sources,” *Physical Review A*, v. 88, 023848, 2013.

H. Chen, M. Golder, F. Wang, R. Jasti, and **A. Swan**, “Raman Spectroscopy of Carbon Nanohoops,” *Carbon*, Vol. 67 2014, pp. 203–213.

A. Kitt, Z. Qi, S. Rémi, H. Park, **A. Swan**, and **B. Goldberg**, “How Graphene Slides: Measurement and Theory of Strain-Dependent Frictional Forces between Graphene and SiO<sub>2</sub>,” *NanoLetters*, Vol. 13, 2013, pp. 2605, 2013.

A. Reddington, M. Monroe, and **M. Unlu**, “Integrated Imaging Instrument for Self-Calibrated Fluorescence Protein Microarrays,” *Review of Scientific Instruments*, Vol. 84, No. 10, October 4 2013.

S. Ahn, D. Freedman, P. Massari, M. Cabodi, and **M. Unlu**, “A Mass-Tagging Approach for Enhanced Sensitivity of Dynamic Cytokine Detection Using a Label-Free Biosensor,” *Langmuir*, Vol. 29, No. 17, pp. 5369–5376, April 2013.

M. Monroe, G. Daaboul, A. Tuysuzoglu, C. Lopez, F. Little, and **M. Unlu**, “Single Nanoparticle Detection for Multiplexed Protein Diagnostics with Attomolar Sensitivity in Serum and Unprocessed Whole Blood,” *Analytical Chemistry*, Vol. 85, No. 7, pp. 3698–3706, March/April 2013.

M. Cretich, M. Monroe, A. Reddington, X. Zhang, G. Daaboul, F. Damin, L. Sola, **M. Unlu**, and M. Chiari, “Interferometric Silicon Biochips for Label and Label-free DNA and Protein Microarrays,” *Proteomics*, Vol. 12, pp. 2963–2977, 2013.

P. Du, C. Chen, H. Lu, and **X. Zhang**, “Investigation of Cellular Contraction Forces in the Frequency Domain Using a PDMS Micropillar-Based Force Transducer,” *Journal of Microelectromechanical Systems*, 22(1): 44–53, 2013.

K. Fan, A. Strikwerda, **X. Zhang**, and R. Averitt, “Three-Dimensional Broadband Tunable Terahertz Metamaterials,” *Physical Review B - Rapid Communications*, 87(16): 161104(4pp), 2013.

P. Du, X. Lin, and **X. Zhang**, “Tunable Electrical and Mechanical Responses of PDMS and Polypyrrole Nanowire Composites,” *Journal of Physics D: Applied Physics*, 46(19): 195303(8pp), 2013.

E. Frohlich, J. Alonso, J. Borenstein, **X. Zhang**, M. Arnaout, and J. Charest, “Topographically-Patterned Porous Membranes in a Microfluidic Device as an in vitro Model of Renal Reabsorptive Barriers,” *Lab on a Chip*, 13(12): 2311–2319, 2013.

K. Fan, H. Hwang, M. Liu, A. Strikwerda, A. Sternbach, J. Zhang, X. Zhao, **X. Zhang**, K. Nelson\*, and R. Averitt\*, “Nonlinear Terahertz Metamaterials via Field-Enhanced Carrier Dynamics in GaAs,” *Physical Review Letters*, 110(21): 217404(5pp), 2013.

G. Keiser, A. Strikwerda, K. Fan, V. Young, **X. Zhang**, and R. Averitt, “Decoupling Crossover in Asymmetric Broadside Coupled Split Ring Resonators at Terahertz Frequencies,” *Physical Review B*, 88(2): 024101(5pp), 2013.

J. Dong, P. Du, and **X. Zhang**, “Characterization of the Young’s Modulus and Residual Stresses for a Sputtered Silicon Oxynitride Film Using Micro-Structures,” *Thin Solid Films*, 545, 414–418, 2013.

G. Keiser, K. Fan, **X. Zhang\***, and R. Averitt, “Towards Dynamic, Tunable,

and Nonlinear Metamaterials via Near Field Interactions: A Review,” *Journal of Infrared, Millimeter, and Terahertz Waves*, 34(11): 709-723, 2013.

X. Wang, C. Wang, S. Anderson, and **X. Zhang**, “Microfabricated Iron Oxide Particles for Tunable, Multispectral Magnetic Resonance Imaging,” *Materials Letters*, 110: 122-126, 2013.

K. Fan, X. Zhao, J. Zhang, G. Keiser, H. Seren, G. Metcalfe, M. Wraback, **X. Zhang**, and R. Averitt\*, “Optically Tunable Terahertz Metamaterials on Highly Flexible Substrates,” *IEEE Transactions on Terahertz Science and Technology*, 3(6): 702-708, 2013.

P. Lemler, W. R. Premasiri, A. DelMonaco, and **L. D. Ziegler**, “NIR Raman spectra of whole human blood: effects of laser-induced and in vitro hemoglobin denaturation,” *Anal. Bioanal. Chem.*, 2013.

## PATENTS

**Theodore Moustakas** (US Patent #8,592,800) “Optical Devices Featuring Non-polar Textured Semiconductor Layers,” Issue Date: November 26, 2013.

**Siddharth Ramachandran** (US Patent #8,478,134) “Compression of Generated Optical Continuum Utilizing Higher Mode-Order Fiber,” Issue Date: July 2, 2013.

**Siddharth Ramachandran** (US Patent #8,507,877) “Non-linear Optical Systems and Techniques,” Issue Date: August 13, 2013.

**Siddharth Ramachandran** (US Patent #8,520,299) “Selectively Pumping a Gain-Dope Region of an Optical Fiber,” Issue Date: August 27, 2013.

**Kenneth Rothschild** (US Patent #8,481,263) “Bead-ligand-nascent Protein Complexes,” Issue Date: July 9, 2013.

**Kenneth Rothschild** (US Patent #8,486,634) “Amplifying Bisulfite-treated Templates,” Issue Date: July 16, 2013.

**Kenneth Rothschild** (US Patent #8,607,658) “Detection of Truncation Mutations by Mass Spectrometry,” Issue Date: August 13, 2013.

**Kenneth Rothschild** (US Patent #8,535,885) “Detection of Disease Related Genes,” Issue Date: September 17, 2013.

## AWARDS

**Dr. Xue Han** received the Presidential Early Career Award for Scientists and Engineers.

**Dr. Jerome Mertz** was named a fellow of the Optical Society of America.

**Dr. Theodore Moustakas** received the Boston University Innovator of the Year Award and was elevated to the grade of fellow of the Institute of Electrical and Electronics Engineers (IEEE).

**Dr. Alice White** was named a fellow of the Optical Society of America.

**Dr. Xin Zhang** received the Boston University Nanoscience & Nanobiotechnology Award.

## PHOTONICS CENTER POSTDOCS

**Professor Enrico Bellotti, ECE**  
Masahiko Matsubara

**Professor Xin Chen, Chemistry**  
Jian Liu

**Professor Luca Dal Negro, ECE, MSE**  
Carlo Forestiere  
Emanuele Pecora

**Professor Dan Ehrlich, BME**  
Man Ching Cheung

**Professor Theodore Fritz, Astronomy**  
Charles Parker

**Professor Lee Goldstein, Psychiatry**  
Noel Casey  
Olga Minaeva  
Juliet Moncaster

**Professor Xue Han, BME**  
Howard Gritton  
Richard Kohman  
Krinsnakanth Kondabolu  
Hua-an Tseng  
Jaimin Zhuo

**Professor Catherine Klapperich, BME, ME**  
Andy Fan  
Shichu Huang  
Jacqueline Linnés  
Sharon Wong

**Professor Jerome Mertz, BME**  
Roman Barakov  
Jean-Cahrlés Baritiaux

**Professor Siddharth Ramachandran, ECE, MSE**  
Michael Grogan

**Professor Bjoern Reinhard, Chemistry**  
Wonmi Ahn  
Jing Wang

**Professor Jason Ritt, BME**  
Benjamin Perrone

**Professor Kenneth Rothschild, Physics**  
Sergey Mamaev

**Professor Alexander Sergienko, ECE**  
David Simon

**Professor Selim Unlu, ECE**  
David Freedman

**Professor Xin Zhang, ME, MSE**  
Stephen Anderson  
Kebin Fan

**Professor Larry Ziegler, Chemistry**  
Ranjith Premasiri

# Educational Programs & Initiatives

## NSF Research Experiences for Teachers in Biophotonics Sensors & Systems

Professor Emeritus Michael Ruane (PI) transferred his status as PI to Professor Thomas Bifano with Cynthia Brossman (co-PI) and Helen Fawcett (co-PI) assisting in the final year of the NSF RET in Biophotonics Sensors & Systems. The funds available allowed for a total of five teachers to have additional research experiences. Two teachers worked as a team with Professor Thomas Bifano, while the others were placed individually in faculty laboratories. All of the teachers were returning from one of the three previous years and were well prepared to present to the photonics community their challenges as teachers in the public schools. Some insight into day-to-day student management was communicated as well as some statistics on how high school students view math and science careers.

The teachers worked in the laboratories for six weeks of the summer. The faculty members who mentored these teachers included Professors Thomas Bifano, David Bishop, Selim Unlu, and Shyamsunder Erramilli. In addition to working in the laboratories, several of the teachers from the first two years participated in cleanroom activities, where they worked on photolithography equipment in the Class 100 cleanroom to spin wafers, expose them with a mask that they created, and develop the final wafers. The teachers then learned about metal deposition and lift-off. The teachers took their wafers home and had a solid understanding of what photolithography processing entailed. The summer ended with a Photonics Center Café poster session where each of the teachers presented their research and applicability to class lessons to a captive audience of researchers, faculty, and graduate students. ■



NSF RET participants capped their six-week summer program with presentations on how they will bring their research experience and learning back to their classrooms.

The following table indicates the teachers who worked in BU Photonics Center laboratories during the summer.

2013 Faculty Projects	2013 RET Teachers	School
Bifano	Maureen Chase	Quabbin Regional High School
	Michelle McMillan	Sanborn Regional Middle School
Bishop	Ashley Lagas	Holliston Middle School
Unlu	Stephanie Giglio	St. John's Preparatory School
Erramilli	Jessica Leach	Marshfield High School

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





# Outreach & Other Activities

## PROGRAMS

### Business Innovation Center

Located on the 6th floor of the Photonics Center building, Boston University's Business Innovation Center (BIC) currently hosts 11 technology companies that are in the early stages of business growth. The mix of companies includes those in life sciences, biotechnology, medical devices, photonics, and clean energy. The top tiers of innovative companies in the Boston area are tenants of BIC, and they are not restricted to BU spinouts. In fact, the non-BU companies are at a recent high of 70% of the total number of tenants. Generally, the companies residing in BIC are staffed with seasoned business executives and subject matter experts who are able to attract financial backing to support their growth.

Five of the 11 tenants are new to BIC over the past year, and only one of the tenants has departed in the past year. Since rebranding from incubator to Business Innovation Center two years ago, there has been an 80% turnover of the tenant companies. This is healthy, as the turnover represented strong company growth and investment in larger facilities and/or displacement of less successful companies by newer innovative technology start-ups. The full list of current tenants is in the table below and includes: BU Ignition Awards winner RayVio, MassChallenge Accelerator award winner NBD Nanotechnologies, and Neurala, which was named as one of the 50 Most

The goal is to accelerate innovation by encouraging collaboration with faculty and providing educational opportunities for graduate and undergraduate students.

Influential Companies in the Global Robotics Industry by *Robotics Business Review*.

BIC also houses a new product spinout from a joint venture (Bioventus) formed by a multi-billion-dollar international corporation and a leading private equity firm. The goal is to accelerate innovation by encouraging collaboration with faculty and providing educational opportunities for graduate and undergrad-

uate students. Most of the internships have gone to undergraduate students and in the past year the incubator companies hired a total of 21 student interns (all paid internships) for at least one semester; 19 of these were BU students. Two offers for full-time

The Business Innovation Center currently has 11 tenants, all highly promising innovators in the early stages of their development.

Company Name	Origin	Technology	Market Sector	Funding
1087 Systems	De Novo Start-up	Cellular Measurement Platform	Health Care	Bootstrap
Aeolus	BU	HVAC Systems	Hi-tech	Bootstrap
Agira	Johns Hopkins University	Photonics	Energy	Bootstrap
Bioventus	License from Pfizer	Bone Growth Protein	Health Care	Corporate and Private Equity
Massachusetts Medical Devices Journal	De Novo Start-up	N/A	Medical Device Journalism	Sales/Advertising
Nano Surfaces	Cornell University	Nano Structured Surfaces	Antifouling Coatings	Angel
NBD Nanotechnologies	MIT	Nano Scale Coatings	Energy	Venture
Neurala	BU	Biological Intelligence	Robotics	Grants
NexGen Arrays	BU	Photonics	Health Care	Grants
Pegasus	De Novo Start-up	Cancer Treatment	Health Care	Corporate
RayVio	BU	UV LEDs	Energy/Cleantech	Venture

employment (at NBD Nanotechnologies) were made after graduation and three other students found full-time employment based on recommendations from their supervisor in the incubator company. These students have become fully engaged in the companies, and at one of the companies (Neurala) a student had made such significant contributions that she was named as a co-author on two patents.

Many of the BIC companies are collaborating with faculty and, in one case, Bioventus has established a histology capability on the Medical Campus that is open to all users at BU and is partially paying for a technician.

For the second year in a row, BIC will be a “Silver” sponsor of the MassChallenge 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. In return, BIC has the opportunity to network with and screen hundreds of potential tenants for the space at the Photonics Center.

#### **Student Satellite Program**

Professor Theodore Fritz continued his efforts with the Air Force student satellite program during 2013–2014. The Air Force University Nanosatellite Project called ANDESITE was submitted as a candidate mission to the NASA CubeSatellite Launch Initiative (CSLI), and NASA has accepted Professor Fritz’s proposal and the project for a launch during the 2015–2017 timeframe. A team of about 20 undergraduate and graduate students worked full-time during the 10-week summer period to complete the design and begin the fabrication of this CubeSatellite mission.

#### **OSA DC Town Hall**

Photonics Center Director Thomas Bifano and Photonics Center Professor Jerome Mertz hosted the Optical Society of Amer-

ica (OSA) Controlled Light Propagation Incubator Meeting in Washington, DC, in March 2014. The meeting served as the 11th in a series of meetings hosted by OSA that was established in 2009. The goal of the meetings was to promote growth and development of emerging fields within the broader optics and photonics research community. Techniques were compared for high-speed imaging in vivo, such as ballistic versus diffusive scattering, as well as what obstacles need to be overcome in order to make widespread use more achievable.

#### **CNN’s Interface between Nanotechnology and Cancer Medicine**

Boston University’s Cross-Disciplinary Training in Nanotechnology for Cancer (XTNC), formed by the Center for Nanoscience & Nanobiotechnology (CNN) as an offshoot of BU’s nanomedicine initiative, is training a community of scientists, engineers, and medical researchers. Photonics Center Professor Bennett Goldberg leads the XTNC effort. XTNC’s primary community outreach activity is with the Boston University Medical Campus CityLab

program. This past year, XTNC trainees developed an evening program for urban high school students, held on December 9 and 11, 2013. Trainees met over the fall semester to develop a nanomedicine curriculum. They gave introductory lectures and led participants through hands-on laboratory

experiments designed to illustrate some of the properties of nanoparticles. Twenty-four high school students in CityLab’s Scholars Program attended over two evenings. Trainees engaged the students in discussions about general principles and applications of nanotechnology, especially nanomedicine, shared their own research experiences, and talked with participants about science and careers in science.

#### **CNN’s Upward Bound Nanocamp**

Center for Nanoscience & Nanobiotechnology (CNN) faculty and graduate students continue to be involved in lectures and laboratory activities for the BU Upward Bound Math & Science pro-

gram. Former CNN director and current CNN faculty member Professor Bennett Goldberg led the effort. This federally funded college preparatory program serves 75 potential first-generation college and low-income public high school students recruited from target schools in Boston. Students enter the program in 9th or 10th grade and remain with the program until graduation from high school.

Services include: an academically intensive six-week summer residential program, after-school tutoring, and additional academic

courses during the school year. Since 2008, CNN has hosted a nanotechnology track called “Nanocamp” for the Upward Bound summer program. In July 2013, CNN faculty member Sean Andersson introduced Upward Bound students to fluorescence microscopy and had them build atomic force microscopy simulators from Legos. Professor Michael Smith helped students explore cell structure and movement as seen through the tension and compression of cellular components. Professor Ramesh Jasti worked with the Upward Bound students to engage in experiments aimed at illuminating the interdisciplinary nature of nanoscience.

#### **Technology Innovation Scholars Program**

The Technology Innovation Scholars Program (TISP) group has developed an outreach module based on Professor Selim Unlu’s research in conjunction with his graduate student, Dr. Alex Reddington, during academic year 2013–2014. Dr. Reddington was instrumental in providing the design for the IRIS instruments. CNN, Photonics, and Professor Unlu’s group sponsored the first five units and the Kern Family Foundation paid for an additional seven units. The group purchased materials to create the IRIS instruments and designed and refined activity so middle and high school students could learn how LEDs can resolve nanoscale viruses and bacteria

The program serves 75 potential first-generation college and low-income public high school students recruited from target schools in Boston.

For the second year in a row, BIC will be a “Silver” sponsor of the MassChallenge Accelerator, a global competition.

for point-of-care detection of disease in low-resource areas and allergens in the developed world. The 50 undergraduate engineers in the TISP piloted and refined the lessons at BU; they included 25 women and 12 underrepresented minorities.

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 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 Cafés and Forums

The Photonics Center hosts two monthly events: The Photonics Café and the Photonics Forum. The Cafés bring together the faculty, students, staff, and incubator company employees in an informal setting for conversation and collaboration. The Cafés are hosted on the second Friday of



As the community expands, the role of community events and outreach becomes even more important.

Professor Siddharth Ramachandran introduces Professor Demetrios Christodoulides at a Photonics Seminar on November 21, 2013.

each month from September through April in the West End Lounge.

The Photonics Forum, held on the fourth Wednesday of each month throughout the fall of 2013 and the spring of 2014, gave the community opportunities to participate in technical

discussions in an open forum over lunch. Speakers are selected to discuss their current research endeavors and the real-world applications of their research.



Photonics Forum topics over the past year gave participants an opportunity to discuss research developments and essential practical information.

Date	Speaker	Presentation
September 24, 2013	Block Engineering, Photonics Innovation Center Company	State-of-the-Art Mid-IR QCL Technology & Common Applications
November 19, 2013	Mr. Dennis Hart, Office of the General Counsel, Boston University	Confidentiality and Noncompetition Agreements
January 29, 2014	Mr. John Kurkomelis, Boston University Radiation Specialist	Annual Laser Safety Training
February 26, 2014	Mr. William Kallinich, Environmental Health & Safety, Boston University	Annual Lab Safety Training
March 26, 2014	Professor Josh Semeter, Boston University	The Ionosphere as Earth System Sensor
April 30, 2014	Professor Scott Bunch, Boston University	Graphene Mechanical Wonders

## 17th Annual Future of Light Symposium

This year, the 17th Annual Future of Light Symposium focused on innovations at the intersections of micro/nanofabrication technology, biology, and biomedicine. There were 180 attendees from Boston University, outside academic institutions, and industry.

The agenda for this year's symposium featured presentations by Photonics faculty members and researchers from leading photonics research institutions. Our speakers included:

Dr. Joanna Aizenberg, Harvard University  
 Dr. Stephan Anderson, Boston University Medical Center  
 Dr. Joseph Charest, The Charles Stark Draper Laboratory  
 Dr. Christopher Chen, Boston University  
 Dr. Patrick Doyle, MIT

Dr. Chih-Ming Ho, UCLA  
 Mr. Jason Kroh, Cardio MEMS  
 Mr. Milan Raj, MC10

The symposium included a lunch speaker, Dr. Donald Ingber, from Harvard University. At the conclusion of this year's conference, a reception was held where participants and speakers discussed their research in an informal setting. ■



**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 2013–2014.

Date	Speaker	Title
September 26, 2013	Dr. David Brady, Duke University	Coding for Compressive Imaging and Tomography
October 31, 2013	Dr. Wolfgang Schade, Clausthal University of Technology	Femtosecond Laser Aided Materials Processing for Novel Photonic Sensors
November 7, 2013	Dr. Nader Engheta, University of Pennsylvania	Metaphotonics
November 13, 2013	Dr. Marcos Dantus, Michigan State University	Developing the Concepts of Ultrashort Laser Pulses as Photonics Reagents and Probes
November 21, 2013	Dr. Demetrios Christodoulides, University of Central Florida	Exploring the World Between Classical and Quantum Optics
January 29, 2014	Dr. Sajeew John, University of Toronto	Light Trapping and Solar Energy Harvesting in Thin Film Photonic Crystals
April 11, 2014	Dr. Robert Boyd, University of Rochester	Quantum Nonlinear Optics: Nonlinear Optics Meets the Quantum World
May 15, 2014	Dr. Ji-Xin Cheng, Purdue University	Spectroscopic Imaging for Biology and Medicine: Pushing the Limits of Speed, Depth, and Resolution



# Facilities & Equipment

## NEW EQUIPMENT

The Equipment Committee, led this year by Professor Jonathan Klamkin, represents the Photonics Center members in the identification and ranking of new equipment purchases. New equipment purchased this year included: a Renishaw Raman microscope with a heating/cooling stage integrated along with three laser sources, a high temperature furnace, and the Bright Field/Dark Field detector for the FEI Osiris TEM.

The committee uses the following criterion in making the decision to support a 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 online.

The Renishaw Raman Microscope will be housed in the Materials Science & Engineering Core facilities in its own bay to allow Photonics and Material Science researchers to use the system in a controlled environment suitable for laser use. This tool will help provide a shared location for collaboration and further exploration of materials within the Photonics Center. A heating/cooling stage and three different lasers were added to the system to create a state-of-the-art system that will cover a wide spectrum of analysis.

A high temperature furnace was acquired to replace the existing furnace in OPF. Additional gases were added to the system along with capabilities for annealing at lower temperatures in a quartz tube, and switching to an alumina tube for high temperature annealing.

The final purchase was a Bright Field/Dark Field (BF/DF) detector for the TEM. The FEI Osiris TEM was installed in March 2014. The BF/DF detector allows overlays of images, EDS, and EELS all on one image.

## BUILDING PROJECTS

### PHO736—Space Technology Laboratory

Construction of the Space Technology Laboratory was completed in FY2014. Professors Joshua Semeter and Raymond Nagem have oversight of this laboratory. The Space Technology Laboratory is set up for testing devices for space flight as part of an undergraduate program in the Space Physics Department. This laboratory is also used to build instrumentation for space-based applications.

### PHO735—Integrated Photonics Laboratory

Construction of the Integrated Photonics Laboratory was completed in FY2014. Professor Jonathan Klamkin's Integrated Photonics Group conducts research in integrated photonic technologies for optical communications, microwave photonics, and sensing. Other research areas explored in the laboratory include silicon photonics, lasers for silicon photonics, integrated nanophotonics and plasmonics, and integrated optical signal processing based on nonlinear optics.

### PHO601—Dennis Laboratory

A new laboratory for Professor Allison Dennis, a member of the Materials Science Division and Biomedical Engineering

Department, was completed in FY2014. The laboratory includes several chemical fume hoods dedicated to processing. Research areas of focus in the Dennis Laboratory include: Nanobiotechnology, fluorescent biosensing, fluorescence resonance energy transfer (FRET), quantum dot chemistry, and single molecule sensing/imaging.

### PHO627—Engineering Materials for Energy & the Environment Laboratory

A new laboratory for Professor Jillian Goldfarb, a member of the Materials Science Division and Mechanical Engineering Department, was completed in FY2014. This laboratory, named the Engineering Materials for Energy & the Environment Laboratory (EME2 Lab), tackles issues surrounding the past, present, and future generation of energy, and its impact on the environment.

### PHO628—Professor Alice White and PHO629—Professor Scott Bunch

Professors Alice White and Scott Bunch have laboratories located on the sixth floor of the Photonics Center. Both of these laboratories are currently under construction and will be completed during the fall of 2014. More information about these labs will be provided in next year's annual report.

### PHO B11C-2—FIB/TEM Facility

Construction in the basement of the Photonics Center began in the summer of 2013 for housing the FEI OSIRIS TEM. Construction was completed during the summer and the installation of the TEM continued from late fall through mid-winter with FEI working to ensure functionality of the instrument for shared laboratory usage.

## SHARED LABORATORY FACILITIES

The Optoelectronic Processing Facility (OPF) includes a Class 100 photolithography cleanroom and a Class 1000 clean-

room with processing and test equipment for die and wafer level processing. The Integrated Optics Laboratory (IOL) includes a flip chip bonding system in the Class 100 cleanroom and a standard laboratory space next door for spectroscopy measurements. The Precision Measurement Laboratory (PML) 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, houses a FEI Focused Ion Beam and Transmission Electron Microscope.

### **Optoelectronic Processing Facility (OPF)**

OPF is a multi-user 2,500 sq. ft. facility located on the 8th floor of the Photonics Center. It contains equipment for semiconductor and optoelectronic water fabrication. The facility includes both a Class 100 and Class 1000 cleanroom and equipment facilitating photolithography, wet chemical processing, thin film depositions, plasma etching and cleaning metallization, 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 6-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 3-inch masks or smaller) and the MA6 (up to 6-inch-square masks). A high-powered optical Nikon microscope provides higher resolution imaging for surface inspection. The Nanonex NBX200, purchased by last year's Capital Equipment Committee, has supported many researchers over the last year. It allows thermal and UV replication

processes for nanoscale structures and can handle up to 3-inch wafers.

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. This contact profilometer requires students to either create measurement fiducials on their structure or work with large features into which the stylus can drop down, reach base surface, and then run back up to the top of the structure. The high-powered optical Nikon microscope allows users to capture still or video images from the sample or wafer.

Dry etching processes available in the OPF cleanroom include plasma etching, reactive ion etching, and a deep reactive ion etch. In addition to dry etching, both acid and separate solvent hoods are available to complete wet chemical etching or cleaning and lift-off. 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 4-inch and 6-inch full wafers.

A majority 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. Last year's Capital Equipment Committee purchased new sputter targets for the Denton Sputtering System, a well-used piece of equipment in the cleanroom. The increased research in coatings validated the support for a high temperature-annealing furnace in the cleanroom. With the support of the Swan Laboratory, rather than duplicate a new furnace setup, the Capital Equipment Committee replaced the Swan Laboratory's furnace with one that would cover both low- and high-temperature annealing.

Wire bonding, wedge bonding, or testing can also be done inside the cleanroom in OPF. The Current Voltage/Capacitance Voltage characterization test setup is used to evaluate devices post wire bonding and pre-integration into test setups on the lab bench. Dicing and scribing capabilities are available outside of the cleanroom facilities.

### **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 (LEDs) 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 to 3300 nm. In addition to measuring reflectance and transmission at a particular wavelength, it can also measure absorption. The Bruker FTIR was upgraded last year as part of the Capital Equipment Committee's purchase. The upgraded system continues to be a heavily used device for spectroscopy applications.

### **Precision Measurement Laboratory (PML)**

The PML comprises 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) monochromator, and an Energy Dispersive Spectrometer (EDS) are available for use. The EDS allows validation of elemental composition and surface contaminants in selected locations over the surface of the sample. The Cathodoluminescence 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 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 Zeiss Supra 55VP FESEM, in addition to imaging using secondary electron detectors, 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 EDS (Energy Dispersive Spectrometer). It is also equipped with an EBSD (Electron Backscatter Diffraction) 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 e-beam blankers to allow for e-beam writing of nanoscale structures.

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

The FIB/TEM Facility comprises two separate rooms with capabilities to measure material composition, image surface morphology, and micro/nano machined

materials. This laboratory houses a FEI Quanta 3D FEG FIB (Field Emission Gun Focused Ion Beam) system in one room and a FEI Tecnai Osiris 200kV S/TEM in a second room.

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 Omni-probe 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 fall semester of 2013, the FEI Tecnai Osiris TEM was installed. The system specifications state a TEM point resolution of 0.25 nm, line 0.102 nm, extended to 0.16 nm with True-Image™ software, and STEM HAADF 0.18 nm. The system includes: Super-X EDX detection system, SDD technology, windowless, shutter-protected, X-FEG electron source, EFTEM with EELS, and a Gatan CCD. The first self-users were trained in the late winter/early spring. Capabilities to align images from the EELS, EDS, and imaging portions of the TEM were assisted by this year's Capital Equipment Committee's purchase of the Bright Field/Dark Field detector on the TEM. ■









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