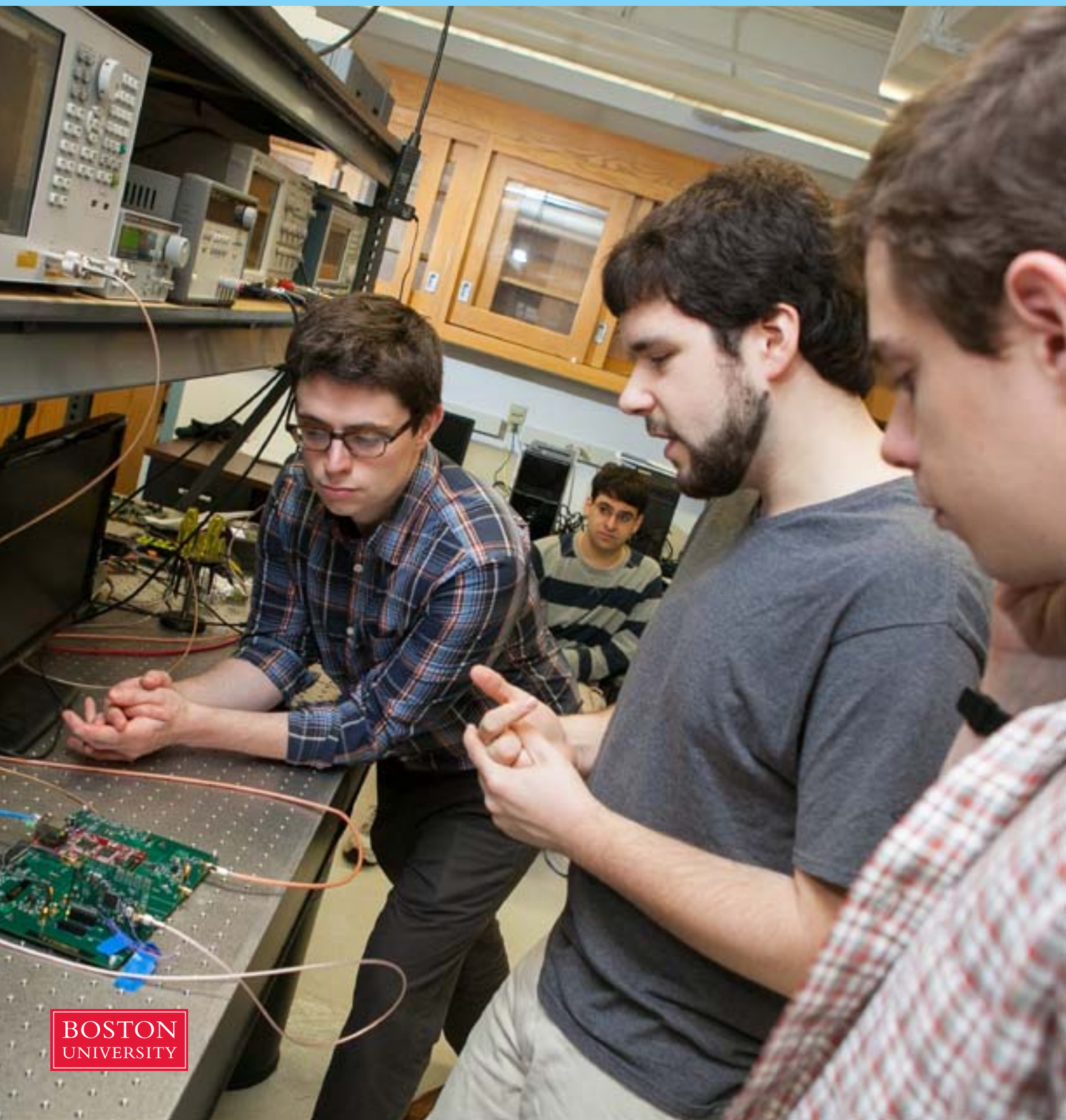
Boston University Photonics Center
Annual Report 2016



Letter from the Director

This annual report summarizes activities of the Boston University Photonics Center in the 2015-2016 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 51 faculty members, 11 staff members, and more than 100 graduate students and postdoctoral fellows.

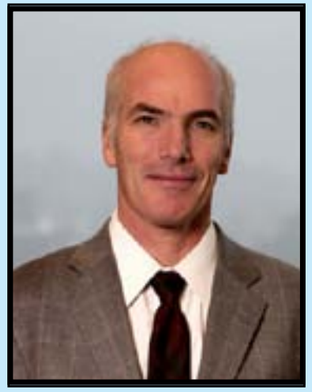
This has been a good year for the Photonics Center. In the following pages, you will see that this year the Center's faculty received prodigious honors and awards, generated more than 100 notable scholarly publications in the leading journals in our field, and attracted $18.9M in new research grants/contracts. Faculty and staff also expanded their efforts in education and training, and cooperated in supporting National Science Foundation sponsored Sites for **Research Experiences for Undergraduates** and for **Research Experiences for Teachers**. As a community, we emphasized the theme of "**Frontiers in Plasmonics as Enabling Science in Photonics and Beyond**" at our annual symposium, hosted by Bjoern Reinhard. We continued to support the National Photonics Initiative, and contributed as a cooperating site in the American Institute for Manufacturing Integrated Photonics (AIM Photonics) which began this year as 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 **Development of Less Toxic Treatment Strategies for Metastatic and Drug Resistant Breast Cancer Using Noninvasive Optical Monitoring** led by Professor Darren Roblyer, continued support of our NIH-sponsored, **Center for Innovation in Point of Care Technologies for the Future of Cancer Care** led by Professor Cathy Klapperich, and an exciting confluence of new grant awards in the area of **Neurophotonics** led by Professors Christopher Gabel, Timothy Gardner, Xue Han, Jerome Mertz, Siddharth Ramachandran, Jason Ritt, and John White. Neurophotonics is fast becoming a leading area of strength of the Photonics Center.

The Industry/University Collaborative Research Center, which has become the centerpiece of our translational biophotonics program, continues to focus on advancing the health care and medical device industries, and has entered its sixth 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



Our iconic building houses world-class research facilities and shared laboratories dedicated to photonics research.

Photonics Center Annual Report 2016

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Mission Statement

THE BOSTON UNIVERSITY PHOTONICS CENTER generates fundamental knowledge and develops innovative technology in the field of photonics. We work on challenging problems that are important to society, we translate enabling research discoveries into useful prototypes, and we educate future leaders in the field.

This mission is executed through:

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

The Photonics Center community of faculty, students, and staff engage in numerous interdisciplinary collaborations to further the field. Below are examples of how the Photonics Center and its diverse community executes each of the four pillars supporting our mission.

Basic Research and Scholarship in Photonics

Photonics Center faculty are involved in research in diverse fields of study anchored by thematic areas of strength in biophotonics, imaging, nanophotonics, nonlinear and quantum photonics, and photonic materials and devices. Strengths in these fields combined with expertise in specialties such as adaptive optics and wavefront control in imaging and optogenetics that enables neuronal control will help lead to an understanding of the connections between brain physiology and human behavior. In fact, these areas formed the core of the NSF Research Traineeship (NRT) proposal that the Photonics Center was just awarded and which will be launched in the next fiscal year.

Academic and Entrepreneurial Programs and Initiatives for Students

While the Photonics Center does not offer academic degrees, the faculty teach a broad array of graduate and undergraduate courses that cut across traditional departmental curricula. Beyond the classroom, students engage in diverse entrepreneurial activities, including internships with companies in the Business Innovation Center, opportunities for engagement/networking with industry, particularly with members of the I/UCRC, and participation in the annual Photonics symposium. The NSF Research Experiences for Undergraduates and Research Experiences for Teachers sites in Integrated Nanomanufacturing are now in their second year. The REU program offers summer research opportunities for undergraduates from around the country with an emphasis on students with limited or no STEM research opportunities in Mechanical, Materials Science, Electrical and Computer and Biomedical Engineering. The RET program focuses on providing engineering support and training for middle and high school teachers from public schools with high percentages of low income families. These sites also provide BU graduate researchers diverse training and mentoring opportunities not often included as part of a graduate education experience.

Highlights of FY2016

External Grant Funding
External grant funding for FY16 totaled over $18.9M, 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 and Systems, and continuation of 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
The Business Innovation Center (BIC) has seen a healthy turnover in the last year with four companies leaving because of growth or acquisition, and three highly innovative and well-funded companies joining the Center. There are currently eleven tenants with management teams fully supportive of the educational objectives of BIC. Management at BIC companies have been featured speakers at the School of Engineering's "Lunch and Learn" series, BU's Upward Bound series, and the Photonics Center Forum series, providing valuable insight to students. The companies have collectively hired 31 interns in FY16, and sponsored Biomedical Engineering Senior Design and MBA Entrepreneurship projects. The Center also completed the renovation of Innovation Center office space into a bio-safety level 2 (BSL-2) laboratory facility outfitted with essential equipment, which was partially funded by a $363,750 grant from the Massachusetts Life Sciences Center (MLSC). This facility will provide affordable and unique space to small companies and enables these companies to focus on product development and business growth.

The 19th Annual Photonics Center Symposium: Frontiers in Plasmonics as Enabling Science in Photonics and Beyond
This year, the annual symposium focused on Frontiers in Plasmonics as Enabling Science in Photonics and Beyond. Professor Bjoern Reinhard chaired the conference, which drew nearly 180 attendees. Faculty from Stanford University, University of Cambridge, Rice University, Northwestern University and University of Michigan delivered talks. The program featured a day full of talks, including a lunch talk, and a reception with electronic poster boards where participants and speakers discussed their research.

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

PHOTONICS CENTER
at a glance

51 faculty members

11 staff members

89 funded R&D projects

funding for R&D
$18.9M

45 photonics courses

147 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 Nanotechnology Innovation Center (BUnano), the Industry/University Cooperative Research Center (I/UCRC) on Biophotonic Sensors and Systems (CBSS), the Center for Innovation in Point of Care Technologies for the Future of Cancer Care, the Materials Science and Engineering Division, and the SMART Lighting Engineering Research Center. With respect to the Materials Division, the Photonics Center has managed substantial renovations for the Materials Division and co-manages shared labs such as the Transmission Electron Microscope (TEM)/Focused Ion Beam (FIB) facility. In addition to these facilities, the Photonics 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 initial five years of the I/UCRC on Biophotonic Sensors and Systems (CBSS) and is operating on a "no-cost" extension until NSF makes a decision on the Center's Phase II proposal. These efforts have yielded a well-functioning collaborative engagement between the two university sites (BU and UC Davis) and participating industry members, and CBSS has become an active hub for industry-focused research in the biophotonic technology sector. There have been a total of 17 corporate members during Phase I, 21 distinct projects were undertaken with corporate funding and at BU at total of 44 students or postdoctoral associates were supported with eight CBSS affiliated students graduating with Ph.D.s.

The resources and expertise of the Photonics Center staff are employed to manage grants for several affiliated centers. These grants include: faculty grants from NIH and NSF related to viral diagnostic technology, Research Experiences for Teachers, Research Experience for Undergraduates, a substantial effort in Research Experiences for Veterans, 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).

The organizational and post-award project management expertise of Photonics Center staff is also employed on leading and supporting major new grants. In addition to the I/UCRC Phase II proposal, the Photonics Center led or significantly contributed to a NSF Research Traineeship proposal in Neurophotonics (subsequently awarded), and a NSF Nanosystems Engineering Research Center (ERC) proposal on Directed Multiscale Assembly of Cellular Metamaterials with Nanoscale Precision (CELL-MET), which is still under review.

At the Business Innovation Center, located on the 6th floor of the Photonics Center, 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, plasmonics, 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

PHOTONICS CENTER PROGRAMS PROMOTE DIVERSITY IN STEM FIELDS

NSF SPONSORS SUMMER RESEARCH BY UNDERGRADS, HIGH-SCHOOL TEACHERS

by Joel Brown

LAUREN STRONG, A COMMUNITY COLLEGE STUDENT FROM PENNSYLVANIA, was searching for an internship that would allow her to develop her engineering skills and feel more at home in a lab. Local high school science teacher George DeGregorio was looking for ways to develop his underprivileged students' interest in science. Both are pursuing their goals thanks to two new summer nanotechnology research programs offered at BU's Photonics Center. The purpose of the programs—both funded by the National Science Foundation (NSF)—is to promote diversity in STEM (science, technology, engineering, and mathematics) fields.

Strong recalls her first year in college, at the University of Pennsylvania in 2008. "I was in computer science, and in my class I was the only woman, and the only black woman, and that really says a lot," she says.

DeGregorio, a science teacher at East Boston High School, says that most of his students "couldn't even imagine themselves being a scientist. There seems to be a disconnect, and I am trying to break those walls down."

The purpose of the two programs, NSF Research Experiences for Undergraduates and NSF Research Experiences for Teachers, "is to make authentic research experiences available for underrepresented minority undergraduates or for teachers who work in underresourced schools," according to Bennett Goldberg, director of BU's STEM Education Initiatives and a principal investigator of the teachers' program. The programs allow participants "to engage in the deep learning that happens with getting involved in research, the whole cycle of inquiry, because that's so important to developing the skill sets and minds of students," says Goldberg, a College of Arts & Sciences professor of physics and a College of Engineering professor of electrical and computer engineering and of biomedical engineering.

"What we tried very hard to do this year was focus strongly on diversity among the students that were coming in and to focus on teachers who were serving underprivileged Boston-area schools," says Photonics Center director Thomas Bifano, an ENG professor of mechanical engineering.

Strong is one of 11 students enrolled in the undergraduate program, about half of them from colleges that offer little in the way of research opportunities in engineering disciplines such as materials science and biomedical engineering. As a computer science major at Penn, she had felt her odd-woman-out status and found that the predominantly young and male engineers often "don't take you as seriously as they should. They live in a bubble and they're not used to seeing people of color and women doing these things and excelling at these things," she says. She left school after a year and traveled, working in China for a while as an au pair, before returning to college last year at Northampton Community College in Pennsylvania, still planning a career in science or engineering.

The college "does have an engineering program but doesn't offer any research opportunities," she says. "So you're pretty much just taking their core classes. You're not really getting any hands-on experience with engineering or photonics or anything like that."

She discovered the BU program on a Facebook page for women engineers while looking for a summer internship and was surprised when her last-minute application was accepted. Since arriving on campus, she's been working with graduate students in the lab of Roberto Paiella, an ENG professor of electrical and computer engineering. Her research involves studying different processes to etch a silicon wafer to a depth of only 500 nanometers, just one preparatory step in a complex project to transmit data between chips via laser.

"It's completely new to me—I never did anything like that," Strong says. "Here, they kinda just throw you in. I'm like, 'Uh, you want me to touch this $100,000-plus

The purpose is to make authentic research experiences available for underrepresented minority undergraduates or for teachers who work in underresourced schools.

NSF UNDERGRADS AND HIGH-SCHOOL TEACHERS GATHER IN THE CLEANROOM

equipment?' I was nervous about breaking everything I touched."

But she's adjusted quickly, and the work is paying real benefits in skills and experience that will set her apart from other undergraduates, she says. And it will also look good on her transcript when applying to four-year colleges next year and later to graduate school.

"It's everything," she says. "Coming here, working with the grad students, seeing what they're doing…gives me ideas for what I want to do. It allows me to focus a lot more on the end goal."

"Lauren came into my office the other day and said, 'Helen, I've been bitten! I've been bitten by the research bug!'" says Helen E. Fawcett (GRS'97), an ENG research assistant professor of mechanical engineering, Photonics Center manager of operations and technical programs, and co–principal investigator of both NSF programs. "And I said, 'Uh-oh, because you were sure computer science was your major.'"

A THRILLING, OCCASIONALLY BOGGLING EXPERIENCE

The Research Experiences for Teachers program brings teachers from high-need Boston-area high schools and community colleges to BU to work with faculty on research projects. The goal is for them to return to their classroom and convey to their students the excitement created by doing hands-on research.

DeGregorio's parents grew up in East Boston, and he spent a lot of time there as a child. He earned a bachelor's degree in biology from UMass Amherst and a master's in science education from Suffolk University. "I wasn't interested in going corporate," he says. "Teaching is: I don't feel like I have a job in the traditional sense. I have a lot of autonomy in the classroom to be myself. I get to make these connections and help kids. It's a way to do something positive."

He has spent his entire career at East Boston High, where he teaches a variety of life sciences classes. He says he feels a deep connection to the school, which his mother and his aunts and uncles attended. Many of today's students are from Central American immigrant families, rather than the predominantly Italian families when he was young.

"It's always been a great place for me," DeGregorio says. "There have been challenges for each of the 17 years I've been there. It's never been a wealthy neighborhood. It's usually been an immigrant neighborhood." Almost all of his students qualify for free or reduced price lunches, he says, and for many, perhaps a majority, English is not their primary language.

"We're trying to move the school forward," he says.

He applied to the BU program instead of teaching summer school and says it's a thrilling and occasionally boggling experience: "You're working in real labs that are producing real scientific papers that are influencing industry. Other projects are sprouting from the ones they've got going here. It's the real deal."

DeGregorio has spent the summer working with grad students in Bifano's lab, setting up a high-tech optical system that among other things can look below the surface of live tissue at the cellular level. As part of his research, he found himself at one point dispatched to the

Medical Campus to pick up some nematodes that had been genetically engineered so their neurons fluoresce. "There's science fiction coming to life in here," he says with a laugh.

But his goals for the summer are serious and long-term. "Whatever connections can be made," he says, "they can help students perceive themselves in science, number one, in college, number two, and at a prestigious institution like BU, number three."

The programs have been interwoven to a degree. The undergrad program runs from June 8 to August 14, the teacher program from July 6 to August 14. In most cases the arriving teachers were partnered with the undergraduates, who had already found their feet at BU, a little bit of a role reversal. "I worried about it, especially in my lab," says Xin Zhang, an ENG professor of mechanical engineering and co–principal investigator of the undergraduate program. "Turned out I was thrilled to see them happily and professionally working together."

The Photonics Center will make an ongoing effort to help both groups transfer their summer's experiences back to their classroom.

"We're not going to say in August, 'Bye! Great knowing you! See ya!' We're going to keep in touch with these students, help them out for grad school," says Fawcett. "We're not going to say to the teachers, 'Great, have fun putting that in your classroom!' The expectation is we are creating a community of nanontechnology STEM teachers, and each year we're going to have a STEM seminar…and grow that community."

There's also a concerted effort to provide a well-rounded experience for both the undergraduates, who live on campus, and the teachers, including brown-bag lunches on topics from the fundamentals of photonics to getting into grad school, as well as field trips to the Museum of Science and the Freedom Trail.

"There's a very strong sense in this community of the value of STEM education, the value of education in general," Bifano says. "It's not a do-good thing just to do good; it's a thing that we more or less have built into the cloth of the place."

BU WINS $13 MILLION IN PATENT INFRINGEMENT SUIT

ENG PROFESSOR'S LED DISCOVERY AT HEART OF CASE

by Joel Brown

A US District Court jury has awarded Boston University more than $13 million after finding that three companies infringed on a BU patent for blue LEDs (light emitting diodes), used in countless cell phones, tablets, laptops, and lighting products.

After a highly technical three-week trial in November, the 10-person jury unanimously found that the companies had willfully infringed on BU's patent for the invention by 2013 Innovator of the Year Theodore Moustakas, College of Engineering Distinguished Professor of Photonics and Optoelectronics Emeritus. Because the jury found the infringement to be willful, the $13,665,000 award could be doubled or tripled by Judge Patti B. Saris. No date has yet been announced for further proceedings.

Despite the amount of damages awarded, "the best part of this is that it validates Professor Moustakas' work," says Michael Pratt (Questrom'12), interim managing director of BU's Technology Development office. "The story is really not about the money. The first thing we want is recognition of his seminal contribution to this field."

Moustakas, who became a professor emeritus when he retired in June but continues to conduct research at the Photonics Center, testified extensively at the trial and was present in court every day. When the judge read the jury's verdict, "I put my head down," he says. "I cried." He describes the jury's decision as "amazing…everything we asked," saying also that his lifetime's work was being challenged.

"Fundamental to our mission as a global research institution is nurturing an environment of discovery that supports our faculty and the incredibly important work they do," says Jean Morrison, provost and chief academic officer. "We are delighted with the verdict in this case. Boston University has successfully fought, and will continue to fight, for our faculty members and the intellectual property they create here."

The three primary defendants, all Taiwan-based, were Epistar Corporation, Everlight Electronics Co., Ltd., and Lite-On Technology Corporation, along with various subsidiaries, most located in the United States. Each is involved in manufacturing or packaging LEDs for use in consumer electronics. A number of big-name electronics manufacturers were initially part of the University's case, but they avoided litigation by joining a settlement that includes licensing and confidentiality agreements.

The University was represented by Michael Shore, a partner at Shore Chan DePumpo LLP, in Dallas, specialists in intellectual property cases, and Erik Belt, a partner specializing in patent disputes at the Boston law firm McCarter and English LLC, which has represented BU before. While it is possible for the defendants to appeal the verdict, Belt says it would be difficult to overturn the jury's clear finding of fact.

The University will receive less than half of the final award, after the attorneys, who took the case on a contingency basis, and previous patent licensees are paid. Moustakas will receive 30 percent of the University's share.

Moustakas joined BU in 1987 and was named the University's inaugural Distinguished Professor of Photonics and Optoelectronics in 2014. A search is under way for his successor, and the Distinguished Professorship will be renamed the Theodore Moustakas Professorship of Photonics and Optoelectronics.

A US District Court jury awarded BU more than $13 million after finding three companies infringed on a BU patent for blue LEDs.

BU WINS PATENT INFRINGEMENT SUIT IN RELATION TO PROFESSOR THEODORE MOUSTAKAS' WORK

Moustakas' invention dates to June 22, 1990, when researchers in his lab were trying to produce microscopically thin layers of gallium nitride to be used in the LEDs, growing crystals of the substance at high temperatures. They discovered that a heater used in the experiment had malfunctioned and the material had cooled to 270 degrees Celsius, far below the intended 600 degrees. But instead of aborting the experiment, Moustakas told them to fix the heater and continue. The snafu led to the growth of a smoother, more translucent gallium nitride layer that also grew much faster when crystallized at the higher temperature, a result replicated—deliberately—the very next day.

The main patent for the LED was issued in 1997, based on an application first submitted in 1991. Since then, blue LEDs have become a key component in many products, because they can generate white light when coated with phosphor.

"The real story is the robustness of Moustakas' technology," says Pratt. "It really did become a personal story. There was an attack, an affront to his creation. They had two experts saying it didn't exist…and the jury wasn't buying that at all."

"To infringe in patent law, you don't have to know about the patent and you don't have to have an intent," says Belt. To prove willfulness, "you basically have to show the other side knew of the patent and they were perhaps recklessly disregarding the fact that they were infringing or willfully blind to it. There's a lot of ways to say it, but you basically have to show that there was willful disregard for BU's patent rights.

"I think this really validates Professor Moustakas' scientific breakthrough and establishes him as one of the great scientists in his field," Belt says.

LIGHT BEAMS AND DNA CAGES COULD DELIVER DRUGS TO JUST THE RIGHT SPOT

BIOMEDICAL ENGINEER XUE HAN SAYS NEW METHOD COULD POTENTIALLY HELP WITH BASIC RESEARCH AND TREATMENT FOR CANCER AND BRAIN DISEASE

by Neil Savage

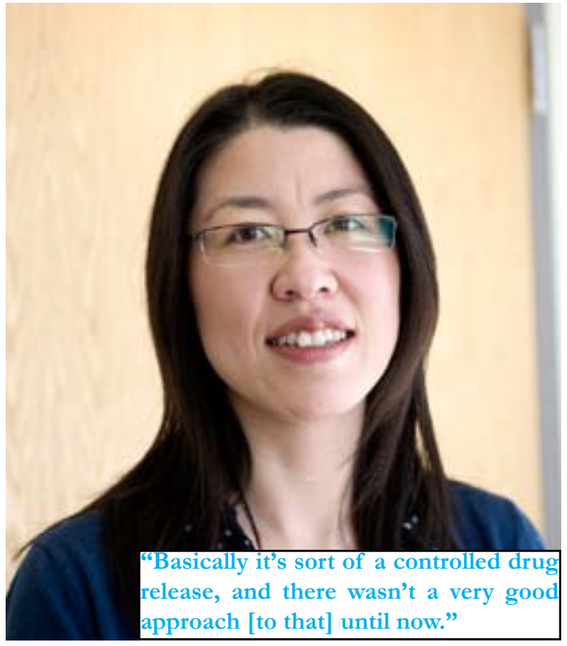
Getting drugs to go just where you want them inside the human body is no easy task, and using high doses of chemicals that are carried by the bloodstream to the wrong tissues or organs can lead to toxic side effects. That's why scientists have been working for years to figure out how to deliver much smaller doses to precise targets—developing chemotherapy drugs that bind only to tumor cells, for instance. Now Boston University researchers have developed a new method that traps drugs or other molecules within tiny cages made of DNA, then releases them once they've reached the right spot with a quick flash of light.

"Basically it's sort of a controlled drug release, and there wasn't a very good approach [to that] until now," says Xue Han, an assistant professor of biomedical engineering in Boston University's College of Engineering. "What we did is to put these drugs physically inside a cage."

Drugs are molecules, many of them big, with different areas on their surfaces that allow them to bind with receptors that have complementary areas, like puzzle pieces fitting together, allowing them to attach to and interact with a cell. The problem is that some cells have receptors that will take up a particular drug, even when they're not the cells that the drug is supposed to target. Scientists have traditionally dealt with this problem by adding small chemical groups to the surface of molecules so the receptor won't recognize it. Han, who is a Peter Paul Career Development Professor, says it's like sticking a tiny chemical hat on the drug to disguise it. For some small-molecule drugs, that can work well.

But some drugs, such as proteins, are just so big that a tiny modification won't disguise it. "A large protein wearing a small hat still looks like the same protein," she says.

Her idea was to enclose the protein in a cage, hiding it completely from the receptors. "The thing that reacts with this drug will not see the drug," she says. "It will see a box." Han and her study co-authors, Richie Kohman, a former postdoctoral fellow in Han's lab, Susie Cha, a graduate student in biomechanical engineering, and



"Basically it's sort of a controlled drug release, and there wasn't a very good approach [to that] until now."

PROFESSOR XUE HAN MAKES SIGNIFICANT MEDICAL GAINS

Hengye Man, an associate professor of biology in the BU College of Arts and Sciences, described their method in a paper published in ACS Nanoletters in March 2016.

To make the box, they turned to a technique called DNA origami, named for the Japanese art of folding sheets of paper into complex shapes, which scientists have been using for the past decade. Scientists can create a strand of DNA with its nucleic acids arranged in the order they want. They heat up the strands to near boiling, then let them slowly cool, and the natural attraction and repulsion between the different nucleic acids causes the strands to bend and fold into a desired shape. Kohman, who is a biomaterials engineer, and Han used DNA origami to create an open-ended barrel about 50 nanometers wide, with a 20-nanometer cavity inside. "That's large enough to fit some big proteins inside," Han says.

To keep their drugs in the enclosure, they left little bits of DNA hanging unattached inside the cage, then added more small molecules to act as tiny chains, binding to the drugs and holding them in place. The chains were designed so that a small jolt of energy from a beam of light would break them, setting the proteins free. Once the cage is in the right spot, the light snaps the chains and the drugs just drift out, winding up where they're wanted.

The researchers tested their system using a fluorescent dye called Oregon Green, which is commonly used to tag proteins and other biological molecules. They trapped molecules of the dye inside the cages, then zapped them with low-power beams of ultraviolet light. After 40 seconds of exposure, almost all the dye had left the cages.

The dye was a small molecule. To see if the scheme would work with larger proteins, the researchers trapped two other kinds of molecules. One was a protein derived from cow's blood. The other was streptavidin, a molecule used to bind drugs to cancer cells. After about a minute of low-level light exposure, most of the proteins had escaped the cages.

Finally, to check that the process didn't repress the biological activity of the molecules, they tried the technique on a small molecule called glutamate that affects the activity of brain cells. They added the caged glutamate to a culture of brain cells, hit them with a brief burst of light, then measured how the flow of calcium in the brain cells had changed. Just a 1 millisecond flash of light was enough to release the glutamate and increase calcium activity in the cells.

It's that finding that has Han most excited. She studies neuroscience, and is looking for ways both to understand the activity of brain cells and to deliver drugs that can affect that activity. For instance, there are certain molecules being studied that might slow the progression of Parkinson's disease, if they can be delivered to the right spot. "I'm really interested in all these neuropeptide hormones. There are so many of them in the brain," Han says. "We know peptide hormones are very important. We just don't know how they work."

One difficulty with any drug treatment for brain disorders, including cancer, is getting the drug past the blood-brain barrier. While that barrier prevents most molecules from moving out of the bloodstream and into brain cells, there are certain ones that pass easily, and it might be possible to use them to carry caged molecules to the brain. That could mean delivering the drug directly to the brain of a Parkinson's patient without having to stick a needle into it.

One question will be how to get light to these cages if they're deep in the body. That's something other people are still working on, Han says. Though the experiment used ultraviolet light, it might work better to use infrared light, which can penetrate tissue fairly deeply and is less likely to damage cells than ultraviolet. Chemists have already created molecular changes that break under infrared light. It might also be possible to shine light into certain areas by using an endoscope to carry it to cavities within the body.

Of course, any use in humans would require approval from the US Food and Drug Administration, which would require years of testing. But for lab studies involving cells in petri dishes, the technique could be used almost immediately, Han says. In fact, the potential uses, from basic research to treating neurological diseases to fighting cancer, could turn out to be many, she says. "I think it has very broad applications."

Han's research was funded by the National Institutes of Health, the Pew Foundation, the Alfred P. Sloan Foundation, and BU's Department of Biomedical Engineering.

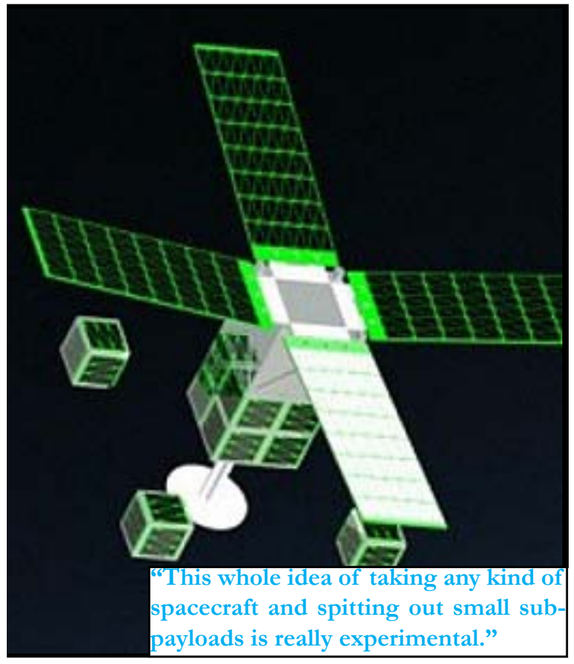
BU SATELLITE TEAM GETS BIG BOOST FROM NASA

WIRELESS SENSORS DEVELOPED BY BUSAT TO BE LAUNCHED INTO SPACE

by Rich Barlow

On March 10, 1989, a solar eruption blasted plasma toward Earth. Canadian utility Hydro-Quebec noticed a hop-skip-and-jump in the voltage on its grid two days later. On March 13, with plasma sweeping Earth's magnetic field and causing electric currents in the outer atmosphere, the grid shut down, plunging the province into darkness for nine hours.

Such bolts from the blue (or black) of space rarely wreak such havoc. But less severe irritants—interrupted radio transmissions, disrupted GPS devices, even rusting of pipelines—can result when electric currents course through the magnetic field, says Joshua Semeter, who'd



"This whole idea of taking any kind of spacecraft and spitting out small sub-payloads is really experimental."

BU ANDESITE TEAM MAKES SIGNIFICANT GAINS WITH NASA

like to know more about this phenomenon (largely because the magnetic field may be an essential ingredient for life on Earth). So would the federal government, which is why NASA has agreed to launch a network of wireless sensors named ANDESITE, developed by Semeter's College of Engineering students to study changes in Earth's magnetic field caused by space weather.

It is the final frontier, finally crossed: the first space launch for eight-year-old BU Student-satellite for Applications and Training, overseen by Semeter (ENG'92,'97), an ENG professor of electrical and computer engineering. Colloquially known as BUSAT, the program engages students in designing and operating small satellites. In 2015, the BUSAT group was one of the teams from a half dozen universities that beat out nine competitors to continue receiving support from the Air Force, which has contributed more than $500,000 to BUSAT projects. (BU also provided funding.) NASA has scheduled the launch for June 2017, Semeter says, assuming the agency's review shows that ANDESITE's ejecting sensors "won't blow up their vehicle."

ANDESITE sensors are DVD-sized boxes packed with electronics boards, and eight of them will hitch a ride on a NASA spacecraft that will spit them out roughly 280 miles above the Earth. Each sensor, traveling at a speed of approximately six miles per second, will complete an orbit of the Earth in roughly 90 minutes. The sensors will measure variations in electrical currents flowing in and out of the upper atmosphere along Earth's magnetic field. "From this we will learn about how turbulence forms in space plasmas and what the eventual effects of this will be" on things like radio signals, allowing for better modeling of those effects, Semeter says.

ANDESITE's success has already led to one terrestrial development, he adds. ENG has hired Brian Walsh (GRS'09,'12) as an associate professor of mechanical engineering. Walsh researches small satellites and space technology.

"This whole idea of taking any kind of spacecraft and spitting out small sub-payloads is really experimental," says Semeter, although ANDESITE employs "technology that's very well established here on Earth. They use it for self-driving cars and finding cabs in a city; Uber uses this kind of thing. This is wireless mesh network technology.…Our innovation was, why can't we use that in space? What science could you do?"

In July 2015, government representatives visited the students' lab at the Engineering Product Innovation Center for a demonstration of how the sensors would deploy during an upcoming zero-gravity test flight, a nausea-inducing trial that previous BUSAT students have experienced firsthand. The students rigged a contraption to gently fire sensors into a mesh net, a form of soccer-meets-space.

"Looks like a good setup," Zane Singleton of the Defense Department's Space Test Program and tech company MEI Technologies said at the demonstration.

Earlier in the history of miniaturized satellites, NASA was underwhelmed with the technology, Semeter says, with one official harrumphing, "Why would somebody who drives a Ferrari care about Matchboxes?" Then the National Science Foundation convinced NASA that solid science research could be done by mini-satellites. Today, ANDESITE is but one government effort to study space weather. In February 2015, a National Oceanic and Atmospheric Administration satellite was launched to record data about solar wind.

Cody Nabong (ENG'15), ANDESITE's project manager, joined BUSAT on a buddy's recommendation after being stymied in his search for an internship. (A picture of his friend on a zero-gravity flight was a grabber.) "I've been interested in aerospace since I came here, so it wasn't a hard decision," says Nabong, who appreciates the hands-on practice of the classroom concepts he's studied that the team has provided. "The computer program that you use to make your 3-D models—I got a lot of practice with that. And then I learned a bunch about communications stuff that I wouldn't have been exposed to if I had just had courses.…The biggest thing I've learned is how you meet requirements for an engineering project," he says, referring to the government competitions and reviews the ANDESITE project has hurdled.

If the foregoing sounds uber-Star Trek-y, BUSAT's members include some liberal arts disciplines majors who came for graduate engineering study through BU's LEAP (Late Entry Accelerated Program) initiative. One BUSAT alumnus was a building contractor from San Francisco, who was "perfectly suited for this job," says Semeter. "He's used to going to the project site, telling people what to do. That's all we needed. And he was technically competent."

Faculty & Staff

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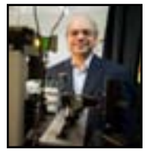
- Nanomechanics and NEMS



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- IR and SERS based approaches

FACULTY COMMITTEES

The Photonics Center has five committees that support and serve its faculty and staff. The Photonics Center Director appoints committee chairs each year.

Photonics Center Guest Speakers:
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:
Chair – Open
The Education Committee investigates methods for applying and enriching education of photonics within the community and BU programs.

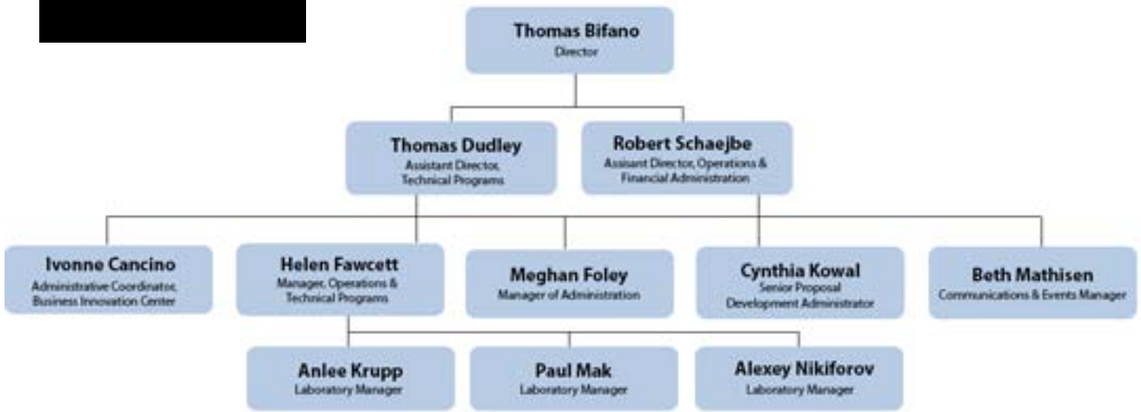
Academic Advisory:
Chair – Dr. Thomas Bifano
The Academic Advisory Committee advises the Director of the Photonics Center on educational and academic issues and is comprised of the chairs from the Center's affiliated departments.

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

Symposium:
Chair – Dr. Bjorn Reinhard
This committee chair organized the 19th annual Photonics Center Symposium that focused on frontiers in plasmonics as enabling science in photonics and beyond. The symposium included external university speakers.

Leadership & Administrative Staff

Photonics Center Organizational Chart



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Research Projects & Technology Development

FACULTY MEMBERS AND STAFF OF THE PHOTONICS CENTER continue to be involved in a number of leading-edge research activities either through support of affiliated units in the Materials Science and Engineering Division, the Nanotechnology Innovation Center (BUnano), the Industry/University Cooperative Research Center (I/UCRC) on Biophotonic Sensors and Systems (CBSS), and the Smart Lighting Engineering Research Center or through the administration of block grants from the National Institute of Health, National Science Foundation (NSF), and Department of the Army and others.
I/UCRC on Biophotonic Sensors and Systems

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. NSF has funded several of these I/UCRC centers, each center is unique and focused on a specific theme. As the title implies, CBSS is focused on biophotonic sensors and systems, and any other university desiring to establish a center in this field would be directed by NSF to collaborate with CBSS. The mission of CBSS is:

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

The BU Photonics Center conceived of and led CBSS through the planning stages and the Phase I award and, along with the partner university site University of California at Davis, has achieved a number of significant results. During Phase I, CBSS engaged more than 50 scientists, engineers, and business professionals at Boston University and the University of California Davis. The current industry membership for CBSS stands at eight corporate members and over the first five years, the Center had a total of 17 corporate members. Some notable accomplishments during Phase I include:

- 21 distinct research projects were supported by affiliated companies.
- 2 new patents were made available to affiliated companies.
- 5 project technologies are being commercialized by affiliated companies.
- 1 spin-out company was launched (also a graduate of the NSF I-Corps).
- 42 publications were associated with CBSS funded research projects.
- At the BU Site: 29 graduate students, 11 postgraduate associates, and 4 undergraduate students were supported, and 8 CBSS-affiliated students graduated with PhDs.
- At the BU Site: 4 REU, 1 RET, and 2 REV/VRS supplements were received.
- Some highlights of impacts to the biophotonics field that are directly attributable to CBSS efforts at the BU site include:

— A cooperative project on biosensing for Urinary Tract Infections (UTIs) led to a direct product launch by a member company (BioTools).

—Technology and results from a cooperative project on Superpenetration multiphoton microcopy were translated to a member company (Thorlabs), where they are being integrated into a new adaptive optics technology for commercial two-photon microscopes.

—Intellectual property developed in a cooperative project on cancer detection using surface reflectance interferometry led to the spin-out of a company (nanoView Diagnostics) that subsequently participated in I-Corps and SBIR programs at NSF.

In the final year of Phase I, seven research projects were approved and funded by the membership. Four of these projects were selected by consensus at the May 2015 program formulation meeting, and the other three were directed projects selected by new members as permitted by the Center bylaws. A summary of these projects appears in the following table, with further details on the BU related projects appearing in the text below.

Project	Project PI	Site	Mentor	Start	End	Budget
Rapid Multiplexed Sample-to-Answer Diagnostic for High Consequence Pathogens	Connor	BU	BD	6/14	6/16	$204K
Near-Field Nanotweezers Raman System for Characterizing SERS Nano Sensors	Chan	UCD	Optoflu-idics	7/15	6/16	$50K
Functional OCT Micrometer Resolution Imaging	Zawadski	UCD	Iris AO	7/15	6/16	$50K
Development of High Resolution, Large Dynamic Range Wavefront Sensor for Adaptive Optics	Mertz	BU	Thorlabs	6/15	6/16	$50K
Chemometrics in the Presence of Large Background Noise	Lane	UCD	eLutions	5/15	6/16	$50K
Low Magnification IRIS Instrument for Antibody Spotting Development and Quality Control	Unlu	BU	Scienion	9/15	TBD	$120K
First Steps Towards fs Laser Surgery: Identify the Optimal Laser Parameters	Wachsmann-Hogui	UCD	Nikon	10/15	TBD	$75K

Note that each of the projects is assigned a mentor from industry, who helps set the direction for research and guide research to achieve results aligned with potential commercial applications.

RAPID MULTIPLEXED SAMPLE-TO-ANSWER DIAGNOSTIC FOR HIGH CONSEQUENCE PATHOGENS – (CONNOR). Professor John Connor, in close collaboration with the IAB mentor Becton Dickinson (BD), has received two years of support for this project to develop diagnostic assays for viral hemorrhagic fever (Lassa, Marburg and Ebola) and malaria. The assays will be "in-liquid ELISAs" compatible with the BD Homogeneous No-Wash System (HNS). Professor Connor 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 and a low expected cost of production.

DEVELOPMENT OF HIGH RESOLUTION, LARGE DYNAMIC RANGE WAVEFRONT SENSOR FOR ADAPTIVE OPTICS – (MERTZ). This project, led by Professor Jerome Mertz, and mentored and funded through a second membership by Thorlabs, developed an adaptive optics strategy to perform real-time de-blurring over large fields of view in a non-scanning, camera based microscopy system. Using key innovations referred to as Partitioned Aperature Wavefront (PAW) sensor and Oblique Back-Illumination Microscopy (OBM) that can be implemented as add-ons to standard microscopes, a large field of view adaptive optics was demonstrated using both non-fluorescent and fluorescent samples. Thorlabs expects to add this technology to their product portfolio.

LOW MAGNIFICATION IRIS INSTRUMENT FOR ANTIBODY SPOTTING DEVELOPMENT AND QUALITY CONTROL – (UNLU). This project is very application specific and involves the development of a label-free interferometric detection technology for quality control checks of liquid dispensing processes used to deposit proteins and cells on various spotting substrates. Initially planned to be used in research, Scienion, the mentor on this project, would expect to ultimately use this in a production scale QC check.

The Phase II I/UCRC proposal was submitted to NSF with a proposed start date to coincide with the February 28, 2017 end date of the "no-cost" Phase I extension. Project timelines and budgets for the FY17 projects are being accelerated to be completed before the start of Phase II.

On a "no-cost" extension through February 28, 2017, CBSS conducted the program formulation meeting for FY17 in May 2016 after a formal solicitation process that resulted in 37 proposals submitted by faculty researchers. A screened set of these proposals were 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. The projects that will be launched in FY17 at Boston University appear in the following table.

Project	Project PI	Mentor	Budget
Low Magnification IRIS Instrument for Antibody Spotting Development and Quality Control *(continued from FY16)*	Unlu	Scienion	$120K
Module for Smart Phone Based Nucleic Acid Detection of Mosquito Borne Viruses	Klapperich	BD	$50K
Dynamic Pupil Engineering in a Microscope	Mertz	Thorlabs	$50K

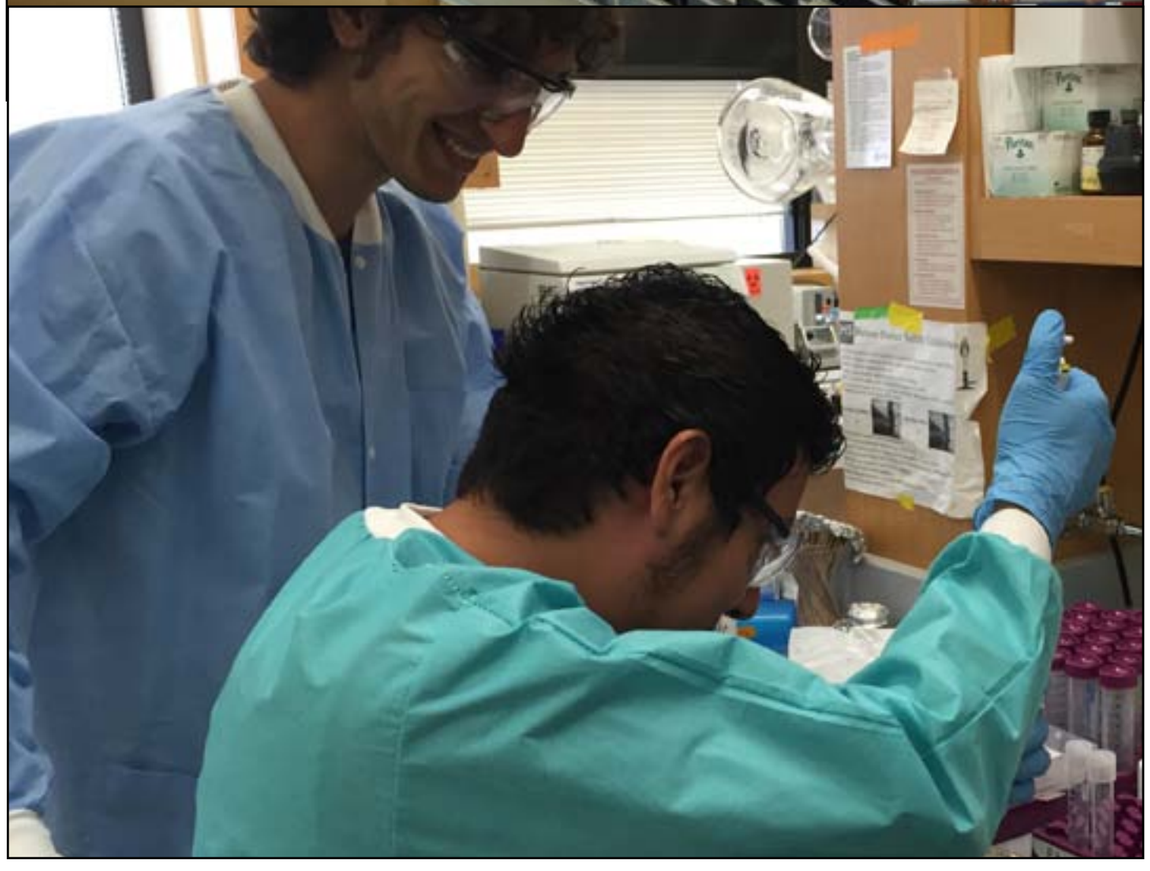
Each of these projects has significant industry support and the outcomes on the research are likely to lead to product line additions or enhancements at the respective mentor companies.

MAJOR PROJECTS MANAGED BY THE CENTER

NIH U54: Center for Innovation in Point of Care Technologies for the Future of Cancer Care
Professor Catherine Klapperich was awarded a five-year U54 cooperative agreement that started on July 1, 2012. The focus of the program is on identification, prototyping, and early clinical assessment of innovative point of care technologies for treating, screening, diagnosis, and monitoring of cancers. Helen Fawcett is the Technical Program Manager and the Outreach Director of this grant. The Photonics Center provides financial and administrative management of this grant. The fourth year of the grant has been completed, and a new set of projects has been initiated in Year 5. For more details and information on the CFTCC, a NIH NIBIB Point of Care Technologies Resource Network member, please visit: http://www.bu.edu/cftcc/.

NIH R01: Development of Near Real-Time, Multiplexed Diagnostics for Viral Hemorrhagic Fever
Professors John Connor (PI) and Selim Unlu (co-PI) were awarded a NIH R01 program on August 1, 2011. This is a five-year grant and is entitled, "Development of Near Real-Time, Multiplexed Diagnostics for Viral Hemorrhagic Fever." This grant has a component that includes partnership with a commercial entity that has been identified and engaged from the start of the program, with the focus of generating a production ready instrument for use in a BL4 laboratory. Faculty members participating in the grant from Boston University, besides the PI and Co-PI 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 BSL4 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. Along with two commercial partners, BD Technologies and NanoView Diagnostics, Inc., the team launched an instrument into UTMB's BSL4 laboratory. With a no-cost extension to July 2017, final testing in varied media with varied viruses will be validated at UTMB and continued support for testing and chips used for incubation. In addition to program management and directing integration with commercial partners, the Photonics Center also provides financial and administrative management for this program.

NIH XTNC: Cross-Disciplinary Training in Nanotechnology for Cancer
This training program, formed by the Nanotechnology Innovation Center (BUnano) as an offshoot of BU's nanomedicine initiative, trains 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 50 pre- and post-doctoral fellows engaged in interdisciplinary mentored research to develop novel nanoscale therapeutic and diagnostic tools for the detection and treatment of cancer. During its sixth and final year, XTNC was funded by BUnano. 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.



LIST OF CURRENT GRANTS

Photonics faculty members received more than **$18.9M** in external funding. The following table lists funds in the fiscal year (July 1, 2015 - June 30, 2016), as reported by the Sponsored Programs office.

PI NAME	Dept.	GRANT TITLE	SPONSOR	AWARD TYPE	PERIOD	AMOUNT FUNDED
BASU SOUMENDRA	ME	PROCESSING OF SOFC ANODES FOR ENHANCED INTERMEDIATE TEMPERATURE CATALYTIC ACTIVITY AT HIGH FUEL UTILIZATION	DEPARTMENT OF ENERGY	COOPERATIVE AGREEMENT	10/1/2015 - 3/30/2017	$200,000
BELLOTTI ENRICO	ECE	CRA: COMPUTATIONALLY-GUIDED DESIGN OF ENERGY EFFICIENT ELECTRONIC MATERIALS (CDE3M)	UNIVERSITY OF UTAH	SUBGRANT	1/1/2014 - 12/31/2015	$160,000
BELLOTTI ENRICO	ECE	CRA: COMPUTATIONALLY-GUIDED DESIGN OF ENERGY EFFICIENT ELECTRONIC MATERIALS (CDE3M)	UNIVERSITY OF UTAH	SUBGRANT	1/1/2014 - 12/31/2015	$298,934
BELLOTTI ENRICO	ECE	CRA: COMPUTATIONALLY-GUIDED DESIGN OF ENERGY EFFICIENT ELECTRONIC MATERIALS (CDE3M)	UNIVERSITY OF UTAH	SUBGRANT	1/1/2014 - 11/30/2017	$100,065
BELLOTTI ENRICO	ECE	CRA: COMPUTATIONALLY-GUIDED DESIGN OF ENERGY EFFICIENT ELECTRONIC MATERIALS (CDE3M)	UNIVERSITY OF UTAH	SUBGRANT	1/1/2014 - 11/30/2017	$406,935
BELLOTTI ENRICO	ECE	2016 NSF-AFOSR-ARO-DTRA WORKSHOP ON REPRODUCIBLE ADVANCED TECHNOLOGIES FOR NEXT-GENERATION NANO/QUA	NATIONAL SCIENCE FOUNDATION	GRANT	6/15/2016 -11/30/2016	$22,717
BELLOTTI ENRICO	ECE	IR DETECTORS DARK CURRENT REDUCTIONS USING DIFFUSION CONTROL JUNCTION CONCEPT	DEPARTMENT OF DEFENSE/AFOSR VIA AFRL	CONTRACT	6/27/2016 - 6/19/2017	$225,000
BIFANO THOMAS	ME	I/UCRC COLLABORATIVE RESEARCH	I/UCRC: INDUSTRY MEMBERSHIPS	GRANT	7/1/2011 - 6/30/2016	$50,000
BIFANO THOMAS	ME	I/UCRC COLLABORATIVE RESEARCH	I/UCRC: INDUSTRY MEMBERSHIPS	GRANT	7/1/2011 - 6/30/2016	$200,000
BIFANO THOMAS	ME	BIOPHOTONICS LAB FOR THE BUSINESS INNOVATION CENTER	MASSACHUSETTS LIFE SCIENCES CENTER	GRANT	7/1/2015 - 9/23/2020	$98,100
BIFANO THOMAS	ME	I/UCRC COLLABORATIVE RESEARCH	I/UCRC: INDUSTRY MEMBERSHIPS	GRANT	7/1/2011 - 6/30/2016	$50,000
BIFANO THOMAS	ME	IUCRC COLLABORATIVE RESEARCH: I/UCRC: CENTER FOR BIOPHOTONIC SENSORS AND SYSTEMS (CBSS)	NATIONAL SCIENCE FOUNDATION	GRANT	3/1/2011 - 2/28/2017	$8,000
BIGIO IRVING	BME	QUANTITATIVE ONCOLOGIC PET-MR	MASSACHUSETTS GENERAL HOSPITAL	SUBGRANT	5/1/2015 - 4/30/2016	$37,699
BIGIO IRVING	BME	TRAINING PROGRAM IN QUANTITATIVE BIOLOGY AND PHYSIOLOGY	NIH/NATIONAL INSTITUTE OF GENERAL MEDICA	GRANT	7/1/2016 - 6/30/2017	$322,743

BISHOP DAVID	ECE	NANOSCALE ADDITIVE MANUFACTURING OF PHOTONIC DEVICES	BELL LABS/ ALCATEL LUCENT	FIXED PRICE CONTRACT	9/23/2013 - 6/30/2017	$35,850
BISHOP DAVID	ECE	ATOMIC CALLIGRAPHY TO BUILD TUNABLE OPTICAL METAMATERIALS	DEPARTMENT OF DEFENSE/AIR FORCE	CONTRACT	6/4/2015 - 9/12/2017	$571,995
BISHOP DAVID	ECE	MEMS DEVICES FOR LGS	LGS INNOVATIONS, LLC	CONTRACT	12/1/2015 - 11/30/2016	$166,167
CONNOR JOHN	MED	POINT-OF-CARE NANOTECHNOLOGY DIAGNOSTIC FOR DIFFERENTIAL FEVER DIAGNOSIS	BECTON, DICKINSON AND COMPANY	SUBGRANT	10/1/2015 - 9/30/2016	$777,700
CONNOR JOHN	MED	BIOMARKER DISCOVERY	JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS	SUBCONTRACT	3/10/2015 - 1/31/2016	$60,000
CONNOR JOHN	MED	DEVELOPMENT OF NEAR REAL-TIME, MULTIPLEXED DIAGNOSTICS FOR VIRAL HEMORRHAGIC FEVER	NIH/NATIONAL INSTITUTE OF ALLERGY & INFE	GRANT	8/1/2011 - 7/31/2016	$708,299
CONNOR JOHN	MED	COMBINED VIRAL LOAD AND SEROLOGY PANEL FOR RAPID POC EBOLA DIAGNOSTICS	NEXGEN ARRAYS LLC	SUBGRANT	3/1/2015 - 2/29/2016	$65,185
CONNOR JOHN	MED	BIOMARKER DISCOVERY	JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS	SUBCONTRACT	3/10/2015 - 3/31/2016	$140,000
CONNOR JOHN	MED	ROLE FOR POLYAMINES IN EBOLA VIRUS REPLICATION	NIH/NATIONAL INSTITUTE OF	GRANT	2/1/2016 - 1/31/2018	$246,251
CONNOR JOHN	MED	ELIMINATION OF PATHOGENIC IGE IN CYSTIC	BRIGHAM & WOMEN'S HOSPITAL	SUBGRANT	2/1/2016 - 7/31/2017	$92,788
CONNOR JOHN	MED	BIOMARKER DISCOVERY	JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS	SUBCONTRACT	3/10/2015 - 6/3/2016	$162,534
DENNIS ALLISON	BME	CLARE BOOTH LUCE FELLOWSHIP - MARGARET	THE HENRY LUCE FOUNDATION, INC.	GRANT	9/1/2015 - 8/31/2016	$64,357
EKINCI KAMIL	ME	EXPLORING NANOMECHANICAL FLUCTUATIONS OF SURFACE-ADHERED BACTERIA FOR NOVEL ANTIBIOTIC SUSCEPTIBILITY TEST	NIH/NATIONAL INSTITUTE OF ALLERGY & INFE	GRANT	6/1/2016 - 5/31/2018	$82,250
EKINCI KAMIL	ME	NANOSCALE FLUID-STRUCTURE INTERACTION: HYDRODYNAMIC SYNCHRONIZATION OF HIGH-FREQUENCY NANOMECHANICAL OSCILLATORS	NATIONAL SCIENCE FOUNDATION	GRANT	7/1/2016 - 6/30/2019	$296,892
ERRAMILLI SHYAMSUNDER	PHY	PHOTONIC DISRUPTION OF VIRUSES WITH FEMTOSECOND LASERS	EMD MILLIPORE	CONTRACT	8/15/2015 - 11/30/2015	$26,500
ERRAMILLI SHYAMSUNDER	PHY	PHOTONIC DISRUPTION OF VIRUSES WITH FEMTOSECOND LASERS	EMD MILLIPORE	CONTRACT	8/15/2015 - 6/30/2016	$100,000
GABEL CHRISTOPHER	MED	MOLECULAR DETERMINATION OF IN VIVO CELLULAR CALCIUM SIGNALING DURING NERVE DAMAGE AND REGENERATION	NIH/NATIONAL INSTITUTE OF NEUROLOGICAL D	GRANT	5/1/2016 - 4/30/2018	$358,094

GARDNER TIMOTHY	BIOLOGY	ELECTRODE-THREAD ARRAY FOR RECORDING AND PLAYBACK OF NEURALSIGNALS ON VISCERAL NERVES	GLAXOSMITH KLINE, INC.	CONTRACT	11/5/2014 - 11/04/2015	$92,318
GARDNER TIMOTHY	BIOLOGY	A TRANSGENIC SONGBIRD TO IMAGE BRAIN PREMOTOR SEQUENCES	CALIFORNIA INSTITUTE OF TECHNOLOGY	SUBGRANT	9/15/2015 - 8/31/2017	$81,529
GARDNER TIMOTHY	BIOLOGY	ELECTRODE-THREAD ARRAY FOR RECORDING AND PLAYBACK OF NEURALSIGNALS ON VISCERAL NERVES	GLAXOSMITH KLINE, INC.	CONTRACT	11/5/2014 - 5/5/2016	$231,403
GARDNER TIMOTHY	BIOLOGY	HIGH-DENSITY RECORDING AND STIMULATION MICROELECTRODES	NIH/NATIONAL INSTITUTE OF NEUROLOGICAL D	COOPERATIVE AGREEMENT	9/30/2014 - 7/31/2017	$516,090
GOLDBERG BENNETT	PHY	MOOC-SPONSORED LEARNING COMMUNITIES FOR FUTURE STEM FACULTY: MULTIPLE PATHS TO ADVANCE EVIDENCE-BASED TEACHING ACROSS THE NATION	MICHIGAN STATE UNIVERSITY	SUBGRANT	10/1/2013 - 9/30/2016	$31,887
GOLDBERG BENNETT	PHY	THE CIRTL NETWORK: 25 UNIVERSITIES PREPARING A NATIONAL FACULTY TO ADVANCE STEM UNDERGRADUATE LEARNING	UNIVERSITY OF WISCONSIN	SUBGRANT	8/15/2013 - 7/31/2016	$61,012
GOLDBERG BENNETT	PHY	THE CIRTL NETWORK: 22 RESEARCH UNIVERSITIES PREPARING A NATIONAL FACULTY TO ADVANCE UNDERGRADUATE SUCCESS	UNIVERSITY OF WISCONSIN	SUBCONTRACT	9/1/2014 - 8/31/2016	$43,100
GOLDBERG BENNETT	PHY	RET IN ENGINEERING AND COMPUTER SCIENCE SITE: INTEGRATED NANOMANUFACTURING	NATIONAL SCIENCE FOUNDATION	GRANT	5/1/2015 - 4/30/2018	$5,000
GOLDSTEIN LEE	MED	VISUAL AND RETINAL CORRELATES OF TRAUMATIC BRAIN INJURY (TBI): BIOLOGY AND BEHAVIOR	CHILDREN'S HOSPITAL, BOSTON	SUBGRANT	9/19/2014 - 9/18/2015	$185,612
GOLDSTEIN LEE	MED	CHRONIC EFFECTS OF NEUROTRAUMA CONSORTIUM	VIRGINIA COMMONWEALTH	SUBGRANT	9/30/2015 - 9/29/2016	$70,000
GOLDSTEIN LEE	MED	THE BLOOD-BRAIN BARRIER AND THERAPEUTIC TARGET FOR TRAUMATIC BRAIN INJURY (TBI)	CROWN PHILANTHROPIES	GRANT	1/1/2016 - 12/31/2016	$250,000
GOLDSTEIN LEE	MED	EFFECTS OF SPACE RADIATION ON HIPPOCAMPAL-DEPENDENT LEARNING AND NEUROPATHOLOGY IN WILD-TYPE AND ALZHEIMER'S DISEASE TRANSGENIC MICE	NASA	GRANT	9/1/2011 - 3/31/2016	$200,000
GOLDSTEIN LEE	MED	VISUAL AND RETINAL CORRELATES OF TRAUMATIC BRAIN INJURY (TBI): BIOLOGY AND BEHAVIOR	CHILDREN'S HOSPITAL, BOSTON	SUBGRANT	9/19/2014 - 9/18/2016	$189,388
HAN XUE	BME	CAUSAL ANALYSIS OF ELECTRICALLY CONNECTED NEURAL NETWORKS	NIH/NATIONAL INSTITUTE OF NEUROLOGICAL D	GRANT	9/30/2013 - 8/31/2017	$323,550

HAN XUE	BME	NEW TOOLS AND PRINCIPLES FOR UNDERSTANDING THE BIOPHYSICAL MECHANISMS OF ULTRASOUND NEUROMODULATION	DEPARTMENT OF DEFENSE/DARPA	GRANT	9/15/2015 - 9/14/2016	$249,619
HAN XUE	BME	CHARATERIZE FUNCTIONAL CONNECTIVITIY OF HIPPOCAMPAL ADULT BORN NEUROGENESIS DURING CRITICAL PERIOD	NIH/NATIONAL INSTITUTE OF MENTAL HEALTH	GRANT	4/15/2016 - 3/31/2018	$246,451
HAN XUE	BME	DRIVE PRINCIPLES OF BRAIN NEURAL NETWORK ARCHITECHTURE USING NOVEL MACHINE LEARNING ALGORITHMS	NORTHEASTERN UNIVERSITY	SUBGRANT	4/1/2016 - 5/31/2018	$15,000
JOSHI AJAY	ECE	CNS:CSR: COLLABORATIVE RESEARCH: LEVERAGING INTRA-CHIP/INTER-CHIP SILICON-PHOTONIC NETWORKS FOR DESIGNING NEXT-GENERATION ACCELERATORS	NATIONAL SCIENCE FOUNDATION	GRANT	10/1/2015 - 9/30/2018	$249,828
JOSHI AJAY	ECE	CAREER: SYSTEM-LEVEL RUN-TIME MANAGEMENT TECHNIQUES FOR ENERGY-EFFICIENT SILICON-PHOTONIC MANYCORE SYSTEMS	NATIONAL SCIENCE FOUNDATION	GRANT	4/1/2012 - 3/31/2017	$100,662
KLAPPERICH CATHERINE	BME	RAPID MOLECULAR DIAGNOSTS FOR CHLAMYDIA AND GONORRHEA AT THE POINT-OF-CARE	NIH/NATIONAL INSTITUTE OF ALLERGY & INFE	GRANT	4/1/2015 - 3/31/2019	$417,101
MERTZ JEROME	BME	ULTRA-MINIATURIZED SINGLE FIBER PROBE FOR FUNCTIONAL BRAIN IMAGING IN FREELY MOVING ANIMALS	NIH/NATIONAL EYE INSTITUTE	GRANT	9/30/2015 - 8/31/2017	$239,361
MERTZ JEROME	BME	HIGH RESOLUTION PHASE CONTRAST ENDOSCOPY	NIH/NATIONAL CANCER INSTITUTE	GRANT	12/15/2013 - 11/30/2017	$345,234
PAIELLA ROBERTO	ECE	GROUP-IV INTERBAND AND INTERSUBBAND SEMICONDUCTOR LASERS BASED ON SIGE NANOMEMBRANES	DEPARTMENT OF DEFENSE/AFOSR	GRANT	9/30/2014 - 9/29/2017	$179,999
PAIELLA ROBERTO	ECE	DIRECTIONAL IMAGE SENSORS FOR ULTRATHIN COMPOUND-EYE CAMERAS	SAMSUNG	CONTRACT	10/1/2015 - 9/30/2016	$99,361
PAVLIDIS DIMITRIS	ECE	IPA ASSIGNMENT - DIMITRIS PAVLIDIS	NATIONAL SCIENCE FOUNDATION		11/3/2014 - 11/02/2016	$247,650
RAMACHANDRAN SIDDHARTH	ECE	MULTIPLEXED MULTIPHOTON INTERROGATION OF BRAIN CONNECTOMICS	NIH/NATIONAL EYE INSTITUTE	GRANT	9/30/2015 - 8/31/2017	$245,750
RAMACHANDRAN SIDDHARTH	ECE	(BRI) HIGH-POWER FIBER LASERS USING INTERMODAL NONLINEARITIES	DEPARTMENT OF DEFENSE/AFOSR	GRANT	9/1/2014 - 8/31/2019	$250,000
RAMACHANDRAN SIDDHARTH	ECE	FUNDAMENTAL RESEARCH ON WAVELENGTH-AGILE HIGH-RATE QUANTUM KEY DISTRIBUTION (QKD) IN A MARINE ENVIRONMENT	UNIVERSITY OF ILLINOIS	SUBGRANT	8/1/2013 - 7/31/2016	$220,186
REINHARD BJORN	CHEM	IDENTIFICATION OF SIGNALS REQUIRED FOR THE ESTABLISHMENT OFHIV INFECTION AND LATENCY	BOSTON MEDICAL CENTER	SUBGRANT	9/2/2015 - 8/31/2016	$119,517
REINHARD BJORN	CHEM	NANOPLASMONIC METAMATERIAL FILTERS	EMD MILLIPORE	CONTRACT	1/1/2016 - 12/31/2016	$100,000
REINHARD BJORN	CHEM	ILLUMINATING DYNAMIC RECEPTOR CLUSTERING IN THE EPIDERMAL GROWTH FACTOR RECEPTOR	NIH/NATIONAL CANCER INSTITUTE	GRANT	5/1/2014 - 4/30/2019	$368,325
RITT JASON	BME	CAREER AWARD AT SCIENTIFIC INTERFACE	BURROUGHS WELLCOME FUND	GRANT	1/1/2010 - 6/30/2016	$1,902
RITT JASON	BME	MULTI-REGION, EXTENDED-DEPTH IMAGING OF NEURAL ACTIVITY VIAA NOVEL NEEDLE MICROENDOSCOPE	NIH/NATIONAL INSTITUTE OF BIOMEDICAL IMA	GRANT	7/1/2015 - 4/30/2017	$204,625
ROBLYER DARREN	BME	DEVELOPMENT OF LESS TOXIC TREATMENT STRATEGIES FOR METASTATIC AND DRUG RESISTANT BREAST CANCER USING NONINVASIVE OPTICAL MONITORING	DEPARTMENT OF DEFENSE/ARMY MEDICAL RESEA	GRANT	9/1/2015 - 8/31/2020	$3,819,134
ROBLYER DARREN	BME	MONITORING PEDIATRIC OSTEOSARCOMA THERAPY RESPONSE USING DIFFUSE OPTICAL SPECTROSCOPIC IMAGING	ST. BALDRICK'S FOUNDATION	GRANT	7/1/2016 - 6/30/2017	$100,000
ROTHSCHILD KENNETH	PHY	STRUCTURE/FUNCTION OF MICROBIAL SENSORY RHODOPSINS	UNIVERSITY OF TEXAS	SUBGRANT	4/1/2013 - 3/31/2016	$95,498
SCHMIDT AARON	ME	THE EM-TECH POLYMER PROJECT	EM-TECH	OTHER TRANSACTION AGREEMENT	1/1/2014 - 12/31/2016	$55,000
SEMETER JOSHUA	ECE	UNP8/BUSAT3: ANDESITE: AD-HOC NETWORK DEMONSTRATION FOR SPATIALLY EXTENDED SATELLITE-BASED INQUIRY AND OTHER TEAM ENDEAVORS	DEPARTMENT OF DEFENSE/AFOSR	GRANT	9/1/2013 - 10/31/2016	$110,000
SEMETER JOSHUA	ECE	MULTI-SCALE STRUCTURING OF THE POLAR IONOSPHERE BY MAGNETOSHERE-IONOSPHERE INTERACTIONS	DEPARTMENT OF DEFENSE/AFOSR	GRANT	9/30/2015 - 9/29/2018	$132,202
SEMETER JOSHUA	ECE	INSPIRE TRACK 1: MAHALI SPACE WEATHER MONITORING EVERYWHERE	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	SUBGRANT	12/1/2013 - 11/30/2016	$59,521
SEMETER JOSHUA	ECE	COLLABORATIVE RESEARCH: RINGS-RISR INVESTIGATION OF THE GEOSPACE SYSTEM	NATIONAL SCIENCE FOUNDATION	GRANT	8/15/2013 - 7/31/2016	$116,965
SEMETER JOSHUA	ECE	THE MILLSTONE HILL GEOSPACE FACILITY	MASSACHUSETTS INSTITUTE OF	SUBGRANT	12/15/2012 - 11/30/2017	$65,832

SUSHKOV ALEXANDER	PHY	COSMIC AXION SPIN PRECESSION EXPERIMENT (CASPER) GRANT	HEISING-SIMONS FOUNDATION	GRANT	9/1/2015 - 8/31/2018	$408,766
SUSHKOV ALEXANDER	PHY	QUANTUM METROLOGY WITH SPINS IN SOLIDS	ALFRED P. SLOAN FOUNDATION	GRANT	9/15/2016 - 9/14/2018	$55,000
UNLU SELIM	ECE	NEW FRONTIER IN DIAGNOSTICS: DIGITAL PROTEIN MICROARRAYS	ASELSAN	CONTRACT	6/1/2016 - 6/1/2018	$455,254
WALSH BRIAN	ME	INTERPRETING ENTRY OF SOLAR WIND PLASMA	NASA	GRANT	1/1/2016 - 6/30/2016	$9,955
WALSH BRIAN	ME	COLLABORATIVE RESEARCH: GEM: SYSTEM STUDY OF THE PLASMASPHERE IN SOLAR WIND-MAGNETOSPHERE COUPLING	NATIONAL SCIENCE FOUNDATION	GRANT	3/1/2016 - 2/28/2019	$36,492
WALSH BRIAN	ME	THE IMPACT OF PLASMAPHERIC PLUME ON RECONNECTION AND MAGNETOSPHERIC DYNAMICS	NASA	GRANT	4/1/2016 - 3/31/2018	$17,422
WALSH BRIAN	ME	THE IMPACT OF PLASMAPHERIC PLUME ON RECONNECTION AND MAGNETOSPHERIC DYNAMICS	NASA	GRANT	4/1/2016 - 3/31/2018	$49,440
WALSH BRIAN	ME	SYSTEM-LEVEL PROBING OF SOLAR WIND-MAGNETOSHPERE COUPLING	NASA	GRANT	5/20/2016 - 5/19/2017	$145,000
WALSH BRIAN	ME	CUPID CUBESAT OBSERVATORY	NASA	GRANT	4/25/2016 -	$48,806
WHITE ALICE	ME	CBL GRADUATE FELLOWSHIP FOR RACHAEL JAYNE	THE HENRY LUCE FOUNDATION, INC.	GRANT	9/1/2015 - 8/31/2016	$86,122
WHITE JOHN	BME	CALCIUM SIGNALING IN A MODEL OF TEMPORAL LOBE EPILEPSY	UNIVERSITY OF UTAH	SUBGRANT	7/1/2015 - 6/30/2017	$148,360
WHITE JOHN	BME	REAL-TIME CONTROL SYSTEM FOR BIOLOGICAL EXPERIMENT	THE JOAN & SANFORD I. WEILL MEDICAL COLL	SUBGRANT	7/1/2015 - 6/30/2016	$32,130
WHITE JOHN	BME	COULTER FOUNDATION TRANSLATIONAL PARTNERS IN BIOMEDICAL ENGINEERING	WALLACE H. COULTER FOUNDATION	GRANT	7/1/2011 - 6/30/2016	$500,000
ZHANG XIN	ME	IMPEDENCE-BASED, CONTINUOUS HEMATOCRIT MONITORING IN THE TRAUMA POPULATION	BOSTON BIOMEDICAL INNOVATION CENTER	SUBGRANT	7/1/2015 - 7/31/2016	$81,850
ZHANG XIN	ME	REU: INTEGRATED NANOMANUFACTURING	NATIONAL SCIENCE FOUNDATION	GRANT	5/1/2015 - 4/30/2018	$10,000
ZHANG XIN	ME	DRAPER LAB FELLOWSHIP (DAVID SUTHERLAND)	DRAPER LABORATORY, INC.	GRANT	9/1/2015 - 5/31/2016	$33,379
					TOTAL:	$18,988,643

Publications, Patents & Awards

BOOK CHAPTERS

I. Bigio, S. Fantini, "Quantitative Biomedical Optics: Theory, Methods and Applications," Cambridge University Press, 2016.

L. Dal Negro, "2D Pseudo-random and Deterministic Aperiodic Lasers," Light Localisation and Lasing: Random and Quasi-Random Photonic Structures, Cambridge University Press, 2016.

G. Kumar, **J. Ritt**, and S. Ching. "Control Theory for Closed Loop Neurophysiology," Closed Loop Neuroscience, Academic Press, 2016.

D. Budker, **A. Sushkov,**"Physics on Your Feet: Berkeley Graduate Exam Questions," Oxford University Press, 2015.

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, World Scientific Press, 2015.

D. Sevenler, L. Ünlü, **S. Unlu,** "Nanoparticle Biosensing with Interferometric Reflectance Imaging," Nanobiosensors and Nanobioanalyses, Springer, 2015.

B. Walsh, "Magnetopause Plasma Parameters and Asymmetries in Solar Wind-magnetosphere Coupling," Dawn-Dusk Asymmetry in Planetary Plasma

JOURNAL ARTICLES

J. Kuyyalil, D. Newby Jr., J. Laverock, Y. Yu, D. Cetin, **S. Basu**, K. Ludwig, and K.E. Smith, "Vacancy Assisted SrO Formation on La0.8Sr0.2Co0.2Fe0.8O3 − δ Surfaces—A Synchrotron Photoemission Study," Surface Science, 2015.

D. Newby Jr., J. Kuyyalila, J. Laverock, K.F. Ludwig, Y. Yu, J. Davis, S. Gopalan, U.B. Pal, **S. Basu**, and K.E. Smith, "Surface Evolution of Lanthanum Strontium Cobalt Ferrite Thin Films at Low Temperatures," Thin Solid Films, 589, 655-661, 2015.

J. Milshtein, D. Gergel, **S. Basu**, U. Pal, and S. Gopalan, "Mixed Ionic Electronic Conducting Powder Bed for Grid Level Energy Storage and Release: A Study of Tungsten Oxide Reduction Kinetics," International Journal of Hydrogen Energy, 40, 9, p. 3624–3632, 2015.

J-P. Xu, V. Sarin, S. Dixit, and **S. Basu**, "Stability of Interfaces in Hybrid EBC/TBC Coatings for Si-based Ceramics in Corrosive Environments," International Journal of Refractory Metals and Hard Materials, 49, p. 339–349, 2015.

J. Milshtein, **S. Basu**, S. Gopalan, and U. Pal, "Simple Method for Determining Metal Powder Oxidation Kinetics with a Zirconia Sensor," Journal of Applied Electrochemistry, 45, 9, p. 1025-1034, 2015.

H. Wen and **E. Bellotti**, "Rigorous Theory of the Radiative and Gain Characteristics of Silicon and Germanium Lasing Media," Physics Review B, 91, 3, p. 035307, 2015.

F. Bertazzi and M. Goano, and X. Zhou and M. Calciati and G. Ghione and M. Matsubara and **E. Bellotti**, "Looking for Auger Signatures in III-nitride Light Emitters: A Full-band Monte Carlo Perspective," App. Phys. Lett, 106, p. 061112, 2015.

A. Wichman, B. Pinkie, and **E. Bellotti**, "Dense Array Effects in SWIR HgCdTe Photodetecting Arrays," Journal of Electronic Materials, 44, 9, p.3134-3143, 2015.

B. Pinkie, A. Wichman, and **E. Bellotti,** "Modulation Transfer Function Consequences of Planar Dense Array Geometries in Infrared Focal Plane Arrays," Journal of Electronic Materials, 44, 8, p.2981-2989, 2015.

M. du Plessis, H. Wen, and **E. Bellotti**, "Temperature Characteristics of Hot Electron Electroluminescence in Silicon," Optics Express, 23, 10, p. 12605-12612, 2015.

A. Wichman, B. Pinkie, and **E. Bellotti**, "Negative Differential Resistance in Dense Short Wave Infrared HgCdTe Planar Photodiode Arrays," IEEE Transaction on Electron Devices, 62, 4, p. 1208-1214, 2015.

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AWARDS

Enrico Bellotti was awarded the 2015 National Defense Science and Engineering Graduate Fellowship.

Thomas Bifano was an R&D100 Award Finalist.

Allison Dennis was a finalist for the Beckman Young Investigator Award.

Xue Han received the DARPA Young Investigator Award.

Xin Zhang was named a fellow of the American Society of Mechanical Engineers (ASME).

Xin Zhang was named a fellow of the Optical Society (OSA).

Xin Zhang was named a fellow of the American Institute for Medical and Biological Engineering (AIMBE).

Xin Zhang received the Boston University Nanoscience Award.

Xin Zhang received the First Schlumberger-BU Research Grant.

PATENTS

Shyamsunder Erramilli (US Patent #20,150,316,502) "Debye Length Modulation" Issue Date: November 5,

Educational Programs & Initiatives

NSF Research Experiences for Undergraduates (REU) in Integrated Nanomanufacturing (INM)

Professors Xin Zhang and Helen Fawcett led the first summer cohort (2015) of REU participants. 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 the 2015 REU participants:

- 36% have no Mechanical, Materials Science, Biomedical, or Electrical and Computer Engineering STEM majors offered at their university.
- 82% have two or fewer STEM majors in Mechanical, Materials Science, Biomedical, or Electrical and Computer Engineering offered at their university.
- 59% are underrepresented minorities (23% Hispanic, 36% African American).
- 64% are female.

The NSF REU INM is working alongside, and integrating where possible, the other REU sites on campus including the Undergraduate Research Opportunities Program (UROP) office. More information about the NSF REU participants can be found at **http://www.bu.edu/photonics-reu.**

Faculty projects from last year's REU program included 11 discrete research projects where the REU student worked alongside the RET participant who joined BU four weeks into the start of the REU program. The following faculty and graduate student mentors worked with the REU/RET participants from June 9 – August 14, 2015.

Summer 2015 NSF REU Participants in Integrated Nanomanufacturing

Faculty Mentor	Dept	Project Title	REU Participant	REU Home Institution
Thomas Bifano	ME	Dynamic Surface Interferometry	Jesus Ramos	Universidad de Puerto Rico Mayaguez Campus
David Bishop	MSE	Atomic 3-D Printing	Salimah Hussien	University of New Hampshire
Scott Bunch	ME	Growing and Characterizing 2D Atomic Membranes	Gabriela Correa	U Mass Amherst
Allison Dennis	BME	Synthesis and Characterization of Thick-shelled InP/ZnSe Quantum Dots	Jacob Highleyman	Carleton College
Kamil Ekinci	ME	Knudsen Transport in Atomically-Smooth Nanochannels	Jose Romero	The University of Texas at El Paso
Bennett Goldberg	BME	Seeing Through Tock: How to Image Through Strongly Scattering Media	Sarai Sherfield	Norfolk State University
Jillian Goldfarb	ME	Biorenewable Nanomaterials: Using Biomass as a Fuel Source and Nano-template	Stephanie Emenyonu	Dartmouth College
Roberto Paiella	ECE	Manufacturing of Group-IV Semiconductor Nanomembranes for Laser Applications	Lauren Strong	Northampton Community College
Darren Roblyer	BME	Nano-based Sensing of Tissue Environments in Deep Tissue	Nicole Weber	Roger Williams University
Aaron Schmidt	ME	Thermal Conductivity of Insect Wings	Rachel Walter	North Carolina State University
Xin Zhang	ME	Mesoporous Titanium Oxide Coating on Diatom Frustules towards Dye-synthesized Solar Cell Applications	Ryan Mcnaughton	Boston University

In addition to the laboratory research, REU participants spent 1.5 hours per week at brown bag seminars on topics ranging from graduate school and career advising, to point of care technologies for resource limited countries and STEM and Societal Engineering at BU. The participants also had three hours a week of cleanroom and laboratory experiences. An outreach applications engineer from FEI joined the group for a week, where he provided a brown bag lecture and demonstrations using the FIB. Professor Alice White also engaged the REU and RET participants and guided them in creating their own structures for fabrication on the Nanoscribe. A brown bag lecture on the instrument and exposure mechanism was met with high regard from the group. At the four-week mark, when the teacher participants arrived, the REU participants presented their research to the teachers along with a few slides describing where they came from, what their educational background was, and what made them decide to pursue engineering. The program ended with a poster session combined with the NSF REU Chemistry program. REU participants were awarded certificates of participation at an ice cream sundae social where their labs acknowledged their excellent research during the summer.

For the summer of 2016, even more applications were received from excellent candidates, and the final statistics of the cohort that will be reported on in next year's annual report are indicated below.

- 50% of the applicants do not have any accredited ENG undergraduate or graduate programs in ME, BME, MSE or ECE at their university/institute.
- 75% have fewer than two accredited ENG undergraduate or graduate programs available in ME, BME, MSE or ECE.
- 67% female/33% male participants.
- All applicants have a GPA of 3.0 or higher.
- 79% of the participants are self-identified URM's, 21% are self-identified white/Asian.

NSF Research Experiences for Teachers (RET) in Integrated Nanomanufacturing

Professors Bennett Goldberg and Helen Fawcett led the first summer cohort (2015) of RET participants. The first cohort arrived at BU on July 6, and continued their participation until the program ended on August 14, 2015.
Teachers were recruited from high-needs public schools within the Massachusetts STEM Pipeline network and from community college faculty in surrounding districts. Teachers were also recruited who have an interest in research opportunities in nanotechnology that they can integrate into their classroom curriculum. The directors assisted in the translation of RET experiences into sustainable STEM education curricula and activities at the teachers' home schools through team-based development and leveraging research mentors in the teacher's partnering 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 http://bu.edu/photonics-ret. The nearby table identifies the project, faculty and graduate student mentors and the teachers and the schools from which they came from.

Summer 2015 NSF RET Participants in Integrated Nanomanufacturing

In addition to laboratory research, RET participants spent 1.5 hours per week at brown bag seminars on topics ranging from point of care technologies for resource limited countries to STEM and Societal Engineering at BU. The participants also had three hours a week of cleanroom and laboratory experiences. An outreach applications engineer from FEI joined the group for a week, where he provided a brown bag lecture and demonstrations using the FIB. Professor Alice White also engaged the RET participants and guided them in creating their own structures for fabrication on the Nanoscribe. A brown bag lecture on the instrument and exposure mechanism was met with high regard from the group. The program ended with a poster session combined with the NSF REU fundamental research in Chemistry addressing problems in biology. RET participants were awarded certificates of participation as well as Professional Development Points (PDP) certificates for instructional time as part of the RET program at an ice cream sundae social. This event provided a forum where their labs could acknowledge their excellent research during the summer. The teachers also led a round table discussion, providing insight on what it is like to teach middle and high school in low resource communities. Interactive discussions between faculty and teachers led to the general agreement on what the ideal teaching practices should be. For the summer of 2016, even more applications were received from excellent candidates, and the final statistics of the cohort that will be reported on in next year's annual report are indicated below.

- 80% of the schools represented are from communities with higher than 40% low income households
- 80% of the schools are receiving level 3 or higher district assistance from Massachusetts
- 40% of the participants are underrepresented minorities
- 70% of the teachers are female

79% of the participants are underrepresented minorities.

Summer 2015 NSF RET Participants in Integrated Nanomanufacturing

Faculty Mentor	Dept	Project Title	RET Participant	RET Home Institution
Thomas Bifano	ME	Dynamic Surface Interferometry	George DeGregorio	East Boston High School, East Boston, MA
David Bishop	MSE	Atomic 3-D Printing	Dina Katz	Methuen High School, Methuen, MA
Scott Bunch	ME	Growing and Characterizing 2D Atomic Membranes	Erika Riddington	Browne Middle School, Chelsea, MA
Allison Dennis	BME	Synthesis and Characterization of Thick-shelled InP/ZnSe Quantum Dots	Ryan Grams	Lexington High School, Lexington, MA
Chuanhua Duan	ME	Exploring the Effect of Surface Active Contaminant on Water Capillary Evaporation in Nanoscale Confined Spaces	Christine DiMauro	McKay Arts Academy, Fitchburg, MA
Kamil Ekinci	ME	Knudsen Transport in Atomically-Smooth Nanochannels	Joan O'Connor	Lynn English High School, Lynn, MA
Bennett Goldberg	BME	Seeing Through Rock: How to Image Through Strongly Scattering Media	Jennifer Wozniak	Rockland High School, Rockland, MA
Jillian Goldfarb	ME	Biorenewable Nanomaterials: Using Biomass as a Fuel Source and Nano-template	Eric Jackson	Dracut High School, Dracut, MA
Darren Roblyer	BME	Nano-based Sensing of Tissue Environments in Deep Tissue	Judith Luber-Narod	Nipmuc Regional High School, Upton, MA
Aaron Schmidt	ME	Thermal Conductivity of Insect Wings	Amanda Dillingham	East Boston High School, East Boston, MA
Xin Zhang	ME	Mesoporous Titanium Oxide Coating on Diatom Frustules towards Dye-synthesized Solar Cell Applications	Sarah Hall	Lynn English High School, Lynn, MA

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 11 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, artificial intelligence, photonics and clean energy. BIC encourages turn-over, viewing this as a healthy sign of a vibrant start-up environment. During FY16, five companies departed the Center and three new companies became tenants. Three of the companies departed as they needed more space to support their growth trajectory, and one of the departing companies was an acquisition target. The turnover supports the Center's objective of making resources available to a large number of companies, establishing relationships that go beyond the period of tenancy, and establishing a reputation for BIC and Boston University for entrepreneurship, business development, job creation and a pipeline for trained scientist and engineers. BIC offers start-up companies a wide array of services and access to the Photonics Center shared labs – facilities, which are extremely difficult and costly for a small company to provide on their own. The management of the tenant companies have given back to the Photonics Center as excellent citizens contributing to enhancing the academic environment. These companies have provided internship opportunities for students, mentored students and increased sponsored research opportunities.

Collectively, the BIC companies have hired a total of 31 interns in FY16. The internships predominately went to BU undergraduate students, but also included some graduate students, a high school student, and a student from BU Questrom's Norwegian summer entrepreneurship program. Many of the internships led to full-time employment offers, and in total the BIC companies hired 11 BU graduates as engineers or scientists.

The tenant companies have been active supporters of the University's educational mission and hosted two Biomedical Engineering Senior Design projects, one MBA Entrepreneurship course project and participated in the EK210 (Introduction to Engineering Design) course work. The management of the BIC companies have also been speakers at the College of Engineering "Lunch and Learn" series, the Society of Asian Scientists and Engineers (SASE) Student group, the BU Upward Bound program and the Photonics Forum series. The speakers were well-received and provided students with a practical perspective on the value of their classroom training.

The full list of FY2016 tenants can be found in the below table with many of the highlights in the past year related to investment and grant funding for some of the BIC companies. Some grant awards include the Department of Energy's SunShot Initiative award to Agira. The SunShot Initiative seeks to make solar energy cost-competitive with other forms of electricity by the end of the decade. Micro-Leads was one of ten teams from around the world selected to receive funding from the Phase 1 GSK Innovation Challenge Fund. Micro-Leads also received the Massachusetts Life Sciences Center's Milestone Achievement Program grant and tied for second place in the M2D2 "Shark Tank" competition. Lattice Automation received a National Science Foundation Small Business Innovation Research (SBIR) Award with the goal of fundamentally changing the way that biological designs are conceived, designed, and physically created. nanoView Diagnostics also received a NSF SBIR award on which BU was a subcontractor. NBD Nanotechnologies and Snapdragon Chemistry both received investments, outgrew the space in BIC and moved to larger facilities in the past year. Beta Bionics, a BU spinout and new tenant in BIC, received a $5M investment from Eli Lilly and Company and Professor Damiano, the company's founder, received the BU Innovator of the Year award for 2016.

Many of the BIC companies were recognized in the press during the past year and have also been generous in recognizing the Photonics Center and the Innovation Center for the help in preparing their businesses for growth. Most notable were comments attributed to Governor Charlie Baker of Massachusetts on one of the BIC companies (Affera) that augurs well for the BU mission of training a pipeline of students to serve life sciences and bio-technology. The governor said, "I congratulate Affera … on the local hiring they are doing as they work to bring new treatments, for heart rhythm disorders to patients here in Massachusetts and throughout the world".

During FY16, the Center completed the renovation of office spaces into laboratory suite 618 and 619. The renovation was partially funded by a $363,750 capital grant from the Massachusetts Life Sciences Center (MLSC). The new laboratory space is meant to provide opportunities to start-up companies in the biophotonic space that would not otherwise be able to afford to lease space in BIC. Typically, a laboratory in BIC is outfitted with a basic infrastructure, and equipping the lab is the responsibility of the tenant company. The concept that is being tested here at Photonics will be to populate the lab with some essential equipment that will be shared among up to four companies. Each company will have a dedicated lab bench, where they can locate specialized equipment for their purposes, and then will have shared access to the common equipment (i.e. centrifuges, microscopes, fume hood, autoclave, and safety equipment). This 450 square foot biophotonics laboratory is also unique in that it is rated as a bio-safety level 2 (BSL-2) facility.

Collectively, the BIC companies have hired a total of 31 BU interns in FY16.

While this places the burden on companies residing in this space to adopt BSL-2 protocols according to the companies approved policies, it provides a facility that is difficult for a small company to replicate.

Science Writers Day at Photonics

The Photonics Center hosted the National Association of Science Writers on October 12, 2015. Fifty science writers from across the country visited the Photonics Center to learn about the Center and its mission. Participants were guided through four laboratories (Professors Thomas Bifano, Selim Unlu, Alice White and Lawrence Ziegler) and were provided with a brown bag lunch. The event provided good publicity and the opportunity for future writing coverage for the Center.

Photonics Research on Tap

The Photonics Center hosted the first in a series of Research on Tap events conceived of by Vice President and Associate Provost for Research Dr. Gloria Waters on September 28, 2015. Twenty Photonics professors provided a brief three-minute overview of their research to attendees. Following this, attendees enjoyed a wine and cheese reception. By all accounts, this was a great event and provided an excellent forum for featuring Photonics faculty research in a lively and entertaining format.

The BU Small Satellite Program

The BU Small Satellite program (commonly referred to as "BUSAT") has contributed to the professional development of over 150 undergraduates spanning multiple departments (ECE, ME, BME, Astronomy, Physics) at Boston University. Led by Photonics Professor Joshua Semeter, the most recent project, called ANDESITE, has been selected by NASA for a June 2017 launch. ANDESITE will eject a set of eight sub-payloads from the main spacecraft, each carrying a miniaturized magnetic sensor. The payloads will form an ad hoc wireless sensor network in space, with the goal of mapping out magnetic deflections produced by small-scale electric currents flowing into and out of Earth's ionosphere. The selection of ANDESITE for launch has catalyzed a transition in BU's small satellite program, from one focused on undergraduate training to one focused on delivering a functioning scientific satellite to NASA. Among the most visible successes of the BUSAT program is the hiring of Assistant Professor Brian Walsh (ME), whose work will seek to expand the presence of space technology programs in the College of Engineering. Within his first year, Walsh was awarded a $2.5M NASA cubesat mission to study X-ray emissions arising from interactions between solar wind and our magnetized planet.

BUnano: The Center for Nanoscience and Nanobiotechnology Renamed

Boston University Center for Nanoscience and Nanobiotechnology changed its name in December 2015, to the Nanotechnology Innovation Center (BUnano). BUnano is a Center where nanomaterials intersect medicine and energy, and the new name better reflects the ground-breaking activity and aspirations of the Center. Now in its tenth year, BUnano is an interdisciplinary academic research center which seeks to attain national and international prominence and recognition for Boston University research and applications in nanoscience, particularly in nanobiosystems and nanophotonics.
BUnano Cross-Disciplinary Fellowships
BUnano's new Cross-Disciplinary Fellowship program for Pre- and Post-Doctoral students is modeled after BUnano's successful Cross-disciplinary Training in Nanotechnology for Cancer (XTNC) program, which was created with funding from the NIH National Cancer Institute. Beginning in fall 2016, BUnano will award up to 10 Cross-Disciplinary fellowships per year to outstanding Boston University graduate student and post-doctoral researchers dedicated to the exploration of interdisciplinary nanoscale science and its practical applications to benefit society in the broad areas of medicine, energy, nanomaterials and nanofabrication.

BUnano Upward Bound Nanocamp

BUnano faculty and graduate students volunteer every summer for the Boston University Upward Bound Math Science Program by hosting "Nanocamp Wednesdays." Upward Bound serves low income and potential first-generation college students recruited from public high schools in Boston. Last summer, their graduate student fellows and Professors Allison Dennis and Ahmad Khalil hosted twelve Upward Bound "nanocamp" students. Graduate students led hands-on laboratory workshops on creating nanocapsules that might be used for drug delivery. Professor Dennis introduced Upward Bound students to colloids and colloidal quantum dots. Professor Khalil exposed students to DNA techniques and synthetic biology.

BUnano CityLab Scholars Program

During the academic year, BUnano's graduate student fellows collaborate with the Boston University CityLab program, a bioscience-learning laboratory partnership between the BU Schools of Medicine and Education. This past year, over six evenings, their students developed and presented a nanomedicine curricula with lectures and laboratory experiments for 24 high school students in the CityLab Scholars program. Throughout, they engaged the students in discussions about nanotechnology and medical applications and shared their experiences as graduate students and postdocs in nanomedicine research, leading to rich discussions between the trainees and high school student participants about science and careers in science.

Events & 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, Boston area universities and 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 the 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 2015 and the spring of 2016, gave the community opportunities to participate in technical discussions in an open forum over lunch. Speakers are selected to discuss their current research endeavors and the real-world applications of their research.

PHOTONICS CENTER GUEST SPEAKERS

Over the year, the Boston University Photonics Center hosted seminars by photonics experts. The following list includes the seminars for 2015–2016.

Date	Speaker	Title
March 31, 2016	Cesare Barbieri	Aqueye and Iqueye: the Fastest Astronomical Photometers

19th Annual Photonics Center Symposium

This year, the 19th Annual Photonics Center Symposium focused on Frontiers in Plasmonics as Enabling Science in Photonics and Beyond. The symposium drew 180 attendees from Boston University, outside academic institutions, and industry. Photonics Professor Bjoern Reinhard, chaired the conference.
The agenda for this year's symposium featured presentations by researchers from leading research institutions.

The speakers included:
Dr. Jeremy Baumberg, University of Cambridge
Dr. Jennifer Dionne, Stanford University
Dr. Suljo Linic, University of Michigan
Dr. Peter Nordlander, Rice University
Dr. George Schatz, Northwestern University
Dr. Vladimir Shalaev, Purdue University

The symposium featured a lunch speaker, Dr. Pramod Khargonekar, Assistant Director for Engineering Directorate at the National Science Foundation. He gave a talk on NSF Enabling Frontier Explorations. At the conclusion of this year's conference, a reception and electronic poster board session was held where participants, students and speakers discussed their research in an informal setting.

PHOTONICS FORUM CALENDAR

Date	Speaker	Presentation
July 23, 2015	High School Teachers	Research Experiences for Teachers Forum
September 30, 2015	Mr. John Kurkomelis, Boston University Radiation Specialist, Boston University	Annual Laser Safety Training
October 28, 2015	Ms. Wei Lee Leong, Senior Specialist, Research Safety, Boston University	Annual Lab Safety Training
January 29, 2016	Professor Brian Walsh, Boston University	Using Small Spacecraft to Understand the near-Earth Space Environment
February 23, 2016	Professor Allison Dennis, Boston University	Engineering 'Giant' Nanocrystal Quantum Dots (g-NQDs) for Biosensing and Bioimaging
March 30, 2016	Professor Keith Brown, Boston University	Mesoscopic Soft Matter: Where Top-down Meets Bottom-up
April 27, 2016	Professor Jason Fleischer, Princeton University	Diffraction Beyond the Diffraction Limit

Facilities & Equipment

This year, rather than acquire new equipment at the Photonics Center, there was a concerted effort to procure smaller capital equipment items to back up critical tools to avoid excessive downtime. Additionally, the coating system from last year's capital equipment purchase was late in arrival, so it came online in the early fall, leaving faculty and students ample time to work with the new tool and evaluate its functionality.

This past year, several purchases were made including replacement of the backing pump for the STS DRIE with a more robust version. This swap allows the use of the new pump as well as conversion to the former pump that is out for refurbishment. A new polisher for the sample preparation room was also purchased as the original tool was not meeting the specifications or needs of the researchers. Some computer upgrades for PML ebeam systems were also included in the past year of equipment upgrades.

BUILDING PROJECTS

PHO 733/735 – PROFESSOR LEI TIEN

Professor Lei Tien, who joined the Boston University Photonics Center in the Electrical and Computer Engineering department in July 2016, moved into his new laboratory space. A handwashing sink and countertop was added to the lab in the summer of 2016 to accommodate future BSL2 collaborations.

PHO 708 – PROFESSOR MILOS POPOVIC

New laboratory space is under design for Professor Milos Popovic, who joined the Boston University Photonics Center and the Electrical and Computer Engineering Department in July 2016. His laboratory construction is expected to commence during the fall/winter 2016.

PHO 618/619 – BIOSAFETY LEVEL 2 LABORATORY SPACE FOR BIC

Through a Mass Life Sciences (MLSC) grant, funding to build out and furnish wet lab space for BSL1/2 work was completed. Laboratory space is available for innovation center companies including an individual laboratory for tissue culture, one for bacterial work and an open room with a chemical fume hood, autoclave, fluorescent microscope and a Beckon Dickinson centrifuge. The shared space has tables for two incubator companies to work on separate BSL1 or 2 work.

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 and Boston University community. In addition to BU usage, the shared facilities are also accessible on a fee for use basis by BIC companies, former BIC companies, outside universities and other companies that generally have sponsored research or collaborated with a BU faculty member. 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 and measurement. The Integrated Optics Laboratory (IOL) includes a SET 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 electron and atomic force microscopy among other analytical surface characterization tools. The Focused Ion Beam/Transmission Electron Microscope Facility (FTF), also located in the basement, houses a FEI Focused Ion Beam (FIB) and a FEI Transmission Electron Microscope (TEM).

Optoelectronic Processing Facility (OPF)

OPF is a multi-user 2500 sq. ft. facility located on the 8th floor of the Photonics Center. The facility contains equipment for semiconductor and optoelectronic wafer and chip 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 (5 mm x 5 mm) 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. The laboratory conveniently provides ovens and a hood for bakes to facilitate photoresist development. Chip and wafer exposure is achieved through the UV exposure tool, the MA6 (up to a 6 inch square masks). A high-powered optical Nikon microscope provides higher resolution imaging for surface inspection. The Nanonex NBX200 allows thermal and UV replication processes for nanoscale structures and can handle up to a 3-inch wafers.
Cleaning, etching or characterization tools are found in the Class 1000 cleanroom. Tools include a KLA Tencor surface profilometer to measure the step height of features on wafers and a high-powered optical Nikon microscope allowing users to captures 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. As part of equipment upgrades this year, a new, more robust backing pump has been installed and will function with the existing software and infrastructure on the vacuum system. 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, where the vapor system is used to release oxide films has addressed safety issues so the user does not have to handle liquid HF. 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 provide students with the ability to

learn about different coating processing methodologies and how to measure the films deposited after processing. The Angstrom instrument from last's years' capital equipment purchase has been installed in OPF and has undergone qualification and training for new users. Increased research in coatings required a high temperature-annealing furnace in the cleanroom that covers both low and high temperature annealing.
Wire bonding, wedge bonding, or testing can also be done inside the cleanroom in OPF. The Current Voltage/Capacitance Voltage characterization test 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 Photonics Center and is stocked with state-of-the-art equipment for bonding and spectroscopic analysis of components.
The Class 100 cleanroom houses a Suss Microtech FC-150 (currently SET) flip chip bonder that is used to generate eutectic bonds either through thermocompression or soldering processes. This is a precise system that uses fiducials to aid in placement accuracy. Several researchers in device packaging (LED's) use this piece of equipment and outside collaborators also use the system for alignment and bonding of devices.
The IOL standard laboratory space includes an area for soft lithography and spectroscopic tools. The soft lithography station uses PDMS to make replicas from masters created through photolithography or e-beam writing. The Varian Cary 5000 UV-VIS-NR spectrometer covers wavelength ranges from 175-3300 nm. In addition to measuring reflectance and transmission at a particular wavelength, it can also measure absorption. The Bruker Vertex 70V FTIR and Hyperion Microscope continue to be a heavily used devices for spectroscopy applications.
Precision Measurement Laboratory (PML)
PML is comprised of two laboratories located in the basement of the Photonics Center. 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.
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 is comprised of two separate rooms with capabilities to measure material composition, image surface morphology and micro/nano machined materials. This laboratory houses a FEI Quanta 3D FEG FIB (Field Emission Gun Focused Ion Beam) system in one room and a FEI Tecnai Osiris 200kV S/TEM in the second room.
The FEI Quanta 3D FEG FIB is a powerful tool with a resolution of 1.2 nm in the HiVac mode, 2.9 nm in LoVac mode, 7 nm with the FIB column. The tool has a wide variety of detectors including: Everhart Thornley detector (EDT), continuous dynode multiplier (CDEM), ion induced secondary electron (SE) imaging, backscattered electron detector (BSED), low vacuum secondary electron detector (LVSED), gaseous analytical solid-state back scattered electron detector (ESEM GAD), high contrast detector (vCD), annular STEM detector (bright field (BF), dark-field (DF), and high-angle annular dark field (HAADF) modes), 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 can be used.
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 Bright Field/Dark Field Detector on the TEM allows users the capability to align and overlay all of the images from the TEM itself, the EELS and EDS.
The neighboring sample preparation room contains the tools needed for making sections for TEM viewing. Included in this preparation room is a cut off saw, a sample core, a polisher and an ion tool for final thinning of TEM samples. The equipment can be used by any trained users who wish to prepare sample for TEM and SEM usage.

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