Boston University Photonics Center

Annual Report | 2015

BOSTON UNIVERSITY

Letter from the Director

THIS ANNUAL REPORT summarizes activities of the Boston University Photonics Center in the 2014–2015 academic year. In it, you will find quantitative and descriptive information regarding our photonics programs in education, interdisciplinary research, business innovation, and technology development.

Located at the heart of Boston University's large urban campus, the Photonics Center is an interdisciplinary hub for education, research, scholarship, innovation, and technology development associated with practical uses of light. Our iconic building houses world-class research facilities and shared laboratories dedicated to photonics research, and sustains the work of 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 $18.6M in new research grants/contracts. Faculty and staff also expanded their efforts in education and training, and were awarded two new 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 **Advanced Materials by Design for the 21st Century** at our annual symposium. We continued to support the National Photonics Initiative, and are a part of a New York–based consortium that won the competition for a new photonics-themed node in the National Network of Manufacturing Institutes.

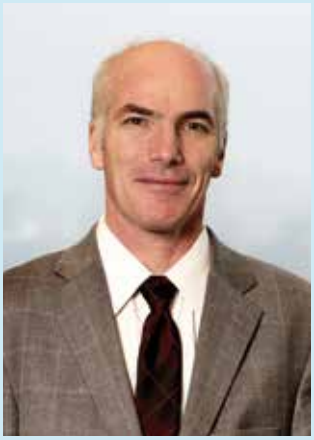
Highlights of our research achievements for the year include an ambitious new DoD-sponsored grant for **Multi-Scale Multi-Disciplinary Modeling of Electronic Materials** led by Professor Enrico Bellotti, continued support of our NIH-sponsored **Center for Innovation in Point of Care Technologies for the Future of Cancer Care** led by Professor Catherine Klapperich, a new award for **Personalized Chemotherapy Through Rapid Monitoring with Wearable Optics** led by Assistant Professor Darren Roblyer, and a new award from DARPA to conduct research on **Calligraphy to Build Tunable Optical Metamaterials** led by Professor Dave Bishop. We were also honored to receive an award from the Massachusetts Life Sciences Center to develop a biophotonics laboratory in our Business Innovation Center.

These programs in research, education, and outreach are indicative of the breadth of the Photonics Center's research interests: from leading multi-institutional research teams in modeling of optoelectronic materials to research projects aimed at development of practical cancer diagnostics, from pioneering new atomic-scale optical fabrication techniques to hosting summer internship programs that target expanded STEM pipelines for students and teachers from diverse communities.

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

3 | Mission Statement

4 | Highlights of FY2015
Photonics Center at a Glance

5 | Photonics Center Strategic Plan

6 | Photonics in the World

12 | Faculty & Staff

16 | Leadership & Administrative Staff

17 | Research Projects &
Technology Development

27 | Publications, Patents & Awards

32 | Educational Programs & Initiatives

34 | Outreach & Other Activities

38 | Facilities & Equipment

Boston University
Photonics Center
Annual Report
2015

Developing rapid viral load test for HIV

6

Innovative research and technology development

17

National Science Foundation research experiences for undergrads and teachers

32

Cover: photo by Christopher McIntosh.
Previous page: photo by Mike Spencer.
Inside back cover and back cover: photo by Christopher McIntosh.

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, imaging, nanophotonics, nonlinear and quantum photonics, and photonic materials and devices. Faculty have particular strengths in hybrid areas that combine specialties such as biophotonics, imaging, and nanophotonics in order to help understand the connections between brain physiology and human behavior. It is noteworthy that at the request of NSF, Professor Bifano chaired a workshop on Non-invasive Imaging of Brain Function in Arlington, VA, during the summer of 2014. Dr. Bifano led a distinguished group of invited government, university, and industry researchers—including White House Science and Technology Policy advisors—through emerging opportunities and imaging modality recommendations.

Academic and Entrepreneurial Programs and Initiatives for Students
While the Photonics Center does not offer academic degrees, our 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 opportunities to engage and network with industry, particularly with members of the Industry/University Cooperative Research Center; and they participate in the annual Photonics Symposium. Our ability to reach out to those not normally exposed to STEM opportunities was recently enhanced by the NSF Research Experiences for Undergraduates in Integrated Nanomanufacturing award. The NSF Research Experiences for Undergraduates and Research Experiences for Teachers sites in Integrated Nanomanufacturing offer an opportunity for undergraduates from around the country with limited or no STEM research, and middle and high school teachers from public schools with high percentages of low-income families, to participate in summer research at BU. These sites provide BU graduate and postdoctoral researchers diverse training and mentoring opportunities not often found as part of a graduate education experience.

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 fourth 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 is 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. BIC is 100% occupied and hit an all-time high of 15 tenant companies during the year. These companies continue to be valued participants in the Photonics Center community. 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 FY2015

External Grant Funding

External grant funding for FY2015 totaled over $18.6M, showing funding from a variety of sources. Highlights of our research achievements for the year include continued support for our Center for Innovation in Point of Care Technologies for the Future of Cancer Care and our Center for Biophotonic Sensors & Systems, and exciting grants from the National Science Foundation to support Research Experiences for Teachers (RET) and Research Experiences for Undergraduates (REU) in Integrated Nanomanufacturing.

Business Innovation Center Developments

This has been an active year for the Business Innovation Center (BIC). The center hit a peak of 15 companies during the year, with 4 companies departing during the year and 6 joining the center. The companies enhanced the academic environment by providing internship opportunities to students and increasing sponsored research opportunities. BIC tenants hired a total of 31 interns in FY2015, comprised of mostly BU undergraduate students. Another notable development for the Innovation Center was a $363,750 grant from the Massachusetts Life Sciences Center (MLSC). This grant will allow for the development of a biophotonics laboratory that will include a small biosafety level 2 (BSL-2) facility within the Innovation Center.

The 18th Annual Photonics Center Symposium: Advanced Materials by Design for the 21st Century

This year, the symposium focused on Advanced Materials by Design for the 21st Century. Professor Enrico Bellotti chaired the conference, which drew nearly 170 attendees. Faculty from Boston University, the University of Utah, and the University of Colorado spoke, as well as representatives from Army Research Laboratory, Naval Research Laboratory, and Sandia National Laboratory. The program featured a day full of talks, including one at lunch, and a reception where participants and speakers discussed their research.

Institute Activities

The center has been conducting business as an institute leading on a number of activities such as managing the BIC, operating and equipping shared laboratories, and administering/supporting block grants and supporting affiliated units. ■

PHOTONICS CENTER AT A GLANCE

46
Faculty Members

10
Staff Members

90
Funded R&D Projects

$18.6M
Funding for R&D
(New funds for current year)

37
Photonics Courses

120
Archival Publications

4
Shared Laboratory Facilities

Photonics Center Strategic Plan

CENTRAL TO THE PHOTONICS CENTER STRATEGIC PLAN is an operational model where the center operates as a centralized resource—promoting, supporting, and sustaining allied research centers and programs across Boston University. Essentially, the center has been conducting business as an institute, leading on a number of activities such as the Business Innovation Center, 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 and co-manages shared labs such as the Focused Ion Beam (FIB) Transmission Electron Microscope (TEM) Facility. In addition to these facilities, the center also 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 four years of the I/UCRC on Biophotonic Sensors & Systems (CBSS) and the program formulation for year five (concurrent with FY2016). 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 in the biophotonic technology sector. Serving as the lead university of this I/UCRC, the Photonics Center has 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 for the I/UCRC grant that has multiplied the initial NSF funding nearly tenfold. The center expects to submit a Phase II I/UCRC proposal in FY2016.

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 back-side 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 DoD grant on Multi-Scale Multi-Disciplinary Modeling of Electronic Materials (MSME). MSME is a major four-year grant involving close collaborations with the ARL's research scientist at the Sensors and Electronic Devices Directorate (SEDD) and interactions with ARL's Enterprise for Multiscale Research of Materials (EMRM), organizations that worked closely with the Photonics Center during the 10-year collaborative research agreement with ARL.

Our staff's same organizational and post-award project management expertise is also employed in leading and supporting major new grants. In FY2015, the Photonics Center led or significantly contributed to multiple proposals. Those still under review include: two separate NSF Partnerships for Innovations: Accelerating Innovation Research proposals (one on a high-resolution IR imager and the second on a metamaterial-based THz focal plane array for imaging surgical resection margins), a Paul Allen Foundation grant, a Department of Energy Computational Material Science program proposal, and several I/UCRC supplements and other proposals that support the Photonics Center's strategic vision. The staff also assisted CNN Director Mark Grinstaff and the Chemistry Department in an NIH U54 Center proposal entitled Centers of Cancer Nanotechnology Excellence.

The Photonics Center staff also leads in supporting and managing major new training grants, including the NSF Research Experiences for Undergraduates and Research Experiences for Teachers sites in Integrated Nanomanufacturing, and is leading on new proposals such as the NSF Research Traineeship (NRT) program on Neurophotonics (not yet reviewed).

At the Business Innovation Center on the 6th floor of the 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. ■

Photonics in the World

BUILDING THE TEST KITCHEN FOR MEDICAL DIAGNOSTICS

ENG PROF INVENTING TECHNOLOGY THAT COULD CHANGE THE FUTURE OF PRIMARY CARE

By Barbara Moran

CATHERINE KLAPPERICH MOVES FAST, talks fast, and has at least 15 different ideas rolling through her head at the same time. How, for instance, can she keep her postdocs on track, guide 134 undergrads through their senior project, and meanwhile invent new technology that may change medicine as we know it? She arrived a few minutes late for an interview, preoccupied with a more immediate concern: she had accidentally spilled water on her iPhone. She ran down to her lab to stick it into the vacuum oven, hoping that would dry it out. Then she ran back to her office and sat down to talk.

Klapperich holds three associate professorships at BU, in the College of Engineering biomedical engineering and mechanical engineering departments and in the Division of Materials Science & Engineering. She also directs the Center for Future Technologies in Cancer Care. Her lab creates point-of-care diagnostics—tools, like a pregnancy test stick, that doctors and consumers can use to immediately test such conditions as high cholesterol or diagnose illnesses like strep throat. One critical need in the developing world is a rapid test for HIV viral load—the amount of HIV in a patient's blood. The number helps doctors monitor the disease, decide when to start treatment, and determine if HIV medications are working.

If you think about cholesterol tests, and HIV yes/no, respiratory infections, strep, these things can be done by the patient.

Biomedical engineer Catherine Klapperich is working on a rapid viral load test for HIV. Photo by Kalman Zabarsky

BU Today recently spoke to Klapperich about her work.

***BU Today*: A lot of your work focuses on public health issues. Where does that interest come from?**

Klapperich: When I got my PhD at Berkeley, I was studying artificial hips and knees. They have a metal part and a plastic part, and we were engineering the plastic part. I became interested in how cells interact with biomaterial surfaces. And that led into my postdoc, which focused on how cells interact with biomaterials at the level of gene expression.

At that time, gene chips were just becoming a routine tool in the laboratory. And I was completely floored by all the steps to use them: breaking the cells open, getting the DNA or RNA out, amplifying it, putting it on a chip, and then turning on the reader to figure out the expression levels. It was a huge number of steps. As an engineer I thought, why? So I became really interested in doing this stuff in a turn-crank way, where I wouldn't have to do all the little steps.

A machine would do it instead?

The machine would do it. The gene chip is a wondrous thing. And yet it took two and a half days to make the material to go onto that chip. So I became very focused on the sample preparation process. Then it became clear to me that this is why point-of-care diagnostics do not exist in the numbers that they should. Because yeah, we have this chip and it can tell us all this information, but all this prep requires someone with a lot of laboratory skill.

So you want to take the diagnostic chip, have some patient spit on it, and then have the answer show up without two and a half days of sample prep?

Right. And so for DNA and RNA it's hard, because most of it is inside of our cells or inside the bugs that infect us. So you have to break cells apart and amplify the DNA or RNA—make many, many copies. Then you tag them with something like a fluorescent protein that allows you to see them. So we need to do three things: we need to extract, we need to amplify, we need to read. Let's do those three things as simply as we can, in as few steps as we can, as reliably as we can. We want to be the test kitchen for this work.

This field has grown a lot, even in the last 10 years.

Yeah—now you can walk into Walgreens and there's a little blue sign hanging over the aisle, where it says things like Foot Powder and Toothpaste, and it says Diagnostics. And I remember the first time I saw that a few years ago. I thought, what? That's crazy! This is now a thing in the aisle.

It's a noun.

Exactly. There are the glucose strips, there's a cholesterol test. You can buy a drug test—

A drug test for what?

For your kid. This is the marijuana one.

Really? This box you're showing me is a marijuana test kit?

Yeah. This is great. You can buy the 4-drug test, the 7-drug test, or the 12-drug test. You can test your kid for depressants, barbiturates, methadone, benzodiazepines, opiates, ecstasy, amphetamines, methamphetamines, cocaine, marijuana, and Oxy. It's pretty amazing. And it's just pee. I think it really empowers people to have information about their own health. If you think about cholesterol tests, and HIV yes/no, respiratory infections, strep, these things can be done by the patient. That can save an office visit, which saves money; it saves the potential of infecting other people; it saves the time of the clinician. I think it will change the primary care model a lot.

What's the first thing out of your lab that might make it into Walgreens?

It's an HIV viral load test that we're working on with a company in San Francisco. A colleague told me last week, from his clinic in South Africa, "We need a viral load test. If people come to see me and I tell them, 'I'm going to take your blood, come back to get the results,' 50 percent of them just don't come back. Something that would help tomorrow is if I could give that person their results right there. And if their viral load is suppressed, then I don't have to expend any resources seeing that person until the following year."

They're testing that right now in South Africa. That could be deployed in a primary care clinician's office, and that's the first thing that will come from our laboratory.

That will be cool.

Yeah, it will be very cool.

Barbara Moran (COM'96) is a science writer in Brookline, MA. She can be reached through her website WrittenByBarbaraMoran.com.

***BU Today* article**

www.bu.edu/today/2014/building-the-test-kitchen-for-medical-diagnostics ■

USING LIGHT TO DIAGNOSE PARKINSON'S

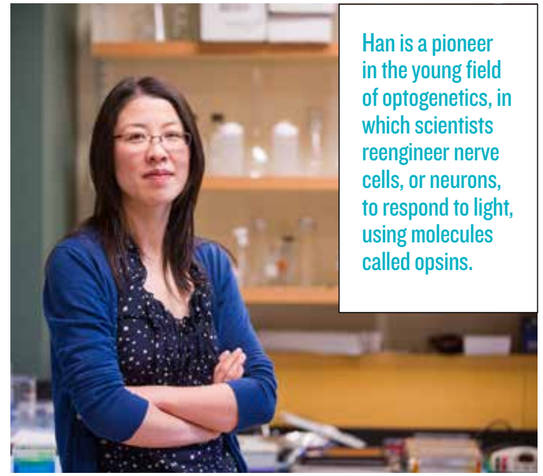
BIOMEDICAL ENGINEER XUE HAN TALKS ABOUT HER WORK IN THE NEW FIELD OF OPTOGENETICS

By Barbara Moran

XUE HAN INVESTIGATES PARKINSON'S DISEASE with an unusual tool: light. Han is a pioneer in the young field of optogenetics, in which scientists reengineer nerve cells, or neurons, to respond to light, using molecules called opsins. Like ice cream, opsins come in many flavors—there's rhodopsin in the human eye and halorhodopsin in bacteria, for instance—but they all share one key characteristic: they change shape when exposed to light.

By finding ways to implant opsins into neurons, Han, a College of Engineering assistant professor of biomedical engineering, has given researchers a simple tool to turn neurons on and off, and thereby study their function. The technique is now widely used to study brain activity, and it is leading to a better understanding of diseases and treatments.

In April 2014, Han traveled to Washington, DC, where President Barack Obama awarded her a Presidential Early Career Award for Scientists and Engineers, the US government's highest honor for science and engineering professionals in the early stages of their independent research careers.



Han is a pioneer in the young field of optogenetics, in which scientists reengineer nerve cells, or neurons, to respond to light, using molecules called opsins.

Boston University bioengineer Xue Han uses a technique called optogenetics—using pulses of light to control brain cells—to investigate psychiatric and neurological disorders. Photo by Cydney Scott

BU Today spoke recently with Han.

***BU Today*: Who came up with the idea of using light to turn neurons on and off?**

Han: Using light to control cells is not so new. In our retina there are all these rhodopsins that naturally are sensitive to light, but we can't easily engineer the whole system into neurons. So the really novel part was sensitizing neurons to light so they're easy to use.

So how did I get involved in this whole thing? I started my postdoc at Stanford in 2005, and that's the same time that Ed Boyden, now an MIT associate professor, along with Karl Deisseroth, used this molecule called channelrhodopsin. They put it in neurons, and they were able to drive neural activities with the light. And the beauty of channelrhodopsin is that it's a very small protein and it's very easy to use.

Then Ed and I were thinking, since there's a technology to excite neurons, can we also silence them? That led to the discovery of halorhodopsin, which allowed us just to do that. But it doesn't do it really well. Who knows why? These are from bacteria, and you're putting them in mammalian cells. That's the complexity of biology.

So we said, let's find a better one. We screened a whole bunch of proteins similar to halorhodopsins, and we found some other

things that were similar, like proton pumps. We did not think they would work, but we thought, you know what? Let's throw a couple in and see what happens. And we did that, and found that these proton pumps are way more effective in silencing neurons. And more importantly, from what we have tested, it's safe for the neurons. It's a powerful engineering tool—that we can excite or silence neurons now.

Are the tools getting closer to being used in patients?

Right now, my group is interested in how, in a disease like Parkinson's, deep brain stimulation works. There are all these hypotheses about deep brain stimulation and its therapeutic effects. So the idea is that if you use light, then we can understand the mechanism and simultaneously see how the neurons respond and how they are contributing to Parkinson's disease. These neurons in the Parkinsonian brain tend to oscillate or synchronize at a frequency of 20 hertz or so.

All the neurons in the brain, or just the Parkinsonian ones?

The Parkinsonian ones in a particular part of the brain.

All the neurons affected with Parkinson's in a certain part of the brain are talking to each other at 20 hertz?

Not all of them. But somehow, more are talking to each other than normal.

That's weird.

But that's what people find. If you think about Parkinson's in particular, it's a dopamine neuron loss. We are trying to figure out how this dopamine loss leads to the generation of these pathological oscillations in the brain. And then what's the relationship of these oscillations to the symptoms?

Do other neurological diseases have different pathological oscillations?

That's a great question. Can we establish some sort of oscillations as biomarkers of specific mental disorders? I think this is definitely a very interesting area. There's certain evidence that a frequency around 40 hertz is associated with schizophrenia, but a coherent understanding would really help.

Why does Parkinson's interest you?

I think for Parkinson's, we are at a stage that things are converging. There's a very good animal model for Parkinson's, and the symptoms can be easily quantified, more easily than major depression or other types of mental disorders, like schizophrenia.

You're married to Ed Boyden, who is also a leader in optogenetics. Do you two collaborate?

Well, we collaborate still. It's hard not to collaborate, right? But you know, we have two small kids, so as soon as we start a conversation someone spills milk, and that conversation goes nowhere.

Do you tell your kids about your work? Are they interested?

Certainly there are scientific terms we use that our babysitter would not really understand. This morning my son was asking me how the Earth was generated. I told him the Earth was here when he was born, and I told him I was here, and so I started to explain it to him a little bit. It's hard not to.

Where do you think diagnosing and treating neurological diseases will be 20 or 30 years from now? How will your work fit it?

A lot of parts can be replaced, but when it comes to the brain, we are not there yet. In Parkinson's and Alzheimer's, we know the neurons are dying. Is there some replacement we can do? If we have a biomarker, we can probably start to develop more human therapies. So that's what I'm hoping: we'll treat these disorders before we're old enough to get them ourselves. So we need to hurry up.

Barbara Moran (COM'96) is a science writer in Brookline, MA. She can be reached through her website WrittenByBarbaraMoran.com.

***BU Today* article**

www.bu.edu/today/2014/using-light-to-diagnose-parkinsons ■

CONTAINING EBOLA WITH NANOTECHNOLOGY

BU TEAM'S DEVICE DETECTS VIRUS QUICKLY AND ON SITE

By Mark Dwortzan

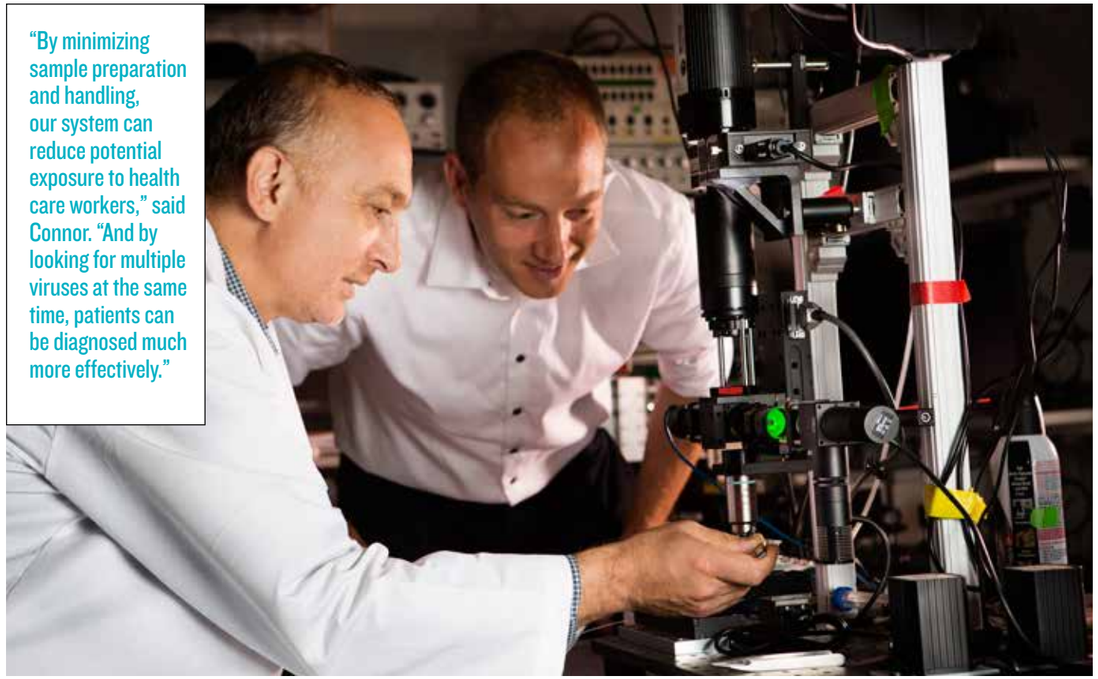
BY LATE JANUARY, 1.4 million people in Liberia and Sierra Leone could be infected with the Ebola virus. That's the worst-case scenario of the Ebola epidemic in West Africa recently offered by scientists at the US Centers for Disease Control and Prevention (CDC). The CDC warns that those countries could now have 21,000 cases of the virus, which kills 70 percent of people infected.

One of the big problems hindering containment of Ebola is the cost and difficulty of diagnosing the disease when a patient is first seen. Conventional fluorescent label-based virus detection methods require expensive lab equipment, significant sample preparation, transport and processing times, and extensive training to use. One potential solution may come from researchers at the College of Engineering and the School of Medicine, who have spent the past five years advancing a rapid, label-free, chip-scale photonic device that can provide affordable, simple, and accurate on-site detection. The device could be used to diagnose Ebola and other hemorrhagic fever diseases in resource-limited countries.

The first demonstration of the concept, described in the American Chemical Society journal *Nano Letters* in 2010 and developed by Professor Selim Ünlü's (ECE, BME, MSE) research group in collaboration with Professor Bennett Goldberg (Physics, BME, ECE), showed the ability to pinpoint and size single H1N1 virus particles. Now, after four years of refining the instrumentation in collaboration with Associate Professor John Connor (MED) and other hemorrhagic fever disease researchers at the University of Texas Medical Branch, the team has demonstrated the simultaneous detection of multiple viruses in blood serum samples—including viruses genetically modified to mimic the behavior of Ebola and the Marburg virus.

Mentioned in *Forbes* magazine as a potentially game-changing technology for the containment of Ebola, the device identifies individual viruses based on size variations due to distinct genome lengths and other factors. Funded by the National Institutes of Health, the research is showcased in *ACS Nano*.

"Others have developed different label-free systems, but none have been nearly as successful in detecting nanoscale viral particles in complex media," said Ünlü, referring to typical biological samples in which a mix of viruses, bacteria, and proteins may be present. "Leveraging expertise in optical biosensors and hemorrhagic fever diseases, our collaborative research effort has produced a highly sensitive device with the potential to perform rapid diagnostics in clinical settings."



Professor Selim Ünlü (ECE, BME, MSE) (left) and Associate Professor John Connor (MED) have developed a rapid, chip-scale photonic device that can detect viruses, including Ebola, on site. Photo by Steve Prue

"By minimizing sample preparation and handling, our system can reduce potential exposure to health care workers," said Connor. "And by looking for multiple viruses at the same time, patients can be diagnosed much more effectively."

NexGen Arrays prototype of SP-IRIS. Image courtesy of NexGen Arrays

Whereas conventional methods can require up to an hour for sample preparation and two hours or more for processing, the current Boston University prototype requires little to no sample preparation time and delivers answers in about an hour.

"By minimizing sample preparation and handling, our system can reduce potential exposure to health care workers," said Connor. "And by looking for multiple viruses at the same time, patients can be diagnosed much more effectively."

The shoebox-sized, prototype diagnostic device, known as the Single Particle Interferometric Reflectance Imaging Sensor (SP-IRIS), detects pathogens by shining light from multi-color LED sources on viral nanoparticles bound to the sensor surface by a coating of virus-specific antibodies. Interference of light reflected from the surface is modified by the presence of the particles, producing a distinct signal that reveals the size and shape of each particle. The sensor surface is very large and can capture the telltale responses of up to a million nanoparticles.

In collaboration with BD Technologies and NexGen Arrays, a BU Photonics Center–based start-up run by longtime SP-IRIS developers David Freedman (EE'10) and postdoctoral fellow George Daaboul (BME'13), the research team is now working on making IRIS more robust, field-ready, and fast—ideally delivering answers within 30 minutes—through further technology development and preclinical trials.

SP-IRIS devices are now being tested in multiple labs, including a Biosafety Level-4 (BSL-4) lab at the University of Texas Medical Branch that's equipped to work with hemorrhagic viruses. Other tests will be conducted at BU's National Emerging Infectious Diseases Laboratories (NEIDL) once the facility is approved for BSL-4 research. Based on the team's current rate of progress, a field-ready instrument could be ready to enter the medical marketplace in five years.

Original article: www.bu.edu/ece/2014/10/02/containing-ebola-with-nanotechnology ■

MOUSTAKAS NAMED DISTINGUISHED PROFESSOR OF PHOTONICS AND OPTOELECTRONICS

HOLDS ENG'S FIRST ENDOWED PROFESSORSHIP

By Mark Dwortzan

BOSTON UNIVERSITY PROVOST Jean Morrison has named Professor Theodore Moustakas (ECE, MSE, Physics) as the inaugural Distinguished Professor of Photonics and Optoelectronics, the College of Engineering's first fully funded, named endowed professorship. Intended to honor and support a BU faculty member with outstanding achievements in research, teaching, and service in the fields of photonics and optoelectronics, the professorship will be jointly funded by the College of Engineering, the Boston University Office of the Provost, and the BU Photonics Center.

Upon Moustakas' retirement, the professorship will be renamed as the Theodore Moustakas Professorship of Photonics and Optoelectronics. The College has begun an unprecedented international search for a senior faculty member in this area of engineering science who will be selected as the inaugural holder of the Moustakas Professorship.

"I am very pleased that Boston University named me as the inaugural Distinguished Professor of Photonics and Optoelectronics," said Moustakas, who has developed a wide range of novel optoelectronic materials and devices ranging from diamond thin films to nitride semiconductors. "Photonics and optoelectronics form the backbone of today's information technology, and the College of Engineering and the BU Photonics Center are world leaders in both domains. The establishment of this Distinguished Professorship will help the University in maintaining its leadership role in these areas."

Since Moustakas joined BU in 1987, the primary focus of his research has been the development of nitride semiconductors for high-performance optoelectronic devices covering the spectral region from the deep ultraviolet (UV) to terahertz. Such devices include light-emitting diodes (LEDs), photo-detectors, and solar cells. He is well known for the development of the nucleation steps for the growth of blue/green LEDs, widely used in flat panel displays on smartphones and televisions as well as for general illumination. He has also developed highly efficient, deep UV LEDs, which are expected to provide environmentally friendly water and air purification as well as food sterilization and various medical applications.

Moustakas has had a significant impact on his field through 31 US patents, hundreds of invited talks, 350 journal papers, 8 co-edited books, and more than 11,000 citations in research literature. Selected as the 2010 Molecular Beam Epitaxy (MBE) Innovator Award winner, he has been named a Fellow of the American Physical Society, Electrochemical Society, National Academy of Inventors, and IEEE. Intellectual property resulting from his work has been licensed to a number of companies, including major manufacturers and users of blue LEDs and lasers. Moustakas is the co-founder of RayVio Corp., a venture-backed company that makes UV LEDs.

A professor of electrical and computer engineering since 1987, professor of physics since 1991, and the current associate head of the Division of Materials Science & Engineering, Moustakas took a leading role in propelling the ECE Department's PhD program into the nation's top-ranked programs, putting the MSE Division on the national map and helping establish BU as a national center of photonics research. He was the 2011 College of Engineering Distinguished Scholar Lecturer and winner of Boston University's 2013 Innovator of the Year award.

Moustakas took a leading role in propelling the ECE Department's PhD program into the nation's top-ranked programs.

Professor Theodore Moustakas (ECE, MSE, Physics)

Prior to joining the BU faculty, Moustakas worked at Harvard University as a research fellow and Exxon Corporate Research Laboratory as a senior scientist. He received a BS in Physics from Aristotle University (Greece) and a PhD in Solid State Science and Engineering from Columbia University.

Original article: www.bu.edu/ece/2014/10/02/moustakas-named-distinguished-professor-of-photonics-and-optoelectronics ■

BU WINS LIFE SCIENCES CAPITAL GRANTS

SUPPORT FOR REGENERATIVE LUNG MEDICINE, TRAINING FOR BIOTECHNOLOGY CAREERS, BIOPHOTONICS START-UPS

By Sara Rimer

THE MASSACHUSETTS LIFE SCIENCES CENTER (MLSC) has awarded $1.74 million to Boston University's Center for Regenerative Medicine (CReM) to help build a new lung regeneration facility. The new facility, to be housed at CReM on BU's Medical Campus, will bring together academic and industry scientists from across the state to apply stem cell biology advances to developing new treatments for cystic fibrosis and other lung diseases.

In two additional capital funding awards to the University, the MLSC gave a $180,000 grant to the undergraduate Biomedical Laboratory & Clinical Sciences (BLCS) program, which is offered by BU Metropolitan College in collaboration with the School of Medicine (MED)—and awarded $363,750 to the University's Photonics Center for a new incubator for biophotonics start-ups.

MLSC, an investment agency that supports life sciences research and development, announced the awards—and an additional $15 million in grants to other educational institutions and medical centers in Boston and Cambridge—at a ceremony on March 18, 2015, at Roxbury Community College.

"We are delighted that both the Center for Regenerative Medicine at Boston Medical Center and Boston University School of Medicine as well as the Biomedical Laboratory & Clinical Sciences program have received this honor from the Massachusetts Life Sciences Center," said Karen Antman, MED, dean and provost of the Medical Campus. "Their investments in these programs will help patients with pulmonary hypertension, cystic fibrosis, and acute lung injury as well as provide students with the necessary equipment as they train for careers in the biotechnology field."

The grant to the Photonics Center will be used to create laboratory space at its Business Innovation Center for up to four start-up companies. The Photonics Center is a national leader in biophotonics research, which uses light to understand cellular behavior and to diagnose and treat diseases.

"We are grateful for the award from the Massachusetts Life Sciences Center for improvements to the biophotonics facilities at the Business Innovation Center and for their support of innovation and economic development in the state," says Thomas Bifano, engineering professor and director of the Photonics Center, who accepted the award at the ceremony. "The Innovation Center has a track record of success in technology transfer and job creation that has helped retain the pipeline of talented engineering and science graduates in the state. The award will further enhance our reputation as a leader in commercialization of biophotonic technologies."

The goal of the new lung regeneration facility is the clinical application of recent discoveries in stem cell research that have been led by CReM director Darrell Kotton, professor of medicine and pathology, and co-directors Gustavo Mostoslavsky and George Murphy, both assistant professors of medicine.

Kotton was honored to receive the award, which will help build the new facility for the Lung Regeneration Initiative. "This facility will enable scale up of the production, banking, and national sharing of pluripotent stem cells made by reprogramming blood specimens from patients who suffer from lung diseases," he said. "Most importantly, the proposed facility will allow both academic and industry scientists from across the state to focus on the goal of achieving personalized treatment applications based on individualized drug tests performed in culture dishes using lung cells made from each patient's banked stem cells. We believe this approach is desperately needed to develop new treatments for the many lung diseases for which there are currently ineffective treatment options. This is an important and exciting step towards our research community's ultimate goal of accomplishing successful lung repair and regeneration in our patients."

The award to Biomedical Laboratory & Clinical Sciences was accepted by Constance Phillips, BLCS program director. It will be used for essential equipment, including a small bioreactor and an HPLC protein chromatography unit, and to help launch an electronic laboratory information and management system to train students in the ever-evolving methods of recordkeeping in the biotech industry. "The BLCS program is grateful and honored to be a grant recipient of the MLSC capital improvement grant," she said. "Their continued support of our programs enables us to enhance our laboratory offerings to students who will help keep Massachusetts strong in the life sciences."

Other institutions that received MLSC capital grants include Roxbury Community College, Boston Children's Hospital, the Forsyth Institute jointly with Brigham and Women's Hospital, and the Massachusetts Institute of Technology.

BU Today article: www.bu.edu/today/2015/bu-wins-life-sciences-capital-grants ■

The grant to the Photonics Center will be used to create laboratory space at its Business Innovation Center for up to four start-up companies.

Darrell Kotton (from left), Constance Phillips, and Thomas Bifano were recipients of capital funding awards from the Massachusetts Life Sciences Center. Photo by Jackie Ricciardi

Faculty & Staff

Soumendra Basu
Professor, ME

730 Commonwealth Ave., EMA 204
617-353-6728
basu@bu.edu

Research interests:
- Environmental degradation of materials at elevated temperatures
- Structure and stability of interfaces
- Characterization of microstructure and phase transformations using electron microscopy techniques

Enrico Bellotti
Professor, ECE

8 Saint Mary's St., 533
617-358-1576
bellotti@bu.edu

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

Thomas Bifano
Professor, ME

8 Saint Mary's St., 927
617-353-8908
tgb@bu.edu

Research interests:
- Microelectromechanical systems
- Adaptive optics

Irving Bigio
Professor, BME, ECE

44 Cummington Mall, 233
617-358-1987
bigio@bu.edu

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

David Bishop
Professor, ECE

8 Saint Mary's St., 609
617-358-4080
djb1@bu.edu

Research interests:
- Low temperature physics
- Mechanical properties of materials at low temperatures
- MEMS and NEMS

Scott Bunch
Assistant Professor, ME

110 Cummington Mall, ENG 404
617-353-7706
bunch@bu.edu

Research interests:
- Experimental nanomechanics of 2D materials
- Molecular transport through porous graphene
- Graphene adhesion

Xin Chen
Assistant Professor, Chemistry

8 Saint Mary's St., 718
617-358-6188
xc2011@bu.edu

Research interests:
- Biophysics
- Materials science
- Environmental science

John Connor
Associate Professor, MED

72 E. Concord St., R516
617-638-0339
jhconnor@bu.edu

Research interests:
- Label-free virus detection
- Identification of biomarkers of infection
- Virus/host interactions

Luca Dal Negro
Associate Professor, ECE, MSE

8 Saint Mary's St., 825
617-358-2627
dalnegro@bu.edu

Research interests:
- Nanophotonics
- Optics of complex media
- Computational electromagnetics

Daniel Ehrlich
Research Professor, BME

44 Cummington Mall, 247
617-358-2919
danehr@bu.edu

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

Kamil Ekinci
Professor, ME

110 Cummington Mall, ENG 408
617-353-8670
ekinci@bu.edu

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

Shyamsunder Erramilli
Professor, Physics, BME

590 Commonwealth Ave., 214
617-353-6114
shyam@bu.edu

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

Helen Fawcett
Research Assistant Professor, ME

8 Saint Mary's St., 935
857-753-1719
hfawcett@bu.edu

Research interests:
- Biodetection, optics, nanoscale lithography, and imaging
- STEM outreach and development

Theodore Fritz
Professor, Astronomy

725 Commonwealth Ave., 501
617-353-7446
fritz@bu.edu

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

Christopher Gabel
Assistant Professor, MED

700 Albany St.
617-638-4267
cvgabel@bu.edu

Research interests:
- Optical neurophysiology
- Femtosecond laser surgery

Bennett Goldberg
Professor, Physics

8 Saint Mary's St., 920
617-353-5789
goldberg@bu.edu

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

Lee Goldstein
Associate Professor, Psychiatry

670 Albany St., 4th floor
617-414-8361
lgold@bu.edu

Research interests:
- Alzheimers disease
- Biometals and metallomics
- Molecular aging disorders

Xue Han
Assistant Professor, BME

44 Cummington Mall, 521
617-358-6189
xuehan@bu.edu

Research interests:
- Neurotechnology
- Optical neural modulation
- Optogenetics

Allyn Hubbard
Professor, ECE

8 Saint Mary's St., 329
617-353-2815
aeh@bu.edu

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

Guilford Jones
Professor Emeritus, Chemistry

8 Saint Mary's St., 829
617-353-2498
giljones@bu.edu

Research interests:
- Photochemistry
- Dye probes

Ajay Joshi
Assistant Professor, ECE

8 Saint Mary's St., 334
617-353-4840
joshi@bu.edu

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

Jonathan Klamkin
Assistant Professor, ECE, MSE

8 Saint Mary's St., 828
617-353-9845
klamkin@bu.edu

Research interests:
- Integrated photonics
- Silicon photonics
- Optical communications

Catherine Klapperich
Professor, BME, ME

44 Cummington Mall, 701A
617-358-0253
catherin@bu.edu

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

Jerome Mertz
Professor, BME

24 Cummington Mall, 202
617-358-0746
jmertz@bu.edu

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

Theodore Morse
Professor Emeritus, ECE

8 Saint Mary's St., 915
617-358-1035
tfmorse@bu.edu

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

Theodore Moustakas
Professor, ECE, MSE, Physics

8 Saint Mary's St., 835
617-353-5431
tdm@bu.edu

Research interests:
- Growth by MBE and HVPE of nitride semiconductors
- Amorphous semiconductors

Roberto Paiella
Professor, ECE, MSE

8 Saint Mary's St., 529
617-353-8883
rpaiella@bu.edu

Research interests:
- Terahertz photonics
- Plasmonics and related optoelectronic device applications

Dimitris Pavlidis
Research Professor, ECE

8 Saint Mary's St., 337
617-353-2811
pavlidis@bu.edu

Research interests:
- Wide bandgap semiconductor materials and devices
- Circuits for high frequency

Siddharth Ramachandran
Professor, ECE, MSE

8 Saint Mary's St., 521
617-353-9881
sidr@bu.edu

Research interests:
- Micro and nano optical fibers
- Optical physics of guided waves

Bjorn Reinhard
Professor, Chemistry

8 Saint Mary's St., 727
617-353-8669
bmr@bu.edu

Research interests:
- Micro and nano optical fibers
- New optical materials

Jason Ritt
Assistant Professor, BME

24 Cummington Mall, 201
617-353-5903
jritt@bu.edu

Research interests:
- Neuroscience of active sensing
- Neurophotonic methods applied to the rodent whisker tactile system

Darren Roblyer
Assistant Professor, BME

44 Cummington Mall, 231
617-358-1554
roblyer@bu.edu

Research interests:
- Diffuse optics
- Therapies in oncology
- Optical functional imaging

Kenneth Rothschild
Professor, Physics

590 Commonwealth Ave., 209
617-353-2603
kjr@bu.edu

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

Michael Ruane
Professor Emeritus, ECE

8 Saint Mary's St., 828
617-358-4769
mfr@bu.edu

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

Michelle Sander
Assistant Professor, ECE

8 Saint Mary's St., 534
617-358-0505
msander@bu.edu

Research interests:
- Femtosecond lasers
- Frequency combs
- Fiber and integrated optics

Aaron Schmidt
Assistant Professor, ME

110 Cummington Mall, 305
617-353-9596
schmidt@bu.edu

Research interests:
- Nanoscale energy transport
- Ultrafast laser metrology
- Laser-material interaction

Joshua Semeter
Professor, ECE

8 Saint Mary's St., 537
617-358-3498
jls@bu.edu

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

Alexander Sergienko
Professor, ECE

8 Saint Mary's St., 729
617-353-6564
alexserg@bu.edu

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

Andre Sharon
Professor, ME

15 Saint Mary's St., 101
617-353-1888
sharon@bu.edu

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

Anna Swan
Associate Professor, ECE, MSE

8 Saint Mary's St., 827
617-353-1275
swan@bu.edu

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

Malvin Teich
Professor Emeritus, ECE, BME, and Physics

8 Saint Mary's St., 916
617-353-1236
teich@bu.edu

Research interests:
- Quantum photonics
- Neural coding

Barry Unger
Associate Professor, MET

808 Commonwealth Ave.
617-353-0940
unger@bu.edu

Research interests:
- High technology
- Venture capital businesses

Selim Ünlü
Professor, ECE, BME, MSE

8 Saint Mary's St., 826
617-353-5067
selim@bu.edu

Research interests:
- Near-field optical microscopy
- Nanoscale imaging of biological samples
- Biosensors

Alice White
Professor, ME

110 Cummington Mall, ENG 107
617-353-4846
aew1@bu.edu

Research interests:
- Nanofabrication
- Optical materials
- Optoelectronic integration and packaging

Xin Zhang
Professor, ME, MSE

8 Saint Mary's St., 921
617-358-2702
xinz@bu.edu

Research interests:
- Micro nanomaterials
- Micro nanomechanics

Lawrence Ziegler
Professor, Chemistry

8 Saint Mary's St., 719
617-353-8663
lziegler@bu.edu

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. The Photonics Center Director appoints committee chairs each year.

Photonics Center Guest Speakers Committee
Chair, Open
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 photonics education within the community and Boston University programs.

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

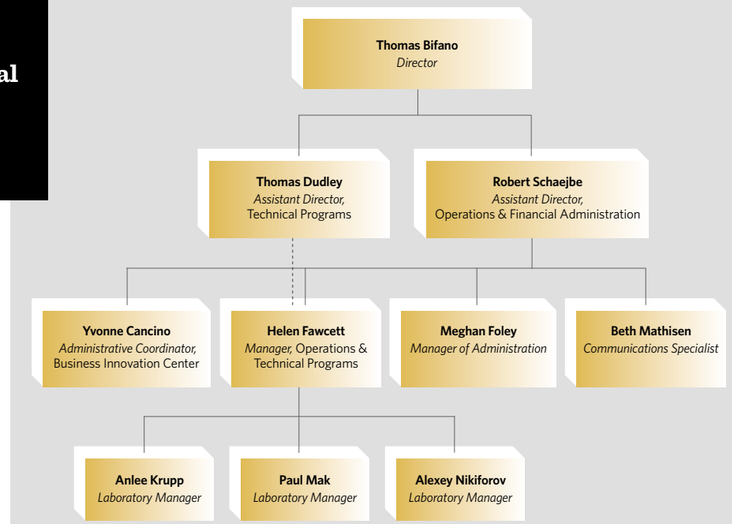
Executive Advisory Committee
Chair, Dr. Thomas Bifano
The Executive Advisory Committee advises the Director of the Photonics Center on educational and academic issues and is comprised of the chairs from the center's affiliated departments.

Space Allocation Committee
Chair, Dr. Thomas Bifano
This committee chair generates policy guidelines for space management.

Symposium Committee
Chair, Dr. Enrico Bellotti
This committee chair organized the 18th annual Photonics Center Symposium that focused on advanced materials by design for the 21st century. The symposium included external government and faculty speakers and internal Boston University faculty speakers. ■

Leadership & Administrative Staff

Photonics Center Organizational Chart



Dr. Thomas Bifano
Director

8 Saint Mary's St., 927
617-353-8908
tgb@bu.edu

Yvonne Cancino
Administrative Coordinator, Business Innovation Center

8 Saint Mary's St., 623
617-358-0480
icancino@bu.edu

Thomas Dudley
Assistant Director, Technical Programs

8 Saint Mary's St., 929
617-358-4924
tjdudley@bu.edu

Dr. Helen Fawcett
Manager, Operations & Technical Programs

8 Saint Mary's St., 935
857-753-1719
hfawcett@bu.edu

Meghan Foley
Manager of Administration

8 Saint Mary's St., 931
617-358-4438
megfoley@bu.edu

Anlee Krupp
Laboratory Manager

8 Saint Mary's St., 933
617-353-9044
ahk@bu.edu

Paul Mak
Laboratory Manager

8 Saint Mary's St., 821
617-353-8869
pmak@bu.edu

Beth Mathisen
Communications Specialist

8 Saint Mary's St., 937
617-353-8907
bethmath@bu.edu

Alexey Nikiforov
Laboratory Manager

8 Saint Mary's St., 831
617-353-9045
alnik@bu.edu

Robert Schaejbe
Assistant Director, Operations & Financial Administration

8 Saint Mary's St., 928
617-358-4257
rschaejb@bu.edu

Research Projects & Technology Development

PHOTONICS CENTER FACULTY AND STAFF MEMBERS 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, the 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' 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 four successful years and the program formulation process for year five. The center has established a mechanism for an organized and functioning collaborative engagement between the 2 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 four years include: Agilent, General Electric's Applied Precision, Becton Dickinson, BioTools, Fraunhofer IPT, Iris AO, Lawrence Livermore National Laboratory, Lincoln Laboratory, Optofluidics, Potomac Photonics, and Thorlabs. This fifth year marks the final one of the Phase I I/UCRC center; a proposal for a Phase II center will be submitted during the next fiscal year. CBSS is already positioning for a Phase II submission by recruiting new members and new university sites. Purdue University has been awarded a Planning Grant to join as a third university site, and the University at Buffalo (SUNY-Buffalo) has submitted a planning grant proposal to join as a fourth university site.

The center continues to be featured by the National Science Foundation as a model for the Industry/University Cooperative Research Center (I/UCRC), and was one of only a handful of NSF centers to be featured on their *Science Nation* video series (see: www.nsf.gov/news/special_reports/science_nation/virusscreening.jsp).

Since the center's inception, 18 projects have been launched (including 4 for FY2016); 13 of them have been completed. Five research projects selected by the membership were initiated in FY2015. Four of them were selected by consensus at the May 2014 program formulation meeting and the fifth was a directed project selected by a new member of the

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
Improving the Speed of Hyperspectral Raman Imaging using a Modulated, Multifocal Detection Scheme	J. Chan	UCD
Rapid, Multiplexed Sample-to-Answer Diagnostic for High Consequence Pathogens	J. Connor	BU
AO Hybrid Microscopy	R. Zawadzki	UCD

center, as permitted by the center bylaws. A summary of these projects appears in this table with a more detailed discussion of results following it.

Integration of Raman Spectroscopy with NanoTweezer System for Analyzing Dynamics of Single Trapped Bacteria Cells. Professor Chan led this project at UCD under the mentorship of Optofluidics. The goal was to develop a laser trap Raman spectroscopy system by integrating micro-Raman spectroscopy capabilities with Optofluidics' 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 completed in FY2015 and is now being incorporated into a feature of Optofluidics' product line.

Superpenetration Multiphoton Microscope (S-MPM) for Deep Tissue Imaging. Professor Bifano led this project with considerable equipment and engineering support from Thorlabs, the project's IAB mentor. 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 and were evaluated and compared with images made on existing MPM commercial instruments. This project was completed in FY2015 after receiving a second year of IAB funding support. The output of this research will be incorporated in the life sciences and biomedical product line of Thorlabs Imaging Systems.

Improving the Speed of Hyperspectral Raman Imaging using a Modulated, Multifocal Detection Scheme. Professor Chan led this project at UCD, mentored by Agilent. Completed in FY2015, this project demonstrated a Raman system to improve the parallel detection in two dimensions at the spectrometer/CCD detector. This significantly improved the imaging speed.

Rapid, Multiplexed Sample-to-Answer Diagnostic for High Consequence Pathogens. Professor Connor, in close collaboration with Becton Dickinson (BD), the Industrial Advisory Board mentor on this project, is developing diagnostic assays for three viruses that cause hemorrhagic fever: Lassa fever virus, Marburg virus, and Ebola virus. The assays will be "in-liquid ELISAs" compatible with the BD Homogeneous No Wash System (HNW). Professor Connor's lab is working with BD to develop SERS nano-tags targeted to the three pathogens and will use them as molecular beacons in the assay development. This establishes a diagnostic platform for these high-hazard viruses that is uniquely capable of detecting multiple pathogens in a broad range of clinical samples with little or no sample preparation needed prior to assay initiation and a low expected cost of production. In FY2015, the team demonstrated assay function at the individual level with acceptable sensitivity. The success of the first year's research has led to a second year of funding for this project in FY2016, where the multiplexed assay will be evaluated. Following this, an assay for malaria will be added and clinically relevant samples of live viruses will be tested.

AO Hybrid Microscopy. Led by Professor Zawadzki at UCD, this project had a third year of IAB support largely directed by mentor Iris AO, which sees commercial potential. The motivation behind this project, which is now completed, 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.

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, seven publications were approved on I/UCRC funded projects.

The program formulation meeting for FY2016 was held in May 2015 after a formal solicitation process that resulted in 23 new proposals being submitted by BU and UCD faculty. A screened set of these proposals was presented at the program formulation meeting and the IAB rank-ordered the projects for funding. The center director and site directors approved the ranking as submitted by the IAB and authorized funding for the following projects:

Project	Project Type	Project Lead	University Site
Near-field Nanotweezers Raman System for Characterizing SERS Nanosensors	New	J. Chan	UCD
Functional OCT Micrometer Resolution Imaging	New	R. Zawadzki	UCD
Rapid, Multiplexed Sample-to-Answer Diagnostic for High Consequence Pathogens	2nd-Year Funding	J. Connor	BU
Development of a High Resolution, Large Dynamic Range Wavefront Sensor for Adaptive Optics	New	J. Mertz	BU

Each of these projects has significant industry support and the outcomes on the research are likely to lead to product line additions or enhancements at Optofluidics, Iris AO, BD, and Thorlabs. Professor Mertz's work on a high resolution, large dynamic range wavefront sensor had such significance for Thorlabs that the membership agreement was amended to create and fund a second membership, as permitted by the bylaws.

On a related endeavor, the Photonics Center completed a Partners for Innovation: Accelerating Innovation Research (PFI:AIR) project on a grant reserved for NSF Centers. Entitled "Nanoplasmonic Metamaterial Antennae for Efficient Wireless Power Transmission," the project was a collaboration with Battelle Memorial Institute and related to the implementation of nanoplasmonics for remote powering of portable devices, including implantable biosensors. This project generated substantial commercial interest and was backed up by a one-for-one match on NSF funds by Battelle, who has also contributed significantly in testing and applications development. A final design review was held at Battelle, where powering a medical sensor and LED displays using wireless power transmission were demonstrated.

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 program focuses on identification, prototyping, and early clinical assessment of innovative point-of-care technologies for treating, screening, diagnosis, and monitoring of cancers. Helen Fawcett is the technical program manager of this grant; the Photonics Center provides financial and administrative management. The third year of the grant has been completed and a new set of projects has been initiated in Year 4. Project solicitation for Year 5 will commence in early fall. For more details and information on this dynamic center, please visit: www.bu.edu/cftcc.

NIH R01: Development of Near Real-Time, Multiplexed Diagnostics for Viral Hemorrhagic Fever
Professors John Connor (PI) and Selim Ünlü (Co-PI) were awarded a NIH R01 program on August 1, 2011. A five-year grant 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 aim of generating a production-ready instrument for use in a BSL-4 laboratory. In addition to the PI and Co-PI, participating Boston University faculty members include Professors Helen Fawcett, Catherine Klapperich, and Mario Cabodi. Collaboration with the University of Texas Medical Branch (UTMB) includes working with Professor Thomas Geisbert, who oversees the BSL-4 testing of the instrument at their facility. The focus of the grant is on development of a photonics-based technology platform, including integration with microfluidics and sample preparation techniques. Alongside two commercial partners, the team is currently preparing to launch an instrument into a BSL-4 laboratory. Starting in August 2015, Year 5 will be the final transition of the research and development work from the laboratory to commercial partners and the final assessment by the UTMB researchers. In addition to program management and directing integration with commercial partners, the Photonics Center also provides financial and administrative management for this five-year program.

> The center continues to be featured by the National Science Foundation as a model for the Industry/University Cooperative Research Center (I/UCRC), and was one of only a handful of NSF centers to be featured on their *Science Nation* video series.

NIH XTNC: Cross-Disciplinary Training in Nanotechnology for Cancer
Formed by the Center for Nanoscience & Nanobiotechnology as an offshoot of BU's nanomedicine initiative, this program is training a community of scientists, engineers, and medical researchers capable of working across disciplines at the interface between nanotechnology and cancer medicine. Funded by the NIH for its first five years, XTNC supported 42 pre- and postdoctoral fellows engaged in interdisciplinary mentored research to develop novel nanoscale therapeutic and diagnostic tools for the detection and treatment of cancer. Now heading into its sixth year, XTNC will be funded by the Center for Nanoscience & Nanobiotechnology. 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.

DoD IARPA: Intelligence Advanced Research Projects Activity
The IARPA grant awarded Professors Bennett Goldberg, Selim Ünlü, and Thomas Bifano ended in June 2015. BU was the prime candidate 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 provided financial and administrative management, and Helen Fawcett is the Program Manager. In the final year, the team transitioned the advanced technology onto a commercial unit that has been delivered to a government facility for further testing and development of a first-generation technology platform. A Cooperative Research and Development Agreement (CRADA) with the Air Force Research Lab (AFRL) is an expected outcome in the summer months following the end of the IARPA award.

LIST OF CURRENT GRANTS

Photonics faculty members received more than **$18.6M** in external funding. The following table lists funds in the fiscal year (July 1, 2014–June 30, 2015), as reported by the Sponsored Programs office.

PI	Dept.	Title of Project	Sponsor	Award Type	Funding Period	Amount Funded in FY15
Bellotti	ECE	CRA: Computationally-Guided Design of Energy Efficient Electronic Materials (CDE3M)	University of Utah	Grant	1/1/14–12/13/15	$300,790
		CRA: Computationally-Guided Design of Energy Efficient Electronic Materials (CDE3M)	University of Utah	Grant	1/1/14–12/31/15	$223,066
		DURIP: Hybrid Computational Architecture for Multi-Scale Modeling of Materials and Devices	Department of Defense/ARO	Grant	7/21/14–7/20/15	$150,000
		Large Detector HGCDTE Detector Optical & Electrical Modeling	DRS Sensors and Targeting Systems	Grant	5/1/14–6/30/15	$60,000
		Next Generation INGAAS Swir Detector Arrays Analysis Modeling	Fulcrum	Contract	9/30/14–9/29/16	$97,060
		Large Detector HDCDTE Detector Optical & Electrical Modeling	DRS Sensors and Targeting Systems	Contract	5/1/14–9/30/15	$25,000
Bifano	ME	2014 Workshop on Noninvasive Brain Imaging	National Science Foundation	Grant	8/1/14–7/31/15	$45,094
		I/UCRC Collaborative Research	I/UCRC: Industry Memberships	Grant	7/1/11–6/30/15	$150,000
		I/UCRC Collaborative Research: I/UCRC: Center for Biophotonic Sensors and Systems (CBSS)	National Science Foundation	Grant	3/1/11–2/29/16	$80,000
Bigio	BME	Optical Imaging of Chemotherapy for Brain Tumors	Columbia University	Grant	4/1/11–3/31/15	$40,000
		Billing Agreement—Support for Hao Li	General Hospital Corp D/B/A Massachusetts General Hospital	Grant	9/1/12–11/30/14	$43,657
		Optical Imaging of Chemotherapy for Brain Tumors	Columbia University	Grant	4/1/11–3/31/16	$32,740
		Training Program in Quantitative Biology and Physiology	National Institutes of Health	Grant	7/1/12–6/20/17	$319,295
Bishop	ECE	MEMS Devices for Detecting the Casimir Energy and Position Sensing for Nanomanufacturing	Department of Commerce/NIST	Contract	1/1/15–12/31/15	$56,465
		Calligraphy to Build Tunable Optical Metamaterials	Department of Defense/Air Force	Contract	6/4/15–9/12/17	$409,099

PI	Dept.	Title of Project	Sponsor	Award Type	Funding Period	Amount Funded in FY15
Bishop	ECE	Agreement with LGS	LGS Innovations, LLC	Contract	11/19/14–11/18/15	$86,040
Bunch	ME	Career: Atomic Scale Defect Engineering in Graphene Membranes	National Science Foundation	Grant	4/15/14–02/29/16	$163,520
		Graphene Membrane Characterization	Lockheed Martin Corporation	Contract	3/5/15–09/01/15	$45,737
		Graphene Membrane Characterization	Lockheed Martin Corporation	Contract	1/13/15–06/30/15	$10,000
Connor	MED	Evaluation of the Mechanism of Action of FDA-Approved Compounds that Show Activity Against Ebola Virus	Department of Defense/Army Medical RESEA	Contract	8/18/14–08/17/15	$140,093
		Biomarker Discovery	Johns Hopkins University Applied Physics	Contract	3/10/15–4/17/15	$45,211
		Development of Near Real-Time, Multiplexed Diagnostics for Viral Hemorrhagic Fever	NIH/National Institute of Allergy & Infectious Diseases	Grant	8/1/11–7/31/16	$872,644
		Biomarker Discovery	Johns Hopkins University Applied Physics	Contract	3/10/15–1/31/16	$134,789
		Evaluation of the Mechanism of Action of FDA-Approved Compounds that Show Activity Against Ebola Virus	Department of Defense/Army Medical Research	Contract	8/18/14–8/17/16	$146,931
		Biomarker Discovery	Johns Hopkins University Applied Physics	Contract	3/10/15–4/17/15	$45,211
Dal Negro	ECE	Eager: Engineering Light-Matter Interaction via Topological Phase Transitions in Photonics Heterostructure with Aperiodic Order	National Science Foundation	Grant	6/15/15–5/31/16	$117,574
Fritz	AST	UNP8/BUSAT3: Andesite: Ad-Hoc Network Demonstration for Spatially Extended Satellite-Based Inquiry and Other Team Endeavors	Department of Defense/AFOSR	Grant	9/1/13–10/31/15	$55,000
Gabel	MED	Wedge-Based Approach for Simultaneous Multi-channel Microscopy	Physical Sciences, Inc.	Grant	10/1/14–7/31/15	$20,000
		Molecular Determination of in vivo Cellular Calcium Signaling During Nerve Damage	NIH/National Institute of Neurological Disorders	Grant	5/1/13–4/30/18	$358,094

PI	Dept.	Title of Project	Sponsor	Award Type	Funding Period	Amount Funded in FY15
Goldberg	PHY	Logic Analysis Tool	DCG Systems, Inc.	Grant	12/8/10–12/7/14	$48,964
		MRI Development of a Holographic Nanoscale Optics Instrument	National Science Foundation	Grant	8/15/14–7/31/17	$383,878
		Boston University Cross-Disciplinary Training in Nanotechnology for Cancer	NIH/National Cancer Institute	Grant	9/1/10–7/31/15	$427,570
		RET in Engineering and Computer Science Site: Integrated Nanomanufacturing	National Science Foundation	Grant	5/1/15–4/30/18	$375,000
		Next Generation Solid Immersion Microscopy for Fault Isolation in Back-Side Analysis	Department of Defense/Air Force	Contract	11/10/10–6/30/15	$115,100
		MOOC-Sponsored Learning Communities for Future STEM Faculty: Multiple Paths to Advance Evidence-Based Teaching Across the Nation	Michigan State University	Grant	10/1/13–9/30/16	$31,263
		The CIRTL Network: 22 Research Universities Preparing a National Faculty to Advance Undergraduate Success	University of Wisconsin	Contract	9/1/14–8/31/15	$43,100
		The CIRTL Network: 25 Universities Preparing a National Faculty to Advance STEM Undergraduate Learning	University of Wisconsin	Grant	8/15/13–7/31/15	$53,285
Goldstein	MED	Quantifying Acute and Chronic Effects of Traumatic Brain Injury (TBI)	Charles Stark Draper Laboratory, Inc.	Contract	7/1/14–6/26/15	$110,000
		The Blood-Brain Barrier as a Diagnostic and Therapeutic Target for Traumatic Brain Injury (TBI)	Crown Philanthropies	Grant	1/1/15–12/31/15	$300,000
		Effects of Space Radiation on Hippocampal-Dependent Learning and Neuropathology in Wild-Type and Alzheimer's Disease Transgenic Mice	NASA	Grant	9/1/11–3/31/16	$250,000
		Effects of Blast Neurotrauma on Alzheimer's Disease Pathogenesis	Department of Defense	Grant	9/16/13–9/15/15	$354,151
Han	BME	Analysis of Biodesign as Drug Permeable Dural Replacement in Blood-Brain Barrier Permeabalizing Mucosal Graft Reconstruction of the Skull Base	Massachusetts Eye and Ear Infirmary	Grant	2/1/15–1/31/16	$5,000
		Causal Analysis of Electrically Connected Neural Network	NIH/National Cancer Institute	Grant	9/30/13–8/31/17	$320,314

PI	Dept.	Title of Project	Sponsor	Award Type	Funding Period	Amount Funded in FY15
Joshi	ECE	Lincoln Scholars Program—Jeffry Warren Little	MIT/Lincoln Laboratory	Contract	9/1/14–12/31/14	$18,374
		Biologically-Inspired Hardware for Land/Aerial Robots (Student: Schuyler Eldridge)	NASA	Grant	8/1/12–7/31/16	$53,346
		Career: System-Level Run-Time Management Techniques for Energy-Efficient Silicon-Photonic Manycore Systems	National Science Foundation	Grant	4/1/12–3/31/17	$96,791
Klamkin	ECE	HELIOS: Heterogeneous Laser Transmitter Integration for Lowswap	NASA	Grant	9/5/14–9/4/17	$400,000
		Microwave Photonic Integrated Circuits for Broadband Beam-forming	Johns Hopkins University Applied Physics	Contract	3/2/15–8/31/15	$14,861
		Microwave Photonic Integrated Circuits for Broadband Beam-forming	Johns Hopkins University Applied Physics	Contract	3/2/15–8/31/15	$60,139
Klapperich	BME	Center for Innovation in Point of Care Technologies for the Future of Cancer Care	NIH/National Cancer Institute	Contract	7/1/12–6/30/17	$1,727,117
		Center for Innovation in Point of Care Technologies for the Future of Cancer Care	NIH/National Cancer Institute	Contract	7/1/12–6/30/17	$55,990
		Rapid Molecular Diagnostic for Chlamydia and Gonorrhea at the Point-of-Care	NIH/National Cancer Institute	Grant	8/5/14–8/4/15	$403,818
		Bacterial Drug Susceptibil-ity Identification by Surface Enhanced Raman Microscopy	Fraunhofer USA	Grant	7/1/10–6/30/15	$68,000
		Paper Microfluidic Chip for Isothermal Amplification and Lateral Flow Detection of HPV DNA	General Hospital Corp D/B/A Massachusetts General Hospital	Grant	4/15/15–6/30/15	$139,425
		A Rapid Instrument Free Molec-ular Diagnostic for B. Pertussis	NIH/National Institute of Allergy & Infectious Diseases	Grant	2/21/14–2/22/15	$57,962
		Rapid Molecular Diagnostics for Chlamydia and Gonorrhea at the Point-of-Care	NIH/National Institute of Allergy & Infectious Diseases	Grant	4/1/15–3/31/19	$143,666
		Center for Innovation in Point of Care Technologies for the Future of Cancer Care	NIH/National Institute of Bio-medical Imaging	Contract	7/1/12–6/30/17	$1,810,561
Mertz	BME	Billing Agreement—Graduate Student Support—Raphael Turcotte	Massachusetts General Hospital	Grant	5/1/12–8/31/14	$3,466

PI	Dept.	Title of Project	Sponsor	Award Type	Funding Period	Amount Funded in FY15
Mertz	BME	High Resolution Phase Contrast Endoscopy	NIH/National Cancer Institute	Grant	12/15/13–11/30/17	$310,709
		High Resolution Phase Contrast Endoscopy	NIH/National Cancer Institute	Grant	12/15/13–11/30/17	$34,525
		UNS: Fluorescence Light-Field Imaging with a Lenseless Flexi-ble Fiber Bundle	National Science Foundation	Grant	6/1/15–5/31/18	$299,997
Moustakas	ECE	Development of High-Efficiency Aigan Deep UV-LEDS on P-SIC Substrates	National Science Foundation	Grant	8/1/14–7/31/17	$336,873
		Surface Structuring for Mono-lithic Phosphors	Osram Sylvania, Inc.	Contract	9/1/12–4/30/14	$25,000
Paiella	ECE	Group-IV Interbrand and Inter-subrand Semiconductor Lasers Based on SIGE Nanomembranes	Department of Defense/AFOSR	Grant	9/30/14–9/29/17	$220,000
		Plasmonic Control of Radiation and Absorption Processes in Semiconductor Quantum Dots	Department of Energy	Grant	8/15/06–12/31/15	$170,000
Pavlidis	ECE	IPA Assignment—Dimitris Pavlidis	National Science Foundation	Contract	11/3/14–11/2/15	$249,924
Ramachandran	ECE	(BRI) High-Power Fiber Lasers Using Intermodal Nonlinearities	Department of Defense/AFOSR	Grant	9/1/14–8/31/19	$250,000
		Fundamental Research on Wavelength-Agile-High-Rate Quantum Key Distribution (QKD) in a Marine Environment	University of Illinois, Urbana-Champaign	Grant	8/1/13–7/31/16	$100,000
		Fundamental Research on Wavelength-Agile-High-Rate Quantum Key Distribution (QKD) in a Marine Environment	University of Illinois, Urbana-Champaign	Grant	8/1/13–7/31/16	$45,000
		Fundamental Research on Wavelength-Agile-High-Rate Quantum Key Distribution (QKD) in a Marine Environment	University of Illinois, Urbana-Champaign	Grant	8/1/13–7/31/16	$256,237
		High Power Blue Green Lasers for Communications	Department of Defense/ONR	Grant	11/1/10–5/31/15	$8,759
Reinhard	CHEM	Illuminating Dynamic Receptor Clustering in the Epidermal Growth Factor Receptor	NIH/National Cancer Institute	Grant	5/1/14–4/30/19	$368,325
		New Optoplasmonic Materials for Next Generation Energy Systems	Department of Energy	Grant	9/1/13–8/31/16	$160,000
Ritt	BME	Multi-Region, Extended-Depth Imaging of Neural Activity VIAA Novel Needle Micro Endoscope	NIH/National Institute of Bio-medical Imaging	Grant	7/1/15–4/30/17	$245,550
Roblyer	BME	Personalized Chemotherapy Through Rapid Monitoring with Wearable Optics	American Cancer Society, Inc.	Grant	7/1/14–6/30/18	$776,000

PI	Dept.	Title of Project	Sponsor	Award Type	Funding Period	Amount Funded in FY15
Rothschild	PHY	Structure/Function of Microbial Sensory Rhodopsins	University of Texas	Grant	4/1/13–3/31/15	$95,498
Schmidt	ME	The EM-Tech Polymer Project	EM-Tech	Contract	1/1/14–1/31/16	$43,000
Semeter	ECE	Collaborative Research: PINOT - PFISR Ion-Neutral Observations in the Thermosphere	National Science Foundation	Grant	10/1/12–9/30/15	$32,359
		Collaborative Research: RINGS-RISR Investigation of the Geo-space System	National Science Foundation	Grant	8/15/13–7/31/16	$113,920
		Draper Urad Contract to BU: Development of a Prototype CPT Magnetometer	Draper Laboratory, Inc.	Grant	9/1/14–6/26/15	$31,820
		Inspire Track 1: Mahali Space Weather Monitoring Everywhere	Massachusetts Institute of Technology	Grant	12/1/13–11/30/16	$60,648
		The Millstone Hill Geospace Facility	Massachusetts Institute of Technology	Grant	12/15/12–11/30/17	$63,915
Sergienko	ECE	Quantum Communication Using Macroscopic Phase Entangled States	University of Maryland, Baltimore County	Grant	9/12/12–9/11/15	$204,570
		Quantum Communication Using Macroscopic Phase Entangled States	University of Maryland, Baltimore County	Grant	9/12/12–9/11/15	$204,570
Swan	ECE	Strain Physics in Graphene—From Friction to Pseudo Magnetic Fields	National Science Foundation	Grant	9/1/14–8/31/17	$539,294
Zhang	ME	REU: Integrated Nanomanufacturing	National Science Foundation	Grant	5/1/15–4/30/18	$360,757
		Draper Laboratory Fellow: David Sutherland	Draper Laboratory, Inc.	Grant	9/1/14–8/31/15	$44,547
		Coupled Evanescent Field Micro-Resonators for Downhole Datarelay	University of Texas	Grant	1/1/10–6/1/16	$295,902
Ziegler	CHEM	Bacterials Drug Susceptibility Identification by Surface Enhanced Raman Microscopy	Fraunhofer USA	Grant	7/1/10–6/30/15	$128,000
		Body Fluid Analysis by Surface Enhanced Raman Spectroscopy for Forensic Applications	Department of Justice/NIJ	Contract	1/1/15–12/31/16	$403,397

PENDING PROPOSAL APPLICATIONS

Photonics faculty members submitted 153 proposals for more than **$114.3M** for the period July 1, 2014–June 30, 2015, as reported by the Sponsored Programs office.

Publications, Patents & Awards

BOOK CHAPTERS

S. Basu and V. Sarin, "Thermal and Environmental Barrier Coatings," *Comprehensive Hard Materials*, Volume 2, edited by V.K. Sarin, Elsevier Ltd., 2014.

T. Bifano, J. Kubby, S. Gigan, "Proceedings of SPIE MEMS Adaptive Optics VIII Introduction," *Mems Adaptive Optics VIII*, 8978, 2014.

N. Cohen, O. Okoro, D. Earle, P. Salkind, **B. Unger**, S. Yen, D. McHugh, S. Polterzycki, and A. Shelman-Cohen, "Fractal-Based Wideband Invisibility Cloak," in *Benoit Mandelbrot: A Life In Many Dimensions*, edited by Michael Frame and Nathan Cohen, World Scientific Press, 2015.

D. Sevenler, N. Lortlar Ünlü, and **M. Ünlü**, "Nanoparticle Biosensing with Interferometric Reflectance Imaging," *Nanobiosensors and Nanobioanalyses*, edited by Vestergaard, Kerman, Hsing, Tamiya, and Springer, February 2015.

W. Premasiri, P. Lemler, Y. Chen, Y. Gebregziabher and **L. Ziegler**, "SERS Analysis of Bacteria, Human Blood and Cancer Cells: A Metabolomic and Diagnostic Tool" in *Frontiers of Surface-Enhanced Raman Scattering: Single-Nanoparticles and Single Cells*, edited by Y. Ozaki, K. Kneipp, and R. Aroca, John Wiley & Sons, 2014.

JOURNAL ARTICLES

Y. Yu, H. Luo, D. Cetin, X. Lin, K. Ludwig, U. Pal, S. Gopalan, and **S. Basu**, "Effect of Atmospheric CO_2 on Surface Segregation and Phase Formation in Thin Films," *Applied Surface Science*, 323, 71–77, 2014.

H. Luo, Y. Shin, Y. Yu, D. Cetin, K. Kudwig, U. Pal, **S. Basu**, S. Gopalan, and X. Lin, "Predicting Oxygen Vacancy Non-Stoichiometric Concentration in Perovskites from First Principles," *Applied Surface Science*, 323, 65–70, 2014.

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*, 34, 3887–3896, 2014.

J.D. Milshtein, **S. Basu**, S. Gopalan, and U. Pal, "Simple Method for Determining Metal Powder Oxidation Kinetics with a Zirconia Sensor," *Annals of Materials Science & Engineering*, 13, 1–7, 2014.

J. Schuster, A. D'Souza, and **E. Bellotti**, "Analysis of InAsSb nBn Spectrally Filtering Photon-Trapping Structures," *Optics Express*, 22, 2014.

J. Schuster, and **E. Bellotti**, "Evaluation of Quantum Efficiency, Crosstalk, and Surface Recombination in HgCdTe Photon-Trapping Structures," *Journal of Electronic Materials*, 43, 2808–2817, 2014.

H. Wen, and **E. Bellotti**, "Numerical Analysis of Radiative Recombination in Narrow-Gap Semiconductors Using the Green's Function Formalism," *Journal of Electronic Materials*, 43, 2841–2848, 2014.

B. Pinkie, and **E. Bellotti**, "Numerical Simulation of the Modulation Transfer Function in HgCdTe Detector Arrays," *Journal of Electronic Materials*, 43, 2864–2873, 2014.

M. Reine, B. Pinkie, J. Schuster, **E. Bellotti**, et al. "Numerical Simulation and Analytical Modeling of InAs nBn Infrared Detectors with n-Type Barrier Layers," *Journal of Electronic Materials*, 43, 2915–2934, 2014.

S. Shishehchi, G. Garrett, S. Rudin, M. Wraback, and **E. Bellotti**, "Theoretical and Experimental Study of Time- and Temperature-Dependent Photoluminescence in ZnO," *Journal of Electronic Materials*, 43, 3033–3040, 2014.

X. Zhou, F. Bertazzi, M. Goano, G. Ghione and **E. Bellotti**, "Deriving k.p Parameters from Full-Brillouin-zone Descriptions: A Finite-Element Envelope Function Model for Quantum-Confined Wurtzite Nanostructures," *Journal of Applied Physics*, 116, 2014.

M. Calciati, M. Goano, F. Bertazzi, M. Vallone1, X. Zhou, G. Ghione, M. Meneghini, G. Meneghesso, E. Zanoni, **E. Bellotti**, G. Verzellesi, D. Zhu and C. Humphreys, "Correlating Electroluminescence Characterization and Physics-Based Models of InGaN/GaN LEDs: Pitfalls and Open Issues," *AIP Advances*, 4, 2014.

M. Hatsubara, L. Pizzagalli, and **E. Bellotti**, "Threading Screw Dislocations in GaN by the Heyd-Scuseria-Ernzerhof Hybrid Functional," *Physica Status Solidi C—Current Topics in Solid State Physics*, 11, 2014.

V. Avrutin, S. Hafiz, F. Zhang, Ü. Özgür, **E. Bellotti**, F. Bertazzi, M. Goano, A. Matulionis, A. Roberts, H. Everitt, and H. Morkoc, "Saga of Efficiency Degradation at High Injection in InGaN Light Emitting Diodes," *Journal Turkish Journal of Physics*, 38, 269–313, 2014.

K. Vigil, Y. Lu, A. Yurt, T. Cilingiroglu, **T. Bifano**, M. Ünlü, and B. Goldberg, "Integrated Circuit Super-Resolution Failure Analysis with Solid Immersion Lenses," *Electronic Device Failure Analysis*, 16, 26–32, 2014.

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," *Neuro-Oncology*, 118, 73–82, 2014.

S. Joshi, R. Singh-Moon, M. Wang, **I. Bigio**, A. Mayevsky, "Real-time Hemodynamic Response and Mitochondrial Function Changes with Intracarotid Mannitol Injection," *Brain Research*, 1549, 42–51, 2014.

E. Rodriguez-Diaz, C. Atkinson, L. Jepeal, A. Berg, C. Huang, M. O'Brien, S. Cerda, F. Farraye, **I. Bigio**, and S. Singh, "Elastic-Scattering Spectroscopy as an Optical Marker of Inflammatory Bowel Disease Activity and Subtypes," *Inflammatory Bowel Diseases*, 20, 1029–1036, 2014.

K. Calabro and **I. Bigio**, "Influence of the Phase Function in Generalized Diffuse Reflectance Models: Review of Current Formalisms and Novel Observations," *Journal of Biomedical Optics*, 19, 2014.

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 Transactions on Biomedical Engineering*, 61, 2336–2340, 2014.

R. Singh-Moon, D. Roblyer, **I. Bigio**, and S. Joshi, "Spatial Mapping of Drug Delivery to Brain Tissue Using Hyperspectral Spatial Frequency Domain Imaging," *Journal of Biomedical Optics*, 19, 2014.

E. Rodriguez-Diaz, Q. Huang, S. Cerda, M. O'Brien, **I. Bigio**, and S. Singh, "Endoscopic Histological Assessment of Colonic Polyps by using Elastic Scattering Spectroscopy," *Gastrointestinal Endoscopy*, 2014.

J. Angelo, V. Venugopal, F. Fantoni, L. Herve, J. Dinten, V. Poher, **I. Bigio**, and S. Gioux, "Depth Sensitive Fluorescence Imaging using Masked Detection of Structured Illumination," *Journal of Biomedical Optics*, 19, 2014.

S. Joshi, R. Singh-Moon, D. Chaudhuri, M. Wang, J. Bruce, **I. Bigio**, and R. Straubinger, "Cationic Surface Charge Enhances Early Regional Deposition of Liposomes After Intracarotid Injection," *Journal of Neuro-oncology*, 120, 489–497, 2014.

S. Joshi, R. Singh-Moon, J. Ellis, D. Chaudhuri, M. Wang, R. Reif, J. Bruce, **I. Bigio** and R. Straubinger, "Cerebral Hypoperfusion-assisted Intraarterial Deposition of Liposomes in Normal and Glioma-bearing Rats," *Neurosurgery*, 2014.

X. Liu, J. Suk, N. Boddeti, L. Cantley, L. Wang, J. Gray, H. Hall, V. Bright, C. Rogers, M. Dunn, R. Ruoff and **J. Bunch**, "Large Arrays and Properties of 3-Terminal Graphene Nanoelectromechanical Switches," *Advanced Materials*, 26, 1571–1576, 2014.

M. Cheung, B. McKenna, S. Wang, D. Wolf, **D. Ehrlich**, "Image-based Cell-resolved Screening Assays in Flow," *Cytometry A*, 87, 541–548, 2015.

C. Lissandrello, F. Inci, M. Francom, M. Paul, U. Demirci, and **K. Ekinci**, "Nanomechanical Motion of Escherichia coli Adhered to a Surface," *Applied Physics Letters*, 105, 2014.

T. Kouh, U. Kemiktarak, O. Basarir, C. Lissandrello, and **K. Ekinci**, "Measuring Gaussian Noise Using a Lock-in Amplifer," *American Journal of Physics*, 82, 778, 2014.

O. Ozsun, R. Thompson, **K. Ekinci**, and J. Tien, "Non-invasive Mapping of Interstitial Fluid Pressure in Microscale Tissues," *Integrative Biology*, 6, 979–987, 2014.

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," *ACS Photonics 1*, 696–702, 2014.

C. Parker, D. Voss, and **T. Fritz**, "Electron and Proton Beam Testing of Pixelated Solid State Detectors, Nuclear Instruments and Methods," *Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 741, 37–41, 2014.

C. Parker and **T. Fritz**, "The Loss Cone Imager," *Space Science Reviews,* 2014.

E. Ziade, C. Patmont, and **T. Fritz**, "Design and Characterization of a Spring Steel Hinge for Deployable Cubesat Structures," *Journal of Small Satellites*, 2014.

L. Waldrop, E. Roelof, and **T. Fritz**, "Energetic Ion Streaming in the Jovian Magnetosphere," *Journal of Geophysical Research*, 2014.

L. Sun, J. Shay, M. McLoed, K. Roodhouse, S. Chung, C. Clark, M. Alkema, and **C. Gabel**, "Neuronal Regeneration in *C. elegans* Requires Sub-cellular Calcium Release by Ryanodine Receptor Channels and Can Be Enhanced by Optogenetic Stimulation," *Journal of Neuroscience*, 34, 15947–56, 2014.

M. Gruner, D. Nelson, R. Hintz, S. Chung, **C. Gabel**, A. van der Linden, "Feedback Modulation of Chemoreceptor Gene Expression Mediated by Feeding State and NPR-1," *PLOS Genetics*, 10, 2014.

S. Remi, **B. Goldberg**, and A. Swan, "Charge Tuning of Nonresonant Magneto-exciton Phonon Interactions in Graphene," *Physical Review Letters*, 112, 2014.

G. Daaboul, C. Lopez, J. Chinnala, **B. Goldberg**, J. Connor, and M. Ünlü, "Digital Sensing and Sizing of Vesicular Stomatitis Virus Pseudotypes in Complex Media: A Model for Ebola and Marburg Detection," *ACS Nano*, 8, 6047–6055, 2014.

M. Banaee, M. Ünlü, and **B. Goldberg**, "Sub - L/10 Spot Size in Semiconductor Solid Immersion Lens Microscopy," *Optics Communications*, 315, 108–111, 2014.

A. Yurt, A. Uyar, T. Cilingiroglu, **B. Goldberg**, and M. Ünlü, "Evanescent Waves in High Numerical Aperture Aplanatic Solid Immersion Microscopy: Effects of Forbidden Light on Subsurface Imaging," *Optics Express*, 22, 7422–7433, 2014.

A. Yurt, M. Grogan, S. Ramachandran, **B. Goldberg**, and M. Ünlü, "Effect of Vector Asymmetry of Radially Polarized Beams in Solid Immersion Microscopy," *Optics Express*, 22, 7320–7329, 2014.

K. Vigil, Y. Lu, A. Yurt, T. Cilingiroglu, T. Bifano, M. Ünlü, and **B. Goldberg**, "Integrated Circuit Super-Resolution Failure Analysis with Solid Immersion Lenses," *Electronic Device Failure Analysis*, 16, 26–33, 2014.

L. Goldstein, A. C. McKee, P. K. Stanton, "Considerations for Animal Models of Blast-Related Traumatic Brain Injury and Chronic Traumatic Encephalopathy," *Alzheimer's Research & Therapy*, 6, 2014.

J. Suh, J. A. Moncaster, L. Wang, I. Hafeez, J. Herz, R. E. Tanzi, **L. Goldstein**, S. Y. Guenette, "FE65 and FE65L1 Amyloid Precursor Protein-Binding Protein Compound Null Mice Display Adult-Onset Cataract and Muscle Weakness," *FASEB J*, 29, 2628–2639, 2015.

D. H. Daneshvar, **L. Goldstein**, P. T. Kiernan, T. D. Stein, A. C. McKee, "Post-Traumatic Neurodegeneration and Chronic Traumatic Encephalopathy," *Molecular & Cellular Neuroscience*, 66, 81–90, 2015.

A. Kondo, K. Shahpasand, R. Mannix, J. Qiu, J. Moncaster, C. H. Chen, Y. Yao, Y. M. Lin, J. A. Driver, Y. Sun, S. Wei, M. L. Luo, O. Albayram, P. Huang, A. Rotenberg, A. Ryo, **L. Goldstein**, A. Pascual-Leone, A. C. McKee, W. Meehan, X. Z. Zhou, K. P. Lu, "Antibody Against Early Driver of Neurodegeneration Cis P-tau Blocks Brain Injury and Tauopathy," *Nature*, 523, 431–436, 2015.

R. Kohman, and **X. Han**, "Light-Sensitization of DNA Nanostructures via Incorporation of Photo-Cleavable Spacers," *Chem. Commun*, 2015.

B. Bleier, A. Kocharyan, A. Singleton, and **X. Han**, "Verapamil Modulates Interleukin-5 and Interleukin-6 Secretion in Organotypic Human Sinonasal Polyp Explants," *Int Forum Allergy Rhinol*, 2015.

R. Kohman, **X. Han**, and B. Bleier, "Heterotopic Mucosal Engrafting Procedure for Direct Drug Delivery to the Brain in Mice," *J Vis Exp,* 2014.

A. Chuong, M. Miri, V. Busskamp, G. Matthews, L. Acker, A. Soresnsen, A. Young, N. Klapoetke, M. Henninger, S. Kodandaramaiah, M. Ogawa, S. Ramanlal, R. Bandler, B. Allen, C. Forest, B. Chow, **X. Han**, Y. Lin, K. Tye, R. Roska, J. Cardin, and E. Boyden, "Noninvasive Optical Inhibition with a Red-shifted Microbial Rhodopsin," *Nature Neuroscience*, 2014.

A. Kocharyan, R. Feldman, A. Singleton, **X. Han**, and B. Bleier, "P-glycoprotein Inhibition Promotes Prednisone Retention in Human Sinonasal Polyp Explants," *Int Forum Allergy Rhinol*, 2014.

B. Bleier, A. Nocera, H. Iqbal, J. Hoang, U. Alvarez, R. Feldman, and **X. Han**, "P-glycoprotein Promotes Epithelial T Helper 2-associated Cytokine Secretion in Chronic Sinusitis with Nasal Polyps," *Int Forum Allergy Rhinol*, 2014.

M. Zangeneh and **A. Joshi**, "Design and Optimization of Nonvolatile Multi-bit 1T1R Resistive RAM," *Very Large Scale Integration (VLSI) Systems, IEEE Transactions on*, 22, 1815–1828, 2014.

F. Raudies, S. Eldridge, **A. Joshi**, and M. Versace, "Learning to Navigate in a Virtual World Using Optic Flow and Stereo Disparity Signals," *Artificial Life and Robotics*, 2014.

S. Wong, M. Cabodi, J. Rolland, and **C. Klapperich**, "Evaporative Concentration on a Paper-based Device to Concentrate Analytes in a Biological Fluid," *Analytical Chemistry*, 2014.

J. Linnes, A. Fan, N. Rodriguez, B. Lemieux, H. Kong and **C. Klapperich**, "Paper-based Molecular Diagnostic for Chlamydia Trachomatis," *RSC Advances*, 4, 42245–42251, 2014.

R. Barankov and **J. Mertz**, "High-throughput Imaging of Self-luminous Objects through a Single Optical Fibre," *Nature Communications*, Nov. 2014.

A. Mertiri, H. Altug, M. Hong, P. Mehta, **J. Mertz**, L. Ziegler, and S. Erramilli, "Nonlinear Midinfrared Photothermal Spectroscopy Using Zharov Splitting and Quantum Cascade Lasers," *ACS Photonics*, 1, 8, 696–702, July 2014.

J. Baritaux, C. Chan, J. Li, and **J. Mertz**, "View Synthesis with a Partitioned-aperture Microscope," *Optics Letters*, 39, 3, 1152–1162, 2014.

J. Giese, T. Ford, and **J. Mertz**, "Fast Volumetric Phase-gradient Imaging in Thick Samples," *Optics Express*, 22, 1, 1152–1162, 2014.

J. Mertz, A. Gasecka, A. Daradich, I. Davison, and D. Cote, "Phase-gradient Contrast in Thick Tissue with a Scanning Microscope," *Biomedical Optics Express*, 5, 2, 407–416, 2014.

H. Sun and **T. Moustakas**, "UV Emitters Based on an AlGaN p-n Junction in the Form of Graded-index Separate Confinement Heterostructure," *Applied Physics Express*, 7, 2014.

I. Gorczyca, T. Suski, G. Staszczak, X. Wang, N. Christensen, A. Svane, E. Dimakis, **T. Moustakas**, "Short Period Polar and Nonpolar mInN/nGaN Superlattices," *Phys. Status Solidi C,* 11, 678–681, 2014.

A. Moldawer, A. Bhattacharyya, L. Zhou, D. Smith and **T. Moustakas**, "Characterization of a-plane GaN Templates Grown by HVPE and High Efficiency Deep UV Emitting AlGaN /AlN MQWs Grown by MBE on Such Templates," *Physica Status Solidi C*, 11, 585–589, 2014.

W. Pan, E. Dimakis, G. Wang, **T. Moustakas**, and D. Tsui, "Two-dimensional Electron Gas in Monolayer InN Quantum Wells," *Appl. Phys. Lett.*, 105, 2014.

K. Tantiwanichapan, X. Wang, A. Swan, and **R. Paiella**, "Graphene on Nanoscale Gratings for the Generation of Terahertz Smith-Purcell Radiation," *Appl. Phys. Lett.*, 105, 2014.

C. Boztug, J. Sánchez Pérez, F. Cavallo, M. Lagally, and **R. Paiella**, "Strained-Germanium Nanostructures for Infrared Photonics," *ACS Nano*, 8, 3136–3151, 2014.

J. Demas and **S. Ramachandran**, "Sub-second Mode Measurement of Fibers Using C2 Imaging," *Opt. Exp.*, 22, 23043, 2014.

A. Yurt, M. Grogan, **S. Ramachandran**, B. Goldberg, and M. Ünlü, "Effect of Vector

Asymmetry of Radially Polarized Beams in Solid Immersion Microscopy," *Opt. Exp.*, 22, 7320, 2014.

P. Steinvurzel, J. Demas, B. Tai, Y. Chen, L. Yan, and **S. Ramachandran**, "Broadband Parametric Wavelength Conversion at 1 μm with Large Mode Area Fibers," *Optics Letters*, 39, 743, 2014.

J. Jung, R. Istfan, **D. Roblyer**, "Note: A Simple Broad Bandwidth Undersampling Frequency-Domain Digital Diffuse Optical Spectroscopy System," *Review of Scientific Instruments*, 85, 2014.

R.P. Singh-Moon, **D. Roblyer**, I.J. Bigio, S. Joshia, "Spatial Mapping of Drug Delivery to Brain Tissue Using Hyperspectral Spatial Frequency Domain Imaging," *Journal of Biomedical Optics*, 19, 2014.

G. Greening, R. Istfan, L. Higgins, K. Balachandran, **D. Roblyer**, M. Pierce, TJ Muldoon, "Characterization of Thin Poly (dimethylsiloxane)-Based Tissue-Simulating Phantoms with Tunable Reduced Scattering and Absorption Coefficients in the Visible to Near-Infrared Domain," *Journal of Biomedical Optics*, 2014.

J. Ogren, S. Mamaev, D. Russano, H. Li, J. Spudich, and **K. Rothschild**, "Retinal Chromophore Structure and Schiff Base Interactions in Red-shifted Channelrhodopsin-1 from Chlamydomonas augustae," *Biochemistry*, 53, 3961–3970, 2014.

J. Ogren, A. Yi, S. Mamaev, H. Li, J. Lugtenburg, W. DeGrip, J. Spudich, and **K. Rothschild**, "Comparison of the Structural Changes Occurring During the Primary Phototransition of Two Different Channelrhodopsins from Chlamydomonas Algae," *Biochemistry*, 2014.

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 Spectrometery*, 28, 49–62, 2014.

G. Norman, C. Yang, H. Ostendorff, Z. Shums, M. Lim, J. Wang, A. Awad, G. Hirschfield, P. Milkiewicz, D. Bloch, **K. Rothschild**, C. Bowlus, I. Adamopoulos, P. Leung, H. Janssen, A. Cheung, C. Coltescu, and M. Gershwin, "Anti-kelch-like 12 and Anti-hexokinase 1: Novel Autoantibodies in Primary Biliary Cirrhosis," *Liver Int*, 35, 642–651, 2015.

J. Yang, E. Ziade, C. Maragliano, R. Crowder, X. Wang, M. Stefancich, M. Chiesa, A. K. Swan, and **A. Schmidt**, "Thermal Conductance Imaging of Graphene Contacts," *Journal of Applied Physics*, 116, 2014.

J. Buongiorno, D. Cahill, C. Hidrovo, S. Moghaddam, **A. Schmidt** and L. Shi, "Micro- and Nanoscale Measurement Methods for Phase Change Heat Transfer on Planar and Structured Surfaces," *Nanoscale and Microscale Thermophysical Engineering*, 18, 270–287, 2014.

J. Yang, E. Ziade, and **A. Schmidt,** "Imaging Thermal Transport in Graphene," *ASME Journal of Heat Transfer*, 137, 020901, 2014.

E. Ziade, J. Yang, T. Sato, P. Czubarow, and **A. Schmidt**, "Thermal Property Imaging of Aluminum Nitride Composites," *ASME Journal of Heat Transfer*, 137, 020902, 2014.

R. Nakamura, T. Karlsson, M. Hamrin, H. Nilsson, O. Marghitu, O. Amm, C. V. Bunescu, H. Constantinescu, U. Frey, A. Keiling, **J. Semeter**, E. Sorbalo, J. Vogt, C. Forsyth, and M. V. Kubyshkina (2014), "Low-Altitude Electron Acceleration Due to Multiple Flow Bursts in the Magnetotail," *Geophysical Research Letters*, 41, 2014.

Dahlgren, H., G. Perry, J.-P. St. Maurice, K. Hosokawa, **J. Semeter**, M.J. Nicolls, and K. Shiokawa, "3D Imaging Reveals Electrodynamics of Polar Cap Aurora," *Astronomy & Geophysics,* 55, 5.26–5.28, 2014.

H. Akbari, and **J. Semeter**, "Aspect Angle Dependence of Naturally Enhanced Ion Acoustic Lines," *Journal of Geophysical Research: Space Physics*, 119, 5909–5917, 2014.

G. Jaeger and **A. Sergienko**, "Entanglement Sudden Death: A Threat to Advanced Quantum Key Distribution?" *Natural Computing*, 13, 459–467, 2014.

D. Simon, G. Jaeger, and **A. Sergienko**, "Quantum Information in Communication and Imaging," *International Journal of Quantum Information*, 12, 143004, 2014.

D. Simon and **A. Sergienko**, "High Capacity Quantum Key Distribution via Hyperentangled Degrees of Freedom," *New Journal of Physics*, 16, 063052, 2014.

D. Simon, G. Jaeger, and **A. Sergienko**, "Entangled-Coherent-State Quantum Key Distribution with Entanglement Witnessing," *Physical Review A*, 89, 012315, 2014.

X. Zhang, G. Daaboul, P. Spuhler, D. Freedman, A. Yurt, S. Ahn, O. Avci, and **M. Ünlü**, "Nanoscale Characterization of DNA Conformation Using Dual-color Fluorescence Axial Localization and Label-free Biosensing," *Analyst*, 13, 2014.

G. Daaboul, C. Lopez, J. Chinnala, B. Goldberg, J. Connor, and **M. Ünlü**, "Digital Sensing and Sizing of Vesicular Stomatitis Virus Pseudotypes in Complex Media: A Model for Ebola and Marburg Detection," *Acs Nano*, 8, 6047–6055, 2014.

C. Yu, C. Lopez, H. Hu, Y. Xia, D. Freedman, A. Reddington, G. Daaboul, **M. Ünlü**, and C. Genco, "A High-throughput Method to Examine Protein-nucleotide Interactions Identifies Targets of the Bacterial Transcriptional Regulatory Protein Fur," *PLoS ONE*, 9, 2014.

A. Yurt, A. Uyar, T. Cilingiroglu, B. Goldberg, and **M. Ünlü**, "Evanescent Waves in High Numerical Aperture Aplanatic Solid Immersion Microscopy: Effects of Forbidden Light on Subsurface Imaging," *Optics Express*, 22, 7422–7433, 2014.

A. Yurt, M. Grogan, S. Ramachandran, B. Goldberg, and **M. Ünlü**, "Effect of Vector Asymmetry of Radially Polarized Beams in Solid Immersion Microscopy," *Optics Express*, 22, 7320–732, 2014.

E. Cevik, D. Freedman, M. Gökkavas, E. Özbay, M. Sahin, and **M. Ünlü**, "Improved Selectivity from a Wavelength Addressable Device for Wireless Stimulation of Neural Tissue," *Frontiers in Neuroengineering*, 7, 1–12, 2014.

X. Cheng, G. Daaboul, **M. Ünlü**, and K. Kerman, "LED-based Interferometric Reflectance Imaging Sensor for the Detection of Amyloid-b Aggregation," *Analyst*, 139, 59–65, 2014.

M. Banaee, **M. Ünlü**, and B. Goldberg, "Sub—L/10 Spot Size in Semiconductor Solid Immersion Lens Microscopy," *Optics Communications*, 315, 108–111, 2014.

C. Wang, X. Wang, S. Anderson, and **X. Zhang**, "Fabrication and Characterization of Composite Hydrogel Particles with X-Ray Attenuating Payloads," *Journal of Vacuum Science & Technology B*, 32, 032001, 2014.

C. Wang, X. Wang, S. Anderson, and **X. Zhang**, "Biocompatible, Micro- and Nano-Fabricated Magnetic Cylinders for Potential Use as Contrast Agents for Magnetic Resonance Imaging," *Sensors and Actuators B: Chemical*, 196, 670–675, 2014.

F. Zhang, S. Anderson, X. Zheng, E. Roberts, Y. Qiu, R. Liao, and **X. Zhang**, "Cell Force Mapping Using a Double-Sided Micropillar Array Based on the Moire Fringe Method," *Applied Physics Letters*, 105, 033702, 2014.

G. Keiser, H. Seren, A. Strikwerda, **X. Zhang**, and R. Averitt, "Structural Control of Metamaterial Oscillator Strength and Electric Field Enhancement at Terahertz Frequencies," *Applied Physics Letters*, 105, 081112, 2014.

H. Seren, G. Keiser, L. Cao, J. Zhang, A. Strikwerda, K. Fan, G. Metcalfe, M. Wraback, **X. Zhang**, R.D. Averitt, "Optically Modulated Multiband Terahertz Perfect Absorber," *Advanced Optical Materials*, 2, 1221–1226, 2014.

H. Hwang, S. Fleischer, N. Brandt, B. Perkins, M. Hoffmann, M. Liu, K. Fan, A. Sternbach, **X. Zhang**, R. Averitt, and K. Nelson, "A Review of Non-Linear Terahertz Spectroscopy with Ultrashort Tabletop-Laser Pulses," *Journal of Modern Optics*, June 2014.

H. Seren, X. Zhao, C. Chen, C. Wang, and **X. Zhang**, "Enabling a Microfluidic RFID Readout System via Miniaturation and Integration," *Journal of Microelectromechanical Systems*, 24, 2, 395–403, March 2015.

Y. Qiu, A. Bayomy, M. Gomez, M. Bauer, P. Du, Y. Yang, **X. Zhang**, and R. Liao, "A Role for Matrix Stiffness in the Regulation of Cardiac Side Population Cell Function," *AJP-Heart and Circulatory Physiology*, 308, 9, May 2015.

X. Zhao, K. Fan, J. Zhang, H. Seren, G. Metcalfe, M. Wraback, R. Averitt, and **X. Zhang**, "Optically Tunable Metamaterial Perfect Absorber on Highly Flexible Substrate," *Sensors and Actuators A: Physical*, 231, 74–80, March 20, 2015.

S. Teo, C. Werley, C. Wang, K. Fan, B. Ofori-Okai, **X. Zhang**, R. Averitt, and K. Nelson, "Visualization of Guided and Leaky Wave Behaviors in an Indium Tin Oxide Metallic Slab Waveguide," *Optics Express*, 23, 11, 14876–96, June 2015.

A. Mertiri, H. Altug, M. Hong, P. Mehta, J. Mertz, **L. Ziegler**, and S. Erramilli, "Nonlinear Midinfrared Photothermal Spectroscopy Using Zharov Splitting and Quantum Cascade Lasers," *ACS Photonics*, 1, 696–702, 2014.

P. Lemler, W. Premasiri, A. DelMonaco and **L. Ziegler**, "NIR Raman Spectra of Whole Human Blood: Effects of Laser-induced and in vitro Hemoglobin Denaturation," *Analytical and Bioanalytical Chemistry*, 406, 193–200, 2014.

PATENTS

Theodore Moustakas (US Patent #8,987,755) "Ultraviolet Light Emitting Diode Structures and Methods of Manufacturing the Same," Issue Date: March 24, 2015.

Kenneth Rothschild (US Patent #8,852,956) "Methods for Diagnostic Primary Biliary Cirrhosis (PBC) Using Novel Autoantigens," Issue Date: October 7, 2014.

Kenneth Rothschild (US Patent #8,906,700) "Methods and Compositions for Phototransfer," Issue Date: December 9, 2014.

AWARDS

Thomas Bifano was named a Kern Fellow by the Boston University College of Engineering.

Ajay Joshi received the Boston University ECE Department Award for Excellence in Teaching.

Catherine Klapperich was named an Inaugural Dorf-Ebner Faculty Fellow.

Catherine Klapperich was elected an American Institute for Medical and Biomedical Engineering (AIMBE) Fellow.

Jerome Mertz was named a Fellow of the American Institute for Medical and Biomedical Engineering (AIMBE).

Theodore Moustakas was named a Distinguished Professor of Photonics and Optoelectronics by Boston University.

Theodore Moustakas was named a Fellow of the Institute of Electrical and Electronics Engineers (IEEE).

Jason Ritt received the National Institutes of Health Debut Award.

Michelle Sander received the Dean's Catalyst Award by the Boston University College of Engineering.

Xin Zhang received the Boston University Nanoscience & Nanobiotechnology Award.

Educational Programs & Initiatives

NSF Research Experiences for Undergraduates (REU) in Integrated Nanomanufacturing

Professors Xin Zhang and Helen Fawcett received notification at the end of January 2015 that the NSF REU Site in Integrated Nanomanufacturing (INM) had been awarded. To remain competitive with other REU programs, within a week of notification the co-directors opened a website and application process. After a month and a half, over 175 applications were received, with 40% of the applications from female candidates and 34% of the applicants from underrepresented minorities. (NSF defines underrepresented minority as Hispanic/Latino, African American, Native Hawaiian or Other Pacific Islander, and American Indian or Alaskan Native. Asian and Caucasian are not considered underrepresented minorities.) The premise for this site was a focus on students who are at institutions with limited to no STEM research for graduate studies. Diversity of applicants was also a priority with a focus on underrepresented minorities, veterans, and female applicants.

The REU site offers an interdisciplinary and transformative experience to students from varying engineering disciplines that reflect the diversity of the BU mentors in integrated nanomanufacturing. Training female and underrepresented minorities from universities and community colleges that have limited STEM research capabilities for graduate studies will provide the largest impact to diversifying future researchers in nanotechnology. Participants will be immersed in research while simultaneously gaining an education in interdisciplinary techniques via mentored training from faculty and graduate students. Through this mentored training, participants will also engage in a training program of nanotechnology content, skills development, and career preparation with a focus on interdisciplinary engineering topics. Students will participate in mentored discovery, engineering of new devices, and fabrication at the nanoscale level to explore optical and integrated nanoscale systems, while developing the critical skills, awareness, and confidence necessary to advance along their career pathways in academics and research.

The first cohort arrived at BU on June 8, 2015, moved into their dorm rooms, and started the program on Tuesday, June 9, 2015. Below are some relevant statistics about our 2015 REU participants:

- 36% have no STEM majors offered at their university
- 82% have two or fewer STEM majors offered at their university
- 59% are underrepresented minorities (23% Hispanic, 36% African American)
- 64% are female

Next year's annual report will cover more information about the REU activities. For now, our website has additional information about the program: www.bu.edu/photonics-reu. In addition to our undergraduate researchers, Emily Biehl, a communications undergraduate from BU's College of Communication, is working with the group to assist in upgrading the website and in future recruiting and continued engagement of current and future participants via networking and social media.

The NSF REU INM is working alongside, and integrating where possible, the other REU sites and researchers on campus, including BU undergraduate researchers at the Undergraduate Research Opportunities Program (UROP) office.

NSF Research Experiences for Teachers (RET) in Integrated Nanomanufacturing

Professors Bennett Goldberg and Helen Fawcett received notification in February 2015 that the NSF RET Site in Integrated Nanomanufacturing had been awarded. The website and application process opened immediately with a deadline of April 6, 2015. Teachers received offers to participate in the program several days after the application deadline closed, and by the end of April 2015, the first cohort was finalized.

Teachers were recruited from high-needs public schools within the Massachusetts STEM Pipeline network and community college faculty in surrounding districts. Teachers who have an interest in seeking research opportunities to integrate into their classroom curriculum are integrated with the interdisciplinary research in nanotechnology on the Boston University campus. These teachers will join research programs where they will work alongside a NSF REU student who has already started in the lab four weeks prior to their arrival. For the RET program, our goal is 25% underrepresented minority and 50% female participation. In addition, at least 80% of the participating school districts must be from resource-limited schools with high percentages of underrepresented minority students.

The directors will assist in the translation of RET experiences into sustainable STEM education curricula and activities at the teachers' home schools through team-based development together with research mentors in the teacher's partnering laboratory. The directors plan to engage teachers from past and current summers in collective workshops on flipped classrooms, online and blended learning, real-time assessment, and other STEM pedagogy advancements, teaming teachers with faculty to focus on the research-intensive faculty's instructional approaches.

The teachers arrived on Monday, July 6, 2015, and joined the undergraduates in the laboratory. Some relevant statistics about the 2015 RET participants are as follows:

- 82% of the schools represented are from communities with higher than 40% low-income households
- 73% of the schools are receiving level 3 or higher district assistance from Massachusetts
- 10% of the participants are underrepresented minorities
- 73% of the teachers are female

More information about the projects and the teachers can be found at bu.edu/photonics-ret. ■

Teachers were recruited from high-needs public schools within the Massachusetts STEM Pipeline network and community college faculty in surrounding districts.

Outreach & Other Activities

Innovation Center Facilities
Located on the 6th floor of the Photonics Center building, Boston University's Business Innovation Center (BIC) currently hosts 13 technology companies that are in the early stages of business growth. The goal of BIC is to accelerate innovation by encouraging industry collaboration with faculty and providing educational opportunities for graduate and undergraduate students. The mix of companies includes those in life sciences, biotechnology, medical devices, photonics, and clean energy. BIC has maintained a 100% occupancy rate, with a waiting list for available space. Despite shrinking by one-half its size over the past three years, at one point during the past year the center hit a peak of 15 companies. Four companies departed during the year, while six are new. The center's philosophy is to encourage turnover, as within two to three years, companies will either succeed and need to expand or will determine that their business is not viable. As part of the University, BIC offers start-up companies a wide array of services and access to the Photonics Center shared labs, which would be extremely difficult and costly for a small company to provide on their own. In return, BIC companies enhance the academic environment by offering internships to students and increasing sponsored research opportunities. The center's objective is to make resources available to a large number of companies, develop relationships that go beyond the period of tenancy, and establish BIC and Boston University as supporters of entrepreneurship, business development, and job creation, and the BIC as a pipeline for trained scientists and engineers.

List of FY2015 Innovation Center Tenants

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
Affera	De Novo Start-up	Systems to Treat Heart Disease	Health Care	Venture
Agira	Johns Hopkins University	Polymer Waveguide	Energy	Bootstrap
Bioventus	License from Pfizer	Bone Growth Protein	Health Care	Corporate and Private Equity
FemtoDx	Assets acquired from Ninth Sense	Point of Care Diagnostic	Health Care	Angel
Lattice Automation	BU	Biological Design Solution	Health Care	Grants
Mass Medical Devices Journal	De Novo Start-up	N/A	Medical Device Journalism	Sales/Advertising
Micro-Leads Inc.	Draper Laboratory	Micro-Electrodes and Implantable Devices	Health Care	Grants
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
Snapdragon Chemistry, Inc.	MIT	Process Flow Chemistry	Pharmaceutical	Corporate
SPR Technologies, Inc.	De Novo Start-up	Microbial Coatings	Health Care	Grants

Through innovative use of space and by making minor investments, the Photonics Center created additional usable space in the smaller footprint to accommodate the growth of BIC companies. Among the changes were conference room conversions to office space and the addition of a wet lab. The two conference room conversions at the west end of the sixth floor involved removing a conference table and chairs and refitting the rooms with cubicles and office furniture. Each of these rooms is now suitable for a company of up to six people. The new lab was carved out of existing office space (Room 614), and took advantage of an available fume hood. Each of these three new spaces is a dedicated space used by three separate companies.

> BIC has maintained a 100% occupancy rate, with a waiting list for available space.

The next significant facility change will occur in the next fiscal year, and will be a result of a $363,750 capital grant from the Massachusetts Life Sciences Center (MLSC). The BU submission in this competitive grant process proposed converting about 450 square feet of office and utility space to a biophotonics laboratory that includes a small bio-safety level 2 (BSL-2) facility. Unlike other labs in BIC, this lab will be equipped with shared or dedicated equipment that most start-up companies would not have the resources to replicate on their own. This concept will be new for BIC, and policies and procedures for the lab's use will be developed in parallel with the build-out.

The full list of FY2015 tenants (see table) includes: BU Ignition Awards winner RayVio, Cleantech and MassChallenge Accelerator award winner NBD Nanotechnologies, and Neurala, which was named as one of the 50 Most Influential Companies in the Global Robotics Industry by *Robotics Business Review*. Four BIC companies received significant venture capital or strategic investment in FY2015 and *Mass Medical Devices Journal* has capped off a five-year stay in BIC with their acquisition by Design World.

NBD Nanotechnologies, which has resided at BIC for two and a half years, will depart at the beginning of FY2016 for much larger facilities to support their growth. In the past year, this company has grown rapidly and has a long list of achievements that include a $5.2 million Series A financing, a $750K Small Business Innovative Research award, the Massachusetts Clean Energy Center InnovateMass Grant, and the naming of one of the founders to the *Forbes 30 Under 30 Energy List*.

All other companies in the Innovation Center have been here less than two years, reflecting the vibrancy of the center. Among these are Neurala, which received seed funding from Draper Ventures and contracts from the National Aeronautics and Space Administration (NASA) and the United States Air Force Research Labs (USAFRL) to develop deep learning controllers that emulate brain functions. Most of the other companies in BIC have also received awards or grants from NSF and/or NIH and are well positioned in many cases to win Phase II SBIR awards. In some of these cases, the company has collaborated with BU faculty, and the emphasis going forward is to increase the amount of faculty collaboration with BIC companies.

Perhaps an excellent model for building a university-wide corporate development model would be the relationship established with Bioventus, a joint venture formed by a multi-billion-dollar international corporation and a leading private equity firm. The company invested in upgrading the center's office space in order to attract the top talent in their field and is staffed with experienced business managers and scientists who have contributed significantly to the broader Photonics Center community. They have led and participated in College of Engineering career development activities, supported multiple senior design groups, sponsored research projects with BU faculty, invested in a mechanical testing device (Photonics Center) and a histology processing system (Medical Campus) that are available for general use, and actively hired student interns, all of whom have been fully involved with the company's development efforts and one of whom will become a full-time employee.

BIC tenants hired a total of 31 interns in FY2015. Most interns were BU undergraduate students, but the group also included one high school student and one student of BU's Bioscience Academy.

BIC continues to be a "Silver" sponsor of the MassChallenge Accelerator, an annual global competition that attracts over 1,200 companies, including leading corporations such as Fidelity and Verizon. BIC will offer space and shared lab access to the top photonics innovators in the 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.

2014 NSF Workshop on Non-invasive Imaging of Brain Function
At the NSF's request, Dr. Thomas Bifano chaired a workshop on Non-invasive Imaging of Brain Function in Arlington, VA. Dr. Bifano led a distinguished cadre of invited government, university, and industry researchers—including White House Science and Technology Policy advisors—through emerging opportunities and imaging modality recommendations that do not require the implantation of devices. Photonics technologies will play a key role in advances in non-invasive imaging of brain function, but this is also a computational/signal processing challenge

that must use neuroscience knowledge in order to get interpretable results. Among the invited guest speakers were Photonics Center members Associate Professor Lee Goldstein and Assistant Professor Xue Han.

CNN's XTNC Collaboration with CityLab Program
The primary community outreach activity of the Center for Nanoscience & Nanobiotechnology (CNN) Cross-disciplinary Training in Nanotechnology for Cancer (XTNC) program is through a collaboration with CityLab, a bioscience-learning laboratory representing a partnership between the Boston University Schools of Medicine and Education. This past year, XTNC graduate student and postdoc trainees developed six evening programs for CityLab's urban high school students. Trainees met regularly throughout the year to develop their nanomedicine curricula. They gave lectures and led participants through hands-on laboratory experiments designed to illustrate properties of nanoparticles. Throughout the year, trainees engaged 24 student participants from CityLab's Scholars Program in discussions about general principles and applications of nanotechnology, especially nanomedicine, and shared their experiences as graduate students and postdocs in nanotechnology cancer research, leading to trainee/student discussions about science and careers in science.

CNN's Involvement in BU's Upward Bound Math and Science Program
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 program. This federally funded college preparatory program serves 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 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. Last summer (2014), CNN faculty member Sean Andersson introduced Upward Bound students to fluorescence microscopy and had them build atomic force microscopy simulators from LEGOs, and Professor Anna Swan engaged students in nanophotonics experiments. A third session was led by graduate student trainees from CNN's Cross-disciplinary Training in Nanotechnology for Cancer (XTNC) program; XTNC trainees guided Upward Bound students through microfluidics experiments and nanoparticle synthesis. This summer, Professors Allison Dennis and Ahmad Khalil and XTNC trainees will host Upward Bound "nanocamp" students.

Photonics Center Summer Interns
During the summer of 2014, Photonics Center Director Thomas Bifano hosted two summer interns at the Photonics Center. Stephanie Pawlyszyn, majoring in Biomedical Engineering, and Sruti Raja, majoring in Biology, joined the Photonics Center to work on the NSF workshop on Non-invasive Imaging of Brain Function chaired by Bifano in Arlington, VA, on July 23 and 24. The interns helped coordinate the conference, interfacing with speakers regarding their poster presentations and providing note-taking support.

Student Satellite Project
Started in 2007 under grants from the US Air Force and the Massachusetts Space Grant Consortium (MASGC), the BU Small Satellite program (BUSAT) has steadily increased in internal popularity and national recognition ever since. Led by Photonics Professor Joshua Semeter, the BUSAT's current focus is a specific mission known as ANDESITE. Sponsored by the Air Force University Nanosat program, this ambitious mission seeks to deploy a network of magnetic sensors from a central mothership. The ejected sensors will operate collectively as a space-based wireless mesh network aimed at studying fine-scale variations in Earth's geomagnetic environment caused by space weather events. The scientific and technological innovations of ANDESITE place it at the cutting edge of the burgeoning cubesat movement. In 2014–2015, ANDESITE achieved several critical milestones, including a Critical Design Review in the summer of 2014, a victory at the final competition review in Albuquerque, NM, in February 2015, and selection by NASA for launch in late 2015.

Technology Innovation Scholars Program
College of Engineering Associate Dean Gretchen Fougere and undergraduate engineers in her Technology Innovation Scholars Program (TISP) piloted the Interferometric Reflectance Imaging Sensor (IRIS) outreach module—based on Photonics Professor Selim Ünlü's research on nanophotonics in conjunction with former graduate student Dr. Alexander Reddington—with three freshman physics classes at BU Academy in May 2015. Having just completed a unit on light and optics, the students quickly grasped the working

18th Annual Photonics Center Symposium

This year, the 18th Annual Photonics Center Symposium focused on Advanced Materials by Design for the 21st Century. The symposium drew 170 attendees from Boston University, outside academic institutions, and industry.

This year's symposium featured presentations by Photonics faculty members and researchers from leading research institutions:

Our speakers included:
Dr. Dmitry Bedrov, University of Utah
Dr. Martin Berzins, University of Utah
Dr. Luca Dal Negro, Boston University
Dr. Matthew Glaser, University of Colorado
Dr. William Mattson, Army Research Laboratory
Dr. Habib Najm, Sandia National Laboratory
Dr. Thomas Reinecke, Naval Research Laboratory
Dr. Sahar Sharifzadeh, Boston University

The symposium included lunch speaker Professor Theodore Moustakas on the topic of Traditional Compounds and Nitride Semiconductors. At the conclusion of this year's conference, a reception was held where participants and speakers discussed their research in an informal setting.

Forum Schedule (see p. 38)

Date	Speaker	Presentation
September 24, 2014	Mr. Bernardo Cordovez, Optofluidics	Chemical Analysis of Submicron Particles Using Near-field Photonics
October 29, 2014	Mr. Sean Burns, Airgas, & Mr. Paul Mak, Boston University	Airgas Training & Optoelectronic Processing Facility Training
November 18, 2014	Mr. William Closs, Instruments NE—Ocean Optics	Ocean Optics Products for Photonics
January 29, 2015	Professor John Connor, Boston University	Novel Imaging Techniques for the Rapid Capture and Visualization of Hemorrhagic Fever Viruses
February 25, 2015	Mr. William Kallinich, Boston University	Annual Laboratory Safety Training
April 29, 2015	Professor Soumendra Basu, Boston University	Novel Electron Microscopy in Materials Science Research

Photonics Center Guest Speakers Over the year, the Boston University Photonics Center hosted several seminars given by photonics experts. The following list includes the 2014–2015 seminars.

Date	Speaker	Title
September 18, 2014	Dr. Hui Cao, Yale University	Disordered Photonics
October 1, 2014	Dr. Brian Cunningham, University of Illinois Champaign-Urbana	Four Orders of Magnitude: Nanophotonics Biosensors for Detection of Molecules to Tissues
October 9, 2014	Dr. Sunil Bhave, Cornell University	Monolithic MEMS and Photonics Systems
December 5, 2014	Dr. Stefan Maier, Imperial College	Nanoplasmonics: Fundamentals, Materials Considerations, and Applications
December 16, 2015	Dr. Aydogan Ozcan, UCLA	Democratization of Next-Generation Imaging, Diagnostics and Measurement Tools through Computational Photonics
January 16, 2015	Dr. Bahram Javidi, University of Connecticut	Three Dimensional Imaging, Visualization, and Display
March 2, 2015	Dr. Yurii Vlasov, IBM Research	Applications of Integrated Photonics Technology—From Optical Interconnects to Neurophotonics
March 3, 2015	Dr. Frank Vollmer, Brigham and Women's Hospital/Harvard University	Advances in Biodetection with Optical and Mechanical Microresonators
March 4, 2015	Dr. Demetri Christodoulides, University of Central Florida	Parity Time Symmetry and Supersymmetry in Optics

Outreach & Other Activities *continued*

principles of the IRIS instruments and connected them to the societal need for a reliable and inexpensive point-of-care viral diagnostic device. Using the IRIS instruments, students were able to identify the recessed or raised quality of nanoscale features embedded on silicon chips, an identification process that models the application of the device to the diagnosis of pathogens. The activity is designed to show how engineers address societal problems, such as global health, by applying scientific concepts taught in the classroom. Several of the TISP members who delivered the activity are also enrolled in the STEM Engineer Educator Program (STEEP), in which they will take an additional year of education classes and graduate with both a BS in engineering and an MA in either math or science education. STEEP is a dual degree program formed in October 2012.

Events and Programs

The Photonics Center offers an exciting array of events and programs throughout the year to engage the community and offer enriching opportunities to BU and other Boston-area universities, as well as local companies. These events foster interdisciplinary discussion and encourage faculty and students to collaborate with a variety of professionals on fundamental research.

Photonics Cafes and Forums

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

The Photonics Forums, held on the fourth Wednesday of each month throughout the fall of 2014 and the spring of 2015, offered the community opportunities to participate in technical discussions in an open forum over lunch. Speakers discussed their current research endeavors and the real-world applications of their research. ■

Facilities & Equipment

NEW EQUIPMENT

The Equipment Committee, led this year by Professor Helen Fawcett with assistance from Professor Roberto Paiella, represents Photonics Center members in the identification and ranking of new equipment purchases. New equipment purchased this year was a new dual-purpose PVD tool for evaporation and sputtering, an Angstrom Engineering Evaporator (EVOVAC).

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.

This year's Capital Equipment Committee recommended the purchase of an Angstrom Engineering EvoVac deposition system, a Windows based SCADA - PLC control interface software with auto sequence and manual mode system operation. It includes three in MAG II sputter sources and one multi-pocket (6x7cc) e-beam source. The system also includes a variable angle deposition stage that can provide tilt capability for various thin film growth patterns. The sputter sources are mounted on z-linear manipulators so that source to substrate distance can be adjusted during the deposition process. The e-beam source package includes a programmable two-axis sweep controller with selectable triangular or sinusoidal waveforms, oscillating circle pattern or rotating line, and backside substrate heating from ambient to 600 degrees Celsius.

The instrument was delivered to Boston University at the end of July and installed in August. Due to space limitations and common functionality, the Sharon vacuum system will be removed from the cleanroom in OPF to accommodate the new Angstrom deposition system. The Sharon system will become part of Professor David Bishop's DARPA A2P award that will be set up in Photonics 603.

BUILDING PROJECTS

PHO 628—Multiscale Laser Lithography Lab–ML^3

Construction of the Multiscale Laser Lithography Laboratory for Professor Alice White was completed in FY2015. Professor White's group conducts research in three-dimensional lithographic structures. In the fall of 2014, a Nanoscribe instrument was installed in the laboratory on the 6th floor and the White group—and other researchers exploring three-dimensional lithography—have used this tool.

PHO 629—Atomic Membrane Lab

A new laboratory for Professor Scott Bunch, a member of the Materials Science Division and Mechanical Engineering Department, was completed in FY2015. The laboratory includes various tube furnaces for materials growth and chemical fume hoods and an atomic force microscope. The lab focuses on nanomechanical properties of a new class of 2D atomically thin materials such as graphene (single atomic layers of graphite).

PHO B10—Sample Preparation Room

In order to complement the TEM in the basement of Photonics, a sample preparation room was constructed and completed in FY2015. Within the sample preparation room are a lapping machine, a grinder, a disc cutter, and hand-polishing set-ups. The room can be used for all sample preparation including for SEM and laboratory usage, but its main users are the Materials Science TEM users.

PHO 805—Professor Enrico Bellotti

Professor Bellotti identified the need for laser space and a segregated ITAR location and as a result, a small lab space was designed to provide laser space and a separate ITAR laser space on the 8th floor. This space was completed in the spring of 2015.

PHO 614B—Innovation Center

A laboratory space for wet chemistry work was designed in the Innovation Center on the 6th floor, which enables a company to use the chemical fume hood and complete wet chemistry work.

PHO 505—Professor Siddharth Ramachandran

Renovations to Professor Ramachandran's laboratory were completed this year. With expanding laser needs, different portions of the laboratory were reconfigured. This work included: separating laser tables, moving related facilities (electrical, plumbing, HVAC), and adding laser curtains.

SHARED LABORATORY FACILITIES

The four shared labs at the Photonics Center contain a variety of instruments and capabilities designed to serve the needs of the Photonics community. The Optoelectronic Processing Facility (OPF) includes a Class 100 photolithography cleanroom and a Class 1000 cleanroom with processing and test equipment for die and wafer level processing. The Integrated Optics Laboratory (IOL) includes a flip chip bonding system in the Class 100 cleanroom and 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 an 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 that contains equipment for semiconductor and optoelectronic water fabrication. The facility includes both a Class 100 and 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 six-inch wafers, while the Suss Microtech Delta 80 is used to spin chrome on glass masters that can be written using the Heidelberg Direct Write Laser System as well as larger wafers. The laboratory conveniently provides ovens and a hood for bakes to facilitate development. Chip and wafer exposure is achieved through two UV exposure tools; the MJB3 (for three-inch masks or smaller) and the MA6 (up to six-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 a three-inch wafer.

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 and faculty so that they do not have to handle liquid HF, but rather can use the vapor system to release oxide films. This system accommodates small pieces of wafers as well as four- and six-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 give students the ability to learn about different coating processing methodologies and how to measure the films deposited after processing. Increased research in coatings led to the installation of a high-temperature annealing furnace in the cleanroom that covers both low- and high-temperature annealing.

Wire bonding, wedge bonding, and testing can also be done inside the cleanroom in OPF. The Current Voltage/Capacitance Voltage characterization test set-up is used to evaluate devices post-wire bonding and pre-integration into test set-ups on the lab bench. 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 place-

ment 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. The upgraded system continues to be a heavily used device for spectroscopy applications.

Precision Measurement Laboratory (PML)

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), and 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 (CL) monochromator allows the detection of energy released in the visible spectrum from electrons in an atom returning to their original energy level after being excited by the bombardment of electrons from the e-beam in the SEM. From the spectrum, elements within the sample can also be determined and emission spectrum can be evaluated. CL spectra provide information about wavelength of the emitted light at areas of interests (dislocations, grain boundaries, lattice imperfections). CL maps provide information about spatial distribution of light and defects in the specimen.

The second laboratory space includes: a Veeco (formerly Digital Instruments) Atomic Force Microscope (AFM) a Pico-Force AFM System, a Zeiss Supra 40VP Field Emission Scanning Electron Microscope (FESEM), a Zygo NewView 6300 and a Zeiss Supra 55VP FESEM. The Pico-Force AFM System enables accurate force measurements and manipulation of biological or material samples at the pico-Newton level, including inter- and intramolecular forces, for applications ranging from drug discovery to basic molecular-scale research. The Zeiss Supra 40VP FESEM allows polymers and plastics to be viewed without conductive coatings, thus a non-destructive way to view a sample. The 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 an FEI Quanta 3D FEG FIB (Field Emission Gun Focused Ion Beam) system in one room and an 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 backscattered 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), Oxford Instruments Energy Dispersive Spectrometry (EDS). The system also includes gas injector modules (GIS) and an Omniprobe micromanipulator can be used for TEM sample preparation and lift-out. For research applications and to study in situ dynamic behavior of materials at different humidity (up to 100% RH) and temperatures (-10 °C to 1000 °C), an additional Peltier/Heating Stage Control Kit was included in the purchase.

The FEI Tecnai Osiris TEM system specifications state a TEM point resolution of 0.25 nm, line 0.102 nm, extended to 0.16 nm with TrueImage™ software, and STEM HAADF 0.18 nm. The system includes Super-X EDX detection system, SDD technology, windowless, shutter-protected, X-FEG Electron Source and also includes EFTEM with EELS and a Gatan 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 the Bright Field/Dark Field detector on the TEM. ■

Boston University Photonics Center

8 Saint Mary's Street, Suite 936
Boston, Massachusetts 02215

www.bu.edu/photonics