Boston University Photonics Center
Annual Report 2017

Letter from the Director

THIS ANNUAL REPORT summarizes activities of the Boston University Photonics Center for the 2016-2017 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 59 faculty members, 10 staff members, and more than a hundred graduate students and postdoctoral fellows.

This has undoubtedly been the Photonics Center's best year since I became Director 10 years ago. In the following pages, you will see highlights of the Center's activities in the past year, including more than 100 notable scholarly publications in the leading journals in our field, and the attraction of more than 22 million dollars in new research grants/contracts. Last year I had the honor to lead an international search for the first recipient of the Moustakas Endowed Professorship in Optics and Photonics, in collaboration with ECE Department Chair Clem Karl. This professorship honors the Center's most impactful scholar and one of the Center's founding visionaries, Professor Theodore Moustakas. We are delighted to have awarded this professorship to Professor Ji-Xin Cheng, who joined our faculty this year.

The past year also marked the launch of Boston University's Neurophotonics Center, which will be allied closely with the Photonics Center. Leading that Center will be a distinguished new faculty member, Professor David Boas. David and I are together leading a new Neurophotonics NSF Research Traineeship Program that will provide $3M to promote graduate traineeships in this emerging new field.

We had a busy summer hosting NSF Sites for Research Experiences for Undergraduates, Research Experiences for Teachers, and the BU Student Satellite Program. As a community, we emphasized the theme of "Optics of Cancer Imaging" at our annual symposium, hosted by Darren Roblyer.

We entered a five-year second phase of NSF funding in our Industry/University Collaborative Research Center on Biophotonic Sensors and Systems, which has become the centerpiece of our translational biophotonics program. That I/UCRC continues to focus on advancing the health care and medical device industries.

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

This has undoubtedly been the Photonics Center's best year since I became Director 10 years ago.

BU Photonics Center Annual Report 2017

Front and Back Page Photos:
Christopher McIntosh

Mission Statement

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

This mission is executed through:

- Basic research and scholarship in photonics.
- Academic and entrepreneurial programs and initiatives for students.
- Technology development for 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 with 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, 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. These areas formed the core of the NSF Research Traineeship (NRT) proposal that the Photonics Center was awarded in August 2016.

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 Industry / University Cooperative Research Center (I/UCRC), and participation in the annual Photonics symposium. The NSF Research Experiences for Undergraduates (REU) and Research Experiences for Teachers (RET) sites in Integrated Nanomanufacturing are now in their third 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 Engineering, Materials Science, Electrical and Computer Engineering 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.

Technology Development
The Photonics Center's technology development activities focus on emerging photonic applications in healthcare. These activities include direct sponsored research collaboration with research labs at major corporations and the successful completion of the 6th and final year of Phase I of the NSF-sponsored, member-supported I/UCRC on Biophotonic Sensors and Systems. The Phase II I/UCRC proposal was submitted in July 2016 and by February 2017, the Center learned that a Phase II grant was awarded. This increased the annual funding and extended the I/UCRC for an additional five years. That program, and its corporate sponsored applied research projects, has become a prime focus for Photonics Center efforts in technology translation. Additionally, our Center for Innovation in Point of Care Technologies for the Future of Cancer Care promotes technology translation in an area of critical national need.

Business Innovation and Commercialization of Photonics Technology
The Photonics Center is a leader in commercialization of photonics technology, an activity that is anchored by its Business Innovation Center (BIC). Individual tenant companies continue to demonstrate growth, attract business financing, and demonstrate commercial potential. BIC is 100% occupied and currently has 11 tenant companies. These companies continue to be valued participants in the Photonics Center community. Preferential selection of prospective tenants that work in areas aligned with the research and scholarship activities of Photonics Center faculty creates an environment rich with opportunities for collaboration and growth in sponsored research. Mentoring and access to shared laboratory and conference facilities are also offered to promising student entrepreneurs.

Highlights of FY17

External Grant Funding
External grant funding for FY17 totaled over $22.1M, 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, continuation of the grants from the National Science Foundation to support Research Experiences for Teachers (RET) and Research Experiences for Undergraduates (REU) in Integrated Nanomanufacturing, and the start of the National Science Foundation National Research Traineeship (NRT) Program on Neurophotonics.

NSF NRT: Understanding the Brain (UtB): Neurophotonics
The Photonics Center led the submission of a five-year training grant through the National Science Foundation National Research Traineeship Program. The training grant entitled Understanding the Brain (UtB): Neurophotonics was awarded on August 31, 2016, and was one of two awards in this category. The first year focused on recruiting from within Boston University's incoming fall 2016 class and recruiting externally for new graduate student applying for fall 2017.

The 20th Annual Photonics Center Symposium: Optics for Cancer Imaging
This year, the annual Photonics Center symposium focused on Optics for Cancer Imaging. Professor Darren Roblyer chaired the conference, which drew nearly 200 attendees. Invited speakers from Harvard University, Johns Hopkins University, Vanderbilt University, the University of Washington and other universities delivered talks. The program featured a day full of talks, and a reception with electronic poster boards, where participants and speakers discussed their research.

Eight New Photonics Center Faculty Members
This year, the Photonics Center welcomed eight new professors with research spanning from neurophotonics to quantum integrated photonics. These Professors are Dr. Stephan Anderson, MED; Dr. David Boas, BME; Dr. Jerry Chen, Biology, BME; Dr. Ji-Xin Cheng, ECE, BME; Dr. Xi Ling, Chemistry, MSE; Dr. Milos Popovic, ECE; Dr. Chen Yang, Chemistry, ECE; and Dr. Ji Yi, Medicine.

PHOTONICS CENTER
At a Glance

59
Faculty Members

10
Staff Members

81
Funded R&D Projects

$22.1M
Funding for R&D

161
Archival Publications

3
Shared Laboratory Facilities

Highlights of FY17 (cont'd)

Photonics Center Endowed Professorship in Optics and Photonics Awarded to Professor Ji-Xin Cheng
The Moustakas Endowed Professorship in Optics and Photonics is named in honor of Professor Theodore Moustakas, who joined Boston University in 1987 and has been a Professor of Electrical and Computer Engineering, Materials Science and Engineering, and Physics until his retirement this year. His pioneering research focused on amorphous and nitride semiconductors, and he was granted 31 U.S. patents in the fields of nitride semiconductors, amorphous silicon and diamond materials. Intellectual property that resulted from his work has been licensed to a number of companies, including major manufacturers and users of blue LEDs and lasers (Cree, Nichia, Philips, OSRAM, Apple, Google, Amazon, Samsung, LG, Sony etc.), and that intellectual property is now used extensively worldwide.

After an expansive search, the Moustakas Endowed Professorship in Optics and Photonics was awarded to Professor Ji-Xin Cheng. Professor Cheng joined BU in the summer of 2017. Previously, he was at Purdue University where he worked for 14 years as a Professor of Biomedical Engineering, Professor of Chemistry, Professor of Electrical and Computer Engineering. He received his Ph.D. from the University of Science and Technology of China in 1998. Professor Cheng has devoted his career to transforming molecular spectroscopy from an in vitro analytical tool to an in vivo label-free imaging platform for the discovery of hidden signatures inside single living cells and the translation of discovery into medical treatment strategies. Since starting his work at Purdue in 2003, he established a highly interdisciplinary and collaborative research team that crossed the boundaries of Chemistry, Physics, Biology, Engineering, Medicine, and Entrepreneurship. His team pursued novel research by breaking the fundamental limits of label-free microscopy, making new scientific discoveries from observation of subtleties, and diving into new fields via cross-disciplinary collaborations. At BU, Professor Cheng will expand on this work and build an interdisciplinary and collaborative research program focusing on the discovery of hidden signatures in living cells and translation of those signatures into precision diagnosis and/or medical treatments.

BU Launches New Neurophotonics Center Led by Professor David Boas
Professor David Boas joined the Photonics Center and the College of Engineering faculty in the summer of 2017. He is a Professor of Biomedical Engineering and the founding Director of the new Neurophotonics Center at BU. Professor Boas previously worked at the Massachusetts General Hospital (MGH) where he was known as a leading expert on neurophotonics research. He received his B.S. in Physics at Rensselear Polytechnic Institute, and his Ph.D. in Physics at the University of Pennsylvania.

The focus of the new Neurophotonics Center, led by Professor Boas, will be to develop and apply new approaches to study the brain with light; using neuro-sensing and manipulation approaches spanning from the microscopic to the macroscopic scale, and with studies spanning from in-vitro, through various animal models, and in humans using invasive and non-invasive recording strategies. At MGH, Boas developed new technologies to examine the brain and understand its functioning and how various diseases affect it. He has found that the interface between photonics and neuroscience has provided a rich breeding ground for spawning new technologies to address outstanding questions in the neurosciences which leads to new questions that spawn new technologies. Professor Boas will accelerate this cycle by engaging the extensive expertise in Neurophotonics and Photonics at BU to ultimately illuminate how the brain works.

A major initial effort will be ramping up the adoption of functional near infrared spectroscopy by BU faculty to measure human brain activity during typical and atypical brain development, to better understand speech processing and generation and the impact of stroke, and the effect of neuro-degeneration and brain injury on brain function. Other efforts will advance the ability to microscopically measure brain function in animal models with greater depth penetration while maintaining high spatial resolution; and extending capabilities to perform measurements while animals are engaged in natural behaviors.

Professor Boas has recruited faculty from around the university to join the Center. Some of the faculty include Professor Thomas Bifano, Director of the Photonics Center; Professor Barbara Shinn-Cunningham, Professor of Biomedical Engineering; Chantal Stern, Professor of Psychological and Brain Sciences; Professor John White, Chair of the Biomedical Engineering department; Professor Xue Han, Associate Professor of Biomedical Engineering; Professor Michael Hasselmo, Director of the Center for Systems Neuroscience; Professor Jerome Mertz, Professor of Biomedical Engineering, Professor Ji-Xin Cheng, Photonics Center Endowed Professor in Optics and Photonics, Professor Siddharth Ramachandran, Professor of Electrical and Computer Engineering, and others. The Neurophotonics Center will work closely with doctoral students who will be part of the new $2.9 million Photonics Center National Research Traineeship grant entitled Understanding the Brain: Neurophotonics from the National Science Foundation.

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 Focused Ion Beam/Transmission Electron Microscope Facility (FTF). 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 successfully submitted a proposal and was awarded Phase II status on the Industry/University Cooperative Research Center (I/UCRC) on Biophotonic Sensors and Systems (CBSS). These efforts 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 were a total of 17 corporate members during Phase I. In addition, 28 distinct projects were undertaken with corporate funding and at BU a total of 44 students or postdoctoral associates were supported with eight CBSS affiliated students graduating with a Ph.D.

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).

Staff contributions to support proposal preparation and networking with government...have become increasingly import to the... strategic mission.

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

WEARABLE WINDOWS INTO BREAST TUMORS

PROFESSOR DARREN ROBLYER LEADS CUTTING-EDGE RESEARCH TO AID BREAST CANCER PATIENTS

by Elizabeth Dougherty

WHEN BIOMEDICAL ENGINEER Darren Roblyer set up his Biomedical Optical Technologies Lab (BOTLab) at BU after arriving in 2012, he immediately started cold-calling doctors. He told them about a device he'd made, a new way of imaging tumors that could help cancer patients. It's worth your time, he told them.

"I knew I wanted to get my device into the clinic," says Roblyer, a College of Engineering assistant professor of biomedical engineering.

That device allows doctors to peer through the skin into breast cancer tumors and see their response to chemotherapy. Its readouts are instantaneous, and preliminary studies offer hope that the technology may someday provide doctors with information that currently eludes them: an immediate alert when drugs aren't working.

"It's a window into the tumor. You can actually see what's going on biologically without taking a biopsy," says Catherine Klapperich, an ENG professor of biomedical engineering and of mechanical engineering and associate dean for research and technology development.

Breast cancer is typically diagnosed with a biopsy after an abnormal mammogram; doctors rarely do additional imaging or biopsies to track progress. Rather, they prescribe a treatment plan, and for the most part, stick with it. The plan varies depending on the genetic makeup of the tumor, the tissue structure, and the size. For some women, particularly those with large tumors that would be difficult to remove without taking the entire breast, doctors prescribe medicine to shrink the tumor first.

The medicine typically includes chemotherapy, which has a range of debilitating side effects. But most women respond extremely well to this therapy—five years later, 75 to 90 percent are cancer-free, according to Naomi Ko, a School of Medicine assistant professor of hematology and medical oncology and a breast oncologist at Boston Medical Center (BMC).

It's the remaining 10 to 25 percent Roblyer hopes his device will help. These women don't respond to the chemotherapy and spend months suffering its side effects without any benefit. Currently, says Ko, the best tool she has to determine if a patient is responding is to feel the tumor with her fingers and get a rough measure of its size using a ruler. "What you don't want is the tumor to grow, meaning the chemo is not working," she says. "That happens. I've had to send a patient emergently to the operating room for surgery."

If clinical tests over the coming years confirm his early results, Roblyer hopes his device will provide doctors with better information more quickly, so they can change a patient's treatment plan and avoid wasted time and emergency surgeries. "We'd like to prevent patients from undergoing months of ineffective treatment," he says. "The idea is to use optical feedback to personalize and improve treatment for each patient."

Roblyer got his first experience working with cancer patients as a Rice University graduate student in biomedical engineering, studying under Professor Rebecca Richards-Kortum. He had landed a spot in a Howard Hughes Medical Institute program intended to bring biomedical engineers closer to medical practice by putting them to work at nearby medical centers.

As part of the program, Roblyer worked at the Texas Medical Center, home of the MD Anderson Cancer Center. He dissected a cadaver to learn anatomy, followed physicians on their rounds, and attended surgeries. He also took a few cancer biology classes. "I became obsessed with cancer and medicine," he says.

As a postdoctoral fellow, he joined the lab of Bruce Tromberg, a University of California, Irvine, professor and director of the Beckman Laser Institute and Medical Clinic. Tromberg was developing a new kind of imaging, called diffuse optical spectroscopic imaging (DOSI), for use in breast cancer.

The technology sends near-infrared light into tissue and measures what is reflected back. The technique can measure tissue several centimeters below the surface of the skin. Near-infrared spectroscopy is used in neuroscience research to detect brain activity near the surface of the brain. The light shines through the skin and skull and detects changes in blood flow that indicate brain activity.

In tumors, DOSI images reveal oxygenated blood flow, as well as fat and water content. These measures give a sense of the metabolic activity in the tumor, whether or not blood is

Darren Roblyer

Until now, cancer researchers could see only snapshots of tumors from mammograms or examine tumor tissue after it's removed from the body.

flowing in different parts of it, and also if fluid is building up, potentially because of cell death. The technology captures changes instantaneously, so it can show real-time changes in response to the administration of a drug.

By the time Roblyer joined Tromberg's group, the team had used DOSI to measure several dozen breast cancer patients, all of them treated with chemotherapy to shrink the tumor prior to surgery. Roblyer analyzed the data, looking for signals that might be connected with a good outcome, meaning that the tumor had decreased in size, or a poor one, meaning that the chemotherapy was not effective.

He found one. In women whose tumors responded to chemotherapy, the DOSI images revealed a flare, a data spike that occurred early in treatment. The flare appeared within 24 hours of infusion with chemotherapy and represented an influx of oxygenated red blood cells into the tumor.

It isn't clear yet exactly how the flare contributes to tumor shrinkage. Roblyer speculates that it may be a sign of inflammation, indicating that the tumor is being damaged by chemotherapy. "We're still trying to figure out what's going on at a molecular level," he says.

Even without understanding the underlying biology, the information could still be valuable for prediction if it can be shown to occur in studies of larger numbers of patients. "The ability to measure the metabolism of these tumors gave us information about what was going to happen to those tumors months later. That's powerful," says Roblyer. "We've been chasing it ever since."

what doors it will it open?

When Roblyer came to BU, his priority was to start those larger studies to validate his findings about the flare. He had reduced the size of the DOSI equipment needed to take measurements and wanted to get his new technology into a clinical trial. Earlier versions of the back end of the device, the part that produces the laser light, were the size of a refrigerator, but his current versions can be carried like a briefcase. "It gives us access to patients in new places, like the infusion suite at a cancer center," he says.

His phone calls and emails to BMC oncologists led him to Ko, who agreed to run a clinical trial with him to test his technology. At this point, the tests involve collecting data from patients as they undergo chemotherapy prior to surgery. Roblyer and Ko will analyze that data to determine if his 2011 findings hold up in a larger group of women. If so, it will add to the evidence that the device could help doctors improve care for patients who don't respond to chemo.

The probe used in the study with Ko is handheld and about the size of a brick. To get a full set of measures requires a few hours with the patient, and for this reason, it has been hard to convince patients to sign up. "A lot of these patients are already anxious about their first chemo, so to ask more of them is a lot," she says.

But she does ask, and she is grateful when they agree. "We do it because we believe that this will further our understanding of breast cancer and how it responds to chemo," Ko says. "I don't know what doors it will open, but there's great potential to learn."

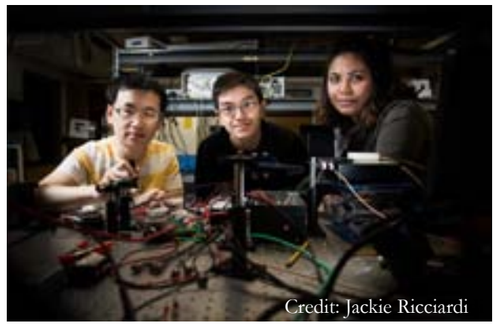
Until now, cancer researchers could see only snapshots of tumors from mammograms or examine tumor tissue after it's removed from the body. "With this device we can see a living tumor reacting to the medicine being infused," says Klapperich. "The technology is opening up the potential to answer new biological questions that couldn't have been answered before."

The ability to see dynamic changes, like the flare Roblyer found as a postdoc, is one thing. But to understand what's happening inside the tumor to produce that flare and how that biological process might be linked to the shrinking of tumors requires more extensive digging, the kind of digging that isn't possible to do in human patients.

So Roblyer also studies mouse models of breast cancer using the BOTLab's imaging technologies. To launch this effort, fifth year graduate student Syeda Tabassum (ENG'18), who works in the lab, confirmed that it was possible to use a form of imaging called spatial frequency domain imaging, or SFDI, to image breast tumors in mice. Similar to DOSI, SFDI uses near infrared light and measures oxygen saturation, water, and fat content. SFDI also allows imaging of the tumors at multiple depths, so it is possible to create, for example, a map of oxygen saturation across the entire tumor.

In new studies, graduate student Kavon Karrobi (ENG'19) is using SFDI in combination with another form of imaging, called multiphoton microscopy (MPM), which creates images of much higher resolution. Using MPM, Karrobi can image a cross section of the tumor and get a detailed look at the blood vessels, tumor cells, and structure of the tissue. It's a bit like taking a slice of the tumor and inspecting it under a microscope, but without touching the tumor.

Combining these tools, Roblyer's team can image the tumor throughout a course of treatment and see how it changes. The work is just beginning, but one observation so far is that tumors don't change uniformly in response to treatment. "There are pockets within a tumor and we're trying to understand how they relate to growth or resistance to therapy," Karrobi says.



Credit: Jackie Ricciardi

FPROFESSOR DARREN ROBLYER'S STUDENTS WORK IN THE LAB

wearable windows

Such heterogeneity within a tumor is common and well known, but Roblyer's tools are allowing his team to visualize them in a completely new way. For instance, Karrobi plans to overlay detailed images of tumor vasculature onto maps of oxygenation. "One provides context for the other and could give us an idea of what is happening inside," he says. "We're still very much in the exploration phase."

This research is helping Roblyer's team learn more about how tumors behave and also what the signals they see with the imaging tools they are testing mean. The more Roblyer understands about the cellular and molecular processes his device detects, the more valuable those signals become. "We're interested in what's going on in a tumor over time," he says. "We can image things other people can't, so we're learning a lot. It could go in many different directions."

Meanwhile, Roblyer's lab continues to advance the DOSI technology. Last year, they created the first wearable DOSI device, improving upon the brick-sized probe. The wearable device is flat, star-shaped, and flexible so it can conform to the shape of the breast and be worn during a chemotherapy infusion, making it more convenient for patients.

To shrink the technology, however, Roblyer had to alter its function. His older probe collects absolute measures, but the new one detects only relative changes. It's a bit like having a heart rate monitor that shows how much faster the heart beats during exercise, but cannot tell the starting or maximum heart rate.

Roblyer is also improving speed and resolution. For instance, he recently completed a second wearable design that has many more light sources and sensors, allowing it to probe more deeply and take a series of images at different depths throughout the tumor tissue, potentially revealing pockets of response or nonresponse to therapy in a patient's tumor.

He and his team of two postdoctoral fellows and seven graduate students have managed to create these new designs in less than two years. The seed money to create the first wearable probe came from the BU Center for Future Technologies in Cancer Care, directed by Klapperich. Roblyer also received a grant to support collaboration with the Fraunhofer Center for Manufacturing Innovation at BU, which helped create the flexible circuit board and skin-safe material in the wearable device. In addition, he has received funding from the American Cancer Society as well as a $4 million five-year grant from the US Department of Defense Breast Cancer Research Program.

He wants to take these newer devices to the clinic. He's

already at work on his next version: a wearable design that can collect absolute measures of oxygenated blood, fat, and lipids. All of his efforts must move forward in parallel, with his team learning from studies of patients and laboratory animals and adjusting their technology each step of the way.

"The most important thing," says Roblyer, "is to figure out if this is the right technology and if it will help people."

ECE SYMPOSOIUM HONORS CAREER OF PROF. EMERITUS THEODORE MOUSTAKAS

PROFESSOR THEODORE MOUSTAKAS CAREER OF INVENTION AND LEADERSHIP HONORED

by Sara Cody

COLLEAGUES FROM AROUND THE WORLD came to campus on Dec. 2 to honor the career of Professor Emeritus Theodore Moustakas (ECE, MSE) at a symposium focused on his signature innovation, a process that makes the glowing screens on today's ubiquitous electronic devices possible, as well as other discoveries.

The symposium, "III-Nitride Semiconductor Materials and Devices Symposium," was fittingly held in the Photonics Center, a building Moustakas had a leading hand in creating.

"The ubiquity of Ted's work in blue LEDs, used in laptops, cell phones and a myriad of other lighting and backlit devices, makes his work seminal to basically everyone in society today," said Boston University President Robert A. Brown in his opening remarks. "However, to me, one of Ted's most important contributions is as an early pioneering research leader at Boston University."

Moustakas invented and patented a process currently being used to create blue light-emitting diodes (LEDs), utilized in many devices today. When LEDs were invented more than 40 years ago, they were made with a compound called gallium arsenide, which emitted a faint red and green glow, and was used in products like digital clocks and calculator displays. It was hypothesized that a compound called gallium nitride, which emits a blue light, would produce a brighter light, but the structure of the semiconductor crystals at the time did not support the much-smaller blue wavelengths.

Moustakas solved this problem by creating the buffer-layer process, a two-step method that bridges the gap between the semiconductor crystals and the blue wavelengths, publishing his findings in 1991. To this day, it is the only known way to

Theodore Moustakas

Along with Moustakas' contributions to the field of LEDs, he was also a key player in the quest to build the Photonics Center, which was established in 1993.

make blue LEDs, and is still used in the technology that people interact with on a daily basis, such as smartphones, televisions and lightbulbs.

Last year, BU and Moustakas won a $13 million judgment in federal court against three major companies which were determined to have willfully infringed on the patented technology he developed. The three Taiwan-based companies manufacture or package LEDs for consumer electronics for big-name electronics companies. Though these major companies were named on the initial case, they settled out of court while agreeing to licensing and confidentiality agreements.

While Moustakas was publishing his findings with gallium nitride, Shuji Nakamura, an engineer from Japan who is now a Professor at the University of California at Santa Barbara, was working on similar technology. Though initially Nakamura and Moustakas were competitors racing to patent their technologies, they remain cordial colleagues, and Nakamura gave a keynote speech about the blue LED technology at the symposium.

In addition to Nakamura, the symposium hosted a variety of speakers, experts in the field of semiconductors, who came to speak about their own work and research and honor Moustakas' career.

Other speakers included:

- Charles Eddy, US Naval Research Laboratory: "Advancing III-N Semiconductors in New Directions."
- Professor Asif Khan, University of South Carolina: "High Al-content AlxGa1-xN Heterojunctions for Devices in the Deep Ultraviolet Part of the Spectrum."
- Professor Philomela Komninou, Aristotle University of Thessaloniki, Greece: "Nanostructures and Interfaces in Epitaxial III-Nitride Semiconductors."
- Eva Monroy, CEA Grenoble: "Plasma-assisted MBE of III-Nitride Semiconductors and its Applications to Intersubband Devices."
- Professor Fernando Ponce, Arizona State University: "Microstructure and Polarization Properties of III-N Semiconductors."
- Professor David Smith, Arizona State University: "Exploring III-Nitrides with Advanced Electron Microscopy Techniques."
- Professor Tadeusz Suski, Polish Academy of Sciences, Warsaw: "From High-Pressure Bulk GaN Crystals to InGaN/GaN Quantum Structures and Light Emitters."

Along with Moustakas' contributions to the field of LEDs, he was also a key player in the quest to build the Photonics Center, which was established in 1993. Today, the Photonics department is a robust collaborative of faculty and graduate students who create new light-based materials, devices and systems, and use them to impact society. When Professor Thomas Bifano (ME), director of the Photonics Center, spoke about the history of the building, he credited Moustakas' leadership in writing a complex grant proposal that led to funding by the Department of Defense.

"Ted, along with his colleagues, wrote a beautifully rich document with very high technical detail filled with great ideas about how the Boston University Photonics Center could transform both defense and society," said Bifano. "Today, the three core values of the Photonics Center are we lead interdisciplinary research, we share community resources and we promote technology translation. There is no doubt that the lead person in establishing this was Ted Moustakas."

When Moustakas stood to provide closing remarks for the symposium, he recounted his life experience that led him to BU. Born in a small village in Greece during the World War II, at a time of political upheaval and civil war in his country, his hometown did not have electricity until he was a teenager. He recounted a formative experience he had growing up that forever altered his outlook on life, when his high school teacher gave him a book written by Greek author Nikos Kazantzakis that included the famous quote "reach what you cannot."

"This quote is what has driven me throughout my life, and I try to instill the same spirit on my children and graduate students. Keep going as far as you cannot go, and you will make discoveries along the way," said Moustakas. "I grew up reading by candlelight or a petroleum lamp, so I feel very humble looking back at my career and hearing your kind words about how I contributed to this technology that produces light."

NEUROPHOTONICS CENTER: ADVANCING UNDERSTANDING OF THE BRAIN

NEW CRITICAL NEUROPHOTONICS CENTER LAUNCHED AT BU WILL BE LED BY PHOTONICS PROFESSOR DAVID BOAS

by Michael Seele

THE UNDERSTAND OF THE HUMAN BRAIN has leaped forward in recent years, with the help of the emerging field of neurophotonics, a noninvasive, light-based technology that allows scientists to study the brain's functioning in real time. Boston University has been a leader in the field and is now capitalizing on its expertise in neuroscience and photonics to create the Neurophotonics Center, led by one of the field's preeminent researchers.

David Boas is joining the College of Engineering faculty as the new center's founding director and a professor of biomedical engineering. He comes from Massachusetts General Hospital, where he has pioneered new technologies to see deep into the brain to improve understanding of its healthy functioning and offer new pathways to understand how strokes, migraines, Alzheimer's disease, and other neurologic maladies affect it. Boas is recruiting faculty from throughout ENG and across the University to pool expertise and further accelerate neurophotonics technologies.

There are tremendous advantages to biomedical and photonics engineers working with neuroscientists," says Boas. "Neuroscientists have questions and problems

...the center will be developing and applying novel approaches to measuring human brain function with light.

David Boas

that engineers want to solve. Those solutions advance the field and lead to new questions and new solutions. Boston University has a wealth of expertise in photonics, biomedical engineering, and neuroscience that is excellent fuel for this virtuous cycle."

Many of the center's efforts will use multiphoton microscopy, a method that even 25 years after it began still has an increasing impact on neuroscience. In addition, the center will be developing and applying novel approaches to measuring human brain function with light.

Human functional brain imaging has been done for several years using fMRI (functional magnetic resonance imaging) scans, which produce sharp images of brain blood oxygenation and flow, key to seeing which areas of the organ are being stimulated at a given time. But fMRI scans require the subject to lie perfectly still in a confining machine for an extended period, obviously not a natural state and a difficult procedure to use with infants, small children, and many others. They are also expensive.

Instead, Boas uses functional near-infrared spectroscopy (fNIR), which penetrates through the scalp and skull as much as a centimeter into the brain, where it detects blood oxygenation, ultimately enabling the imaging of brain function. The images aren't as crisp as fMRI scans, but the wearable device allows wearers to move around naturally, engage socially, and go about their activities while researchers observe blood flow and oxygenation changes in the brain in real time at a far lower cost. Furthering this research is expected to be one of the Neurophotonics Center's initial projects.

Faculty from the College of Arts & Sciences, Sargent College of Health & Rehabilitation Sciences, and the School of Medicine will join ENG faculty in the center, among them Thomas Bifano, an ENG mechanical engineering professor and director of the Photonics Center, Barbara Shinn-Cunningham, an ENG biomedical engineering professor, and Howard Eichenbaum and Chantal Stern, both CAS psychological and brain sciences professors. The Neurophotonics Center will draw on the work of doctoral students through the new $2.9 million Research Traineeship grant for neurophotonics from the National Science Foundation, which will award its first fellowships in 2017.

BU SANDER RECEIVES AIR FORCE RESEARCH GRANT

PROFESSOR MICHELLE SANDER
RECEIVES GRANT TO STUDY INFRARED LIGHT

by Sara Cody

ASSISTANT PROFESSOR MICHELLE SANDER (ECE, MSE) has won a prestigious Young Investigator Research Award from the Air Force Office of Scientific Research (AFOSR). Fewer than one in four of the 230 applicants were awarded funding under the program this year.

Sander's laboratory research centers on novel ultrafast laser sources at infrared wavelengths and photothermal imaging techniques in the mid-infrared wavelengths. Her AFOSR project proposal, "Cell Membrane Dynamics in Infrared Nerve Stimulation and Blocking," will focus on stimulating nerves using infrared lasers to understand the biophysical mechanisms of how cells will interact with infrared electromagnetic waves.

"I am very excited to have this opportunity to study how optical infrared light can be used to stimulate or inhibit nerves and the associated underlying biophysical mechanisms," says Sander. "In the long term, this technology has the potential to advance therapeutic approaches for nerve control, pain management and neurological diseases."

The AFOSR research grant award recognizes researchers within five years of obtaining their doctorate degrees who "show exceptional ability and promise for conducting basic research."

Michelle Sander

New Photonics Center Faculty

Professor Stephan Anderson, MED
Dr. Anderson is an Associate Professor in the Department of Radiology at Boston University Medical Center. Dr. Anderson's clinical interests lie in the imaging of diffuse liver disease as well as hepatocellular carcinoma, and his research is focused on the development of micro- and nanofabrication strategies for biomedical imaging and sensing applications.

Dr. Anderson graduated from the University of Maryland with an M.D., completed a Diagnostic Radiology residency at Boston University Medical Center, and an Abdominal Imaging fellowship at the Beth Israel Deaconess Medical Center.

Professor Jerry Chen, Biology, BME
Professor Jerry Chen is the Stuart and Elizabeth Pratt Career Development Professor and an Assistant Professor of Biology and Biomedical Engineering at Boston University. He received his B.A. from the University of California, Berkeley, and a Ph.D. from the Massachusetts Institute of Technology. His research interests include studying the principles of long-range cortical communication, technologies for large-scale imaging of neuronal populations, and long range cortical circuits during development.

His lab studies the relationship between local circuits and long-range networks in the mammalian neocortex. They take an integrative approach by combining large-scale in vivo imaging technology with molecular and genetic tools in the awake-behaving animal.

Professor Xi Ling, Chemistry, MSE
Professor Xi Ling is an Assistant Professor of Chemistry and Materials Science and Engineering at Boston University. She earned a Ph.D. in Physical Chemistry at Peking University under the guidance of Jin Zhang and Zhongfan Liu in 2012, and a B.S. in Chemistry from Lanzhou University in 2007. Following her doctoral work, she was a postdoctoral associate with Mildred Dresselhaus at the Massachusetts Institute of Technology from 2012 to 2016.

Professor Ling leads an interdisciplinary research group focused on the fundamental science and applications of nanomaterials and their hybrid structures. The group specialized in the synthesis of two-dimensional (2D) van der Waals materials, their characterization through spectroscopy, and their implementation to develop novel nanodevices. Ling has co-authored 45 peer-reviewed publications, two patent applications, and has received the Materials Science and Engineering Innovation award from Boston University and the Electrical Engineering and Computer Science rising star award from MIT.

Professor Milos Popovic, ECE
Professor Milos Popovic is an Assistant Professor in the Electrical and Computer Engineering department. Professor Popovic has authored or co-authored over 25 patents and 150 journal and conference papers. He is also co-founder and advisor of Ayar Labs, a tech startup that helps companies manage their data through cutting-edge silicon chip technology. His research interests include silicon photonics, first-principles theory and design of integrated photonic devices and circuits, CMOS photonics integration and nano-optomechanical devices.

Before joining the Boston University faculty, he was an Assistant Professor of Electrical Engineering and a GE/Donnelly Faculty Fellow at the University of Colorado Boulder. He was awarded a fellowship by the David and Lucile Packard Foundation in 2012. Dr. Popovic received a Ph.D. in Electrical Engineering from the Massachusetts Institute of Technology in 2007. He also holds a B.Sc.E. in Electrical Engineering from Queen's University in Canada and a M.S. in Electrical Engineering from the Massachusetts Institute of Technology.

Professor Chen Yang, Chemistry, ECE
Professor Chen Yang is an Associate Professor in the Chemistry and Electrical and Computer Engineering departments at Boston University. She graduated from the University of Science and Technology in China with a bachelor's degree in Chemical Physics in 1999. She obtained a Master in Philosophy in 2000 from the Hong Kong University of Science and Technology, and a Ph.D. from Harvard University in 2006.

She joined the department of Chemistry and the department of Physics at Purdue University in August 2007. Professor Yang's research focuses on nano materials for their potential applications in nanoscale devices and biological applications. Her research was published in the publications Science and Nature, and she won awards such as the NSF Career Award and the Purdue University Seed of Success.

Professor Ji Yi, Medicine
Professor Ji Yi is an Assistant Professor in the Medicine department at Boston University. Professor Yi's work focuses on novel optical techniques for early disease detection, and the monitoring of disease progression and prognosis. Among other inventions, he developed various imaging methods that enable non-invasive detection of nanoscale structural alterations in tissue and the local tissue metabolism. By applying those techniques, he demonstrated the detection of the earliest form of colorectal and pancreatic cancers, colonization of metastatic breast cancer cells, and blinding retinal diseases such as diabetic retinopathy. He also studied the nanoscale structural changes in both cellular and extracellular components in field carcinogenesis.

His research is at the interface of Physics, Engineering, Biology and Medicine that ultimately aims to improve the health care of general public. He received a B.S. in Biomedical Engineering from Tsinghua University in Beijing, China, and a M.S. and Ph.D in Biomedical Engineering from Northwestern University.

Faculty & Staff

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- Structure and stability of interfaces

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- Semiconductor materials

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- Adaptive optics

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- Mechanical properties of materials at low temperatures
- MEMS and NEMS

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Research interests:
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Research interests:
- Top-down pattering and bottom-up assembly
- Mesoscale soft materials
- Scanning probe techniques

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Research interests:
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- Molecular transport through porous graphene
- Graphene adhesion

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Research interests:
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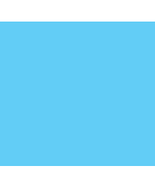
- Medical Photonics



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- Identification of biomarkers of infection
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- Optics of complex media
- Computational electromagnetics

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Research interests:
- Nanobiotechnology
- Flourescent biosensing
- Quantum dot chemistry
- Flourescence resonance energy transfer (FRET)

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

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

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- Quantum cascade laser sources
- Ultrafast infrared spectroscopy

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- STEM outreach and development

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- Space plasma physics
- Magnetosphere physics
- Rocket and satellite experiments

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- Femtosecond laser surgery

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Research interests:
- Mechanisms of temporal sequence perception and production
- Vocal learning in songbirds

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

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- Alzheimers disease
- Biometals and metallomics
- Molecular aging disorders

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- Neurotechnology

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- Computer architecture

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Research interests:
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- Microfluidic device design

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- Synthesis of van der Waals materials

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Research interests:
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- High resolution imaging

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

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Research interests:
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- Amorphous semiconductors

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Research interests:
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- Plasmonics and related optoelectronic device applications

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Research interests:
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- Circuits for high frequency

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Research interests:
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- First-prinicples theory and design of integrated photonic devices

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Research interests:
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- Optical physics of guided waves

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- New optical materials

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- Neurophotonic methods applied to the rodent whisker tactile system

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Research interests:
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- Therapies in oncology
- Optical functional imaging

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

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- Resonant cavity biosensors
- Optical design
- K-12 outreach and education

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- Frequency combs
- Fiber and integrated optics

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- Carbon nanotubes

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- Gigapixel 3D microscopy
- Compressive imaging

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- Nanoscale imaging of biological samples
- Biosensors

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- Space plasma dynamics
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- Nanoscale 3D printing
- Mechanical metamaterials

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Research interests:
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- Pathophysiology of epilepsy
- Computational neuroscience

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Research interests:
- Nano materials for their potential applications in nanoscale devices and biological applications

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Research interests:
- Novel optical techniques for early disease detection
- Monitoring disease progression and prognosis

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Research interests:
- Micro nanomaterials
- Micro nanomechanics

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

FACULTY COMMITTEES

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

Photonics Center Guest Speakers:
Chair – Tim Weber
This year, the Photonics Center initiated a new Distinguished Speaker Seminar Series managed by student leaders of the BU student chapters of the Optical Society of America and SPIE. With support by the Photonics Center for travel and seminar expenses, students host a distinguished speaker of their choice each semester. The inaugural Distinguished Speaker was Professor Peter So, of MIT.

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

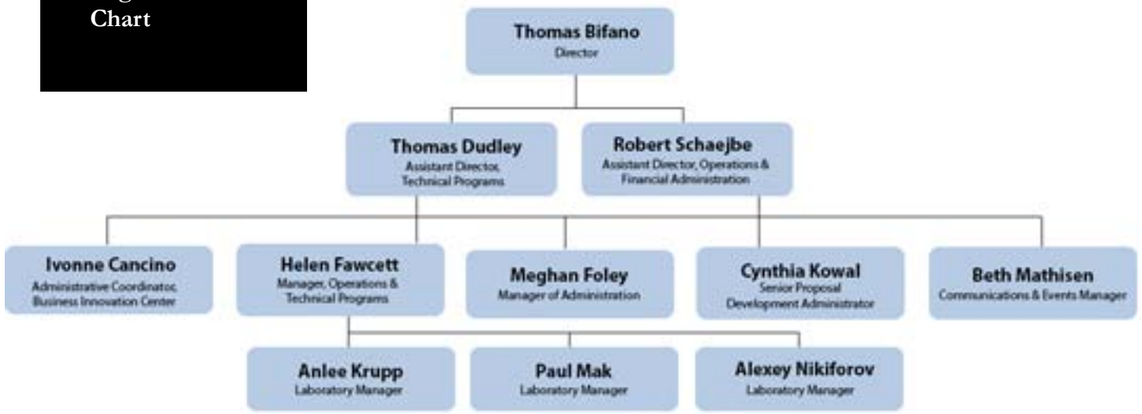
Academic Advisory:
Chair – Dr. Thomas Bifano
The Academic Advisory Committee advises the Director of the Photonics Center on educational and academic issues and is comprised of the chairs from the Center's affiliated departments.

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

Symposium:
Chair – Dr. Darren Roblyer
This committee chair organized the 20th annual Photonics Center Symposium that focused on optics for cancer imaging. The symposium included external university speakers.

Leadership & Administrative Staff

Photonics Center Organizational Chart



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Photonics Center Recruits New Senior Proposal Development Administrator

Cynthia Kowal joined the Photonics Center staff in April 2016 to serve as the Senior Proposal Development Administrator at the Photonics Center. Cynthia worked for 26 years in the BU Office of Sponsored Programs where she worked with natural science and related research center faculty to finalize and submit large proposals by providing expert guidance on formatting and submission.

In her new role, Cynthia is responsible for providing strategic advice, critical review, management and logistical support to add value for large scale, complex collaborations proposed for external sponsorship, including research and educational projects. She advises PIs, other faculty leads, and Center staff on the responsiveness to federal and private funding solicitations, sponsor culture, best practices of proposal development and aspects of post-award project administration, and compliance matters from sponsor and University perspectives.

Thus far, she has worked on the National Science Foundation (NSF) Engineering Research Center proposal, the Photonics Center NSF Research Experiences for Undergraduates and Research Experiences for Teachers proposals, and helped guide faculty through numerous efforts to develop and submit research proposals.

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 (NIH), 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.

An emphasis on research and training are reflected in some of the Center's statistics. Each year the Center conducts a program formulation process, where faculty submit proposals in response to a solicitation that outlines the member's technology needs. In aggregate, the research faculty generated 145 proposals which were reviewed by the Industry Advisory Board (IAB). The IAB reviews and rank orders the projects, selecting those to be funded. Over Phase I, 28 proposals were funded and completed, some with commercial potential. Each funded project has an industry mentor and were reviewed twice during the year.

In the no-cost extension year of Phase I, eight research projects were approved and funded by the membership. 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
Low Magnification IRIS Instrument for Antibody Spotting Development and Quality Control	Unlu	BU	Scienion	9/15	6/17	$120K
Pre-clinical Study of Raman Spectroscopy for in vivo and ex vivo Probing of Retina in Animal Models of Age-Related Macular Degeneration (AMD)	Zawadski	UCD	Photonics Cross-roads	7/16	6/17	$60K
Module for Android Phone Based Nucleic Acid Detection of Mosquito Borne Viruses	Klapperich	BU	BD	7/16	6/17	$50K
Enhancing Raman Imaging Speeds with Modulated Multifocal Detection and EMCCD Camera	Chan	UCD	Nikon	7/16	6/17	$90K
Lens-Free Ultrathin Compound-Eye Camera	Paiella	BU	Thorlabs	10/16	2/17	$34K
Woofer Tweeter Wavefront Sensorless Imaging System	Zawadski	UCD	IRIS AO	7/16	6/17	$61K
Dynamic Pupil Engineering in a Microscope	Mertz	BU	Thorlabs	7/16	6/17	$100K
Raman-Based Method for Screening anti-Alzheimer's Drug Candidate	Voss/Chan	UCD	Moxtek	7/16	6/17	$50K

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.

The major positive development for the year was the award of Phase II status to CBSS, therefore a further objective during the final year of Phase I was to spend down all funds from both membership and NSF sources. As the Center transitioned from Phase I to Phase II, it was important to clearly identify Phase I funding and milestones. Phase I ended on February 28, 2017 and the Center seamlessly transitioned to Phase II on March 1.

Low Magnification IRIS Instrument for Antibody Spotting Development and Quality Control – (Unlu). Scienion, the mentor on this project, expects to ultimately use the output in a production scale QC check. Scienion was able to convince enough other members to support this project for a second year, bringing the total project funding to $120K. 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. The effort during the most recent fiscal year focused on automating the platform for better performance in a manufacturing environment.

Module for Nucleic Acid Detection of Mosquito Borne Pathogens- (C. Klapperich). The goal of this project was to develop a cost-effective, serotype, point-of-care diagnostic device for blood borne pathogens. Originally targeting Dengue for initial testing, the team switched to malaria to de-risk the development of the disposable chip and detection module, which are being designed to operate with the Google Modular Smartphone.

Lens Free Ultra-thin Compound-Eye Camera – (R. Paiella). This project was initiated later in the year when it became obvious that there would be excess Phase I funds in the I/UCRC budget. The funding was a relatively modest at $34K and provided supplemental funding for an existing sponsored research agreement with Samsung. This project was aimed at the development of a lens-free ultrathin camera based on compound-eye vision modality. The research can benefit a wide range of imaging applications where miniaturization, wide-angle vision, and high temporal resolution are of particular importance.

Dynamic Pupil Engineering in a Microscope – (Mertz). Using a tilt-tip-piston (TTP) deformable mirror developed in Professor Bifano's lab, this project focused on demonstrating a dynamically reconfigurable mask to change the angle or phase of the microscope pupil. Using the TTP-DM to discriminate spatial frequency components, new techniques for high throughput, label-free flow cytometry are enabled. Thorlabs was a mentor on this project and there is some interest in commercializing the technology.

The initial program formulation meeting of Phase II was held in May 2017 to determine the project selection and funding levels for FY18. After reviewing a record 37 projects, the Center Director and Site Directors approved the ranking as submitted by the IAB and funded eight projects which will be launched in FY18. The projects were evenly split between BU and our partner university (UC Davis). The projects that will run at Boston University appear in the table below.

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.

Project	Project PI	Mentor	Budget
Protein and Small Molecule Dynamic Analysis in Microwell Plates	Unlu	Scienion	$77K
High Speed 3D Imaging with a Standard Microscope	Mertz	Thorlabs	$50K
Computational Microscopy for Label-free, High-Throughput 3D Cellular Imaging	Tian	Thorlabs	$48K
IRIS Instrument for Label-free and Multiplexed Protein Binding Measurements	Unlu	Inbios	$50K

MAJOR PROJECTS MANAGED BY THE CENTER

NSF NRT: Understanding the Brain (UtB): Neurophotonics

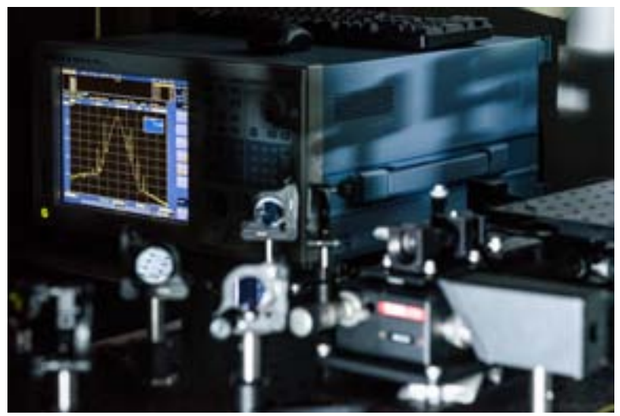
The Photonics Center led the submission of a five-year training grant through the National Science Foundation National Research Traineeship Program. The training grant was awarded on August 31, 2016 on the topical area Understanding the Brain (UtB): Neurophotonics. BU was one of two awards in the Understanding the Brain category. The first year focused on recruiting from within Boston University's incoming fall 2016 class and recruiting externally for new graduate student applying for fall 2017. The fall was focused on recruiting and the winter and spring focused on engaging the neurophotonics community through seminars and social networking events. The first cohort (fall 2016 students) applied to be NRT trainees in April. Traineeships form the essential core of the NRT student community and all trainees have access to the many benefits and opportunities afforded by our traineeship grant. Our program's emphasis is on community building, collaborations, interdisciplinary research, and professional development opportunities for trainees. Fellows are trainees whose stipends are supported by NSF funds for two years. Eighteen trainees have been accepted into the training program and three fellowships from these first year trainees were awarded. More information about the NRT UtB: Neurophotonics can be found on the program website: http://www.bu.edu/neurophotonics-nrt/.

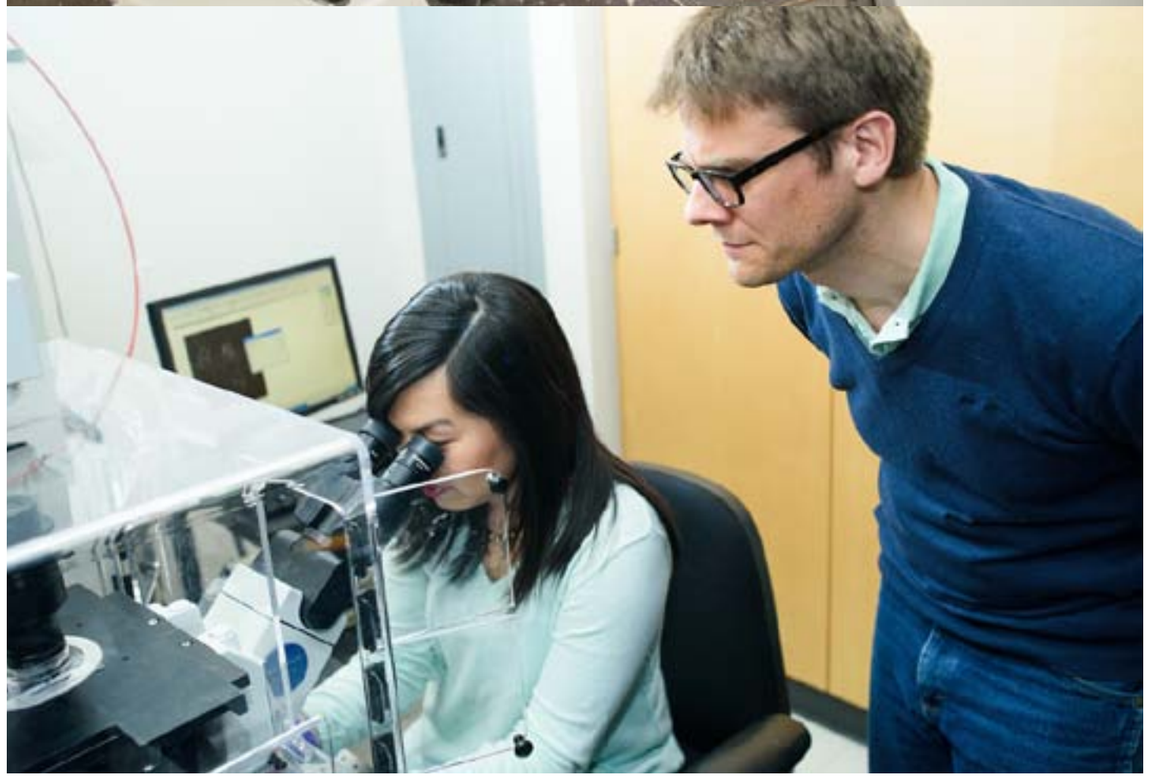
NIH U54: Center for Innovation in Point of Care Technologies for the Future of Cancer Care

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 Clinical Outreach Director of this grant. The Photonics Center provides financial and administrative management of this grant. The final year of the grant was completed with a one-year no cost extension. The projects from Year 5 are complete with a few follow-on projects that will be funded in the no-cost extension year to continue integrating the technologies. This year, CFTCC engaged with the BU-BMC Cancer Center as well as BU Henry M. Goldman School of Dental Medicine, Hariri Institute for Computing, Interdisciplinary Biomedical Research Office, and General Internal Medicine for combined seminars and training events. 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 was a five-year grant entitled, "Development of near Real-Time, Multiplexed Diagnostics for Viral Hemorrhagic Fever." This grant has a component that includes partnership with a commercial entity that has been identified and engaged from the start of the program, with the 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. The no-cost extension ends in July 2017, with demonstration of a manufacturable cartridge system and final testing in varied media with diagnostics of bona-fide viruses being validated at UTMB. In addition to program management and directing integration with commercial partners, the Photonics Center also provides financial and administrative management for this program.





LIST OF CURRENT GRANTS

Photonics faculty members received more than **$22.1M** in external funding. The following table lists funds in the fiscal year (July 1, 2016 - June 30, 2017), as reported by the Sponsored Programs office.

GRANT TITLE	PI NAME	SPONSOR	FUNDING PERIOD	AMOUNT FUNDED
CRA: COMPUTATIONALLY-GUIDED DESIGN OF ENERGY EFFICIENT ELECTRONIC MATERIALS (CDE3M)	BELLOTTI ENRICO	UNIVERSITY OF UTAH	01/01/2014 - 01/31/2018	$11,354,015
DARPA WIRED - POLYCRISTALLINE SEMICONDUCTORS - TASKS TA1	BELLOTTI ENRICO	HRL LABORATORIES, LLC	06/28/2016 - 12/28/2017	$494,008
DARPA WIRED - COLLOIDAL QUANTUM DOT DETECTORS - TASKS TA1 AND TA2	BELLOTTI ENRICO	DRS ADVANCED ISR, LLC	06/28/2016 - 06/30/2017	$535,926
NRT UTB: NEUROPHOTONICS	BIFANO THOMAS	NATIONAL SCIENCE FOUNDATION	09/01/2016 - 08/31/2021	$2,928,842
PHASE II I/UCRC TRUSTEES OF BOSTON UNIVERSITY: CENTER ON BIOPHOTONIC SENSORS AND SYSTEMS	BIFANO THOMAS	NATIONAL SCIENCE FOUNDATION	07/01/2011 - 02/28/2017	$1,096,667
I/UCRC COLLABORATIVE RESEARCH	BIFANO THOMAS	I/UCRC: INDUSTRY MEMBERSHIPS	07/01/2017 - 06/30/2018	$90,170
PERSONNEL AGREEMENT FOR RESEARCH SERVICES OF ELADIO RODRIGUEZ-DIAZ	BIGIO IRVING	VA BOSTON HEALTHCARE SYSTEM	07/01/2017 - 06/30/2018	$90,170
DEVELOPMENT OF OPTICAL INSTRUMENTS FOR SENSING SKIN DISEASE	BIGIO IRVING	DERMASENSOR, INC.	08/01/2016 - 10/31/2017	$224,124
BILLING AGREEMENT FOR HAO LI - RESPIRATORY GATING RECONSTRUCT	BIGIO IRVING	GENERAL HOSPITAL CORP D/B/A MASSACHUSETT	05/01/2015 - 04/30/2016	$23,364
ATOMIC CALLIGRAPHY TO BUILD TUNABLE OPTICAL METAMATERIALS	BISHOP DAVID	DEPARTMENT OF DEFENSE/AIR FORCE	06/04/2015 - 01/12/2019	$1,667,888
MEMS DEVICES FOR DETECTING THE CASIMIR ENERGY	BISHOP DAVID	DEPARTMENT OF COMMERCE/NIST	01/01/2017 - 01/31/2018	$104,458
DETECTING THE CASIMIR ENERGY	BISHOP DAVID	NATIONAL SCIENCE FOUNDATION	07/01/2017 - 06/30/2020	$370,000
MEMS DEVICES FOR LGS	BISHOP DAVID	LGS INNOVATIONS, LLC	12/01/2015 - 06/30/2017	$226,167
(MURI 15) A 4D NANOPRINTER FOR MAKING AND MANIPULATING MACROSCOPIC MATERIAL	BROWN KEITH	NORTHWESTERN UNIVERSITY	12/15/2016 - 03/14/2018	$250,000
CLOSED-LOOP, TIP-DIRECTED NANOCHEMISTRY	BROWN KEITH	NATIONAL SCIENCE FOUNDATION	09/01/2017 - 08/31/2020	$400,886
REALIZING AN ELECTRIC FERROFLUID THROUGH RATIONAL NANOPARTICLE DESIGN	BROWN KEITH	AMERICAN CHEMICAL SOCIETY PETROLEUM RESE	09/01/2017 - 08/31/2019	$110,000
NEURAL CIRCUIT BASIS FOR CORTICAL OSCILLATIONS AS A BIOMARKER FOR NEUROLOGICAL DISORDERS	CHEN JERRY	BRAIN & BEHAVIOR RESEARCH FOUNDATION	01/15/2017 - 01/14/2019	$70,000

GRANT TITLE	PI NAME	SPONSOR	FUNDING PERIOD	AMOUNT FUNDED
CIRCUIT MECHANISMS FOR LONG-RANGE COMMUNICATION IN THE NEOCORTEX	CHEN JERRY	RICHARD AND SUSAN SMITH FAMILY FOUNDATION	03/01/2017 - 02/28/2018	$100,000
ROLE FOR INTER-AREAL CORTICAL DYNAMICS DURING PERCEPTION	CHEN JERRY	WHITEHALL FOUNDATION, INC	07/01/2017 - 06/30/2018	$75,000
BIOMARKER DISCOVERY	CONNOR JOHN	JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS	03/10/2015 - 12/31/2016	$571,015
ROLE FOR POLYAMINES IN EBOLA VIRUS REPLICATION	CONNOR JOHN	NIH/NATIONAL INSTITUTE OF ALLERGY & INFE	02/01/2016 - 01/31/2018	$451,876
ELIMINATION OF PATHOGENIC IGE IN CYSTIC FRIBROSIS	CONNOR JOHN	THE BRIGHAM AND WOMEN'S HOSPITAL, INC.	08/01/2016 - 07/31/2017	$85,562
INCLUSIVITY AND EXCLUSIVITY TESTING OF ADVANCED ASSAYS FOR FEVER OF UNKNOWN ORIGIN	CONNOR JOHN	BECTON, DICKINSON AND COMPANY	04/13/2017 - 04/12/2018	$67,500
ENHANCED SOLAR ENERGY CONVERSION BY ULTRA-SLOW PHOTON SUB-DIFFUSION IN APERIODIC MEDIA	DAL NEGRO LUCA	NATIONAL SCIENCE FOUNDATION	09/01/2016 - 02/28/2018	$119,995
TUNABLE SI-COMPATIBLE NONLINEAR MATERIALS FOR ACTIVE METAPHOTONICS	DAL NEGRO LUCA	NATIONAL SCIENCE FOUNDATION	07/01/2017 - 06/30/2020	$349,059
EFFECT OF DISORDER AND HOMOGENIZATION ON METAMATERIALS	DAL NEGRO LUCA	MIT/LINCOLN LABORATORY	06/01/2017 - 11/30/2017	$75,000
ENHANCED LIGHT EMISSION FROM LEDS WITH APERIODIC NANOSTRUCTURES	DAL NEGRO LUCA	OSRAM SYLVANIA, INC.	08/01/2016 - 05/31/2017	$82,394
CLARE BOOTH LUCE FELLOWSHIP - MARGARET CHERN	DENNIS ALLISON	THE HENRY LUCE FOUNDATION, INC.	09/01/2015 - 08/31/2017	$234,854
EXPLORING NANOMECHANICAL FLUCTUATIONS OF SURFACE-ADHERED BACTERIA FOR NOVEL ANTIBIOTIC SUSCEPTIBILITY TEST	EKINCI KAMIL	NIH/NATIONAL INSTITUTE OF ALLERGY & INFE	06/01/2016 - 05/31/2018	$164,500
NANOSCALE FLUID-STRUCTURE INTERACTION: HYDRODYNAMIC SYNCHRONIZATION OF HIGH-FREQUENCY NANOMECHANICAL OSCILLATORS	EKINCI KAMIL	NATIONAL SCIENCE FOUNDATION	07/01/2016 - 06/30/2019	$306,892
RET IN ENGINEERING AND COMPUTER SCIENCE SITE: INTEGRATED NANOMANUFACTURING	FAWCETT HELEN	NATIONAL SCIENCE FOUNDATION	05/01/2015 - 04/30/2018	$390,000
MOLECULAR DETERMINATION OF IN VIVO CELLULAR CALCIUM SIGNALING DURING NERVE DAMAGE AND REGENERATION	GABEL CHRISTOPHER	NIH/NATIONAL INSTITUTE OF NEUROLOGICAL D	05/01/2016 - 04/30/2018	$1,535,846
SINGLE NEURON MECHANISM OF SENSORY-MOTOR LEARNING	GARDNER TIMOTHY	NIH/NATIONAL INSTITUTE OF NEUROLOGICAL D	09/15/2014 - 06/30/2019	$2,864,752

GRANT TITLE	PI NAME	SPONSOR	FUNDING PERIOD	AMOUNT FUNDED
HIGH-DENSITY RECORDING AND STIMULATION MICROELECTRODES	GARDNER TIMOTHY	NIH/NATIONAL INSTITUTE OF NEUROLOGICAL D	09/30/2014 - 07/31/2017	$1,679,622
A TRANSGENIC SONGBIRD TO IMAGE BRAIN PREMOTOR SEQUENCES	GARDNER TIMOTHY	CALIFORNIA INSTITUTE OF TECHNOLOGY	09/15/2015 - 08/31/2017	$165,529
A PLATFORM FOR INNOVATION IN MINIATURE MICROSCOPY	GARDNER TIMOTHY	NIH/NATIONAL INSTITUTE OF NEUROLOGICAL D	08/01/2016 - 06/30/2020	$558,802
HIGH DENSITY MICROFIBER INTERFACES FOR DEEP BRAIN OPTICAL RECORDING AND STIMULATION	GARDNER TIMOTHY	NIH/NATIONAL EYE INSTITUTE	09/30/2016 - 07/31/2018	$478,083
ELECTRODE-THREAD ARRAY FOR RECORDING AND PLAYBACK OF NEURALSIGNALS ON VISCERAL NERVES	GARDNER TIMOTHY	GLAXOSMITHKLINEINC.	11/05/2014 - 12/31/2016	$665,627
GADOLINIUM DISTRIBUTION IN RAT BRAIN AFTER SYSTEMIC ADMINISTRATION OF GADOLINIUM-BASED CONTRAST AGENTS	GOLDSTEIN LEE	GE HEALTHCARE, INC.	10/01/2016 - 06/18/2019	$2,964,216
THE BLOOD-BRAIN BARRIER AS A DIAGNOSTIC AND THERAPEUTIC TARGET FOR TRAUMATIC BRAIN INJURY (TBI)	GOLDSTEIN LEE	PRAIRIE MINERALS FOUNDATION	01/01/2017 - 12/31/2017	$250,000
NEW TOOLS AND PRINCIPLES FOR UNDERSTANDING THE BIOPHYSICAL MECHANISMS OF ULTRASOUND NEUROMODULATION	HAN XUE	DEPARTMENT OF DEFENSE/DARPA	09/15/2015 - 09/14/2017	$499,464
CHARATERIZE FUNCTIONAL CONNECTIVITIY OF HIPPOCAMPAL ADULT BORN NEUROGENESIS DURING CRITICAL PERIOD	HAN XUE	NIH/NATIONAL INSTITUTE OF MENTAL HEALTH	04/15/2016 - 03/31/2018	$431,513
CAUSAL ANALYSIS OF ELECTRICALLY CONNECTED NEURAL NETWORKS	HAN XUE	NIH/NATIONAL INSTITUTE OF NEUROLOGICAL D	09/01/2016 - 08/31/2017	$323,550
LIGHT-ACTUATABLE NANOROBOTS FOR MOLECULAR UNCAGING	HAN XUE	NIH/NATIONAL INSTITUTE OF NEUROLOGICAL D	09/01/2017 - 06/30/2018	$493,750
RAPID MOLECULAR DIAGNOSTS FOR CHLAMYDIA AND GONORRHEA AT THE POINT-OF-CARE	KLAPPERICH CATHERINE	NIH/NATIONAL INSTITUTE OF ALLERGY & INFE	04/01/2015 - 03/31/2018	$1,195,548
CENTER FOR INNOVATION IN POINT OF CARE TECHNOLOGIES FOR THEFUTURE OF CANCER CARE	KLAPPERICH CATHERINE	NIH/NATIONAL INSTITUTE OF BIOMEDICAL IMA	07/01/2016 - 06/30/2017	$1,790,893
RAPID PAPER-BASED DIAGNOSTICS OF CT/TRICH	KLAPPERICH CATHERINE	MICRO ANALYSIS LLC	08/15/2016 - 01/31/2017	$50,247
HIGH RESOLUTION PHASE CONTRAST ENDOSCOPY	MERTZ JEROME	NIH/NATIONAL CANCER INSTITUTE	12/15/2013 - 11/30/2017	$2,780,450
ULTRA-MINIATURIZED SINGLE FIBER PROBE FOR FUNCTIONAL BRAIN IMAGING IN FREELY MOVING ANIMALS	MERTZ JEROME	NIH/NATIONAL EYE INSTITUTE	09/30/2015 - 08/31/2017	$486,111

GRANT TITLE	PI NAME	SPONSOR	FUNDING PERIOD	AMOUNT FUNDED
HIGH DYNAMIC RANGE MULTIPHOTON MICROSCOPY FOR LARGE-SCALE IMAGING	MERTZ JEROME	NIH/NATIONAL EYE INSTITUTE	09/30/2016 - 07/31/2018	$485,885
GROUP-IV INTERBAND AND INTERSUBBAND SEMICONDUCTOR LASERS BASED ON SIGE NANOMEMBRANES	PAIELLA ROBERTO	DEPARTMENT OF DEFENSE/AFOSR	09/30/2014 - 09/29/2017	$559,999
IPA ASSIGNMENT - DIMITRIS PAVLIDIS	PAVLIDIS DIMITRIS	NATIONAL SCIENCE FOUNDATION	11/03/2014 - 11/02/2017	$745,224
OP: COLLABORATIVE RESEARCH: COHERENT INTEGRATED SI-PHOTONIC LINKS	POPOVIC MILOS	NATIONAL SCIENCE FOUNDATION	09/01/2016 - 08/31/2019	$143,999
MEMORY SYSTEM WITH MONOLITHIC CMOS PHOTONIC NETWORKS FOR HIGH-PERFORMANCE ENERGY-EFFICIENT EMBEDDED MANYCORE MACHINES	POPOVIC MILOS	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	09/01/2016 - 05/31/2017	$90,937
FUNDAMENTAL RESEARCH ON WAVELENGTH-AGILE HIGH-RATE QUANTUM KEY DISTRIBUTION (QKD) IN A MARINE ENVIRONMENT	RAMACHANDRAN SIDDHARTH	UNIVERSITY OF ILLINOIS	08/01/2013 - 07/31/2018	$2,105,776
(BRI) HIGH-POWER FIBER LASERS USING INTERMODAL NONLINEARITIES	RAMACHANDRAN SIDDHARTH	DEPARTMENT OF DEFENSE/AFOSR	09/01/2014 - 08/31/2019	$750,000
MULTIPLEXED MULTIPHOTON INTERROGATION OF BRAIN CONNECTOMICS	RAMACHANDRAN SIDDHARTH	NIH/NATIONAL EYE INSTITUTE	09/30/2015 - 08/31/2017	$492,500
HIGH THROUGHPUT TIP-ENHANCED NEAR FIELD MICROSCOPY USING RADIALLY POLARIZED FIBER MODES	RAMACHANDRAN SIDDHARTH	NATIONAL SCIENCE FOUNDATION	07/15/2016 - 06/30/2019	$360,684
POWER-SCALABLE BLUE FIBER LASERS	RAMACHANDRAN SIDDHARTH	DEPARTMENT OF DEFENSE/ONR	04/15/2017 - 04/14/2019	$267,256
ILLUMINATING DYNAMIC RECEPTOR CLUSTERING IN THE EPIDERMAL GROWTH FACTOR RECEPTOR	REINHARD BJOERN	NIH/NATIONAL CANCER INSTITUTE	05/01/2014 - 04/30/2018	$2,908,380
OP: PLASMONIC ENHANCEMENT OF CHIRAL FORCES FOR ENANTIOMER SEPARATION	REINHARD BJOERN	NATIONAL SCIENCE FOUNDATION	09/01/2016 - 08/31/2019	$400,740
SPATIOTEMPORAL CONTROL OF LARGE NEURONAL NETWORKS USING HIGH DIMENSIONAL OPTIMIZATION	RITT JASON	NIH/NATIONAL EYE INSTITUTE	09/30/2016 - 07/31/2018	$492,662
BIOENGINEERING OF CHANNEL RHODOPSINS FOR NEUOROPHOTONIC AND NANOPHOTONIC APPLICATIONS	KENNETH ROTHSCHILD	NATIONAL SCIENCE FOUNDATION	06/01/2017 - 05/31/2020	$520,000
NONLINEAR PULSE DYNAMICS IN FIBER LASERS AT THE VERGE OF MODE-LOCKING AND IN TRANSITION REGIMES	SANDER MICHELLE	NATIONAL SCIENCE FOUNDATION	07/01/2017 - 06/30/2020	$360,529
CELL MEMBRANE DYNAMICS IN INFRARED NERVE STIMULATION AND BLOCKING	SANDER MICHELLE	DEPARTMENT OF DEFENSE/AFOSR	04/28/2017 - 04/27/2020	$119,739

GRANT TITLE	PI NAME	SPONSOR	FUNDING PERIOD	AMOUNT FUNDED
THE NAMICS PROJECT	SCHMIDT AARON	NAMICS NORTH AMERICAN R&D CENTER - DIEMA	01/01/2017 - 12/31/2017	$55,000
THE MILLSTONE HILL GEOSPACE FACILITY	SEMETER JOSHUA	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	12/15/2012 - 11/30/2017	$285,953
MULTI-SCALE STRUCTURING OF THE POLAR IONOSPHERE BY MAGNETOSHERE-IONOSPHERE INTERACTIONS	SEMETER JOSHUA	DEPARTMENT OF DEFENSE/AFOSR	09/30/2015 - 09/29/2018	$268,312
SOLAR ECLIPSE OBSERVATIONS WITH A DENSE NETWORK OF SINGLE-FREQUENCY GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS) RECEIVERS	SEMETER JOSHUA	NATIONAL SCIENCE FOUNDATION	06/01/2017 - 05/31/2018	$83,851
EFRI ACQUIRE: MICROCHIP PHOTONIC DEVICES FOR QUANTUM COMMUNICATION OVER FIBER	SERGIENKO ALEXANDER	UNIVERSITY OF CALIFORNIA, SAN DIEGO	01/01/2017 - 12/31/2017	$97,000
EAGER: DESIGN AND EXPLORATION OF OPTICAL NANOANTENNA TECHNOLOGY FOR ADVANCED IC TESTING AND HARDWARE SECURITY	UNLU SELIM	NATIONAL SCIENCE FOUNDATION	08/15/2016 - 07/31/2018	$150,209
INTERFEROMETRIC IMAGING BIOSENSOR FOR SMALL MOLECULE - PROTEIN KINETICS	UNLU SELIM	COMM. OF MASS./ MASSACHUSETTS TECHNOLOGY	04/01/2017 - 06/30/2017	$10,000
CBL GRADUATE FELLOWSHIP FOR RACHAEL JAYNE	WHITE ALICE	THE HENRY LUCE FOUNDATION, INC.	09/01/2015 - 08/31/2017	$302,976
CALCIUM SIGNALING IN A MODEL OF TEMPORAL LOBE EPILEPSY	WHITE JOHN	UNIVERSITY OF UTAH	07/01/2016 - 06/30/2017	$184,605
REAL-TIME CONTROL SYSTEM FOR BIOLOGICAL EXPERIMENT	WHITE JOHN	THE JOAN & SANFORD I. WEILL MEDICAL COLL	07/01/2016 - 06/30/2017	$32,130
TRAINING PROGRAM IN QUANTITATIVE BIOLOGY AND PHYSIOLOGY	WHITE JOHN	NIH/NATIONAL INSTITUTE OF GENERAL MEDICA	07/01/2017 - 06/30/2018	$368,849
REU: INTEGRATED NANOMANUFACTURING	ZHANG XIN	NATIONAL SCIENCE FOUNDATION	05/01/2015 - 04/30/2018	$390,757
COUPLED EVANESCENT FIELD MICRO-RESONATORS FOR DOWNHOLE DATA RELAY	ZHANG XIN	UNIVERSITY OF TEXAS	01/01/2010 - 12/31/2017	$1,062,801
DRAPER LAB FELLOWSHIP (MATTHEW PONSINI)	ZHANG XIN	DRAPER LABORATORY, INC	09/01/2016 - 05/31/2017	$33,159
DRAPER LAB FELLOWSHIP (DAVID SUTHERLAND)	ZHANG XIN	DRAPER LABORATORY, INC.	06/01/2016 - 05/31/2017	$46,039
PLASMONICALLY ENHANCED STIMULATED COHERENT SPECTROSCOPY	ZIEGLER LAWRENCE	NATIONAL SCIENCE FOUNDATION	07/15/2016 - 06/30/2019	$550,000

TOTAL: $ 22,130,446

Publications, Patents & Awards

BOOK CHAPTERS

L. Li, D. Guillen, N. Neelameggham, L. Zhang, J. Zhu, X. Liu, **S. Basu**, N. Haque, T. Wang, D. Verhulst, and A. Pandey, "Energy Technology 2016: Carbon Dioxide Management and Other Technologies," TMS, John Wiley & Sons, Inc., 2016.

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

A. Capretti, Y. Wang, and **L. Dal Negro**, "Engineering Nonlinear Sources with Silicon-compatible Optical Materials," Silicon Nanophotonics: Basic Principles, Present Status, and Perspectives, Pan Stanford Publishing, 2016.

L. Dal Negro, N. Lawrence, J. Trevino "Engineering Aperiodic Spiral Order in Nanophotonics: Fundamentals and Device Applications," Nanodevices for Photonics and Electronics: Advances and Applications, Pan Stanford Publishing, 2016.

J. Vierinen, A. Bhatt, M. Hirsch, **J. Semeter,** S. Zhang, P. Erickson, "High Temporal Resolution Observations of Auroral Electron Density using Superthermal Electron Enhancement of Plasma Lines," Abstract SM22A-07, 2016.

JOURNAL ARTICLES

Y. Yu, A. Nikiforov, T. Kaspar, J. Woicik, K. Ludwig, S. Gopalan, U. Pal, and **S. Basu**, "Chemical Characterization of Surface Precipitates as Cathode Material for Solid Oxide Fuel Cells," Journal of Power Sources, Vol. 333, p. 247-253, 2016.

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AWARDS

Keith Brown was awarded the Boston University Moorman Simon Interdisciplinary Career Development Professorship.

Keith Brown received the Materials Science and Engineering Innovation Award at Boston University.

Jerry Chen received the Federation of European Neuroscience Societies EJN Young Investigator Prize.

Jerry Chen received the Cajal Club Krieg Cortical Kudos Explorer Award.

Jerry Chen was awarded the Stuart and Elizabeth Pratt Career Development Professorship at Boston University.

Allison Dennis received the Dean's Catalyst Award at Boston University.

Ajay Joshi received the Boston University Office of Technology (OTD) Award for 2016.

Siddharth Ramachandran was awarded the Distinguished Visiting Fellowship by the UK Royal Society of Engineering in 2016.

Darren Roblyer received the Rice University Department of Bioengineering Outstanding Graduate Alumnus Award.

Kenneth Rothschild was elected to the National Academy of Inventors.

Michelle Sander received the Air Force Office of Scientific Research Young Investigator Research Award.

Michelle Sander received the Institute of Electrical and Electronics Engineers (IEEE) Photonics Society Most Innovative Chapter Award in 2016.

Alexander Sushkov was awarded the 2016 Sloan Fellowship.

Selim Unlu received the Boston University Charles DeLisi Distinguished Lecturer Award.

Brian Walsh received the NASA Robert H. Goddard Exceptional Achievement for Science Award.

Xin Zhang received the 2016 the Institute of Electrical and Electronics Engineers (IEEE) Sensors Council Technical Achievement Award.

Xin Zhang was elected a Fellow of The American Association for the Advancement of Science (AAAS).

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

Xin Zhang was elected a Fellow of the Institute of Electrical and Electronics Engineers (IEEE).

Xin Zhang was elected an Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA).

Xin Zhang received the Boston University Materials Science Innovation Grant Award.

Xin Zhang received the Boston University Dean's Catalyst Award.

Xin Zhang received the Schlumberger/ Boston University Innovation Award.

PATENTS

S. Ramachandran (US Patent #9,417,381) "Optical Fiber Systems for Delivering Short High Power Pulses" Issue Date: August 16, 2016.

M. Lim, V. Bergo, and **K. Rothschild** (US Patent #9,513,285) "Global Proteomic Screening of Random Bead Arrays using Mass Spectrometric Imaging" Issue Date: December 6, 2016.

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M. Sahin, **S. Unlu**, D. Freedman, and A. Abdo (US Patent #9,526,904) "System and Method for Neural Stimulation via Optically Activated Floating Microdevices" Issue Date: December 27, 2016.

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Educational Programs & Initiatives

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

Professors Xin Zhang and Helen Fawcett led the second summer cohort (2016) of REU participants. The student cohort arrived at BU to move into their dorm rooms and start the 10-week program in June 2016. Below are some relevant statistics regarding the 2016 REU participants:

• 50% of the applicants do not have any accredited Engineering undergraduate or graduate programs in Mechanical Engineering (ME), Biomedical Engineering (BME), Materials Science and Engineering (MSE) or Electrical and Computer Engineering (ECE) at their university/institute.

• 75% have fewer than two accredited Engineering 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 Underrepresented Minorities (URMs), 21% are self-identified white/Asian.

• 75% of the participants indicated an interest in a graduate degree, with 50% of those participants intending to pursue a Ph.D.

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.

Summer 2016 NSF REU Participants in Integrated Nanomanufacturing

Faculty Mentor	Dept	Project Title	REU Participant	REU Home Institution
Thomas Bifano	ME	Adaptive Biological Microscope	Kylee O'Dell	East Central University
David Bishop	MSE	Atomic Scale 3D Printing	Allisen Goncalves	Western New England University
Keith Brown	ME/ Physics/ MSE	Biomineralization in Drops	Jarom Beus	Eastern Arizona College
Chuanhua Duan	ME	Facile and Scalable Fabrication of PDMS-Glass Nanochannel Devices	Kaily Granados	Anne Arundel Community College
Helen Fawcett	ME	Evaluation of Automated Incubation of Viral Hemorrhagic Fever Virus	Ramon Sanchez	University of Puerto Rico Mayaguez
Elise Morgan	ME	Bone Quantity and Bone Quality in Osteoarthritis	Cianael Paasewe	Northampton Community College
Michelle Sander	ECE/ MSE	Characterization and Imaging with Mid-Infrared Vibrational Photothermal Spectroscopy	Casey Biederman	SUNY Polytechnic Institute
Sahar Sharifzadeh	ECE	Computational Design of Organic Semiconductors	De'Ja Rogers	Norfolk State University
Xin Zhang	ME/ MSE	Uniformly Oriented Diatom Frustule Monolayers: Formation And Analysis	Mahetem Moges, Javier Morales	Georgia Perimeter College/Georgia Tech, nter American University of Puerto Rico, Bayamón Campus
Roberto Paiella	ECE	Manufacturing of Lens-Free Image Sensors for Ultrasmall Compound-Eye Cameras	Lauren Strong (I/UCRC REU Supplement)	Northampton Community College
Michael Smith	BME	Tensional Homeostasis of Smooth Muscle	Stephanie Emen-yonu (NSF RET Supplement)	Dartmouth

Last year's program included 11 discrete research projects and 12 REU participants. In most cases, the REU student worked alongside an RET participant who joined BU four weeks into the start of the REU program. We were able to bring back two students from the prior year's program with funding provided by NSF REU Supplements. The following faculty and their graduate student mentors worked with the REU/RET participants from June 7 – August 12, 2016.

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. The participants also had three hours a week of cleanroom and laboratory experiences. The students and teachers engaged in scientific presentations by many of the participating faculty mentors including Professors Paiella, Duan and Brown. Professor Klapperich led a discussion on global technologies in health care that was well received. 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 their educational background, where they came from, 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. More information on the REU INM program can be found at: http://www.bu.edu/photonics-reu/.

NSF Research Experiences for Teachers (RET) in Integrated Nanomanufacturing

Professors Bennett Goldberg and Helen Fawcett led the second summer cohort (2016) of RET participants in the six week program, July 5 – August 12. 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 based on their 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 2016 RET participants are as follows:

- 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.

More information about the projects and the teachers can be found at http://bu.edu/photonics-ret. The table below identifies the project, faculty mentor, the teachers and the schools from which they came from.

> **The participants also had three hours a week of cleanroom and laboratory experiences.**

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. The students and teachers also engaged in scientific presentations by many of the participating faculty mentors including Professors Paiella, Duan and Brown. Professor Klapperich led a discussion on global technologies in health care that was well received. 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 Point (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. More information on the NSF RET INM program can be found at: http://www.bu.edu/photonics-ret/.

Summer 2016 NSF RET Participants in Integrated Nanomanufacturing

Faculty Mentor	Dept	Project Title	RET Participant	RET Home Institution
Thomas Bifano	ME	Adaptive Biological Microscope	Kelly Kilts	Lexington High School
David Bishop	MSE	Atomic Scale 3D Printing	Sarah Benat	East Boston High School
Keith Brown	ME/ Physics/ MSE	Biomineralization in Drops	Joshua Karlowicz	Greater Lawrence Tech School
Chuanhua Duan	ME	Facile and Scalable Fabrication of PDMS-Glass Nanochannel Devices	Michelle Gallagher	Fuller Middle School
Helen Fawcett	ME	Evaluation of Automated Incubation of Viral Hemorrhagic Fever Virus	Jessica Sullivan Jenny Bello	Malden High School West Roxbury Academy
Elise Morgan	ME	Bone Quantity and Bone Quality in Osteoarthritis	Dana Bowers	Malden High School/Bunker Hill Community College
Michelle Sander	ECE/ MSE	Characterization and Imaging with Mid-Infrared Vibrational Photothermal Spectroscopy	Karl Muench	Collins Middle School
Sahar Sharifzadeh	ECE	Computational Design of Organic Semiconductors	Nifemi Mabayoje	East Boston High School
Xin Zhang	ME/ MSE	Uniformly Oriented Diatom Frustule Monolayers: Formation And Analysis	Amy Saccoccio	Randolph Community Middle School
Helen Fawcett/ Xin Zhang	ME/ MSE	Development of NGSS-MA Curriculum	Amanda Dillingham (NSF REU Supplement)	East Boston High School

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. During FY17, two companies departed the Center and there was one new tenant. One of the departing companies landed $14M in Series A financing and needed additional space to accommodate their rapidly growing business. 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. Some of the additional benefits and services available to BIC companies include: facility management, EH&S support, conference and catering services, library resources, invitations to Photonics Center conferences, symposia, guest lectures and all network events, opportunities for collaboration with leaders in Photonics, Nanotechnology and Materials research, and a pipeline of talented and entrepreneurial young scientist/engineers available for internships.

The available space includes shared office space, private office space, and wet lab and optical laboratory spaces. Additionally, BIC also has room for four companies in a bio-safety level 2 (BSL-2) space, which was partially funded by Massachusetts Life Sciences Center (MLSC), a quasi-public investment agency of the Commonwealth of Massachusetts. Since the BSL-2 lab is state sponsored, the Center has additional tracking and reporting requirements, which shows the 450 square foot lab provided employment for 12 engineers/scientists providing a combined compensation of $949,000. This data shows good evidence for job creation and the economic benefits of small business enterprises.

The management of the tenant companies have given back to the Photonics Center and have supported the educational and research elements of the Photonics Center mission. These companies have provided internship opportunities for students, mentored students and increased sponsored research opportunities.

Some of the activities supported by the BIC companies include hosting Biomedical Engineering Senior Design projects, serving as reviewers or judges on the School of Engineering's Medical Design course and participating as guest lecturers in design courses on biosensors and medical diagnostics. On one of the Senior Design projects, the students far exceeded expectations and the mentor company (Bioventus) helped sponsor their registration and travel expenses for the 2017 Northeast Bioengineering Conference. The management of the BIC companies have also been speakers or panelists at the College of Engineering "Lunch and Learn" series, the Photonics Forum series, Questrom's Health and Life Sciences Conference, BU's Digital Health Initiative Round Table and participated in other networking events. In all situations, the speakers were well-received and provided students with a practical perspective on the value of their classroom training. The tenant companies have also participated in School of Engineering career nights and have been very pro-active in hiring undergraduate student interns. At least four of these interns were hired as full-time employees upon graduation. In addition to BU students, some of the undergraduate interns came from Northeastern, WPI, Bucknell University and the University of Pennsylvania. Interestingly, students were hired from these schools as they had a longer availability for internships. After training, they were able to stay on with the company a bit longer and had greater opportunities to make a contribution.

The full list of FY17 tenants can be found in the nearby table. These companies made full use of the BU facilities to continue product development, solicit investment and cultivate their initial customers. Two of the BIC companies received their Series A round of investment, and four of the companies have secured non-dilutive investment through SBIR awards.

Two of the BIC companies received their Series A round of investment, and four of the companies have secured non-dilutive investment through SBIR awards.

The BIC companies have also engaged faculty on collaborative research. As an example, Bioventus sponsored research in Professor Chen's lab as well as an Undergraduate Research Opportunity (UROP) student to investigate the effects of the company's drug on the intracellular signaling pathways and differentiation of mesenchynal progenitor cells. In another example, Jana Care has initiated an equipment loan agreement with Professor Cabodi where a tool is provided that can provide a quantitative readout in the development of new assays. Several other collaborations are in the early stages such as an effort between Poly6 Technologies and Professor White's lab for the development of inks for the printing of 3D bio-material structures. This initiative could be very valuable should the Center win the NSF Engineering Research Center (ERC) award.

As another example of the contributions of the BIC companies to the Photonics Center mission, Bioventus is a member of the I/UCRC on Biophotonic Sensors and Systems, which is the core of Center's technology development efforts. During FY18, an effort will be made to recruit the more mature BIC companies into joining and having a seat on the Industry Advisory Board of the I/UCRC.

List of Photonics Center FY17 Innovation Center Tenants

Company Name	Origin	Status Change	Technology	Market Sector	Funding
Agira	John Hopkins University	None	Polymer Waveguide	Energy	Self-funded
Beta Bionics	Boston University	None	Artificial Pancreas	Healthcare	Grants and Venture
Bioventus	License from Pfizer	None	Bone Growth Protein	Healthcare	Corporate and Private Equity
ClearIt	De Nova Start-up	New	Pain-free Tattoo Removal	Healthcare	Self-funded
JanaCare	Harvard	None	Diagnostics for Chronic Diseases	Healthcare	Grants
Lattice Automation	Boston University	None	Biological Design Solution	Healthcare	Grants
Micro-Leads Inc.	Draper Labs	None	Micro-Electrodes and Implantable Devices	Healthcare	Grants
Neurala	Boston University	Departed	Biological Intelligence	Robotics	Grants and Venture
nanoView Diagnostics (formerly NexGen Arrays)	Boston University	None	Photonics	Healthcare	Grants and Venture
Poly6 Technologies	MIT	None	High Performanc Polymers	Healthcare	Grants

National Science Foundation (NSF) Engineering Research Center (ERC)

The Photonics Center played a prominent role in developing the final proposal and site visit for a $20-40M proposal for a 5-10 year NSF Engineering Research Center (ERC). Photonics Center staff developed budgets, technical and diversity components, CVs and current and pending lists, and provided oversight and an overall compliance check on this large and complex proposal. The proposal outlined how BU-led researchers would grow tissue and ultimately be able to repair or replace diseased human organs. The Photonics Center also organized and managed a three-day site visit by the National Science Foundation and their team of experts from around the country who were evaluating BU's presentation and overall effort. Photonics Center Professor David Bishop will serve as the PI for the ERC should it be awarded.

New Photonics Center Website

The Photonics Center launched a newly redesigned website in January 2017. The new website features dynamic Center videos, a new events and news section, and a redesigned faculty research section. Please visit the new website at http://www.bu.edu/photonics.

Tech, Drugs and Rock n' Roll

The Photonics Center participated in the BU Tech, Drugs and Rock n' Roll event on July 12, 2016 to network with industry and academia and promote the Photonics brand. The Photonics Center hosted a promotional booth and provided marketing materials to guests.

Professor Michelle Sander's Women in Photonics Events

Professor Michelle Sander, serving as the faculty host for the BU student chapter of OSA/SPIE, organized several important networking events for faculty, staff and students at the Photonics Center. One event that was hosted in conjunction with the Women in Photonics group and OSA/SPIE, was the Women's Salary Negotiation workshop held on April 20, 2017. The speaker at this event provided attendees with important tips for negotiating salary and asking for the salaries that they deserve.

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 Forum and the Photonics Cafes. The Photonics Forums, held on the fourth Wednesday of each month throughout the fall of 2016 and the spring of 2017, 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.

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.

PHOTONICS CENTER GUEST SPEAKERS

Over the past year, the Boston University Photonics Center hosted seminars by photonics experts and distinguished speakers. The following list includes the seminars for 2016–2017.

Date	Speaker	Title
Oct. 6, 2016	Dr. David Stork, Rambus Labs	Ultra-miniature Lenseless Computational Imagers and Sensors Using Optics for Computing and Computing for Optics Photometers
April 27, 2017	Professor Peter So, MIT (Photonics Distinguished Seminar Speaker)	High-Resolution Shaping and Sensing Light: From Neurobioogy to Sickle Cell Disease

20th Annual Photonics Center Symposium

This year, the 20th Annual Photonics Center Symposium focused on Optics of Cancer Imaging. The symposium drew 200 attendees from BU, other academic institutions, and industry. Photonics Professor Darren Roblyer chaired what turned out to be a very successful and important conference.

The agenda for this year's symposium featured presentations by researchers from leading academic institutions.

The speakers included:
Dr. Samuel Achilefu, University of Washington
Dr. Jennifer Barton, The University of Arizona
Dr. Irving Bigio, Boston University
Dr. Paul Campagnola, University of Wisconsin, Madison
Dr. Ji-Xin Cheng, Purdue University
Dr. Xingde Li, Johns Hopkins University
Dr. Charles Lin, Harvard University/Mass General Hospital
Dr. Anita Mahadevan-Jansen, Vanderbilt University
Dr. Melissa Skala, University of Wisconsin, Madison
Dr. Bruce Tromberg, University of California

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
September 28, 2016	Mr. Thomas Bernatavitz, Boston University	Annual Lab Safety Training
November 20, 2016	Dr. Anurag Agrawal, Double Helix	Double-Helix PSF Universal Module for 3D Localization
January 25, 2017	Professor Lei Tian, Boston University	Computational Microscopy: Illumination Coding and Nonlinear Optimization Enables Gigapixel 3D Phase Imaging
February 22, 2017	Professor Alexander Sushkov, Boston University	Quantum Science in the Laboratory: From Magnetic Imaging of Single Atoms to Searching for Dark Matter
March 29, 2017	Professor David Boas, Boston University	Speckle Fluctuations to Probe Dynamics on the Macroscopic to Microscopic Scales

Facilities & Equipment

This year, rather than acquire new equipment for the Photonics Center, there was a concerted effort to identify tools which needed an upgrade to their operating systems and identify essential back up components for older pieces of equipment.

BUILDING PROJECTS

PHO 708 – Professor Milos Popovic

New laboratory space is under construction for Professor Milos Popovic, who joined the Boston University Photonics Center and the Electrical and Computer Engineering Department in July 2016.

PHO 627A, B21 – Temporary Biosafety Level 2 and Laser Laboratory Space for Professor Ji-Xin Cheng

Laboratory space is currently under design/construction for Professor Ji-Xin Cheng, a new Boston University Photonics faculty member serving in the Moustakas Chair Professorship in Photonics and Optoelectronics. To accommodate his research needs, several laboratories were renovated and will be used until his new laboratory is completed and approved by Environmental Health and Safety (EHS). A BSL2 laboratory will be located in 627A and a Class IV laser laboratory with capability for BSL2 is available in the basement room B21.

PHO 603A, OPF – Temporary Wet Chemistry Laboratory Space for Professor Chen Yang

Laboratory space is currently under design/construction for Professor Chen Yang, a new Boston University Photonics faculty member. To accommodate her research needs, some of her wet chemistry equipment will be in the MSE Core Laboratory (603A) and in OPF where her ALD system will be temporarily housed until her new laboratory has been completed.

SHARED LABORATORY FACILITIES

The three shared labs at the Photonics Center contain a variety of instruments and capabilities, designed to serve the needs of the Photonics Center and Boston University community. In addition to BU usage, the shared facilities are also accessible on a fee for use basis by current and former Business Innovation Center (BIC) companies, outside universities, and outside companies. 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 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 a Class 1000 cleanroom and equipment facilitating photolithography, wet chemical processing, thin film depositions, plasma etching and cleaning, metallization, thermal oxidation, thermal annealing, wire bonding, and electrical characterization.

The Class 100 cleanroom has capabilities for photolithography, mask fabrication and nanoscale replication. Two types of photoresist spinners are available for use by all self-users in OPF. The standard Headway Research spinner is designed to accommodate small chip level (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 capture still or video images from the sample or wafer.

Dry etching processes available in the OPF cleanroom include plasma etching, reactive ion etching, and a deep reactive ion etch. As part of equipment upgrades last year, a new, more robust backing pump was installed to 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 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.

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.

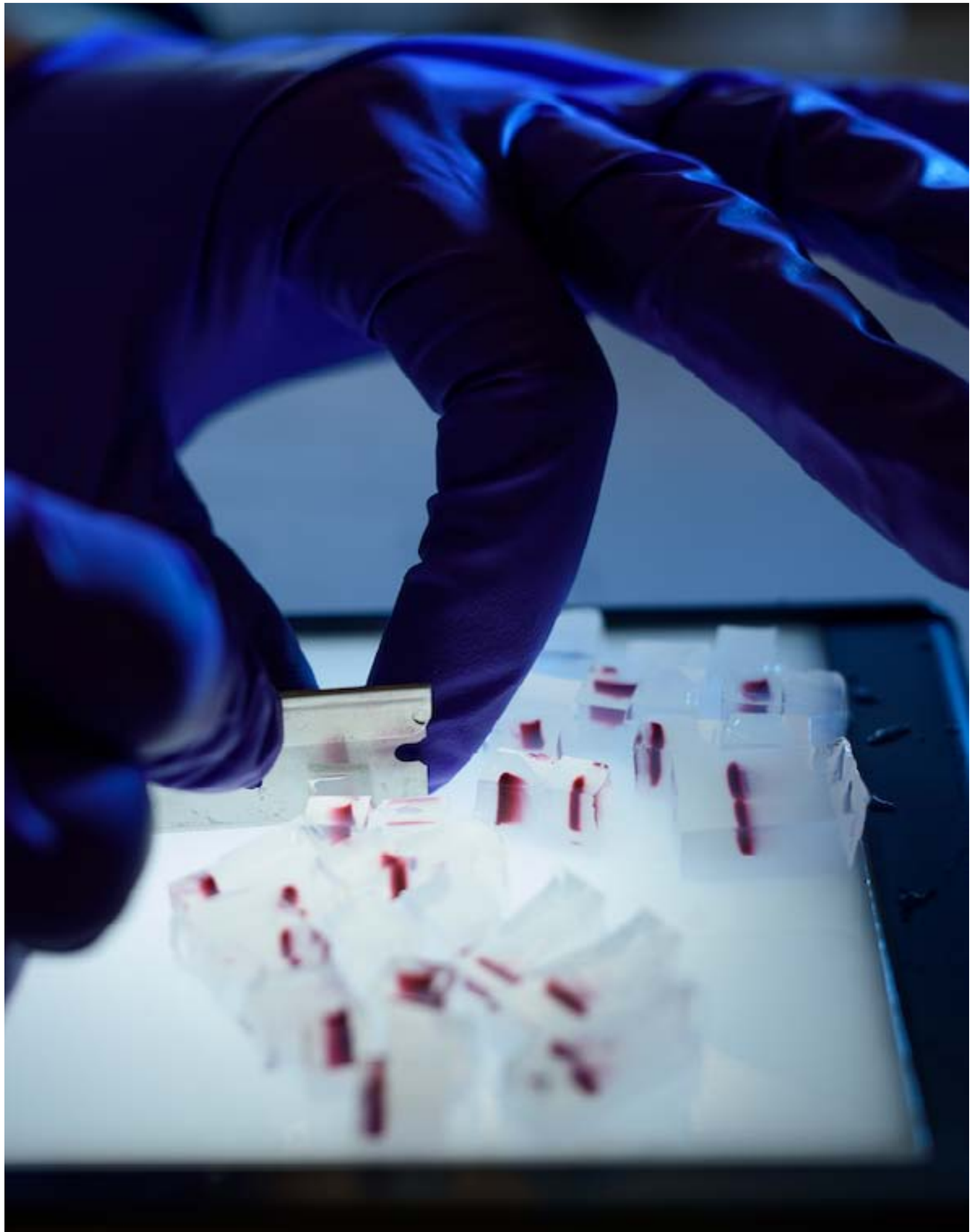
The second laboratory space includes: a Veeco (formerly Digital Instruments) Atomic Force Microscope (AFM) a Pico-Force AFM System, a Zeiss Supra 40VP Field Emission Scanning Electron Microscope (FESEM), a Zygo NewView 6300 and a Zeiss Supra 55VP FESEM. The Pico-Force AFM System enables accurate force 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. 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 Field Emission Gun Focused Ion Beam (FEG FIB) 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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