Boston University Photonics Center

Annual Report | 2022

BOSTON UNIVERSITY

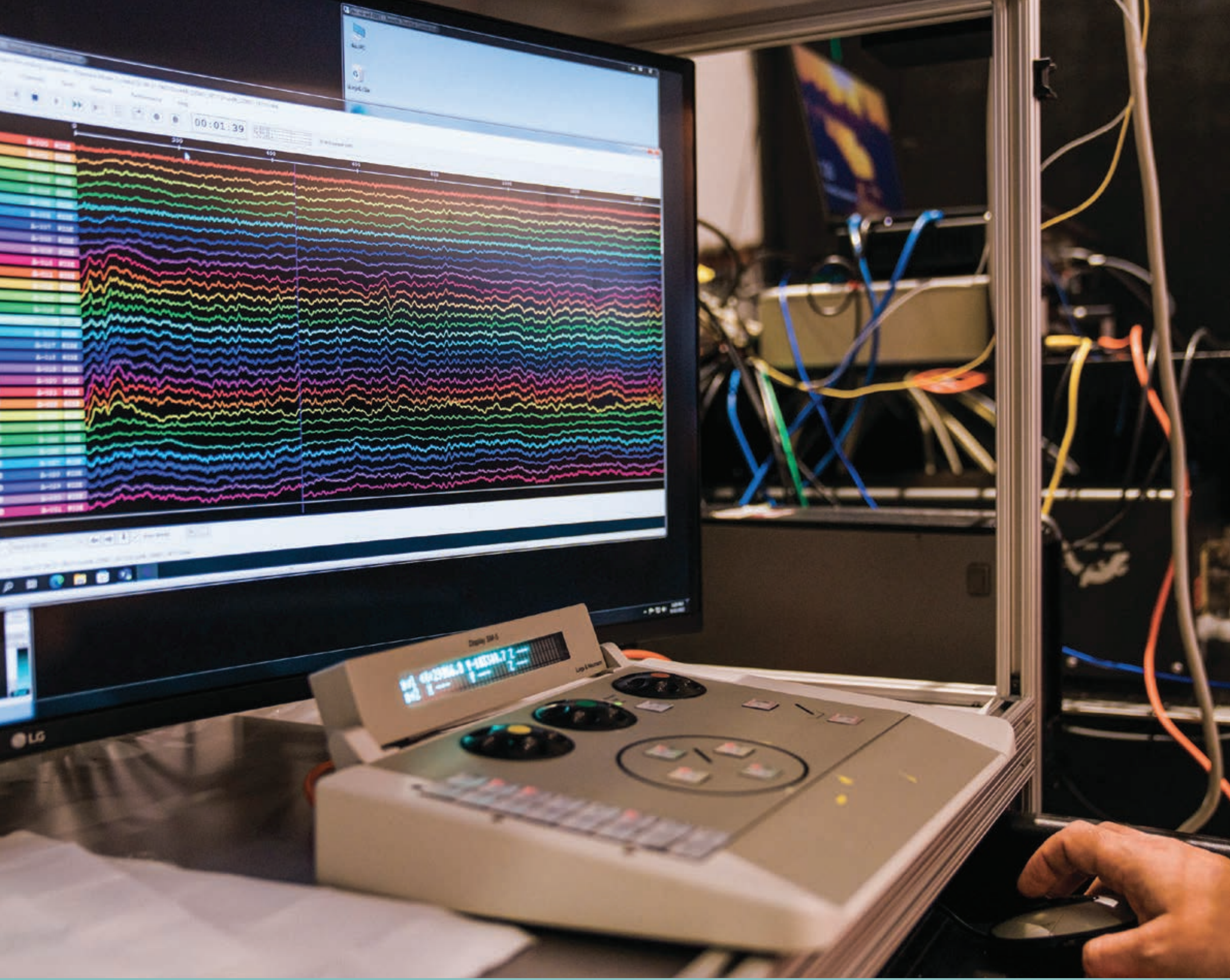
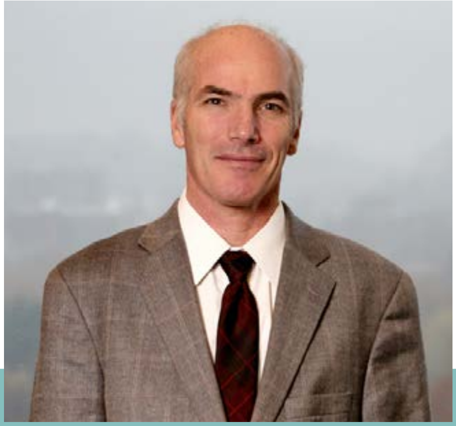


Photo taken in Anna Devor's lab. Credit: Christopher McIntosh

Front Cover: A photo of the BU Photonics Center. Credit: Christopher McIntosh

LETTER FROM THE CENTER DIRECTOR



The Photonics Center is an interdisciplinary hub for education, research, scholarship, innovation, and technology development associated with practical uses of light.

THIS ANNUAL REPORT SUMMARIZES ACTIVITIES OF THE PHOTONICS CENTER for the 2021-2022 academic year. In it, you will find quantitative and descriptive information regarding our photonics programs in research, education, and business innovation.

New grant funding awarded to Photonics Center faculty for this annual year **totaled more than $45M, another record high, tripling our annual funding from a decade ago**. The credit for this growth belongs to our extraordinary cohort of **distinguished and collaborative faculty**, but I want to make special mention of the exceptional staff support that has enabled our research activities to thrive. Our staff identify funding opportunities, prepare proposals, manage contracts, process purchase orders, conduct training programs, organize symposia, renovate laboratories, provide access to shared facilities, engage industry affiliates, and promote career development. Their generous and enthusiastic support is a major factor in the Photonics Center's sustained record of success, and I am grateful to them, collectively, for their professionalism and dedication.

Located at the heart of Boston University's urban campus, the Photonics Center is an interdisciplinary hub for education, research, scholarship, innovation, and technology development associated with practical uses of light. Our nine-story building houses world-class research facilities and shared laboratories dedicated to photonics research and sustains the work of 49 active (and 8 emeritus) faculty members, 16 staff members, and 16 Business Innovation Center (BIC) affiliate companies.

As a longstanding Boston University institution, the Photonics Center has adopted a mission to help to establish and support newer research centers and university initiatives in allied fields. **We routinely provide critical resources, infrastructure, and support for the creation of new units** such as the Neurophotonics Center and the Materials Science and Engineering Division, and **we help win and manage a portfolio of major research and training grants** that have catalyzed transformative growth in prominent allied research areas such as biological design, precision diagnostics, and neuroscience. BIC, which has always been a hub for industry/university engagement, currently houses an all-time high of sixteen tenants, including many BU spinouts and strategic optics/photonics industry partners. Under Rana Gupta's leadership, BIC has strengthened its connectivity to our academic and educational programs in the past year.

This year, the Photonics Center continued to help our faculty win and administer large, complex, multi-university interdisciplinary grants that aim to impact society through optics and photonics innovation. We added two exciting new efforts to that portfolio this year with a $14M NIH *BRAIN Initiative Award* on neuromodulation and control, led by Associate Professor **Anna Devor**, and a major award from the *Rajen Kilachand Fund for Life Sciences and Engineering* on ultra-low field MRI, led by Professor **Xin Zhang**. Under the leadership of Professor **Ji Xin Cheng**, supported by staff members **Cara McCarthy** and **Beth Mathisen**, our new *Graduate Student Initiative* has begun to transform our programs for doctoral student recruitment, doctoral training, and community-building. Under the leadership of Professor **Xin Zhang**, supported by staff member **Brenda Hugot**, our *Summer Internship Programs* were again an overwhelming success, with 42 enthusiastic and engaged participants. We look forward to hosting our *Annual Symposium* again this Fall after a two-year hiatus, with a powerful lineup of speakers on the topic of *Photonics and Artificial Intelligence*, hosted by Professor **Luca Dal Negro**.

I am delighted to be associated with the faculty, staff, students, and industry affiliates of the Photonics Center, and appreciate your interest in our programs.

Dr. Thomas Bifano, Center Director

**Boston University
Photonics Center
Annual Report
2022**

PHOTONICS CENTER AT A GLANCE

16
Business Innovation Center Companies

$37.3M
Research Expenditures

$55.4M
Proposals Submitted

$436K
Revenue Generated

Faculty Members
49

$45.8 MILLION
Funding for R&D

4
Shared Lab Facilities

148
Funded R&D Projects

$2.13M
Operating Budget

16
Staff Members

215
Publications

HIGHLIGHTS OF FY22

CELL-MET Engineering Research Center
In its first five years, our National Science Foundation (NSF) Engineering Research Center (ERC) on Cellular Metamaterials (CELL-MET), administered by the Photonics Center, has made significant advances toward its overall goal of engineering functional heart tissue for cardiac repair and creating a robust community to advance engineering workforce development, diversity, and culture of inclusion, as well as an innovation ecosystem. Our renewal Site Visit with NSF took place on June 13-16, 2022. CELL-MET was renewed for another five years for $17.5M with the team receiving a rating in the top tier that noted both remarkable technical progress and exemplary commitment to diversity, equity, and inclusion.

Photonics Center faculty and staff continue to play a prominent role in all aspects of the ERC, led by PI David Bishop. Professor Thomas Bifano, Photonics Center Director, leads Budget and Strategy in addition to his imaging research; Cara Ellis McCarthy, Director for Finance, Administration & Personnel Management, serves as Administrative Director. Cynthia Kowal is Team Associate and manages budgets, compliance, and supplemental programs for the ERC; and Meghan Foley, Senior Manager of Finance, works across the team for purchasing, expense tracking, and compiling financial data for reporting. John Hartnett joined the team from the BU Industry Engagement Office to lead the Innovation Thrust. Photonics Center staff members Nozomi Ito, Administrative Manager, and Akeem Chambers, Administrative Coordinator, are fully dedicated to the ERC. Partners and collaborators in CELL-MET include University of Michigan (UM), Florida International University (FIU), Harvard University, Harvard/Wyss Institute, Columbia University, North Carolina State University, Fort Valley State University, Nueta Hidatsa Sahnish College, and Brown University.

Grant Support
In another productive year for external grant support, the Photonics Center faculty were awarded more than $45M in new annual-year funding. Photonics Center faculty annual grant income has risen steadily to a level three times higher than it was a decade ago.

Highlights among new grants funded include ($ amounts for total anticipated funding):

- *Local Neuronal Drive Neuromodulatory Control of Activity in the Pial Neurovascular Circuit,* new award, $14.1M, NIH, led by **Anna Devor**.
- *Major Research Instrumentation Grant: Acquisition of a Spinning Disk Confocal Super-Resolution Microscope for Transcriptomics Research at Boston University,* $615K, NSF, led by **Thomas Bifano**.
- *Optimization and Validation of Quantitative Birefringence Microscopy for Assessment of Myelin Pathologies Associated with Cognitive Impairments and Motor Deficits in Young and Old Aging Monkey Brain,* new award, $2.8M, NIH, led by **Irving Bigio**.
- *Nanosystems Engineering Research Center for Directed Multiscale Assembly of Cellular Metamaterials with Nanoscale Precision:* (five-year renewal), $17.5M total, NSF ERC, led by **David Bishop**.
- *High-Throughput Mapping of Synaptic Connectivity Between*

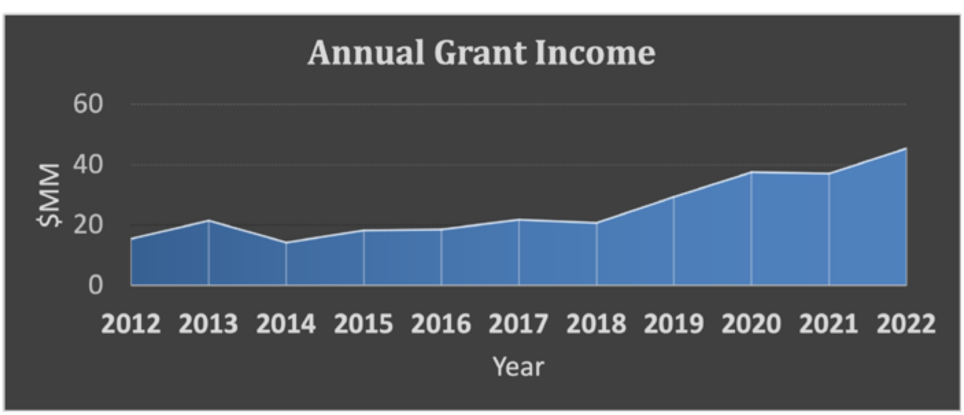


Photo taken in Xi Ling's lab. Credit: Christopher McIntosh

Transcriptomically Defined Cell Types, $1.4M, NIH/NIMH, led by **Michael Economo**.

- *High-Content High-Speed Chemical Imaging of Metabolic Reprogramming by Integration of Advanced Instrumentation and Data Science,* $2M, NIH, led by **Ji-Xin Cheng**.
- *Major Research Instrumentation Grant: Acquisition of a Universal Optical Tweezer Platform to Probe Nanoscale Structure and Function of Single Polymers Using Force and Optical Spectroscopy,* $256K, NSF, led by **Maria Kamenetska**.
- *Early Breast Cancer Treatment Response Monitoring with Real-Time Diffuse Optical Imaging,* new award $820K total, DoD, led by **Darren Roblyer**.
- *Ultra-low field MRI,* new award, $1.5M, Boston University Rajen Kilachand Fund for Life Sciences and Engineering, led by Professor **Xin Zhang**.

Research Summer Programs

The Photonics Center's summer research experience programs in 2022 were among the largest, most successful, and most diverse to date. Our 2022 cohort consisted of 42 participants, including teachers supported by our NSF *Research Experiences for Teachers* (RET) Site, teachers supported by our CELL-MET RET Supplement, undergraduates (including five from community colleges) supported by our NSF *Research Experiences for Undergraduates* (REU) Site, undergraduates supported by our CELL-MET REU Supplement, undergraduates supported by our CELL-MET *Research Experience and Mentoring* (REM) Supplement, undergraduates supported by the *Photonics Center's Photonics Undergraduate Research Summer Experience* (PURSuE), and high school students supported by our CELL-MET *STEM Outreach* program. The Photonics Center's primary aim for all our summer programs is to provide immersive interdisciplinary research experiences that promote graduate study in our field by talented students from diverse backgrounds, filling an important graduate recruitment pipeline. Our 2022 teacher and undergraduate participants' self-identified race/ethnicity include: 18 (43%) Black participants, 4 (10%) Asian participants, 13 (31%) White participants, 1 (2%) Native American participant, 1 (2%) Pacific Islander participant, and 9 (21%) Hispanic participants. Twenty-three (55%) of the participants self-identified as women. Five REU participants attend community colleges with the intent to transfer to four-year institutions to pursue bachelor's degrees.

Doctoral Training Program in Neurophotonics

The Photonics Center's prestigious NSF Research Traineeship Program: Understanding the Brain: Neurophotonics (NRT) for doctoral students in neurophotonics completed its final year of operation this year. This program supported 21 doctoral fellowships and an additional 77 trainees with $3M in support from NSF. The program is notable for having exceeded all proposed targets for support of fellowship awardee diversity. Led by Thomas Bifano (PI), and Helen Fawcett (Program Manager), the NRT's thriving student-centered focus on skills development, student-led symposia, career planning, interdisciplinary research, and active mentoring and sponsorship have become a model for interdisciplinary graduate community building at BU. The NRT program will be sustained in a joint venture between the Photonics Center and the Neurophotonics Center (NPC), led by NPC Director David Boas.

Faculty Awards and Promotions

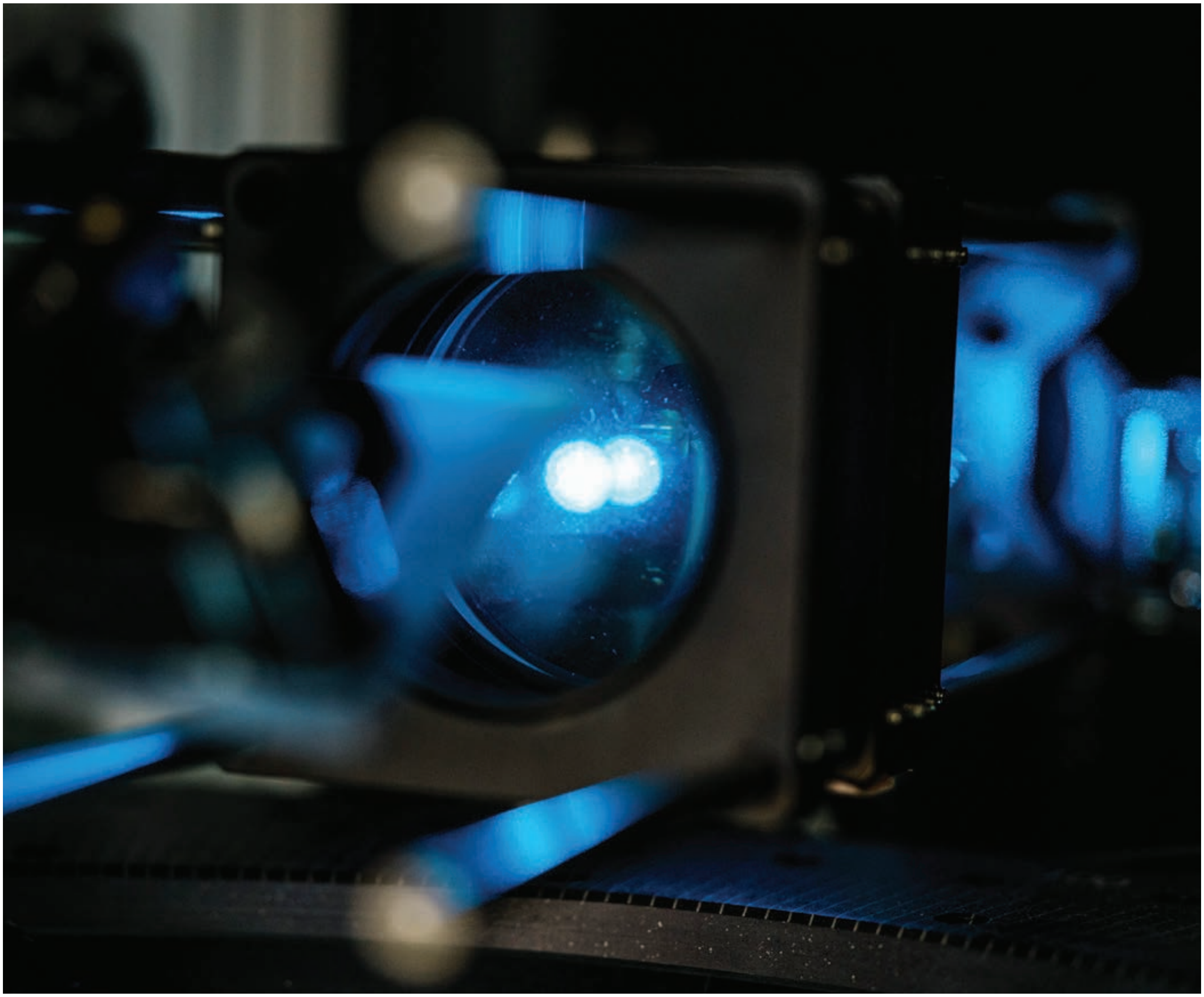
Among the awards and promotions received by Photonics Center faculty for their scholarly and academic achievements, some highlights include:

- Associate Professor **Keith Brown** was awarded tenure and promotion to the rank of Associate Professor in the Department of Mechanical Engineering, and he received the 2021 Early Career Research Excellence Award from the BU College of Engineering.
- Assistant Professor **Abdoulaye Ndao** was named a 2021 Global Rising Star of Light by the Nature journal Light Science and Applications; and he was given the 2021 Reidy Family Career Development Professor by the BU College of Engineering.
- Professor **Selim Ünlü** was awarded BU's 2021 Innovator of the Year.
- Associate Professor **Alexander Sushkov** was awarded tenure and promotion to the rank of Associate Professor in the Department of Physics, and he received the 2021 NSF CAREER award from the National Science Foundation.
- Assistant Professor **Lei Tian** earned the 2021 Early Career Excellence in Research from the BU College of Engineering.
- Associate Professor **Brian Walsh** was awarded tenure and promotion to the rank of Associate Professor in the Department of Mechanical Engineering.
- Professor **Xin Zhang** was awarded a 2022 Guggenheim Fellowship.

Faculty Scholarly Works

Scholarship by Photonics Center faculty included 215 publications of prominent articles in high-impact journals. Some highlights include the following articles:

- Rodríguez, C., Chen, A., Rivera, J., Mohr, M., Liang, Y., Natan, R., **Bifano, T.** . . . Ji, N. (2021). An Adaptive Optics Module for Deep Tissue Multiphoton Imaging in Vivo. *Nat Methods,* 18(10), 1259-1264. doi:10.1038/s41592-021-01279-0
- Cheng, X., Sie, E., Naufel, S., **Boas, D.**, & Marsili, F. (2021). Measuring Neuronal Activity with Diffuse Correlation Spectroscopy: A Theoretical Investigation. *Neurophotonics*, 8(3), 035004. doi:10.1117/1.NPh.8.3.035004
- Clough, M., Chen, I., Park, S., Ahrens, A., Stirman, J., Smith, S., & **Chen, J.** (2021). Flexible Simultaneous Mesoscale Two-Photon Imaging of Neural Activity at High Speeds. *Nat Commun*, 12(1), 6638. doi:10.1038/s41467-021-26737-3
- Trojak, J., Gorsky, S., Murray, C., Sgrignuoli, F., Pinheiro, A., **Dal Negro, L.**, & Sapienza, L. (2021). Cavity-Enhanced Light–Matter Interaction in Vogel-Spiral Devices as a Platform for Quantum Photonics. *Applied Physics Letters*, 118(1), 011103. doi:10.1063/5.0034984
- Xiao, S., **Davison, I.**, & **Mertz, J.** (2021). Scan Multiplier Unit for Ultrafast Laser Scanning Beyond the Inertia Limit. *Optica*, 8(11), 1403. doi:10.1364/optica.445254
- Finkelstein, A., Fontolan, L., **Economo, M.**, Li, N., Romani, S., & Svoboda, K. (2021). Attractor Dynamics Gate Cortical Information Flow During Decision-Making. *Nat Neurosci*, 24(6), 843-850. doi:10.1038/s41593-021-00840-6



- Tsang, J., Gritton, H., Das, S., Weber, T., Chen, C., **Han, X.**, & **Mertz, J.** (2021). Fast, Multiplane Line-Scan Confocal Microscopy Using Axially Distributed Slits. *Biomed Opt Express*, 12(3), 1339-1350. doi:10.1364/BOE.417286
- Li, R., Ma, X., Li, J., Cao, J., Gao, H., Li, T., . . . **Ling, X.** (2021). Flexible and High-Performance Electrochromic Devices Enabled by Self-Assembled 2D TiO2/MXene Heterostructures. *Nat Commun*, 12(1), 1587. doi:10.1038/s41467-021-21852-7
- Bahari, B., Hsu, L., Pan, S., Preece, D., **Ndao, A.**, El Amili, A., . . . Kanté, B. (2021). Photonic Quantum Hall Effect and Multiplexed Light Sources of Large Orbital Angular Momenta. *Nature Physics*, 17(6), 700-703. doi:10.1038/s41567-021-01165-8
- Lin, H., Lee, H., Tague, N., Lugagne, J., Zong, C., Deng, F., **Tian, L.**, . . . **Cheng, J.** (2021). Microsecond Fingerprint Stimulated Raman Spectroscopic Imaging by Ultrafast Tuning and Spatial-Spectral Learning. *Nature Communications*, 12(1). doi:10.1038/s41467-021-23202-z
- Cao, W., Alsharif, N., Huang, Z., **White, A.**, Wang, Y., & **Brown, K.** (2021). Massively Parallel Cantilever-Free Atomic Force Microscopy. *Nature Communications*, 12(1), 393. doi:10.1038/s41467-020-20612-3
- Chen, C., Kaj, K., Zhao, X., Huang, Y., Averitt, R., & **Zhang, X.** (2022). On-Demand Terahertz Surface Wave Generation with Microelectromechanical-System-Based Metasurface. *Optica*, 9(1), 17. doi:10.1364/optica.444999

Photo taken in Mike Economo's lab. Credit: Christopher McIntosh

Mission

BUPC IS A UNIVERSITY-WIDE CENTER with a mission to generate fundamental knowledge and develop innovative technology in the field of photonics. We work on challenging problems that are important to society; translate enabling research discoveries into useful prototypes, and we train future leaders in the field. The Photonics Center community of faculty, staff, and students engage in interdisciplinary collaborations to advance the frontiers of optics and photonics science and engineering. This mission is executed through:

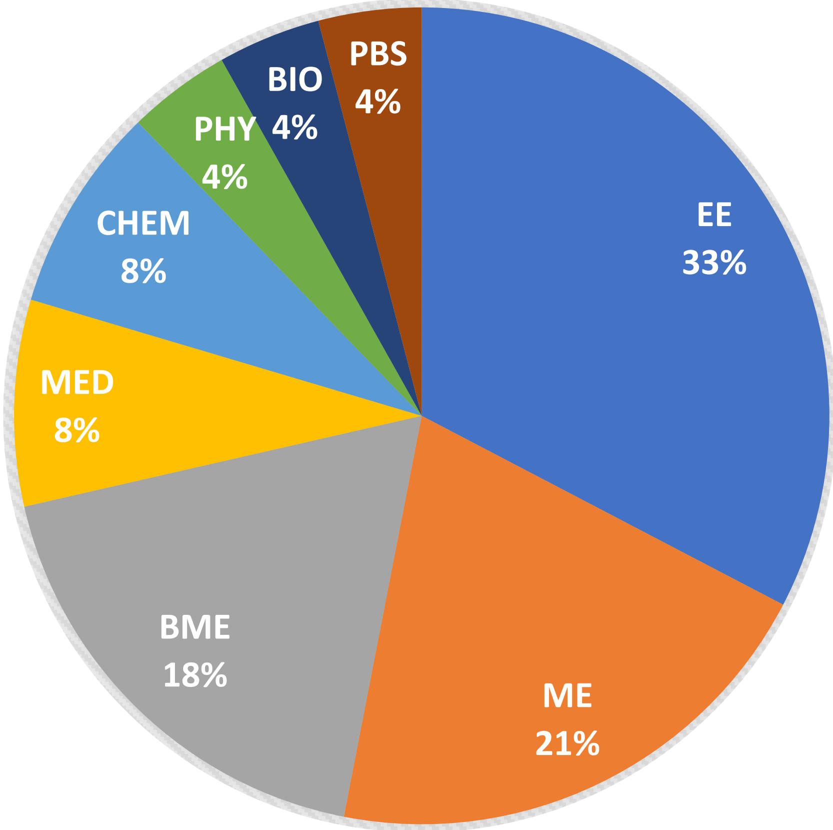
- **Basic research and academic scholarship in photonics**
- **Training programs and immersive research experiences for students**
- **Technology development for defense, security, and healthcare applications**
- **Business incubation and commercialization of photonics technology**

In support of its overall mission, the Center maintains a physical infrastructure (the Photonics Center Building) at the heart of Boston University's Charles River Campus. The Center supports thirty faculty laboratories in its facility and supports research infrastructure needs for additional faculty laboratories housed in other academic units. It manages four large, shared core laboratories with state-of-the-art equipment and assumes responsibility for providing training, maintenance, technical support, and capital equipment purchases associated with those facilities. Its business innovation center is composed of about a dozen small technology companies, university spinout companies, and large company satellites for engagement with academia.

The Center provides administrative, technical, and logistical support for large, complex, multi-institutional grants. Its resources are allocated primarily to accelerate research outcomes and to train graduate students. BUPC membership includes sixty faculty and their associated groups of graduate students and postdoctoral researchers. Affiliates include the Materials Division of the Boston University College of Engineering, for which BUPC manages faculty labs and shared facility space, and the Neurophotonics Center, which BUPC supports with core funding and shared administrative support.

BUPC's membership includes faculty from eight academic departments across BU campus. Over the past 10 years, the membership has increased by 29%, from 38 members to 49 members. There are 8 emeritus faculty.

Membership by Department



Listed below are some of the ways in which the Photonics Center community pursues each of its four mission-specific themes.

Basic Research and Scholarship in Photonics

Photonics Center research is distributed broadly across all areas of optics and photonics; however, areas of particularly cohesive research strength and national prominence include imaging, biosensing, neurophotonics, photonic materials, metamaterials, lasers, nonlinear optics, and quantum photonics.

In addition to its core faculty-led research program, the Photonics Center is also a closely associated with two distinct scholarly units within BU: the Neurophotonics Center (NPC) and the Materials Science and Engineering Division (MSE). Our affiliation with NPC is the direct result of the Photonics Center's previous strategic plan, through which we deliberately and successfully built a neurophotonics program at BU in collaboration with the Center for Systems Neuroscience. Now led by David Boas and housed in BU's Kilachand Center for Integrated Life Sciences and Engineering, NPC continues to receive technical, financial, and doctoral training support from the Photonics Center and shares substantial overlap with our mission. Our strong collaborative relationship with the MSE derives in part from the fact that MSE's facilities and core faculty research labs are housed in the Photonics Center, and in part from MSE's scholarly focus on photonic-related materials research. The Photonics Center also maintains, staffs, and shares costs related to a large complement of MSE shared laboratory facilities.

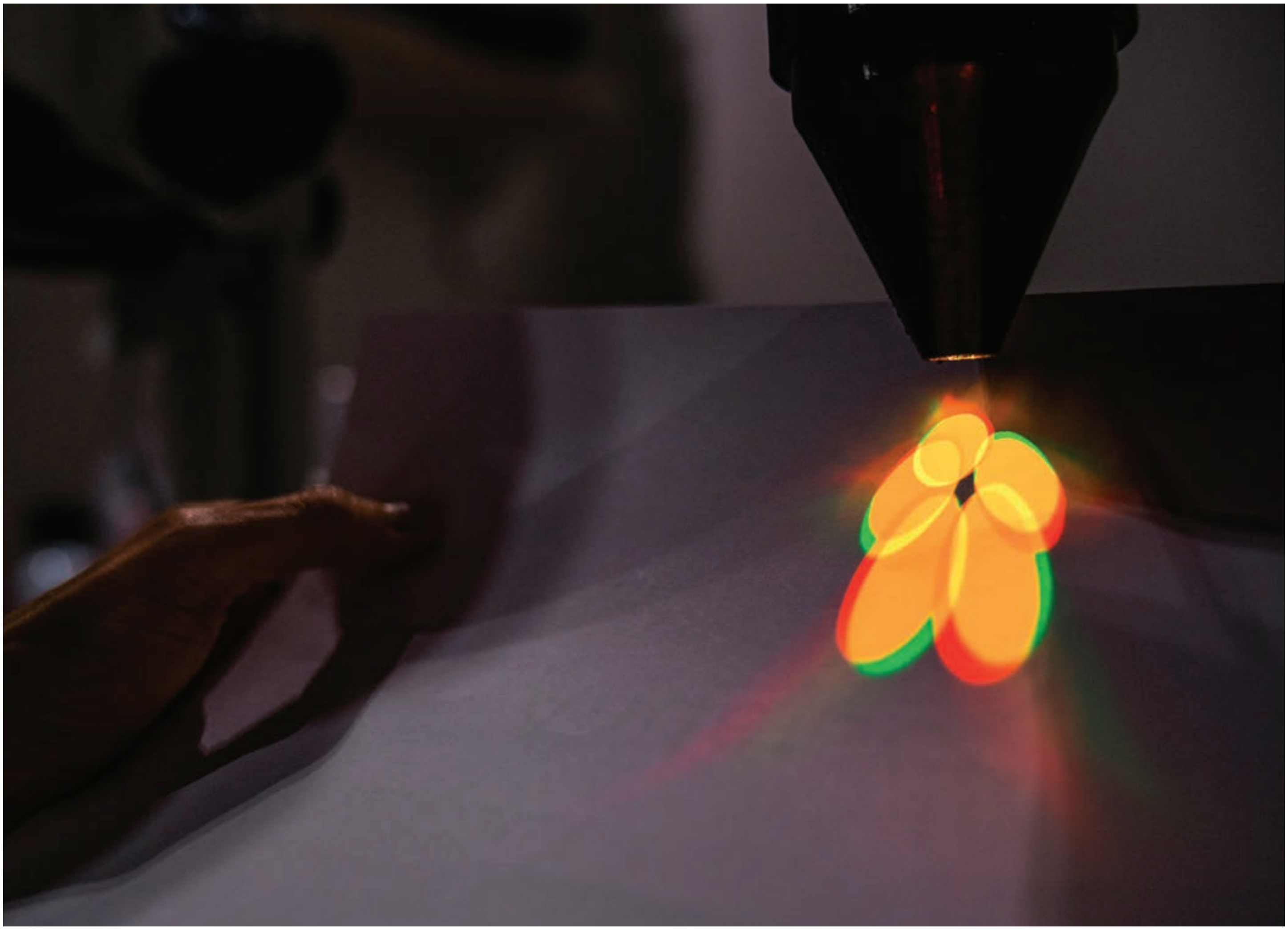
Training and Student Initiatives

While the Photonics Center does not offer academic degrees, its faculty teach a broad array of graduate and undergraduate courses that cut across traditional departmental curricula, and the foundation of its research program is interdisciplinary doctoral education. Our most direct programs for training and student-focused initiative are associated with Photonics Center led, externally supported, photonics-themed training programs. The four main operational programs for training, all funded by NSF, include our NRT doctoral training program that has supported ~100 PhD trainees (21 with full fellowships) in the past five years and our combined REU, RET, and REM immersive summer experience programs that have supported ~110 undergraduate and HS teacher participants in the past five years.

Beginning in 2021, the Photonics Center added a new summer research experience opportunity to its summer programming. The Photonics Undergraduate Research Summer Experience (PURSuE) aims to recruit academically talented undergraduates from leading photonics and optics programs at peer institutions for immersive summer experiences in the labs of our leading researchers, with the goal of attracting these students to the doctoral programs of our cognate departments. The Photonics Center supported three PURSuE students in 2021 and two in 2022. PURSuE students get to select faculty labs for their summer research experience. To date, Professors Ji-Xin Cheng, Jerome Mertz, Lei Tian, and John White have hosted PURSuE students. All five students have applied or plan to apply for admission to BU doctoral programs.

The Center also participates in professional development for its graduate students, sponsoring student chapters of the leading optics and photonics societies (SPIE and OSA) and paying student fees for memberships; providing travel awards to

EE: Electrical and Computer Engineering (16)	**ME: Mechanical Engineering (10)**
BME: Biomedical Engineering (9)	**MED: Medicine (4)**
CHEM: Chemistry (4)	**PHY: Physics (2)**
BIO: Biology (2)	**PBS: Psychological and Brain Sciences (2)**



doctoral students who have a paper accepted for presentation at a national optics or photonics symposium; and hosting student-led booths at conferences.

Students also organize and run the Photonics Center's Distinguished Seminar Series, through which they select and invite nationally and internationally renowned speakers to BU for a day-long visit that includes a plenary talk and multiple small group meetings with students and faculty.

Finally, the Center supports a series of Journal Club Lunches in which faculty and students within relatively narrow thematic areas (e.g., microscopy) meet regularly for student-led discussion of recent seminal publications.

Business Innovation and Photonics Technology Development

The Photonics Center is a leader in the commercialization of photonics technology, an activity that is anchored by the Business Innovation Center (BIC). The BIC ended last year with a record 16 member companies. BIC is anchored by three multi-national leaders in opto-electronics, micro-electromechanical devices, and imaging. The year also saw a doubling to a total of six companies that are spin-outs of BU research. While the member companies exhibited good fiscal management policies, harnessed opportunities created during the pandemic and had supportive investors, they also credited the support of the Photonics Center with helping them thrive in a difficult year. The BIC companies continue to be valued participants in the Photonics Center community, collaborating with faculty, training students, and creating a career option for engineering graduates. Preferential selection of prospective tenants that work in areas aligned with the research and scholarship activities of Photonic Center faculty supports this environment of collaboration and fosters potential for growth in sponsored research.

Photo taken in Anna Devor's lab. Credit: Christopher McIntosh

Strategic Goals

The Photonics Center operational plan is driven by five major strategic goals:

1) Support and catalyze major research projects
2) Lead training and educational enrichment programs
3) Promote technology development through the Business Innovation Center
4) Foster a cohesive community through events and programming
5) Provide an enabling infrastructure of shared facilities for research

MAJOR RESEARCH PROJECTS

The Photonics Center continues to serve the University as a leader in helping to propose, win, administer, and manage large research grants. Currently supported major awards include the NSF-sponsored *CELL-MET Engineering Research Center*, led by Professor David Bishop, that aims to engineer heart tissue for cardiac repair, which includes a supplement grant for a US-Ireland R&D Partnership Collaboration, led by Professor David Bishop, Alice White, and Chris Chen to study *Cardiac Organoid Systems*. This past year we began administering a new NIH-sponsored $14M U19 multi-university program, led by Professor Anna Devor, to study *Local Neuronal Drive and Neuromodulatory Control*. We also continue to run NSF funded research experience programs for undergraduates (REU), high school and community college teachers (RET), and mentoring in STEM fields (REM), as well as a special CELL-MET Novice Skills Program for rising college freshman from East Boston High school in summer 2022.

NSF ERC (CELL-MET)

The NSF ERC, Directed Multiscale Assembly of Cellular Metamaterials with Nanoscale Precision (CELL-MET) has a vision to develop cell and tissue engineering technologies with the goal of delivering therapeutics to restore normal function to diseased or damage hearts. This is a comprehensive program that involves research in biomaterials, nano-engineering, imaging, optogenetics and fundamental research in cell and tissue engineering. CELL-MET will drive these technologies to the clinical environment by building an innovation ecosystem of industry, medical and regulatory stakeholders, and training a pipeline of skilled engineers and scientist. This workforce will be diverse and inclusive, and engagement of future leaders will begin at the K-12 and continue through post-doctoral levels. Photonics Center staff play significant leadership roles in the research, inclusiveness, training, administration, and technology transfer efforts of CELL-MET.

The CELL-MET ERC is in its fifth year of operation and now faces an exciting transition to a renewal for an additional five years and $17.5M of funding, after a very successful Site Visit with NSF in June 2022.

More information about the NSF CELL-MET ERC can be found on the program website: https://www.bu.edu/cell-met/

NSF Center to Center (C2C) project

The C2C project, Cardiac Organoid Systems Partnership (COSP) is a collaboration between CELL-MET, the SFI Research Center for Medical Devices (CURAM) out of the National University of Ireland, Galway and the Wellcome-Wolfson Institute for Experimental Medicine (WWIEM) out of Queens University Belfast. These Centers have a common goal to cure heart disease and the complementary skills of this C2C collaboration provide a force multiplier that enhances the opportunity for success. The COSP intends to pursue development of high throughput techniques for fabrication of nanoscale scaffolds and functionalization of those scaffolds with cardio biosystems. Partnerships like this are possible due to the Photonics Center's reputation and leadership position in the biophotonics sector and established corporate partnerships. The NSF and their counterparts in Ireland awarded funding to BU CELL-MET and Irish partners for this international collaboration during the 3rd quarter of this fiscal year, and the program is now ramping up.

NIH U19 BRAIN Initiative Award

This multi-university project to study Local Neuronal Drive and Neuromodulatory Control of Activity in the Pial Neurovascular Circuit is led by Associate Professor Anna Devor with BU faculty Michael Economo, Laura Lewis, Lei Tian, and administered through the Photonics Center, this $14M, multi-institutional award involves partners from Massachusetts General Hospital, University of California San Diego, and University of Illinois Chicago. The goal is to develop a method for extracting information about neuronal circuit activity from functional Magnetic Resonance Imaging (fMRI) scans.

Kilachand Fund for Integrated Life Sciences and Engineering

This project, led by Professor Xin Zhang with BU faculty Stephan Anderson and Ioannis Paschalidis, and administered through the Photonics Center, aims to develop an ultra-low field (ULF) MRI system with much smaller magnets, developing a metamaterial-enhanced hardware to physically boost the signal received by the imaging system. Their metamaterials—materials engineered to have properties that don't occur naturally—will be optimized by using a specifically developed computational material designer. In addition, an artificially intelligent image reconstruction algorithm will be developed to achieve optimal image quality for clinical diagnosis. Their proposed ULF-MRI technology would disrupt existing limitations in MRI and lead to low-cost technology that is readily portable and mobile and could mitigate financial constraints that prevent MRI from being used prevalently throughout the world.

TRAINING PROGRAMS AND INITIATIVES

In training and education, the Photonics Center administers and manages the NSF NRT in Neurophotonics; the NSF REU and RET Sites in Integrated Nanomanufacturing; and NSF REM, REU, and RET Supplements to the ERC in Cellular Metamaterials. In Academic Year 2020-21, the Photonics Center also developed and piloted a K-12 outreach program in partnership with East Boston High School (EBHS). Supported in part by a grant from the Brown Rudnick Charitable Foundation, that program engaged hundreds of students at high school, middle school, and elementary school levels in university-mentored, multi-level peer-peer learning at sites in Detroit, Miami, and Boston. This past year, BU Photonics and East Boston continued and deepened their outreach partnership with in-person classroom outreach and summer programming for 2022 EBHS graduates.

NSF NRT: Understanding the Brain (UtB): Neurophotonics

The NSF NRT Program - Understanding the Brain (UtB): Neurophotonics was BU's first NSF NRT award. Traineeships form the essential core of the NRT student community, and all trainees have access to the benefits and opportunities afforded by the grant. The program's emphasis is on community building, interdisciplinary research and collaboration, and professional development opportunities for trainees. A subset of the trainees is supported on NSF fellowships that provide stipend, tuition, and fees for two years. (Ninety-eight students were accepted into the training program, and 21 were awarded fellowships.) The NRT program completed its final year of operation this year, but the program will be sustained in a joint venture between the Photonics Center and the Neurophotonics Center, led by NPC Director David Boas.

Photonics Research Training (PRT)

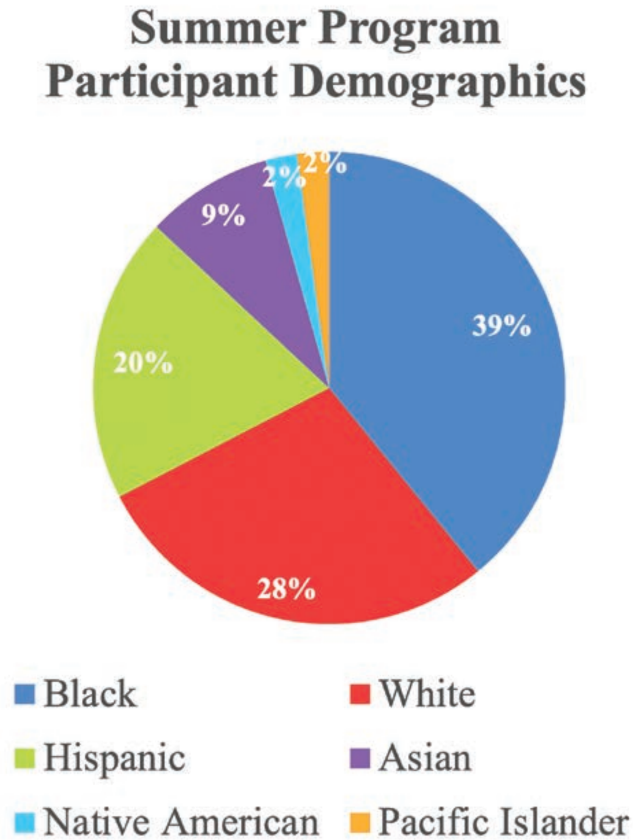
In Spring of 2022, the Photonics Center announced its own training program for doctoral students who use optics and photonics in their research. The new Photonics Research Training (PRT) program will officially launch in AY 2022-2023. Like the NRT described above, the goals of the PRT program are to promote a thriving and interconnected community of Photonics students from across Schools and departments at BU, and to provide unique opportunities for their professional development. The program will be largely student-directed, with advisement by Photonics Center faculty and staff. Seventy doctoral students answered the initial call for applications, indicating strong interest in Photonics-themed training and community.

NSF REU/RET/REM Summer Programs

The Photonics Center's summer research experience programs in 2022 consisted of a large, diverse, and successful group. The Photonics Center's aim for all our summer programs is to engage underrepresented groups to build a STEM pipeline and inspire technical careers. Our 2022 cohort consisted of 42 participants, including:

- Ten teachers in our RET Site Program on the topic of Integrated Nanomanufacturing, including eight STEM instructors from elementary, middle, and high schools that predominantly serve minority students and two community college faculty members.
- Three STEM high school teachers in our CELL-MET RET Program.
- Nine undergraduates (including 5 from Community Colleges) in our REU Site Program on the topic of Integrated Nanomanufacturing.
- Eight undergraduates in our CELL-MET REU Program distributed among our three active sites (BU, UM, and FIU).
- Five undergraduates in our CELL-MET Research Experience and Mentoring (REM) supplemental program distributed among our three active sites (BU, UM, and FIU).
- Two undergraduates from leading undergraduate optics and photonics programs in our self-funded Photonics Undergraduate Research Summer Experience (PURSuE).
- Five rising freshmen undergraduate students funded by CELL-MET, engaged in laboratory experiences and STEM outreach curriculum development.

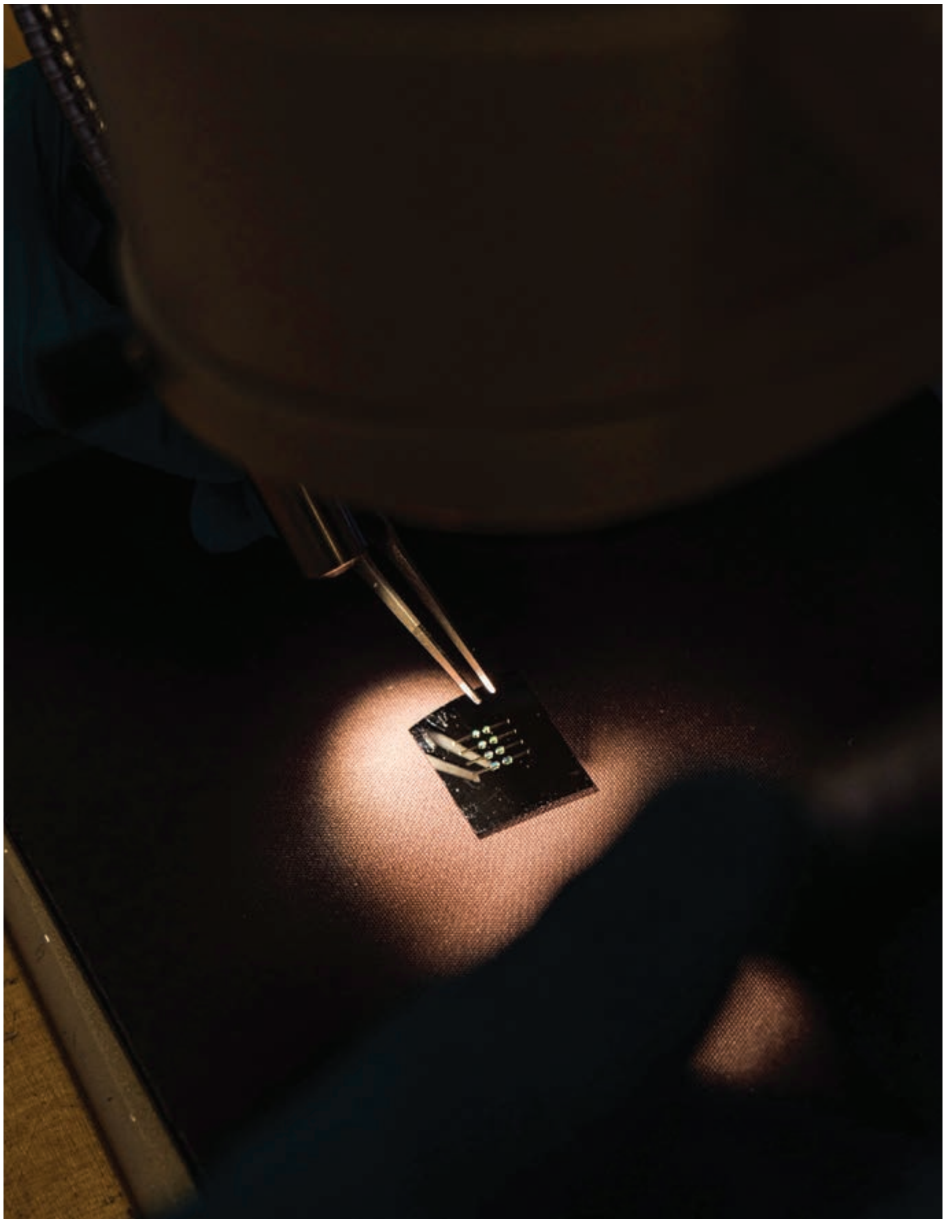
Our programs culminate with a combined REU/RET poster session, a lively event hosted at the Photonics Center and attended by more than 100 BU students and faculty.



Photonics Center K-12 Outreach Initiative

In support of its mission to promote photonics-themed educational pathways and careers, particularly for students from racial and ethnic minority groups, the Photonics Center leads a robust outreach program with K-12 schools. Our closest and longest-lasting affiliation is with East Boston High School (EBHS), where we have partnered with STEM program leaders and teachers to engage in spirited multi-level interactions with students from that primarily Hispanic-serving institution. In AY 2020-2021, the Photonics Center piloted its ambitious new *Engineering Engagement Curriculum Mentoring Program (EECMP)* in partnership with EBHS. The program was inspired by the tissue engineering-themed CELL-MET NSF ERC that the Photonics Center leads. Together, the Photonics Center and EBHS developed an engineering outreach program based on near-peer mentoring in which EBHS students would be coached and mentored by their teachers and Photonics Center faculty and students to prepare them to teach and mentor 3rd and 6th grade students at partner schools in the Boston area, inspiring their younger peers with hands-on learning activities in STEM topics.

The content for this outreach program was adapted from the highly successful Engineering Engagement Kits (EEK!) that were developed for CELL-MET. BU Photonics worked with CELL-MET partner sites at FIU and UM to implement this pilot program at schools serving underrepresented populations in Miami and Detroit. In the Spring of 2022, AP Biology and Chemistry students from EBHS visited 3rd and 6th grade classrooms



at Otis Elementary School in East Boston four times (approximately once per month). Their fifth and final meeting in June consisted of a field trip for all participants to the Museum of Science. The high school students improved the EECMP curriculum based on experiences from the previous year. BU graduate student volunteers attended each outreach event at the Otis School, to support the high school students as they taught STEM lessons, assist with tough questions, and help the younger kids with lesson activities. The topics covered were:

- **Feb. 18**
  Gr 3&6: What is an Engineer?
- **Mar. 25**
  Gr 3&6: Polymers
- **Apr. 29**
  Gr 3: Nanoscale Materials and Properties
  Gr 6: Feel the Beat (Heart Rates and Cardiovascular Disease)
- **May 20**
  Gr 3: UV Radiation
  Gr 6: Tissue Engineering and Cell Scaffolding.

Students graduating from EBHS in 2022, who were involved in the EECMP in East Boston, were invited to apply to a program piloted at the Photonics Center this summer, created specifically for rising freshmen undergraduate students interested in STEM. Five students were accepted and, together, they were introduced to laboratory experiences such as photolithography and 3D printing; they engaged with Photonics REU participants who gave them tours of their labs; and they attended seminars on topics such as entrepreneurship, STEM careers, and BU's Newbury Center. While three of these five students delved deeper into laboratory activities, the other two students spent part of their time focused on learning about STEM outreach models and refashioning the EECMP curriculum used this past spring into a package of four lessons on engineering concepts that will be used in East Boston – and other school districts – going forward.

BU Photonics envisions that our Engineering Engagement Curriculum Mentoring Program will expand to other schools in and beyond the Boston area – beginning in Revere. Three 2022 RETs from Revere Public Schools are interested in implementing the program next year, and another RET from North Shore Community College is interested in recruiting community college student mentors for EECMP in Revere. Program Manager Brenda Hugot will coordinate with the teachers and the Director of STEM Disciplines for Revere Public Schools, to help ensure that outreach events run smoothly. With continuous improvement to the EECMP curriculum, we envision that future students will have opportunities to engage in these STEM activities with near-peer mentors, who provide a visible pathway for younger students to envision themselves as future scientists.

Photo taken in Mike Economo's lab. Credit: Christopher McIntosh

Business Innovation Center

THE PHOTONICS CENTER owes a debt of gratitude to Tom Dudley who previously led the BIC and who retired on December 31, 2021. Photonics Center staff member Rana Gupta started as Director of the BIC in February 2022, and Beth Mathisen started as Program Manager of the BIC, Events, and Initiatives in June 2022.

The BIC is a facility located at the Photonics Center that houses industry tenants engaged in commercial activities that are complementary to the Center's mission. Currently, the BIC is comprised of about 6000sf of space that includes large and small office suites, multi-company shared office spaces, common areas, and dedicated shared laboratory spaces including a biosafety level 2 (BSL2) space built with funding from the Massachusetts Life Sciences Center. The BIC now hosts 16 companies.

The goal of the BIC is to accelerate innovation by encouraging industry collaboration with faculty and to provide educational opportunities for graduate and undergraduate students. Innovation occurs at large companies as well as at start-ups, so BIC is comprised of start-up and mid to large-size business enterprises in life sciences, biotechnology, photonics, and materials technologies. The three large companies in the BIC are AEMtec, Analog Devices (ADI) and Thorlabs. The other eight outside (non-BU) entities are smaller companies and there are five BU faculty spinout companies. Following are some BIC highlights from the last year.

AEMtec GmbH is a German company based in Berlin who joined us in September 2021. They chose the BIC after surveying several other facilities in the Boston area but the BIC's operational and spatial flexibility made it an attractive location for their first U.S. office and a hub to support their salespeople in the field. Their strength is the high accuracy die placement of components like chips, optics, and lenses. The range of applications of the products they build are from semiconductor industry (parts for lithography machines), medical industry (CT scanner parts, part time implants, medical equipment), machine manufacturing and more.

The goal of the BIC is to accelerate innovation by encouraging industry collaboration with faculty and to provide educational opportunities for graduate and undergraduate students.

Analog Devices' BIC team are working on a low cost, rapid, personal Covid test. Their team at the BIC are a self-named "intrapreneur shop" with a "lab to fab" mindset as part of the Analog Garage which reports to the CTO at ADI headquarters. They're here to engage with startups and look for win-win situations: "we bring the manufacturing, marketing, and distribution. You bring the tech." The ADI BIC team moved from the Garage at ADI's facility because they wanted to develop biosensors, but ADI is known for chips, not bio, "we needed a lab" says the team leader, Mohammed Azize, "so we moved to the BIC."

Thorlabs, a long-time supporter of the Photonics Center, made BIC the hub of their outreach to other universities and businesses in the Boston area tech community. The Boston location of Thorlabs seeks partnerships with Boston area universities and researchers for (1) accelerating research through offering early access to Thorlabs prototype technologies, (2) licensing startup or university owned patents, (3) increasing federal funding through letters of support and collaborative research, and (4) providing research opportunities for current students and career paths to graduating students while facilitating recruitment to Thorlabs of highly trained and skilled workers needed to support continued strong yearly growth of the company. Of particular note is Thorlabs' announcement of a first commercial sale of the Reverb technology licensed from BU (Jerome Mertz and Thomas Bifano were the PIs involved with the licensed technology).

The BIC congratulates **Bitome** for their acquisition by Ginkgo Bioworks. In June 2021 Ginkgo Bioworks acquired certain assets from Bitome for an undisclosed sum. Bitome had developed technology leveraging machine learning to provide continuous monitoring of cell culture media, illuminating the performance of cells in real-time and enabling faster rates of bioprocess optimization. For the Ginkgo Bioworks cell programs portfolio, Bitome's technology is expected to support accelerated product development timelines. Bitome had hired one full-time BU hire in their team.

Virex Health, a BU faculty spinout, was acquired this year by **Sorrento Therapeutics**. With technology from Virex, Sorrento will commercialize a next-generation at-home Covid diagnostic to rival PCR level sensitivity. Professors Mark Grinstaff and Scott Schaus were the PIs behind the Virex technology, licensed from BU. Sorrento continues to occupy space at the BIC after the acquisition to remain close to the BU PIs while they develop the test.

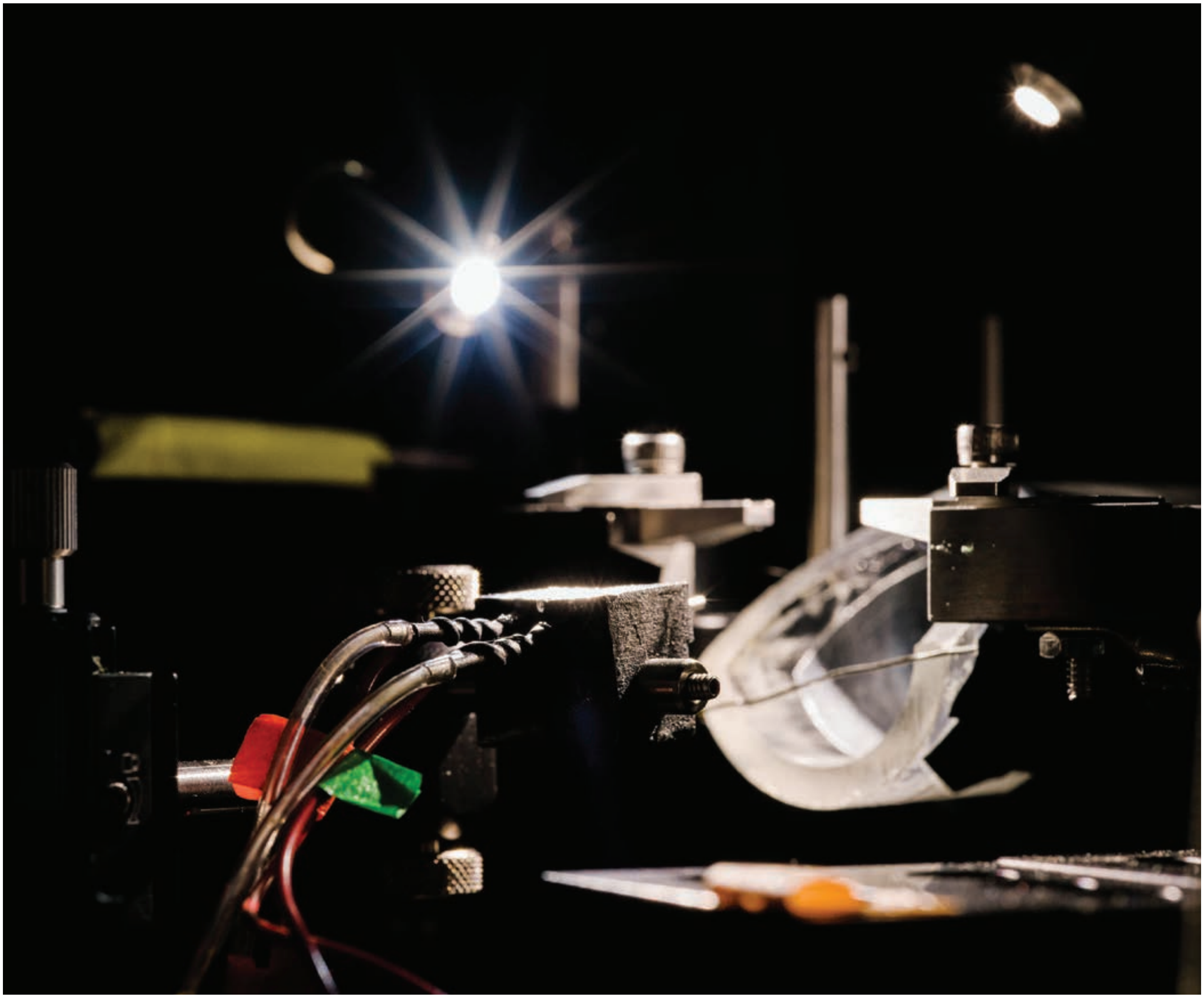
Including **Sorrento**, five of the 16 BIC tenants are BU faculty spinouts. Professors Stephan Anderson and Xin Zhang have two spinouts in the BIC. **Acoulent** is working on a metamaterial-based noise cancellation product. **Primetaz** makes materials that increase the signal of MRI machines. The value proposition for a hospital is higher throughput (less time per session). **149Medical** hired a new CEO. They are developing a non-invasive blood profusion monitor that will provide neonatologists in the NICU a view inside the cranium of a baby to address ventricular hemorrhaging, a condition common in premature babies under 30 weeks. They hired two interns in the last academic year. **iRiS Kinetics** is the fifth BU spinout, founded by Professor Selim Ünlü who was named 2021 BU Innovator of the Year. iRiS Kinetics develops and markets imaging biosensor platforms for applications ranging from molecular binding affinity measurements to single biological particle detection. They hired three undergraduate interns and two doctoral student interns. iRiS Kinetics is a recipient of the EU Transition Grant – NEXUS.

A newcomer is **Stata Dx**, a spinout from Harvard's Wyss Institute. They are building a next-generation blood diagnostic platform. Their first product will be a portable "liquid MRI" for the brain enabling at-home monitoring of neurodegenerative conditions such as Multiple Sclerosis and Alzheimer's as well as rapid triage for acute neurological conditions like Traumatic Brain Injury. The value proposition is quicker, more effective, safer, more personalized care. Stata Dx is supporting one BU intern, an undergraduate student focused on the integration of their electrochemical sensors with a microfluidic cartridge.

Leuko Labs, an MIT spinout is developing their PointCheck™ device, which is used for non-invasive white cell monitoring had a big year. The value proposition of their device is to improve clinical outcomes for more than >2M cancer chemotherapy patients a year in the US and Europe, reduce their chemotherapy-related hospital readmissions by 50% and save >$6B annually in healthcare cost. Their FDA pre-submission for the PointCheck™ device is complete. Leuko hired five student interns. They received the "most exciting technology in oncology" award from AstraZeneca. They were also first prize winner at the InnoSpark AI Pitch Competition and named best medtech startup at the EIT Health Catapult competition. They were awarded $300,000 from MassVentures' START program. Even more, they have a signed term sheet for a $5M Series A.

PlenOptika makes technology that frees vision exams from the clinic, unlocking the regulated eyeglass prescription market. The value proposition is to break the prescription bottleneck with technology that democratizes eyeglass prescriptions. They currently have one BU intern but have supported several interns since their coming to the BIC in 2018. They also have a collaboration with Professor Lei Tian. Plenoptika was a winner of both the SPIE PRISM Award and the Eddies (NE Innovation Showcase). They were awarded a MassVentures START Stage 2 grant and a Trish NASA grant. Lastly, they had two publications, one in Nature and the other in Science Direct.

Neural Dynamics Technologies (NDT) creates implantable high-resolution electrodes for basic research and clinical purposes. For basic research applications, they develop custom high-density electrodes for recording brain activity in the form of local field potentials and single neuron action potentials in any brain region. For clinical applications, they are developing electrodes for the treatment of Parkinson's and epilepsy using deep brain stimulation (DBS). We use nanotechnology manufacturing approaches, pioneered at MIT in the laboratory of Professor Ed Boyden, to creative minimally invasive, high-resolution electrodes that are 10-100 times smaller and higher in resolution than current DBS electrodes. In addition, their electrodes offer both recording & stimulating capabilities, therefore establishing a closed loop platform for adaptive stimulation during DBS. NDT was awarded a three year $2.7M NIH grant and raised $680,000 in equity funding. They also received investment and support from the startup accelerator YCombinator.



NDT is collaborating with Professor Xue Han to test device prototypes.

JanaCare is a long-time tenant in the BIC. They continue to develop their products focusing on diabetes and heart failure. Their approach is to measure biomarkers in blood. Their technology transforms smartphones into a diagnostic platform for these indications to monitor disease progression and thereby improve disease management.

Beta Bionics, a BU spinout led by Ed Damiano that was a previous BIC tenant, is a clinical stage medical technology company committed to the design, development, and commercialization of the iLet® Bionic Pancreas System. Beta Bionics closed a $57 million Series C equity financing. Proceeds from the financing will support product development, regulatory submissions, and preparations for the commercialization of the insulin dosing iLet® Bionic Pancreas System following FDA clearance.

- The financing round was co-led by existing Series B and B-2 investors Soleus Capital, Perceptive Advisors, Farallon Capital Management, L.L.C., RTW Investments, LP, and Eventide Asset Management
- New investor Pura Vida Investments participated in the round
- Other participants included existing Series B and B-2 investors ArrowMark Partners, LifeSci Venture Partners, and strategic partner Novo Nordisk

Nanoview Biosciences, a BU spinout and a previous BIC tenant was acquired by Unchained Labs for an undisclosed sum. NanoView's ExoView technology sits in pole position for characterizing exosomes and their recently launched LentiView platform is a game-changer for gene therapy researchers working with lentivirus.

Photo taken in Mike Economo's lab. Credit: Christopher McIntosh

FY22 Innovation Center Tenants					
Company Name	**Origin**	**Status Change**	**Technology**	**Market Sector**	**Funding**
Acoulent	Boston University	New	Metamaterials	Noise Cancellation	Grants
AEMtec	Corporate Spin-out	Existing	Optoelectronic Circuits	Medical Technology, Telecomm	Corporate
Analog Devices Inc.	Corporate Spin-out	Existing	MEMS	Healthcare	Corporate
Bitome	MIT	Existing	Nuclear Magnetic Resonance (NMR) Spectroscopy	Healthcare	Grants/Angel Funding
Iris Kinetics	Boston University	New	Instrument to characterize molecular kinetics	Healthcare	Grants
Coalesenz	Wellman Center	New	Optical Sensor	Healthcare	Grants
JanaCare	Harvard University	Existing	Diagnostics for Chronic Diseases	Healthcare	Grants and Venture
Leuko Labs	MIT	Existing	Non-Invasive White Blood Cell Monitor	Healthcare	Grants and Venture
Stata Dx	Harvard University	New	Diagnostics for neurodegenerative	Healthcare	Grants
Neural Dynamics Technologies	MIT	Existing	Micro-Electrodes and Implantable Devices	Healthcare	Grants
NXTEC Corporation	Boston University	Existing	Software as a Service (SaaS)	Healthcare	Grants and Venture
PlenOptika	MIT	Existing	Autorefractor Using Wavefront Aberrometry	Healthcare	Grants and Angel
Primetaz	Boston University	Existing	Metamaterials	Healthcare	Grants
Thorlabs	Corporate	Existing	Optical Tools	Multiple	Corporate
Sorrento Therapeutics	Boston University	New	Biotechnology	Healthcare	Corporate
149 Medical	Boston University	Existing	Imaging	Healthcare	Grants and Strategic Partners

CELL-MET Innovation Ecosystem

One of the broader impacts goals of an NSF Engineering Research Center is to create a thriving innovation ecosystem with corporate members who bring industry perspective and facilitate and accelerate technology development and transfer to clinical use. These members form an Industry and Practitioner Advisory Board (IPAB) who regularly interact with the ERC, including engagement with trainees for workshops, Perfect Pitch competitions, professional development, and mentorship. The Photonics Center Director of Industry Engagement and Technical Programs, Thomas Dudley, led the effort as the Industry Liaison Officer over the first four years until his retirement, and then this role transitioned to John Hartnett, Director of Industry Engagement in the BU IE Office.

The NSF prescribes levels of membership and corresponding fees which can include both cash and in-kind contributions. Over the course of the 10-year ERC, the key to sustainability of the center's work beyond the NSF funding is through industry participation and support. John Hartnett developed a sustainability plan with the Senior Leadership Team of CELL-MET as part of the renewal plans for Years 6-10.

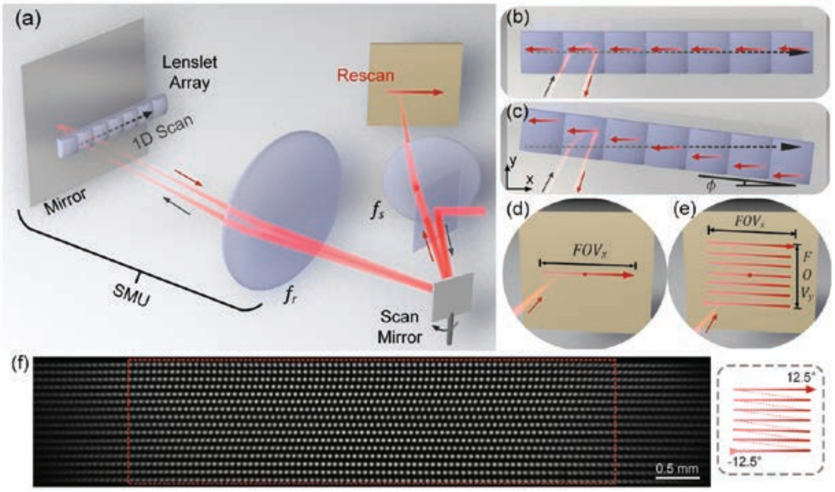
Highlights over first five years of the CELL-MET ERC include the establishment of an Industry Practitioner Advisory Board with 12 members contributing funds, equipment, mentoring, and internship/research opportunities; membership contributions totaling $892K; and support of 5 seed projects for commercialization totaling $435K. CELL-MET has submitted 19 patent filings to date with two licenses granted and three licenses currently in negotiation. In addition, CELL-MET industrial affiliates have supported 4 sponsored research projects directly with CELL-MET participants, including projects with Boston Micromachines Corporation, Imagion, Analog Devices, and IBM. As part of its Innovation Ecosystem activity, CELL-MET hosted a two-day "Industry Engagement" workshop in November, 2021 with its Industry Affiliates.

A summary of support received by CELL-MET from its industrial affiliates is shown in the adjacent Table.

CELL-MET Innovation Ecosystem Support

		TOTAL YEARS 1-5		
		Oct 2017-Sep 2022		
Company	**Start Date**	**Cash**	**In Kind**	**Total**
BioMetrix	1/26/2018	$1,667	$0	$1,667
Bioventus	3/1/2018	$39,583	$0	$39,583
Boston Micromachines Corp	2/1/2018	$4,667	$0	$4,667
Boston Scientific	1/1/2018	$68,750	$19,750	$88,500
Corning	10/1/2019	$47,917	$0	$47,917
Hamamatsu	11/1/2019	$125,000	$850	$125,850
Imagion	2/1/2018	$50,000	$0	$50,000
Lightwave Advisors	7/1/2020	$0	$136,000	$136,000
Nanoscribe/BICO	2/1/2018	$4,667	$0	$4,667
Poly6	3/1/2018	$2,583	$0	$2,583
Stembiosys	12/1/2021	$1,000	$0	$1,000
Sublime	1/1/2021	$2,000	$0	$2,000
Tara	8/1/2020	$3,000	$0	$3,000
Thorlabs	1/1/2018	$187,500	$196,599	$384,099
		$538,334	$353,199	$891,533

Faculty Journal Articles



Xiao, S., Davison, I., & Mertz, J. (2021). Scan Multiplier Unit for Ultrafast Laser Scanning Beyond the Inertia Limit. *Optica*, 8(11), 1403. doi:10.1364/optica.445254

A passive add-on greatly multiplies the sweep rate of any mechanical scanner while also enhancing throughput, enabling a single linear scanner to produce ultrafast 1D or 2D laser scans for general applications.

Lin, H., Lee, H., Tague, N., Lugagne, J., Zong, C., Deng, F., Tian, L., . . . Cheng, J. (2021). Microsecond Fingerprint Stimulated Raman Spectroscopic Imaging by Ultrafast Tuning and Spatial-Spectral Learning. *Nature Communications*, 12(1). doi:10.1038/s41467-021-23202-z

We report a fingerprint spectroscopic SRS platform that acquires a distortion-free SRS spectrum at 10 cm−1 spectral resolution within 20 µs using a polygon scanner. Meanwhile, we significantly improve the signal-to-noise ratio by employing a spatial-spectral residual learning network, reaching a level comparable to that with 100 times integration. Collectively, our system enables high-speed vibrational spectroscopic imaging of multiple biomolecules in samples ranging from a single live microbe to a tissue slice.

THE QUEST FOR A HEART ATTACK CURE

A BU-LED TEAM IS ENGINEERING SMALL PATCHES OF CARDIAC MUSCLE THAT COULD REPAIR THE HEART, TREAT HEART DISEASE, AND SPEED DRUG DEVELOPMENT

by David Levin for *The Brink*

Heart disease is one of the world's most deadly and insidious killers. In the United States alone, it causes one in every four deaths nationwide—that's a staggering 659,000 people each year, or roughly equivalent to the entire population of Portland, Ore.

It's perhaps not surprising that the heart is so vulnerable to damage. It's arguably the hardest working tissue in the human body: one of the first organs to form in the womb, it must keep ticking, without end, for the rest of our lives. Astoundingly, though, the cells within it can't easily divide and reproduce. If damage occurs to any of them, that's it—the injured region of tissue won't be able to repair itself. Instead, the undamaged parts of the organ will limp along as best as they can until the bitter end.

"Once it's damaged, heart tissue is basically gone forever. You're just going to have to make do for the rest of your life with the healthy tissue that remains," says David Bishop, a materials scientist at Boston University College of Engineering.

Bishop is the director of CELL-MET, a National Science Foundation Engineering Research Center in Cellular Metamaterials led by BU, which is focused on developing treatments for cardiac disease. Together, Bishop and his colleagues are taking a bold new approach: growing viable heart tissue in the lab from scratch. If their efforts are successful, he says, the team will be able to create small patches of cardiac muscle that could be transplanted directly into patients' hearts, effectively mending the damaged areas of the organ.

This method would be an entirely novel way to reverse heart disease, says Bishop, an ENG professor and head of materials science and engineering. "If you break your leg, your doctor will talk about fixing you up as good as new. If you have a heart attack, though, you'll never hear those words, because right now there isn't any way to fix that damage," he says. "Our dream is to build a cure for heart attacks."

Alice White says one of the next big challenges is making heart patches closer in scale to actual heart tissue. Credit: Christopher McIntosh

Beating the Immune System, Promoting Healthy Tissue Growth

Creating implantable heart patches comes with a long list of challenges, beginning even at the most basic cellular level. Normally, when foreign tissue is grafted into a patient's body, the immune system—especially without intervention from immunosuppressant drugs—will recognize its cells as invaders and attack them. If that happens, it will gradually kill the implant, and potentially take its host along with it.

To avoid this problem, CELL-MET researchers plan to use a patient's own skin cells as a starting point. Through a complex biological process, the group can reprogram those cells, turning them into pluripotent stem cells—a sort of universal cell that can become almost any kind of tissue in the body. From there, the researchers can slowly coax the cells into becoming cardiomyocytes, the pulsating muscle cells that do the bulk of the heart's work. Because they originated from parts of the patient's own body, there's almost no chance that the newly formed cells will trigger an immune response.

The procedures involved in making those cells are nothing new: scientists have already been doing it for more than a decade. Turning them into working tissue, however, is a different story. You can't just plop heart cells into a dish—if you want them to grow into healthy cardiac muscle, they need to be anchored onto a structure with just the right physical properties.

"Heart cells are what we call mechanically active: they need to contract and generate force as they grow. The way they develop is greatly impacted by their mechanical environment," says Christopher Chen, a BU William F. Warren Distinguished Professor and an ENG professor of biomedical engineering. "If that environment is too rigid, a cardiomyocyte won't be able to contract. You need scaffolding that's stiff enough to support the cells, but soft enough that it can crunch down when the cells pull on it." With the right materials and structure to support them, adds Chen, who is also deputy director of CELL-MET, the cardiomyocytes can more easily mature, align themselves into strings of muscle, and start beating in unison.

"I think a lot of our success comes from the fact that we're doing transdisciplinary research. We've all stopped thinking about our individual fields, and started thinking about solving a common problem"

–David Bishop

To provide this sort of environment, the CELL-MET team is making a fleet of tiny structures called scaffolds. Each one is only a few microns wide, and acts like a minuscule frame that nestles cells inside it. In order to make detailed structures this small, the team has turned to nanoscale 3D printing techniques originally developed for the semiconductor industry and recently commercialized by Nanoscribe, says Alice White, an ENG professor and chair of mechanical engineering.

White is leading a team testing several different materials and patterns to help enable healthy tissue growth—from a nest-like cluster of nanofibers to a more complex engineered honeycomb—and using them to help CELL-MET colleagues create early proof-of-concept heart tissue patches. At the moment, these experimental patches are just a few hundred cells thick, White says—one of the remaining hurdles is figuring out how to make them closer in scale to actual heart tissue, which can be on the order of one centimeter (roughly half an inch) thick.

"The main problem there is vasculature. To get thicker tissue, you need blood vessels and nutrients inside a block of cells. That's where the difficulty level really starts to ramp up," she adds. "That's the next challenge we'll be working on."

Speeding Heart Drug Development and Testing

CELL-MET researchers are currently attempting two ways of creating blood vessels within their patches. One involves White's carefully designed scaffolds; the other involves 3D printing cells themselves. Using a slurry of cardiomyocytes as a "living ink," the group could potentially lay them down in layers that mimic the shape of living heart muscle, building tissue with hollow paths inside that could act as nascent blood vessels.

While existing thin patches of heart cells can't be implanted, says Chen, they may still be useful for developing drug therapies. It's fairly common for new drug candidates for a wide range of diseases to have major side effects on the heart—but the standard process of testing those substances in animals can sometimes obscure these effects until the drug reaches clinical trials.

"The problem is that the human heart can react very differently to a drug than animal heart cells," Chen says. "It's very possible to miss something. If you do, you've wasted a huge amount of resources developing a compound that ultimately turns out to be toxic to cardiac tissue." Lab-made human heart tissue, however, might help researchers catch those issues early, making drug development faster and more accurate.

CELL-MET's heart patches might also help scientists better understand rare heart diseases in the first place. By using skin cells taken from patients with congenital heart diseases, Chen says, the group could re-create the cardiac abnormalities that exist in their body, and test new treatments directly in a patch of diseased tissue.

Educating New Generations of Scientists

Even though implantable heart tissue is still a ways off, the fact that CELL-MET has made so much progress in five years is remarkable, says Bishop.

To tackle a problem as thorny as growing heart tissue, the center has had to bring together a massive team of researchers from 14 institutions around the globe. They specialize in many different disciplines—biology, electrical engineering, computer science, nanotechnology, chemistry, and the list goes on.

So far, this approach seems to be working. In addition to their early heart tissue patches, those collaborations have already resulted in a living heart chamber replica, tiny heart valves on a chip, new nanoscale 3D printing methods, and other advances. It has also led to some offshoot discoveries, including a new contactless electrocardiogram that can sense the heart's electric field using magnets, and is now being developed by a company spun out of Bishop's lab. Each of these incremental steps represents a major scientific achievement, and may help scientists create other types of organ tissue in the future.

"I think a lot of our success comes from the fact that we're doing transdisciplinary research. We've all stopped thinking about our individual fields, and started thinking about solving a common problem," says Bishop. "In the old days, you would have called it a skunk works—you put 100 people with different expertise into a warehouse in Nevada, and together, they come up with an airplane nobody thought was possible. No one says, 'I'm a wing person,' or 'I'm an engine person,' you're just all part of a team working on a common problem."

To foster that kind of thinking in the future, CELL-MET is focusing a large part of its mission on educating new generations of students. Teaching others to think across disciplines, Bishop notes, may lead to new innovations that would otherwise be impossible to achieve. They're starting not only with undergraduates, but also younger students, offering a range of education and outreach experiences, from preschool STEM programs to high school science lessons.

"Our work goes beyond just creating cardiac patches. We hope it will be a role model for how to do research going forward," Bishop says. "Our education, diversity, and outreach programs—training the inclusive workforce of the future—are a vital part of that. Inclusion is also critically important to the cardiac tissues themselves—there are significant demographic differences that we study and need to consider in what we are building."

Between its work in the lab and in the classroom, the center's efforts might eventually prove pessimists everywhere wrong. Maybe, just maybe, a broken heart can be mended.

Other institutions involved in CELL-MET include Brown University, CNEA (Argentina), Columbia University, École Polytechnique Fédérale de Lausanne (Switzerland), Fort Valley State University, Florida International University, Harvard Medical School, National University of Ireland, NHS College, North Carolina State University, Queen's University Belfast (Northern Ireland), University of Michigan, and the Wyss Institute.

GROWING TISSUE AND ENGINEERS

CELL-MET SUMMER PROGRAMS BROADEN THE PIPELINE OF RESEARCH ENGINEERS

by Patrick L. Kennedy for Boston University College of Engineering

"Graduate school was never a thought," says Nicole Bacca. As a teenager applying to Florida International University (FIU), Bacca picked engineering for a major because she couldn't imagine following four years of college with additional years of law or medical school.

"I thought engineering meant you graduated after four years, got a good salary, and were all set," says Bacca, who was born in Colombia and raised in Florida. "I had always associated it with industry—I didn't know there was this whole research component of engineering, that people got their PhD in it."

But then, after Bacca had enrolled at FIU, Helen Fawcett visited the campus. Fawcett is a research assistant professor of mechanical engineering at the Boston University College of Engineering and the director of student engagement for the NSF Engineering Research Center in Cellular Metamaterials (CELL-MET).

Fawcett told Bacca and other students about CELL-MET's mission. (FIU and the University of Michigan are partner institutions in CELL-MET, which is led by BU.) Launched in 2017 with funding from the National Science Foundation, CELL-MET is developing a kind of living bandage for the heart. CELL-MET envisions a cardiac tissue patch that would be made from the patient's own cell samples and implanted to repair an organ damaged by a heart attack.

That mission spoke to Bacca, whose mother was dealing with cardiac issues at the time. So, Bacca applied to CELL-MET's Research Experience and Mentoring (REM) program, a summer research experience that was designed to identify and mentor FIU undergraduates and expose them to cutting-edge engineering research. It is one of three programs connected to CELL-MET that aim to fill the engineering workforce pipeline by encouraging engineering undergraduates to pursue graduate school or positions in industry, and training high school teachers to nurture STEM interest in their students.

The summer before sophomore year, Bacca helped Professor and Chair of Mechanical Engineering Alice White design, 3D-print, and test scaffolding used to grow cells. Today, she is a PhD student in mechanical engineering at BU. "If I had not done that first REM experience, I would

Noelle Pierce, PhD student in materials science and engineering

not have pursued grad school," she says. "That is 100 percent certain."

Bacca is not alone. Dozens of students from all over the country have taken part in summer research experiences in CELL-MET labs and been inspired to pursue engineering research in academia. For example, Bacca's FIU classmate Elisa Bravo, another REM participant, spent that same summer in the lab of Professor Kamil Ekinci (ME, MSE), manipulating fluids to learn about boundary conditions for the vasculature of a cardiac patch.

"That definitely changed my whole career path," says Bravo, who is now a PhD student in mechanical engineering at Michigan. "The REM program is great because you get to experience something new that you might not have considered, and you get some experience under your belt."

That's the point, says Cara Ellis McCarthy, CELL-MET administrative director. Along with creating the heart patch, CELL-MET's mission includes developing a diverse engineering workforce. "The summer programs," she says, "bring together all those priorities."

An easy fit

The REM is nearly identical and was integrated into the existing NSF Research Experiences for Undergraduates (REU) Site in Integrated Nanomanufacturing, led by Professor Xin Zhang (ME, ECE, BME, MSE) and Fawcett. Student participants hail from a range of minority-serving institutions, community colleges, and universities that often lack undergraduate research opportunities or graduate programs in engineering. It has existed at the BU Photonics Center, which administers CELL-MET, since 2015. Because that apparatus was already in place, Fawcett was able to launch the summer research experiences for CELL-MET with relative ease in 2018.

In both programs, students receive housing, a stipend, and travel expenses, and spend 10 weeks learning and applying nanofabrication techniques and conducting research in state-of-the-art facilities. They also attend technical and professional development seminars, and take part in social outings.

For most of the students, this is their first time in a lab. "It's a very newbie-friendly way to get into tissue engineering," says Francisco Sanchez, who, as an undergrad at the University of Puerto Rico–Mayaguez, spent one REU summer at UM and one at BU (CELL-MET labs are sited at BU as well as its partner institutions, UM and FIU.) "Most of the REUs who go into CELL-MET haven't had research experience, and they're usually first-generation college students."

At UM, Sanchez worked with Professor Stephen Forrest, who recommended Francisco for another summer. The following summer Sanchez worked at BU in the lab of Professor Thomas Bifano (ME, MSE, BME, ECE), director of the Photonics Center. Sanchez designed a setup to measure the effects of mechanical stimulation on heart tissue.

He is now a PhD student in Bifano's lab. "My decision to go to grad school was based on my experience working in CELL-MET labs," says Sanchez, who was also drawn to CELL-MET by its mission. In his native Puerto Rico, Sanchez said, "A lot of people suffer from heart conditions, my family included. So, I do see it as a good end goal. People have to do this work."

Noelle Pierce, came to Boston the summer after sophomore year at Norfolk State University in Virginia to eliminate engineering as a career path. "There were a whole bunch of things I was interested in as a kid," she says. "I really wanted to rule out engineering at this point, when I'd already done two years of a bachelor's in chemistry."

Pierce came to BU as part of the NSF REU Site in Integrated Nanomanufacturing and ended up working on biosensors in the lab of Professor David Bishop (ECE, Physics, MSE, ME, BME), director of CELL-MET.

"In our first conversation, Dr. Bishop said, 'I'm gonna make an engineer out of you.' I was like, 'Ha-ha, little do you know, I'm gonna be working in chemistry.'"

Instead, says Pierce, "the REU changed the trajectory of my career. I realized, 'Wow, this is what I want to do.' It really motivated me to get through the rest of college."

Today, Pierce is an MSE PhD student in Bishop's lab.

Whether REM or REU, mentoring from grad students and faculty is critical to the experience. "Professor Alice White was always there," says Bacca. "I never felt like I was struggling. I had great mentors, and great female mentors, which in engineering can be difficult to find."

Teaching teachers about Engineering

The third component of CELL-MET's workforce development effort is the Research Experience for Teachers (RET) program, in which high school science teachers engage in cutting-edge research and bring that experience back to the classroom. As with the REU programming, BU had an existing NSF RET in Integrated Nanomanufacturing. Leveraging and integrating the ERC RET into the existing RET site helped foster a community rather than siloed teacher experiences.

Amanda Dillingham, science director at East Boston High School, has come to BU for several RETs over the years. Among other things, she has researched vascular density and grown capillaries in the lab of Professor Christopher Chen (BME, MSE), deputy director of CELL-MET.

"It totally transformed my teaching—I rewrote an entire curriculum because of it," she says. "I integrated engineering into a biology class. Having that lab experience is extremely important in science teaching, and not every teacher has it," added Dillingham, who recruited several other teachers to take part in the program.

The REM and REU undergraduates are involved, too, effectively teaching the teachers. The students are a few weeks into their research program when the teachers arrive.

"It's amazing to see the students' growth," says Fawcett of the students. "On day one, they're completely overwhelmed and maybe don't have confidence in their abilities. And four weeks later, they understand what they're doing and they're able to give a presentation about their research to the teachers."

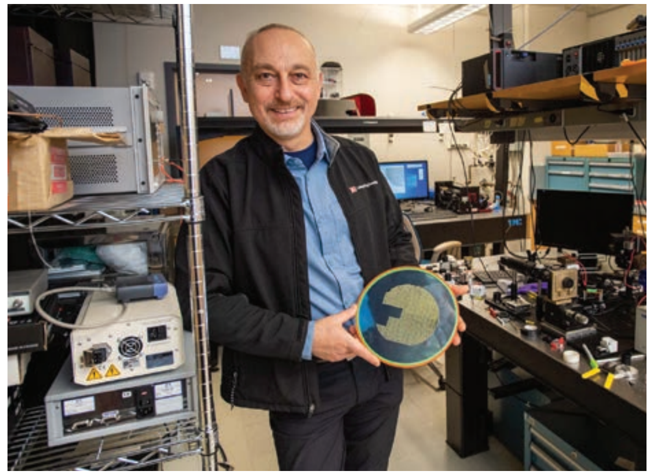
The outreach doesn't end there. Some REU students and current CELL-MET graduate students, under Fawcett's guidance, give biomedical engineering presentations, help train high school students to teach those same concepts to younger kids, and are on hand to assist in the classroom visits.

Fawcett's outreach in high schools continues to bear fruit. One young woman who worked with Fawcett is now in college, majoring in biomedical engineering. She is coming to BU this summer to conduct research in Ekinci's lab, thanks to supplemental funding from the NSF.

BU'S INNOVATOR OF THE YEAR USES HISTORY TO SHAPE THE FUTURE

TO HELP STUDENTS INVENT THE TECHNOLOGY OF TOMORROW, SELIM ÜNLÜ STARTS WITH A LESSON ABOUT THE BREAKTHROUGHS OF THE PAST

by Andrew Thurston for *The Brink*



Selim Ünlü, a BU College of Engineering professor of electrical and computer engineering, has pioneered devices and technologies that help hunt for security flaws in the construction of computer chips and detect viral pathogens in medical samples. Photo by Cydney Scott.

Electrical and computer engineer Selim Ünlü's lab is filled with the future, a hotbed of technological innovation that brims with gadgets. Much of what's happening sounds like it could've been pulled straight out of science fiction: high-resolution subsurface imaging techniques to study the spectroscopy of quantum dots, nanoscale microscopy to examine fluorescent molecules, imaging biosensors for DNA arrays.

And yet one of the first lessons his students get isn't about the technology and science of tomorrow, or even the present—it's about the breakthroughs of the past. Ünlü, who has been named Boston University's 2021 Innovator of the Year, shares with the class a few stories about history's pioneers and visionaries.

"Science history is extremely important," says Ünlü, a BU College of Engineering professor of electrical and computer engineering. Instead of jumping in to teach sophomores essential engineering rules, like voltage divided by current equals resistance or the diffraction of light around objects, he puts them in the shoes of the people who first calculated those theories—such as American physicist Albert A. Michelson and English mathematician and astronomer George Airy—telling lively tales of how they put names to dazzling new concepts.

"If you learn something at this level, with these anecdotes around it, with historical things, you will not forget it," he says. "Otherwise, it's just equations you memorize. That's not how people figure things out. Knowing what people thought at the time is instrumental for someone learning the subject. A hundred years ago, much smarter people struggled with these concepts."

It's characteristic of Ünlü that his students get a lesson on ingenuity and invention on day one—and that it probably isn't the lecture they expected.

As they travel through his classes—and perhaps into his Optical Characterization & Nanophotonics Laboratory as doctoral students and researchers—they'll get used to his novel approach to innovation.

Making the Complex Seem Simple

Ünlü holds 18 patents (with more pending) and has helped launch three companies, all focused on using light to make precise measurements. And yet he describes himself as someone who doesn't look for big innovations, but smaller, more iterative ones.

"Magnetic resonance imaging, MRI, is fantastic and the idea came out of physics—I don't think I can do such things," he says. "My strength is that I can see a new application of some simple concept."

Much of Ünlü's work is concentrated in what's called interferometric sensing, a photonics discipline that uses light waves, or photons, to make extremely accurate measurements. He has pioneered devices and technologies that help hunt for security flaws in the construction of computer chips, detect viral pathogens in medical samples, and look for microscopic disease clues in cells and tissues. A fellow of the American Institute for Medical and Biological Engineering, the Institute of Electrical and Electronics Engineers (IEEE), and Optica, he's also a former editor in chief of the *IEEE Journal of Quantum Electronics*.

One of his signature inventions is a biosensing technique called Interferometric Reflectance Imaging Sensor (IRIS), which can help researchers scrutinize biomolecules—such as nucleic acids and proteins—and biological nanoparticles, which can include viruses, with exceptional sensitivity. It's been used to help detect pathogens and support drug development and other life sciences research.

"Professor Ünlü has a knack for recognizing inventions in the experimental results from the laboratory work—sometimes it is just a small tweak to an optical design that unlocks a strong detection signal," says Michael Pratt (Questrom'13), managing director of technology development at BU. "In a way, he mirrors his own invention by having the ability to see things in the data that other people—or other technologies—miss."

Learning from Others' Mistakes

Ünlü traces his approaches to teaching and mentoring back to his own early career experiences—but not because they were necessarily all positive ones. He says he was never taught how to protect his intellectual property and had an advisor who ruled by fear. He's learned from others' mistakes, being a friend to his students (he used to play on an intramural soccer team with them) and having complete transparency about his work outside of BU—including how much his consulting pays. He also frequently includes students in his patent applications and fledgling businesses so they can see how to protect and monetize ideas.

"In Selim's lab, we focused on solving real-world problems, which allowed us to come up with practical and translatable solutions," says George Daaboul (ENG'09,'13), who was mentored by Ünlü during his doctoral studies. He's now chief scientific officer at NanoView Biosciences, a biotechnology company he cofounded and that has its roots at BU. "NanoView's core technology was developed in Selim's lab. I benefited a lot from Selim's mentorship—he allowed us autonomy in his lab, which enabled us to be independent, but he was very supportive when needed."

In the classroom and in the lab, Ünlü aims to give his students time for unstructured free thinking—he hopes it opens their minds, giving them space to innovate. "Curiosity is hard to teach," says Ünlü. "Everybody can work hard, but you cannot force yourself to be more curious—as a role model, I'm always curious."

TINY SATELLITE WILL TAKE WIDEST EVER IMAGES OF EARTH'S AND THE SUN'S MAGNETIC FIELDS COLLIDING

IMAGES CAPTURED BY THE PROBE, DEVELOPED BY BU ENGINEERS, COULD REVEAL NEW INSIGHTS INTO RADIATION THAT IMPACTS SATELLITES, ASTRONAUTS

by Kat J. McAlpine for *The Brink*

A first-of-its-kind satellite, designed and built by Boston University engineers, hitched a ride in September 2021 aboard a NASA rocket launched from Vandenberg Space Force Base in California. About 340 miles above our planet's surface, the shoebox-size satellite containing an X-ray telescope will capture images of where the magnetic fields of the Earth and the sun meet in space.

Known as CuPID, which stands for Cusp Plasma Imaging Detector, the satellite is designed to capture images that will help scientists learn more about the way energy from the sun is transferred into the near-Earth space environment. The team behind the satellite's development has been led by Brian Walsh, a BU College of Engineering professor of mechanical engineering, and supported by a $2.4 million, four-year NASA grant. In addition to BU engineers, the team is made up of collaborators from NASA's Goddard Space Flight Center, Johns Hopkins University, Drexel University, and Merrimack College.

"It's not every day that the hardware you have been working on for four years, the software you have written, the computer you have been talking to every day, is closed up in its launch vehicle going somewhere you'll never see it again," says Emil Atz, a BU graduate student pursuing a PhD in mechanical engineering in Walsh's lab.

X-ray imaging is not a new technology for observing Earth and space phenomena. But previous orbiting telescopes have been limited by their field of view, capturing images of specific areas one by one. CuPID is the first such satellite to have a wide field of view, which will allow scientists to study the boundary between the Earth and the sun's magnetic fields using much bigger, more comprehensive images.

"CuPID will image the invisible," Walsh says. "For decades, scientists have studied a process called magnetic reconnection." As charged particles emitting from the sun collide with Earth's atmosphere, electrons are exchanged and X-rays are given off. During periods of high solar activity, charged particles can leak into the Earth's atmosphere, potentially putting satellites and astronauts in harm's way.

"The more we roam and observe our universe, the more we see [magnetic reconnection] occurring and controlling phenomena everywhere from the surface of the sun to the black holes to the 'magnetic bubble,' or magnetosphere, surrounding the Earth," Walsh says. "It has been studied routinely through pinpoint measurements…but we've never been able to image the process as a whole with a zoomed-out view." He adds that CuPID will help scientists "answer a fundamental question: Under what conditions does reconnection occur in explosive bursts versus a steady continuous hum?"

For the imaging power it contains, CuPID is remarkably small. It's about as big as a shoebox, whereas other X-ray telescopes tend to be closer to the size of a school bus.

"X-rays are notoriously hard to focus onto a detector," Walsh says. "They just pass through or get absorbed by the types of lenses we wear in our glasses. For several decades, researchers have used a [so-called] Wolter focusing technique…[which] can provide a great image but is large, heavy, and produces a narrow field of view, a fraction of a degree in the sky."

To capture and focus wide-field images from its tiny package, CuPID employs a new type of imaging element called lobster-eye optics. "Working closely with scientists and engineers from NASA Goddard, Johns Hopkins, and the University of Leicester in the UK, [we developed] lobster-eye focusing," Walsh says. "This technique uses a slumped piece of thin glass with tiny pores, each roughly the size of a human hair. Each pore has the ability to focus an X-ray coming through. The technique is similar to how the eye of a lobster works with many pores, hence the name."

The lobster-eye lens allows CuPID to make wide-field-of-view X-ray images at a fraction of the size and weight of traditional focusing tools, Walsh says. To make sure that CuPID withstands the violent and bumpy launch, and its journey in orbit, the BU team put the satellite through rigorous testing.

"Vibration testing is pretty exciting, but you never want an exciting result," Atz says. "The best result is when nothing happens. We were required to shake CuPID extremely hard. When you shake things that hard they make this noise that you can't unhear. It's like the satellite is screaming."

Fortunately for CuPID and its engineers, the vibration test mimicking the bumpy ride to space didn't result in any damage to the satellite. To see how CuPID would fare in orbit required a different approach.

"We use a vacuum chamber that reaches high vacuum, nearly the vacuum of space," Atz says. "In the chamber, we test our instruments with energetic particles created by either radioactive sources, or an X-ray generator. These help us to calibrate the instruments to what they will see in orbit. That chamber is our workhorse of the lab. When we are running tests, that chamber will be running for months at a time."

For Atz, the experience of working on CuPID has shaped where he wants his career to go. "I just want to build satellites….I think the future has many, many more satellites with my initials hidden somewhere on the hardware or in the software," he says with a smile.

LAB SPOTLIGHT

IN XI LING'S LAB GROUP, THE DISCOVERY—AND SOMETIMES, *REDISCOVERY*—OF 2D MATERIALS FUELS THE TEAM'S CURIOSITY AND COLLABORATION

by Kat J. McAlpine

As one lab member of Xi Ling's lab put it, "I'm not afraid of asking anything." That freedom to question and explore, embraced by Ling and the 15 doctoral, graduate, undergraduate, and visiting researchers making up her lab group, has allowed the team to push the limits of material science. In the last year, they've published papers in *Nature Materials, Cell Reports Physical Science, ACS nano, Science Advances, Nature Electronics, Nature Communications* and more.

"We focus on 2D materials, we do a lot of materials chemistry research in the group, and we use spectroscopy methods to analyze existing and novel materials in new ways," says Ling, a Photonics Center faculty member, College of Arts & Sciences assistant professor of chemistry, and College of Engineering assistant professor of materials science engineering. "We like to bring new ideas and technologies to life."

Photos: Christopher McIntosh

"IF YOU HAVE A CHIP WITH NANOSTRUCTURES ON IT, AND YOU WANT TO ADD MORE, YOU NEED A GENTLER PROCESS FOR INTEGRATING AND LAYERING THOSE MATERIALS WITHOUT DISRUPTING THEIR QUALITY." *– Xi Ling*

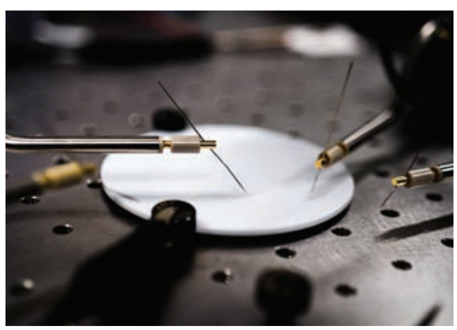
Ling and her team are interested in 2D materials because the "flat" arrangement of crystals make attractive building blocks for semiconducting chips found in electronic devices, phones, and computers, as well as components of highly-sensitive chemical sensing methods. But the lab isn't laser focused on developing new real-world applications just yet. Instead, they're passionate about fundamental discovery.

"In the past year, we discovered that certain 2D crystals—of tin disulfide—can help us sense an incredibly small number of molecules," Ling says. "It has very high sensitivity for detecting an extremely low concentration of chemicals."

When combined with Raman-enhanced spectroscopy, a process that analyzes how light scatters as photons collide with materials under observation, tin disulfide seems to help excite molecules of interest, increasing the energetic activity of electrons and ultimately producing a stronger signal of light that can be detected.

Now, Ling and the group are doing more research to understand what properties of tin disulfide make it so useful for sensing the merest traces of other materials. "Could this help us someday better detect contamination on foods? We are looking to see how we can control the structure of the material to make it perform even better," she says.

"I'm particularly interested in this project because it's essentially a fingerprinting technique, says Hikari "Rick" Kitadai, a PhD candidate in his sixth and final year in the Ling lab. "Enhanced Raman scattering is an established process, but there are some notable challenges. Most commercial applications rely on gold or silver nanoparticles to enhance the scattering of light and enable foreign

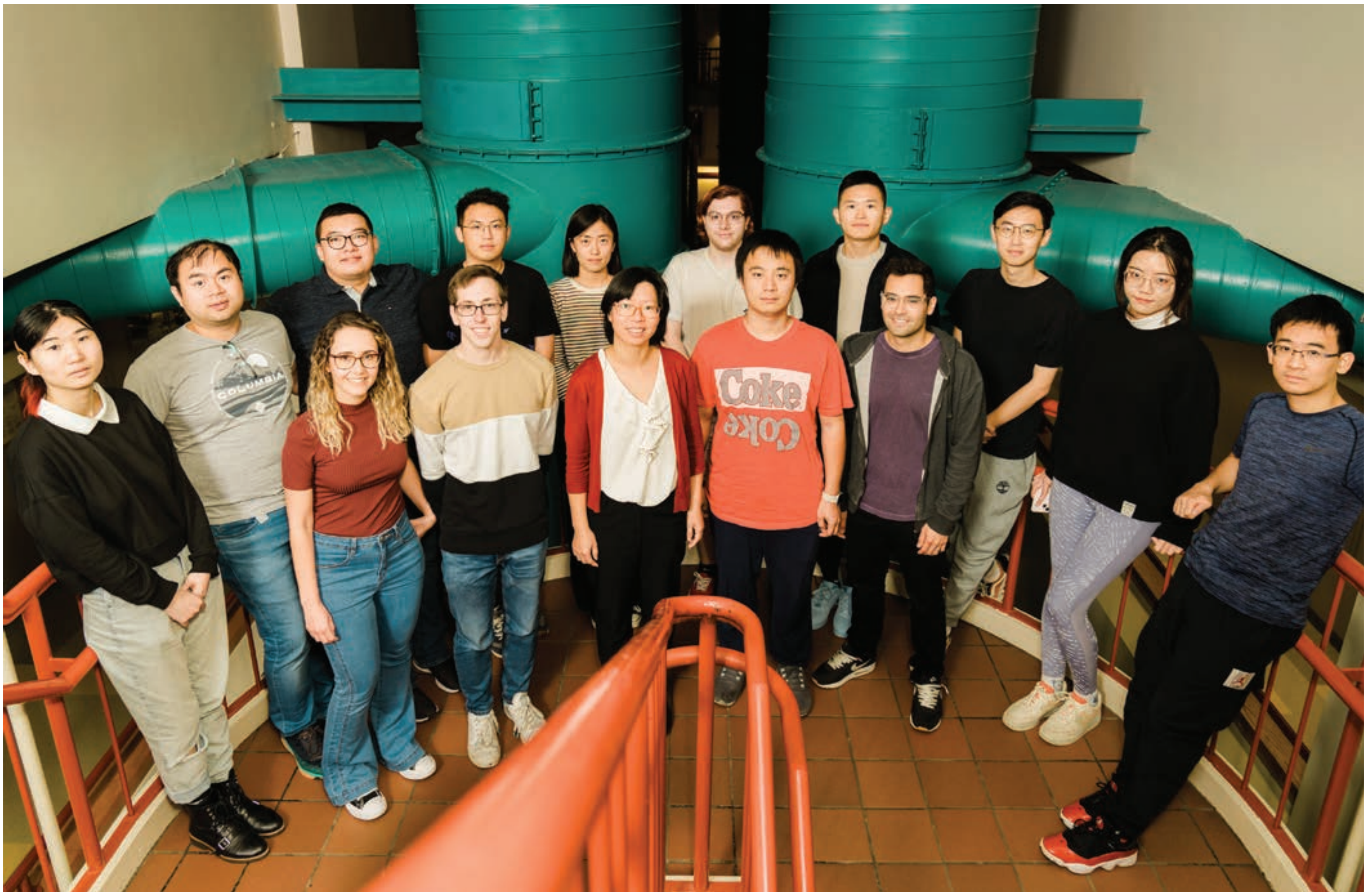


structure under light, making it hard to reliably detect miniscule amounts of the molecules you're interested in."

Kitadai is now investigating which types of molecules tin disulfide has the strongest attraction to—lighting up the strongest signals under enhanced Raman spectroscopy—to understand how 2D crystals can be modified and tailored to allow for detection of specific molecules.

even the methods that allow them to do so with precise control. "We already know that some materials have very useful properties, so we want to join them together with other materials," she says. The team is especially interested in developing new materials and structures to build better semiconducting chips.

"Usually, 2D materials are synthesized during a process that reaches up to 700 degrees Celsius," Ling says. "But a temperature that high can damage or create defects in delicate crystal structures. If you have a chip with nanostructures on it, and you want to add more, you need a gentler process for integrating and layering those materials without disrupting their quality."



Jun Cao, a fourth-year PhD candidate, is working with Ling and other members of the group to develop new strategies that use a near room-temperature process to trigger synthesis of 2D materials that are challenging using conventional synthesis methods. (The project was first launched by former lab member Tianshu Li, who after completing her PhD is now a process engineer at Applied Materials, Inc.)

> "I'D LIKE EVERYONE ON THE BU CAMPUS AND IN THE BOSTON RESEARCH COMMUNITY TO KNOW ABOUT IT—THE PHI XPS WILL BE PART OF BU'S SHARED EQUIPMENT FACILITY SO THAT OTHERS CAN USE IT AS WELL." *– Xi Ling*

Inside a special tube, Cao places materials upon a chip, then seals the tube and runs hydrogen gas and plasma over the surface of the materials. As hydrogen interacts with the plasma, its electrons get excited and that reaction triggers synthesis of new 2D materials. The device is still a prototype, and the bonds formed in the tube don't remain stable when taken out of the chamber. Next, the team is working on another step that would use ammonia to form bonds that are more stable and long-lasting.

Another lab member, Lu Ping, a fourth-year PhD student, is studying 2D transition metal hydroxide synthesis, after noticing that it was noticeably absent from existing scientific literature. Already, Ping says the team has "successfully synthesized >20 micrometer 2D crystals [of nickel hydroxide and cobalt hydroxide], which have the largest domain size that ever been reported." The team also found the nickel hydroxide and cobalt hydroxide crystals could potentially work as a dielectric material, which could someday have implications for electronic devices.

"We just started a new collaboration with a semiconducting company, to test whether these materials can be useful and high performing," Ping says.

Third-year PhD candidate, Hongze Gao, another member of the team, studies the electrical properties of 2D materials synthesized by his lab-mates to understand what makes them conductive. "We keep synthesizing and studying new materials because they are the building blocks that could someday improve electronic devices or allow us to do something that hasn't been done before—that's the long-term plan."

Gao collaborates with Boston College researcher Kenneth Burch and his lab group, teaming up to use their instruments on some of his experiments. "In the Ling lab, we have many opportunities to partner with other scholars in the field."

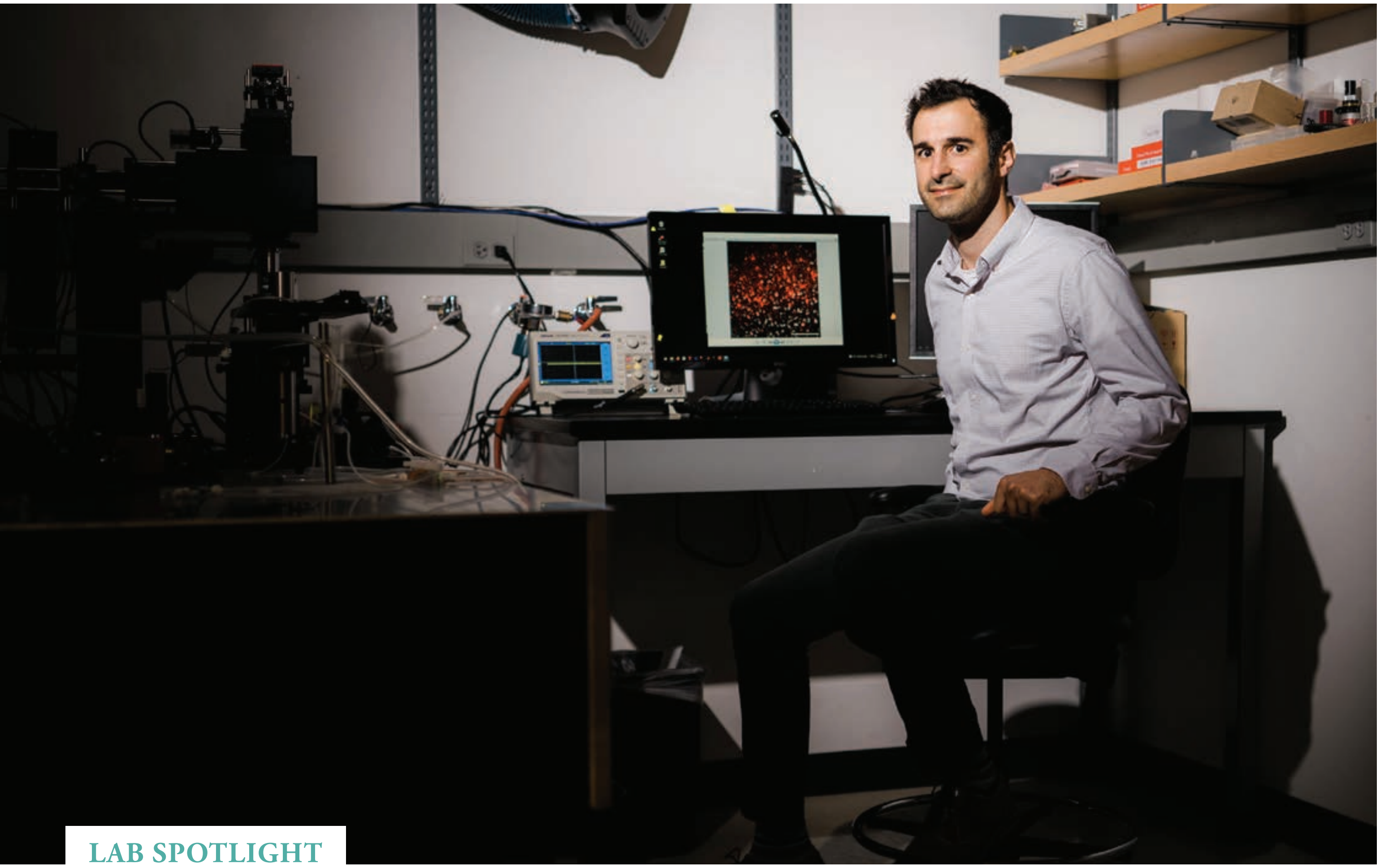
As another example, the team hopes that the upcoming arrival of a next-generation spectrometer, funded by a grant from the National Science Foundation, will be a boon to scientists across BU and the entire Boston region. "We have a new x-ray photoelectron spectrometer (XPS) arriving soon," Ling says. The XPS, built by the company PHI, is expected to be first released in November 2022. "It's going to be the newest system in the U.S., it's very modern, and it has some new functions that will allow us to see the full picture of materials' electronic structures. I'd like everyone on the BU campus and in the Boston research community to know about it—the PHI XPS will be part of BU's shared equipment facility so that others can use it as well."

Also on the horizon for the Ling group is increased focus on studying magnetic 2D materials to evaluate how they can be used to enable quantum computing technologies.

"In magnetic materials, the direction of electronic spin is predictable. And we've found that it's polarized, meaning the direction can be switched to represent two different possible states," Ling says. "If we could potentially control the direction of the spin between those two different states, that would theoretically mean the group could create every possible state between spin happening in one direction versus another—a feasibility that could help create basic units required to build a quantum computer."

Whereas today's computers operate on binary units, represented by 0s and 1s, a quantum computer would be based on units capable of representing 0, 1, and everything in between those two digits *at the same exact time*. That's why quantum computers could revolutionize computing and data analysis, greatly expanding the power of computing to calculate complex equations.

"I get a lot of inspiration from discussions with my students, that's really important to me," Ling says. ■



LAB SPOTLIGHT

NEW TECHNOLOGIES ARE HELPING MICHAEL ECONOMO'S LAB GROUP SHAKE UP WHAT'S KNOWN ABOUT HOW THE BRAIN CONTROLS MOVEMENT

by Kat J. McAlpine

"When we think about movement and motor skills, we tend to think a lot about our limbs," Michael Economo says. "But facial movements are among the most important for our survival, allowing us to drink, chew, and communicate." In patients with neurodegenerative diseases like ALS, changes in tongue and facial movements are often the first sign that something is wrong.

Economo and members of his lab are using light-based techniques and other technologies to probe the motor circuits of the brain that control how humans and other animals move, using facial movements as a model. In the last year, the lab has tripled in size—going from three to nine full-time researchers—and further expansion is on the horizon. The growing lab (supported by funding from the Whitehall Foundation, the BRAIN

Photos: Christopher McIntosh

Initiative, the Klingenstein-Simons Foundation, National Institutes of Health RO1 grants and U19 projects, and more) is working with mice to understand how specific cells and neural circuits in the mammalian brain work together to allow us to move.

To do so, they train mice to perform specific movements while recording their brain activity using electrodes that are thinner than a strand of human hair. “We can record which neurons are activated in the brain, at exactly which times, all simultaneously at multiple points throughout the brain,” says Economo, a Photonics Center faculty member and a College of Engineering assistant professor of biomedical engineering.

One behavior lab mice are commonly trained to perform is to lick a water spout for a reward. Meanwhile, electrodes record their brain activity. Although facial movements such as licking water may seem strangely specific for researchers to focus on, they engage the same key circuits of the brain necessary for controlling other parts of the body.

“Mice are not very limb-centric animals, they’re very face-centric,” Economo says. “They’re nocturnal, they need to use their whiskers to sense their environment in the dark, they have a really keen sense of smell…. Their head and face are where the action is, and a lot of brain circuitry is dedicated to controlling those movements.”

Not only does that make licking an effective behavior for the team to study in mice, but it also can help shed light on how changes in brain circuits lead to disorders that disrupt facial movements in humans. “Patients often die from ALS and other movement disorders because they lose the ability to consume liquids and chew and swallow food,” he says. “And not being able to speak has a huge impact on their quality of life. All of these behaviors rely on facial movements.”

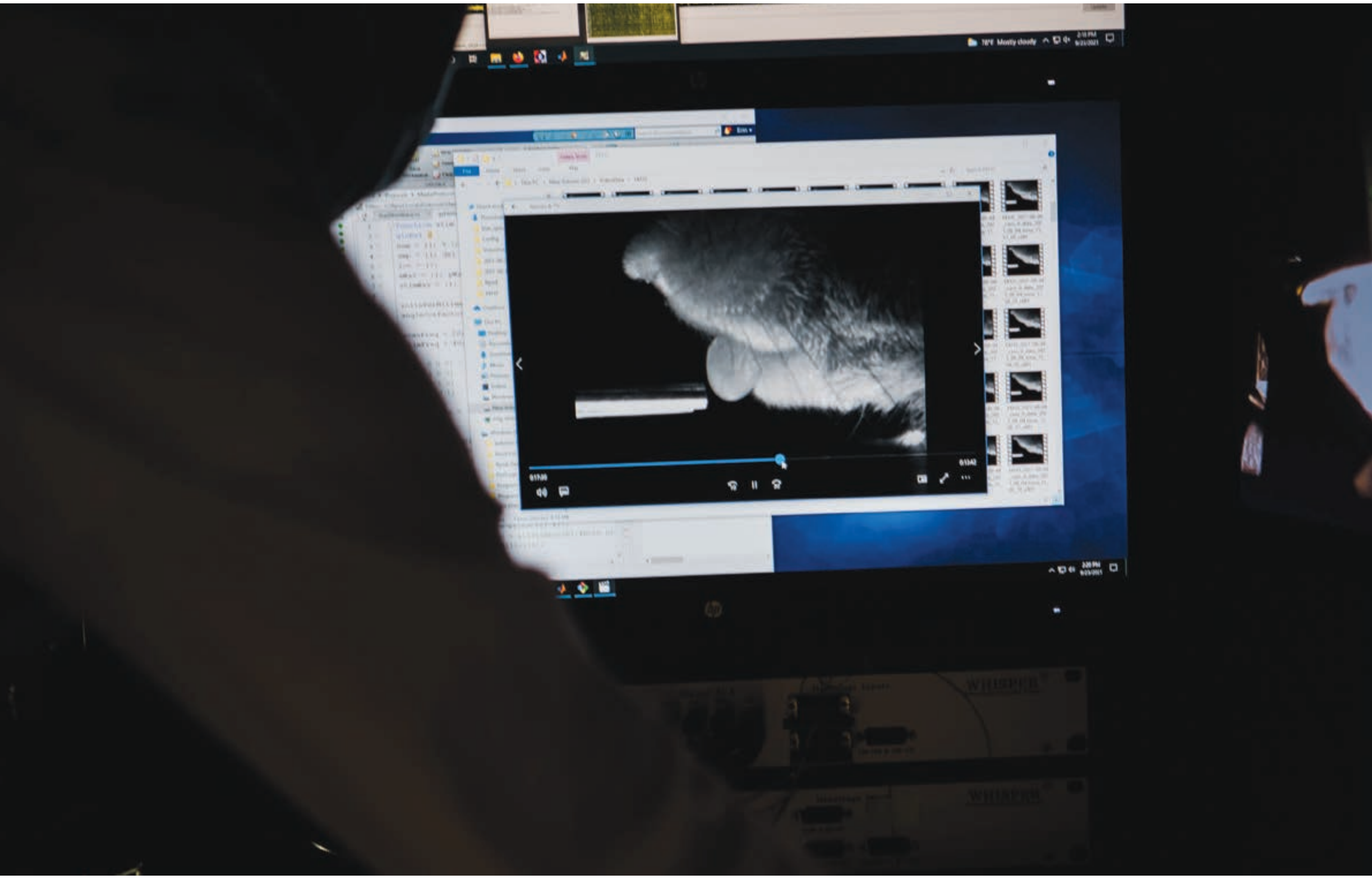
To best glean exactly which brain activity is linked to a specific behavior like licking, mice would preferentially not be moving their faces or bodies in any other way while electrodes are recording. “We would [ideally] train mice to move in specific ways at specific times, and also to be still during other times,” says Jaclyn Birnbaum, a third-year PhD candidate. But it’s rather difficult to ask a mouse to hold still.

“This is really pushing us to tackle a new level of complexity,” Economo says. “There are always postural movements happening, pervasive movements going on throughout the body, and these are reflected in strong, distributed activity that dominates neural signals all across the brain.”

Those movements and the brain activity linked the them have historically made it very difficult for researchers studying mice and other animals to determine which neural activity is linked to specific behaviors versus spontaneous movements.

To solve for this problem, researchers in the Economo Lab use high-speed video to capture the movements of mice in exquisite detail. As electrodes record what’s happening in the brain while mice lick water or perform other learned movements, the team is able to cross-reference moments of movement recorded on video with corresponding brain activity recorded via electrodes. “Using machine-vision-

“WE CAN RECORD WHICH NEURONS ARE ACTIVATED IN THE BRAIN, AT EXACTLY WHICH TIMES, ALL SIMULTANEOUSLY AT MULTIPLE POINTS THROUGHOUT THE BRAIN.” *– Michael Economo*



based video tracking of a mouse's body during behavior, we can automatically determine when and how animals move," Birnbaum says.

The combination of skill sets in the lab makes these types of advances possible. "About half our group is engineers, the other half neuroscientists," Economo says.

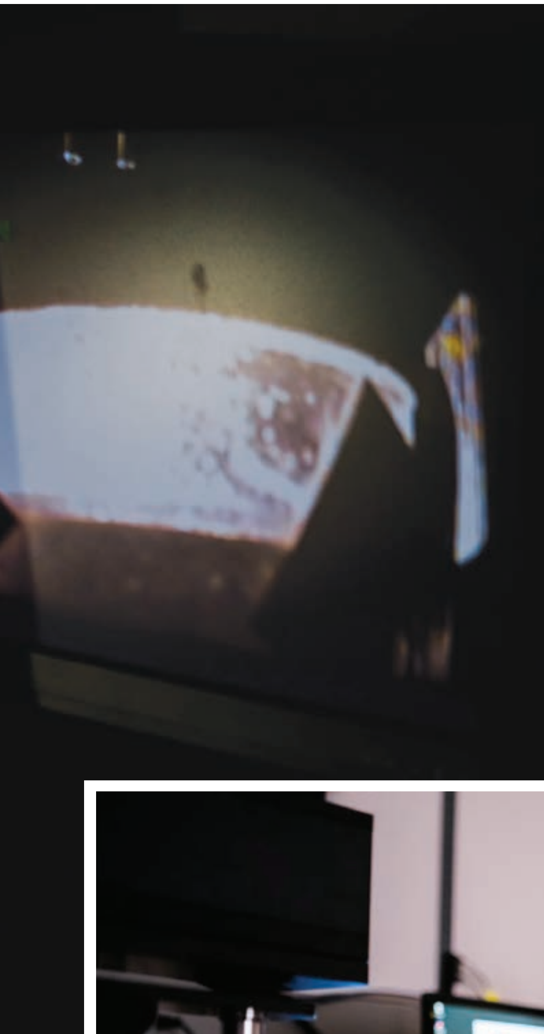
"Every day, we're learning new things in the lab," says Juan Luis Ugarte Nunez, a post-baccalaureate researcher. "Just yesterday, I learned more about coding [to control the water ports in the behavioral activity rig]. If you need help with any project you're working on, other members of the team are always willing to help."

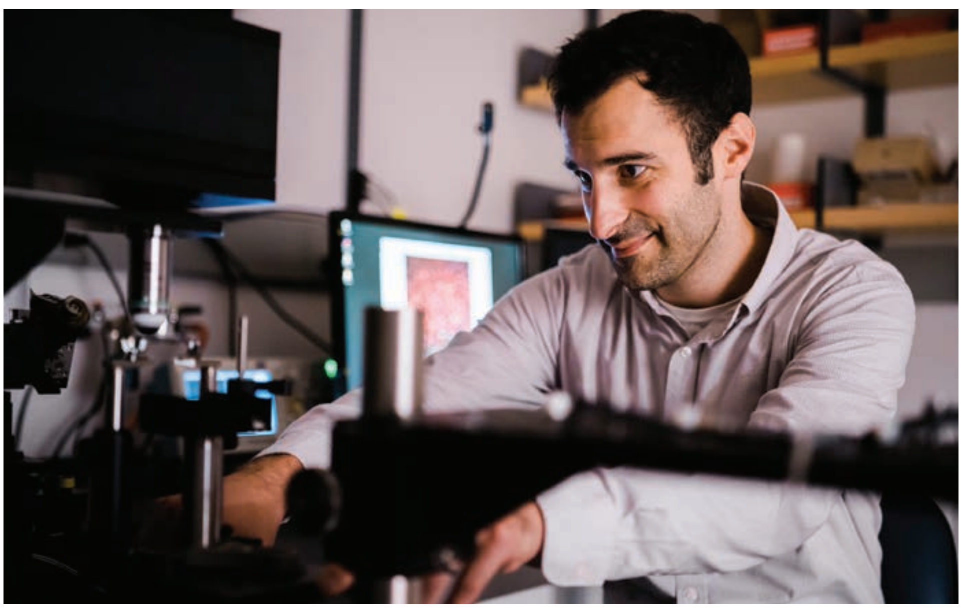
"Starting off in this lab, I didn't know anything about neuroscience," says Preshita Dave, who is pursuing her master's in bioinformatics. She's currently studying the brainstem, using single-cell RNA sequencing data to understand circuits responsible for facial movements at the molecular level. "With single-cell RNA sequencing, we're able to pick out individual cells and find out which genes are turned on and turned off."

"WITH SINGLE-CELL RNA SEQUENCING, WE'RE ABLE TO PICK OUT INDIVIDUAL CELLS AND FIND OUT WHICH GENES ARE TURNED ON AND TURNED OFF."

– Preshita Dave

She's using this approach to determine whether neural circuits in the brainstem are organized in a similar way to those in the spinal cord. "If we find that the same genes are turned on in the [brainstem] cells controlling facial movements as those in the spinal cord controlling limb and torso movements, that will help us understand if the same neural architectures are used for controlling different kinds of movements," Economo says.





of what's likely to happen when you step on it. You need to determine alternative movements and predict their consequences. Then you have to select the right one that's going to let you get across the ice without slipping and plan the precise sequence of muscle contractions that will allow you to make that movement. If you do start to slip, you brain needs to detect and correct for that slippage deftly."

"What brain circuits are responsible for canceling your planned movements?" Birnbaum says she wants to find out. She and other team members of Economo's lab are starting to develop a framework for studying how humans and animals plan, begin, and stop movements, out what's happening inside the brain."

Recently, Economo has partnered with Jerome Mertz within the Photonics Center to develop even more powerful tools for understanding brain activity. They're working on a microscope that's capable of imaging extremely fast changes in voltage, which is how neurons communicate with one another through electrical activity.

Their new system requires them to first genetically engineer mice so that their brain cells fluoresce when they are electrically active. Then, they can illuminate brain tissue with one color of light and measure how the fluorescence of individual neurons changes over time, which happens incredibly fast.

"We have to build an imaging system that can form an image about one thousand times per second in order to see the voltage changes in neurons that encode information," Economo says. "Using new techniques we developed, we can see spikes in electrical activity in specific cells, and see when lots of neurons are firing to better understand how they work together in circuits."

Economo is also excited about the recent addition of an advanced, super-resolution spinning disc confocal microscope, secured through teamwork with Tom Bifano to land a grant from the National Science Foundation—because it will help researchers in his group and their collaborators better understand the diversity of brain cells.

"Classically, we knew about four types of excitatory neurons in the brain, and four types of inhibitory cells. Now, sequencing and other technologies have revealed at least a hundred different types of cells behaving in specific ways in the brain," he says. ■

The team's research also seeks to understand how neural processes that control movements respond as situational context changes. "Normally, when you're walking down the sidewalk, it doesn't require a lot of mental effort. But on a winter day when the sidewalk is icy, your brain all of sudden has to do a lot of complicated things," Economo says. "Your visual system needs to recognize the sheen of ice. You need to have a mental model

just like someone might do if they're walking along an icy sidewalk and start to lose balance. They will create new behavioral tasks for lab mice and apply optogenetics—a technique that uses harmless pulses of laser-light to switch specific circuits in the brain on or off—to see how these circuits work.

"There are some hypotheses about this based on research in humans," Economo says. "But in humans, we don't have the same level of tools to test

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 Boston University, 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.

When faculty, staff, and students fully returned to campus in June 2021 after some time working from home time during covid, we were excited to host our summer ice cream truck in July and cookout in August outdoors. We also hosted several outings for staff at local area restaurants. Since our regular Photonics Cafes were put on hold because of covid, we hosted a number of outdoor coffee hours with faculty, staff, and students which allowed a great opportunity to reconnect our community. It was also great to reconnect and have an in-person holiday party with Photonics Center staff in room 906 at Photonics and celebrate the accomplishments and retirements of Photonics staff members Thomas Dudley and Anlee Krupp. Everyone thoroughly enjoyed connecting and celebrating the season.

PHOTONICS EVENTS AND SPEAKERS

Date	Speaker	Title
December 7, 2020	**OSA/SPIE BU Student Chapter Hosted Virtual Photonics Center Distinguished Lecture with Dr. Nimmi Ramanujam, Duke University**	"Shedding Light on Tissue Mechanopathology for Diagnostic Applications"
November 9, 2021	**Early Career Faculty Funding Virtual Workshop**	n/a
November 10, 2022	**Photonics Center Seminar with Dr. Phil Perconti, Former Army Chief Scientist**	"On Shifting from Basic & Applied to Convergent & Translational Research"
March 2022	**Recruiting Presentations at Department Open House**	"Photonics Center Graduate Student Trainee Opportunities"
April 7-8, 2022	**2022 Big Brain Imaging Workshop with Assistant Professor Jerry Chen**	n/a
June 9-10, 2022	**Green Action Expo Poster Session**	n/a

CELL-MET ERC EVENTS

Date	Event
November 2-3, 2021	**CELL-MET ERC Innovation Ecosystem Days (Hybrid: In-Person & Virtual)**
June 13-16, 2022	**CELL-MET ERC Annual NSF Site Visit (Hybrid: In-Person & Virtual)**

In addition, Photonics Center staff supported a Perfect Pitch competition, monthly Journal Clubs, monthly technical workshops, monthly Inclusion Thursday meetings, monthly professional development workshops for students and postdocs, monthly team calls, trainee socials, annual advisory board meetings, and various community outreach events on campus and at collaborating institutions and schools.

NEUROPHOTONICS EVENTS

The Photonics and Neurophotonics Centers continued to co-sponsor Neurophotonics/NRT seminars with a focus on Neurophotonics. Photonics Center staff played a role in planning and managing the following seminars and symposia and supported additional smaller events for the Neurophotonics Center.

Date	Speaker	Title
January 12, 2022	**Neurophotonics Center's 5th Annual Virtual Symposium**	n/a
March 16, 2022	**Virtual Neurophotonics NRT Seminar: Professor Alice Cronin-Golomb, Boston University**	"Vision, Perception, and Cognition in Parkinson's Disease"
May 27, 2021	**Virtual Neurophotonics, Photonics Center, and Biology Seminar: Professor Elly Nedivi**	"Mapping Synapses onto Individual L2/3 Pyramidal Neurons, Implications for Cortical 'Read out' of Visual Input"
June 3, 2021	**Virtual Neurophotonics NRT Seminar: Professor Emily Gibson**	"Understanding the Brain with Adaptive Optics"

Photo taken in Alice White's lab. Credit: Christopher McIntosh

Shared Facilities for Research

THE PHOTONICS CENTER is committed to supporting and promoting research infrastructure that provides advantages to its researchers. That commitment was realized in the past year through financial and technical staff support for the following:

- New faculty startup for research lab equipment and renovations, as well as routine laboratory upgrades and repairs.
- One-time building projects that leverage new opportunities or initiatives within the Photonics Center to enhance research productivity.
- Operation of major shared laboratory facilities and support by technical personnel to maintain those facilities and train students.
- Infrastructure and equipment grant proposal writing through a staff hire in August 2022 of a Senior Manager of Technical Programs, Hossein Alizadeh, PhD, who will collaborate with staff and faculty to prepare and submit proposals.

Shared Laboratory Facilities

The Photonics Center staffs and maintains four shared core equipment laboratories for its community. These shared facilities provide researchers with access to essential infrastructure for optics and photonics device fabrication and measurement. Faculty, staff, and student access to training and usage is unrestricted, and all operational costs, except for individual researcher supplies, are supported by Photonics Center's core budget. Shared facilities access is also available on a fee-for-use basis by current and former BIC companies, outside universities, and outside companies. A train the trainer model is utilized with graduate students becoming super-users each year and offering training and support in OPF and PML.

This summer in particular, the Lab Managers were involved in the novice skills CELL-MET research experience program.

Optoelectronic Processing Facility – The Optoelectronic Processing Facility (OPF) is a multi-user 2500 sq. ft. laboratory dedicated to fabrication of optoelectronic and photonic devices. The facility is housed in a cleanroom with processing and test equipment for die and wafer level thin film deposition, photolithography, wet and dry chemical processing, plasma etching and cleaning, metallization, thermal oxidation, thermal annealing, wire bonding, electrical characterization, test, and assembly. It is managed by Photonics Center Lab Manager Paul Mak.

The Precision Measurement Laboratory (PML) is dedicated to measurement and analysis of photonic components and to e-beam writing of nanoscale photonic structures. It consists of two laboratory spaces with equipment for field emission scanning electron microscopy, atomic force microscopy, surface mapping interferometry, and Fourier transform infrared spectroscopy, and scanning electron beam writing. Following the retirement of Lab Manager, Anlee Krupp this past year, we hired Rajendra Dulal, PhD as Lab Manager of PML, who joined us in April 2022.

The Focused Ion Beam/ Transmission Electron Microscope Facility (FTF) is dedicated to atomic-scale machining and characterization of material composition, image surface morphology, and micro/ nano machined materials. It consists of a laboratory with a focused ion beam tool and a transmission electron microscope, along with facilities for sample preparation and characterization. It is managed by Photonics Center Lab Manager Alexey Nikiforov.

The Materials Science Core Facility (MSCF) is dedicated to materials science characterization. It consists of processing hoods for materials preparation and equipment for X-ray crystallography micro computed tomography, atomic force microscopy, and Raman Microscopy. It is managed collectively by staff from the Photonics Center with support from the Materials Science and Engineering Division of the College of Engineering.

Scientific and Technical Themes

The Photonics Center research themes are:

- Imaging/Biosensing
- Neurophotonics
- Nanophotonics
- Photonic Materials and Devices
- Photonic Metamaterials

These research themes are not all-encompassing of our members' areas of interest, but they represent areas in which we have substantial activity and reputation, and in which we have made significant investments in research infrastructure through shared lab facilities and other infrastructural support.

The outcomes of research in these thematic areas have impact on society in applications including medical imaging systems, diagnostics, laser communication, chemical and biological material synthesis, laser system development, automation, and defense. In general, research at the Center focuses on practical uses of light-based technologies.

If/How Priorities and Strategic Goals Were Met this Year

Central to the Photonics Center strategic plan is an operational model where the Center functions as a University resource – promoting, supporting, and sustaining allied research centers and interdisciplinary programs across BU. The Center has been conducting business as an Institute, leading on several activities such as the BIC, managing and equipping shared laboratories, and administering/supporting major grants and supporting affiliated units.

Some of the affiliated units include the Materials Science and Engineering Division, the Neurophotonics Center, and most recently the CELL-MET ERC. With respect to the Materials Division, the Photonics Center has managed substantial renovations for the Materials Division and co-manages its shared facilities.

In support of its strategic goal of expanding core programs for research support, the Photonics Center provides strategic advice, critical review, management, and logistical support for large scale, complex collaborations proposed for external sponsorship, including research and educational projects. Major successes were the award of the NRT grant on Understanding the Brain (UtB) in FY17, and the award of the CELL-MET ERC in FY18. The support continues post-award with project administration and assistance on compliance matters from sponsor and University perspectives. The Photonics Center provides outsized support for the CELL-MET ERC, assuming leadership roles in Administration, Innovation Ecosystems, and in one of the four Research Thrusts. The Photonics Center is also taking on the implementation and management of the new multi-institutional NIH U19: Local Neuronal Drive and Neuromodulatory Control of Activity in the Pial Neurovascular Circuit. This was awarded to Professor Anna Devor as PI through the NIH BRAIN Initiative.

The resources and expertise of the Photonics Center staff are employed to manage several training grants that include RET, REU, and NRT grants. In addition, the Center also supports major faculty-awarded grants such as the Department of Defense supported Multi-Scale Multi-Disciplinary Modeling of Electronic Materials (MSME). MSME involves close collaborations with the ARL's research scientist at the Sensors and Electronic Devices Directorate and interactions with ARL's Enterprise for Multiscale Research of Materials.

At the BIC, Photonics Center staff are implementing strategic priorities that align the Center more closely with ongoing faculty member research and educational activities. Placing an emphasis on translational research, BIC has added three companies in the past year. Additionally, BIC now has three strategic partners that have the resources to exploit photonics technologies anchor our educational, innovation, and technology transfer efforts.

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FACULTY AWARDS

- Associate Professor *Keith Brown* was awarded tenure and promotion to the rank of Associate Professor in the Department of Mechanical Engineering, and he received the 2021 Early Career Research Excellence Award from the BU College of Engineering.
- Assistant Professor *Maria Kamenetska* was named the Scialog Chemical Machinery of the Cell Fellow from the Research Corporation for Science Advancement.
- Assistant Professor *Abdoulaye Ndao* was named a 2021 Global Rising Star of Light by the Nature journal Light Science and Applications; and he was given the 2021 Reidy Family Career Development Professor by the BU College of Engineering.
- Professor *Selim Unlu* was awarded BU's 2021 Innovator of the Year.
- Associate Professor *Alexander Sushkov* was awarded tenure and promotion to the rank of Associate Professor in the Department of Physics, and he received the 2021 NSF CAREER award from the National Science Foundation.
- Assistant Professor *Lei Tian* earned the 2021 Early Career Excellence in Research from the BU College of Engineering.

Photo taken in Anna Devor's lab. Credit: Christopher McIntosh

- Associate Professor *Brian Walsh* was awarded tenure and promotion to the rank of Associate Professor in the Department of Mechanical Engineering.
- Professor *Xin Zhang* was awarded a 2022 Guggenheim Fellowship.
- Professor *Lawrence Ziegler* earned the 2021 Society for Applied Spectroscopy Fellow Award.

PATENTS [3]

Ramachandran, S., Lu, Y., & Kristensen, P., (2021, July 30), CN1095643525 B, *Optical imaging system employing vortex optical fibers for multimode illumination*

Chen, C., Subramanian, S., Michas, C., **White, A.**, & **Bishop, D.**, (2021, August 8), 11,084,215 B2, *Systems and methods for fabricating three-dimensional conductive electrodes*

Klapperich, C., Rodriguez, N. M., & Linnes, J. (2021, October 5), 11,136,620, *Detection device having capture region and detection region*

Ünlü, S., Yurdakul, C., & Marn, A., (2021, October 5), 11,137,343, *Apparatus and method for biomolecular analysis*

Zhang, X., Anderson, S., Zhao, X., & Duan, G., (2022, January 11), 11,219,384 B2, *Nonlinear and smart metamaterials useful to change resonance frequencies*

Mertz, J., Beaulieu, D., & **Bifano, T.**, (2022, January 18), 11,226,474 B2, *Reverberation microscopy systems and methods*

Cheng, J., & Lin, H., (2022, February 1), 11,237,111 B2, *High-speed delay scanning and deep learning techniques for spectroscopic SRS*

Paiella, R., & Kogos, L., (2022, February 22), 11,257,856 B2, *Lens-free compound eye cameras*

Ünlü, S., Bergstein, D., **Ruane, M.**, & **Goldberg, B.**, (2022, March 15), 11,275,030 B2, *Structured substrates for optical surface profiling*

Bishop, D., Barrett, L., and Forrest, S., (2022, April 5), *Microelectromechanical shutters for organic vapor jet printing*

Dal Negro, L., Lenef, A., Raukas, m., Gorsky, S., & Zhang, R., (2022, April 5), 11,294,195 B2, *Aperiodic nano-optical array for angular shaping of incoherent emissions*

[3] Patents are reported for the University Fiscal Year, July 1, 2021 – June 30, 2022.

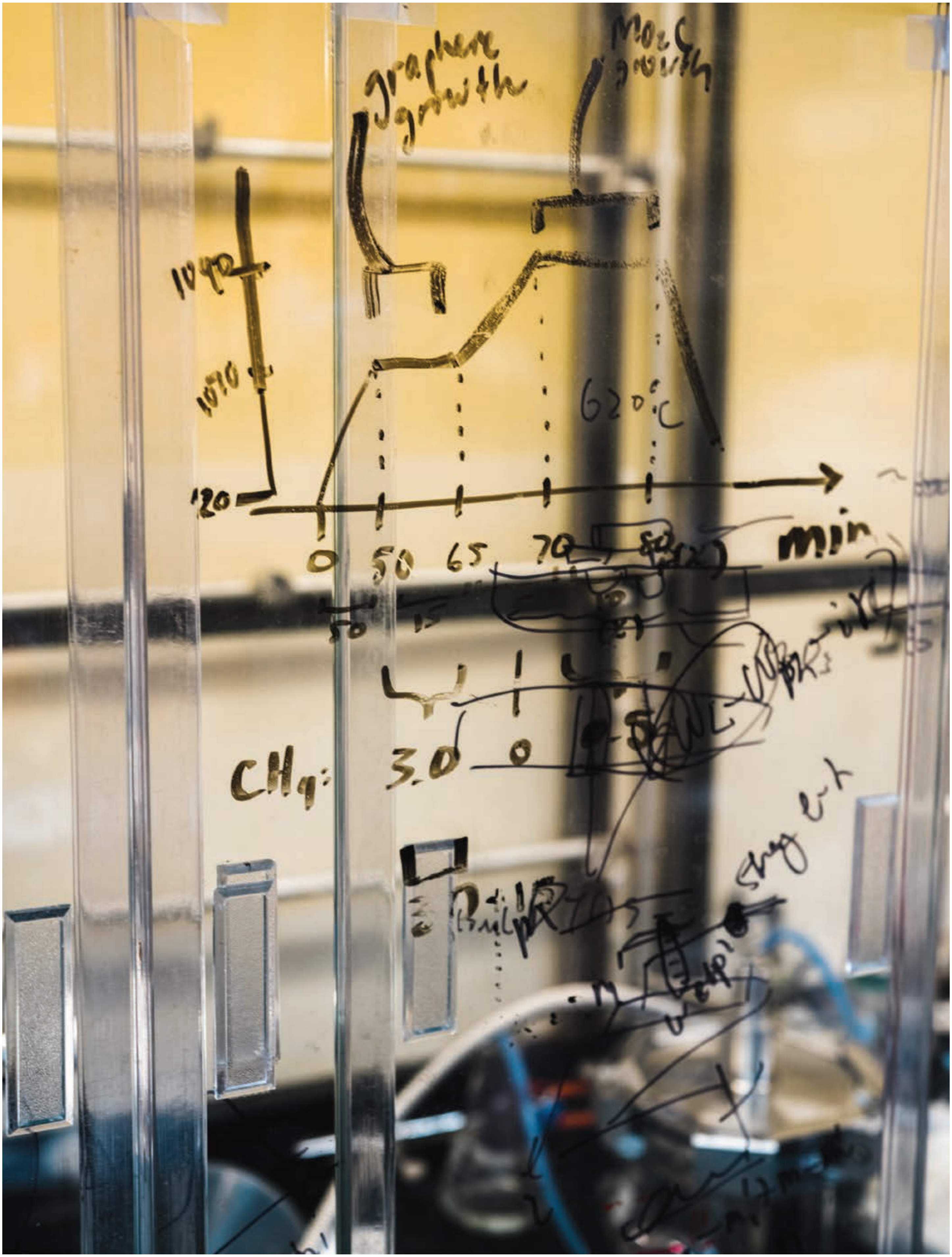

Photo taken in Xi Ling's lab. Credit: Christopher McIntosh

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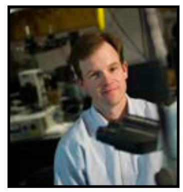

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617-358-0253
xiling@bu.edu

Research interests:
- Nanomaterials and their hybrid structures
- Synthesis of van der Waals materials

Jerome Mertz
Professor, BME, ECE, Physics

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

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

Aboudlaye Ndao
Assistant Professor, ECE

8 St. Mary's St., 725
617-353-3251
andao@bu.edu

Research interests:
- Prototype device development

Roberto Paiella
Professor, ECE, MSE

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

Research interests:
- Terahertz photonics

Milos Popovic
Associate Professor, ECE

8 St. Mary's St., 726
617-358-6188
mpopovic@bu.edu

Research interests:
- Silicon photonics

Siddharth Ramachandran
Professor, ECE, MSE, Physics

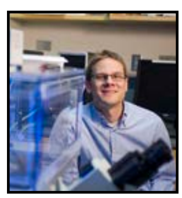
8 St. Mary's St., 521
617-353-9881
sidr@bu.edu

Research interests:
- Micro and nano optical fibers

Steve Ramirez
Assistant Professor, Psychological & Brain Sciences

610 Commonwealth Ave., 905C
617-358-1554
dvsteve@bu.edu

Research interests:
- Memory and Optogenetics



Bjoern Reinhard
Professor, Chemistry

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

Research interests:
- Micro and nano optical fibers

Darren Roblyer
Associate Professor, BME

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

Research interests:
- Diffuse optics
- Therapies in oncology

Michelle Sander
Associate Professor, ECE, MSE

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

Research interests:
- Femtosecond lasers

Ben Scott
Assistant Professor, Psychological & Brain Sciences

610 Commonwealth Ave., 705C
617-353-7682
bbs@bu.edu

Research interests:
- Neural Dynamics
- Optical Imaging

Joshua Semeter
Professor, ECE

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

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

Alexander Sushkov
Associate Professor, Physics, ECE

590 Comm. Ave, 213
617-353-2619
asu@bu.edu

Research interests:
• Quantum tools for precision measurements
• Magnetic imaging

Selim Ünlü
Professor, ECE, BME, MSE

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

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

John White
Professor, BME

44 Cummington Mall, 403
617-353-2805
jwhite@bu.edu

Research interests:
• Mechanisms of episodic memory
• Pathophysiology of epilepsy
• Computational neuroscience

Alexander Sergienko
Professor, ECE

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

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

Anna Swan
Associate Professor, ECE, MSE, Physics

8 St. Mary's St., 828
617-353-1275
swan@bu.edu

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

Brian Walsh
Associate Professor, ME, ECE

110 Cummington Mall, 303
617-353-3414
bwalsh@bu.edu

Research interests:
• Space plasma dynamics
• Solar wind-planetary coupling
• Small spacecraft

Chen Yang
Associate Professor, Chemistry, ECE

8 Saint Mary's St., 829
617-358-4837
cheyang@bu.edu

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

Andre Sharon
Professor, ME, MSE

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

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

Lei Tian
Assistant Professor, ECE

8 St. Mary's St., 830
617-353-1334
leitian@bu.edu

Research interests:
• Computational imaging and sensing
• Gigapixel 3D microscopy
• Compressive imaging

Alice White
Professor, ME, MSE, BME, Physics

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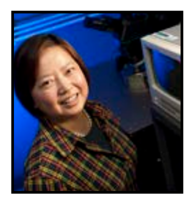
aew1@bu.edu

Research interests:
• Nanoscale 3D printing
• Mechanical metamaterials



Xin Zhang
Professor, ME, MSE, ECE, BME

8 St. Mary's St., 921
617-353-2702
xinz@bu.edu

Research interests:
• Micro nanomaterials
• Micro nanomechanics

Lawrence Ziegler
Professor, Chemistry

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

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

FACULTY COMMITTEES

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

Photonics Center Guest Speakers: 2021-2022 Chair – Anup Tank
The Distinguished Speaker Seminar Series is managed by student leaders of the BU student chapters of the OSA and SPIE. With support by the Photonics Center for travel and seminar expenses, students host a distinguished speaker of their choice each semester.

Academic Advisory: 2021-2022 Chair – Professor 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: 2021-2022 Chair – Professor Thomas Bifano
This committee chair generates policy guidelines for space management.

Symposium: 2021-2022 Chair – Postponed Due to COVID-19 Pandemic
The Photonics Center Symposium was postponed due to COVID-19. The next symposium will be held as an in-person event on December 1, 2022, chaired by Professor Luca Dal Negro.

Education Committee: 2021-2022 Chair – Professor Ji-Xin Cheng
This committee will focus on the recruitment of graduate students with a particular interest in photonics or optics to graduate programs in the Photonics Center's cognate departments, as well community building and applying for training grants and fellowships for graduate students. Faculty members on the committee are Darren Roblyer and Bjoern Reinhard and staff members are Cara Ellis McCarthy, Beth Mathisen, and Brenda Hugot.

Photonics Center Membership: Professors Emeriti

Bennett Goldberg
Professor Emeritus, Physics

goldberg@bu.edu

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

Allyn Hubbard
Professor Emeritus, ECE

aeh@bu.edu

Research interests:
- Auditory physiology
- Neurocomputing and biosensors

Theodore Morse
Professor Emeritus, ECE

tfmorse@bu.edu

Research interests:
- Photonic material processing

Theodore Moustakas
Professor Emeritus, ECE, MSE, Physics

tdm@bu.edu

Research interests:
- Amorphous semiconductors

Kenneth Rothschild
Professor Emeritus, Physics

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

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

Michael Ruane
Professor Emeritus, ECE

mfr@bu.edu

Research interests:
- Resonant cavity biosensors

Malvin Teich
Professor Emeritus, ECE, BME, Physics

teich@bu.edu

Research interests:
- Quantum photonics
- Neural coding

Barry Unger
Professor Emeritus, MET

unger@bu.edu

Research interests:
- High technology
- Venture capital businesses

Photonics Center PhD Students and their Dissertation Titles

Photonics Center Faculty Member	Academic Year 2021-2022 Ph.D. Graduates and Dissertation Titles
Soumendra Basu	**Zhikuan Zhu** *"Mitigation of Chromium Poisoning on Solid Oxide Fuel Cell Cathodes"*
Enrico Bellotti	**Ilya Prigozhin** *"Advanced Numerical Modeling of Avalanche Infrared Photodetectors"*
David Boas	**Smrithi Sunil** *"Wide-Field Optical Imaging of Neurovascular Coupling during Stroke Recovery"*
Jerry Chen	**Cameron James Condylis** *"Cell Type-Specific Encoding and Routing of Sensory Information in Mouse Primary Somatosensory Cortex during Behavior"*
Xue Han	**Sanaya Ness Shroff** *"Optimization and Application of a High- Performance Genetically-Encoded Fluorescent Sensor for Membrane Voltage Imaging"* **Dana Zemel** *"Pathological Neural Circuit States of the Dorsal Striatum in Parkinson's Disease"*
Ajay Joshi	**Furkan Eris** *"Leveraging Machine Learning for Hardware Design and Optimization"*
Ajay Joshi	**Sadulla Canakci** *"Directing Greybox Fuzzing to Discover Bugs in Hardware and Software"*
Catherine Klapperich	**Justin Michael Rosenbohm** *"Qualitative and Semiquantitative Isothermal Detection of Nucleic Acids for Point-of-Care Testing Applications"*
Milos Popovic	**Josep Fargas Cabanillas** *"Rapid Adiabatic Devices Enabling Integrated Electronic-Photonic Quantum Systems on Chip"* **Hayk Gevorgyan** *"Sensitive Electro-Optic Signal Transducers and Modulators in Silicon CMOS Photonics"*
Bjoern Reinhard	**Xingda An** *"Nanoplasmonics: Properties and Applications in Photocatalysis, Antimicrobials and Surface-Enhanced Raman Spectroscopy"* **Behnaz Eshaghi** *"HIV-1 Mimicking Lipid-Coated Polymer Nanoparticles: Fundamentals and Applications"* **Sandy Zhang** *"Gold Nanoparticles as Probes in Epidermal Growth Factor Receptor Clustering and Second Messenger Mediated Activation"*
Michelle Sander	**Junjie Zeng** *"Real-Time Characterization of Transient Dynamics in Thulium-doped Mode-Locked Fiber Laser"*
Alexander Sushkov	**Eric Boyers** *"Prospects for Spin Squeezing in Nuclear Magnetic Resonance Dark Matter Searches"*
Anna Swan	**Zhuofa Chen** *"Characterizing and Evaluating 2D Material Properties Using Spectroscopic Methods and Machine Learning"*
Lei Tian	**Yujia Xue** "*Computational Miniature Mesoscope for Large-Scale 3D Fluorescence Imaging"*
Selim Unlu	**Elisa Chiodi** *"Dynamic Characterization of Multi-Scale Analytes by Real Time Interferometric Imaging"*
John White	**Jad Noueihed Noueihed** *"Unsupervised Tracking and Automated Analysis of Multi-Population Neural Activity under Anesthesia"*
John White & Steve Ramirez	**Bahar Rahsepar** *"Novel Strategies for the Modulation and Investigation of Memories in the Hippocampus"*
Xin Zhang	**Chunxu Chen** *"Integrating Microsystems with Metamaterials Towards THZ and Infrared Metadevices"*
Lawrence Ziegler	**Matthew Rotondaro** *"Nonlinear Optical Spectroscopic Studies of Dense Gases, Supercritical Fluid Solutions, and Self-Assembled Monolayer Interfaces"*

Leadership & Staff

Dr. Thomas Bifano
Center Director
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617-353-8908
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Yvonne Cancino
Building Operations Manager (transferred October 2021)
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Akeem Chambers
Administrative Coordinator, ERC
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Thomas Dudley
Director of Industry Engagement (retired 2021)
8 St. Mary's St., 929
617-358-4924
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Rajendra Dulal
Laboratory Manager (joined April 2022)
8 Saint Mary's St., 909A
617-353-9044
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Helen Fawcett
Director of Operations & Program Management (resigned May 2022)
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Rana Gupta
Director, Business Innovation Center (joined January 2022)
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Brenda Hugot
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Nozomi Ito
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Cynthia Kowal
Senior Proposal Development Administrator (retired 2022)
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Anlee Krupp
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8 Saint Mary's St., 910A
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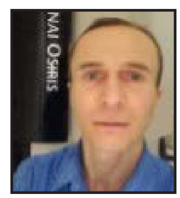

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Sandra Rodegher
Program Manager, ERC
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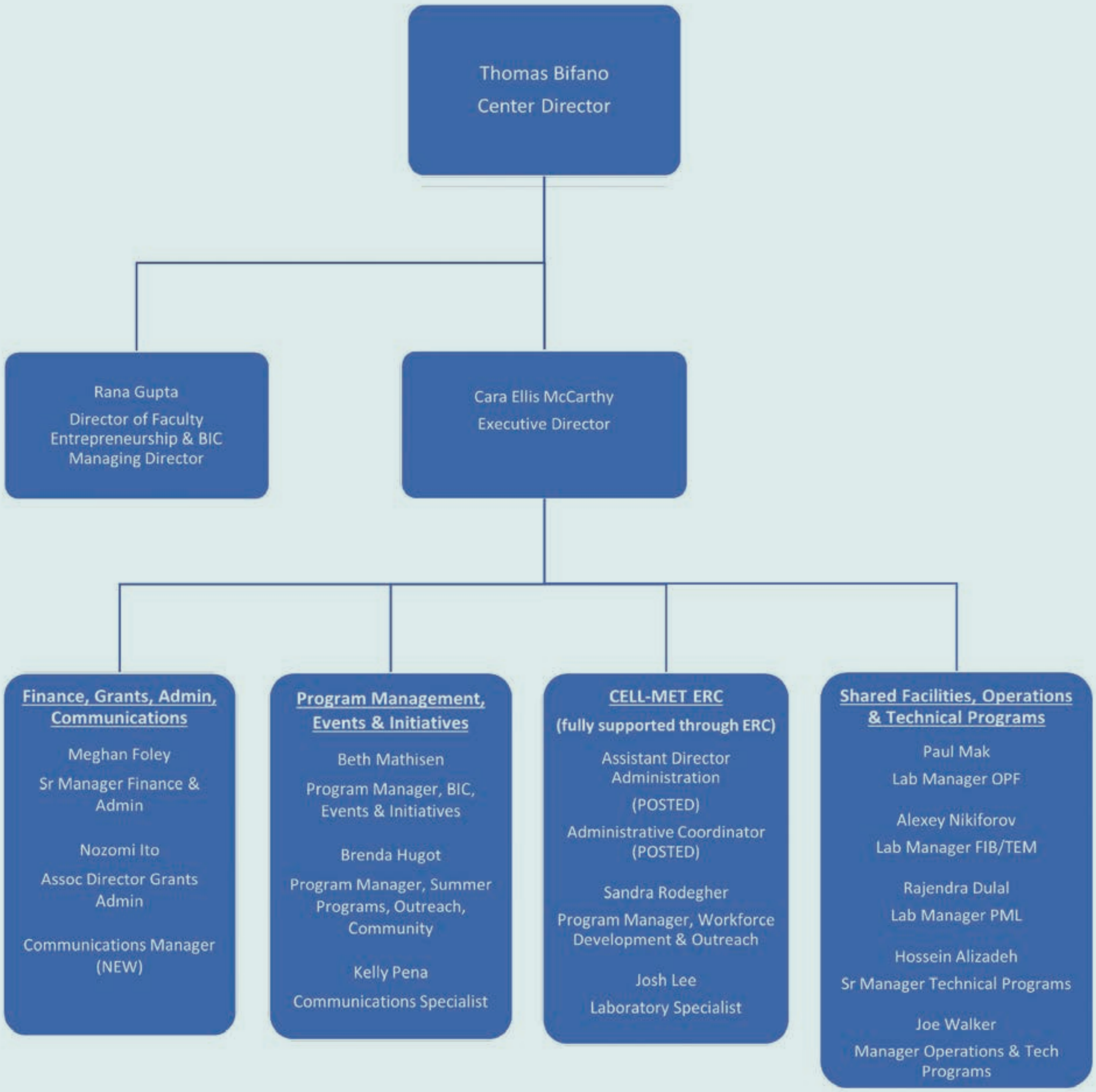
STAFF RETIREMENT

Senior Proposal Development Administrator **Cynthia Kowal** retired in August, 2022. Following a 20+ career in the central Sponsored Programs Office at BU, Cynthia joined the Photonics Center in April 2016. Cynthia supported Photonics Center pre-award proposal development, working closely with faculty and staff to prepare and submit proposals to provide expert advice. She was a member of the CELL-MET ERC Operations Team and Budget Committee and played an instrumental role in the proposal submission, annual budgeting, compliance, and supplemental programs for the ERC. In her role, she also provided faculty with advice on responsiveness to federal and private funding solicitations, sponsor culture, best practices of proposal development and post-award project administration, and compliance matters from sponsor and University perspectives. We appreciate her contributions to the Photonics Center.

She is retiring to spend more time with family and to pursue hobbies such as painting and gardening.

Organizational Chart



Sponsored Research Awards, Proposals, and Expenditures and Sources of Funding

LIST OF CURRENT GRANTS AWARDED IN FY22 (total: $45.76M)

Photonics faculty members received $45.76M in external funding. The following table lists funds in the fiscal year (July 1, 2021 – June 30, 2022), as reported by the BU Sponsored Programs office. Grants shaded in blue represent grants which were led by the Photonics Center, and grants shaded in yellow represent grants which were catalyzed by the Photonics Center.

AWARD TITLE (FULL)	PI	SPONSOR	PROJECT START DATE	PROJECT END DATE	ADDITIONAL FUNDS THIS BUDGET PERIOD (TOTAL OBLIGATED)*
A BIO-INSPIRED LATENT TGF-BETA CONJUGATED SCAFFOLD FOR PATIENT-SPECIFIC CARTILAGE REGENERATION	ALBRO MICHAEL	NIH/National Institute of Arthritis & Mu	06/01/2022	05/31/2027	478,735.00
MECHANOBIOLOGICAL ACTIVATION OF LATENT TGF-BETA IN INTRINSIC REPAIR OF MUSCULOSKELETAL TISSUES MECHANOBIOLOGICAL ACTIVATION OF LATENT TGF-BETA IN INTRINSIC REPAIR OF MUSCULOSKELETAL TISSUES	ALBRO MICHAEL	National Science Foundation	07/01/2019	06/30/2022	16,000.00
PHASE I: DEMONSTRATION OF CONFORMAL OXIDATION RESISTANCE COATINGS DEPOSITED BY ELECTROPHORETIC DEPOSITION ON DENSE AND POROUS SUBSTRATES	BASU N SOUMENDRA	Nissan North America Inc.	03/23/2020	08/31/2023	10,000.00
CLARE BOOTHE LUCE GRADUATE FELLOWSHIP FOR JILLIAN RIX	BASU N SOUMENDRA	The Henry Luce Foundation, Inc.	09/01/2020	08/31/2022	15,064.00
CLARE BOOTHE LUCE GRADUATE FELLOWSHIP FOR JILLIAN RIX	BASU N SOUMENDRA	The Henry Luce Foundation, Inc.	09/01/2020	08/31/2022	48,233.00
CRA: COMPUTATIONALLY-GUIDED DESIGN OF ENERGY EFFICIENT ELECTRONIC MATERIALS (CDE3M)	BELLOTTI ENRICO	University of Utah	01/01/2014	04/01/2022	17,820.00
CENTER FOR SEMICONDUCTOR MODELLING	BELLOTTI ENRICO	Department of Defense/ ARL	09/01/2017	11/30/2022	630,000.00
CENTER FOR SEMICONDUCTOR MODELLING	BELLOTTI ENRICO	Department of Defense/ ARL	09/01/2017	11/30/2022	75,000.00
FIELD EMITTER ROBUST VACUUM INTEGRATED NANOELECTRONICS (FERVIN)	BELLOTTI ENRICO	Florida International University	07/15/2019	02/14/2024	129,821.00
ACCELERATED RESPONSE SEMICONDUCTING CONTACTORS AND SURGE ATTENUATION FOR DC ELECTRICAL SYSTEMS (ARC-SAFE)	BELLOTTI ENRICO	Sandia National Laboratories	11/09/2021	02/09/2023	180,000.00
DETECTOR DEVICE MODELING AND SIMULATION SERVICES	BELLOTTI ENRICO	DRS Network & Imaging Systems, LLC	06/29/2020	01/15/2022	37,747.89
DARPA/HRL FOCII PROGRAM PHASE II	BELLOTTI ENRICO	HRL Laboratories, LLC	08/24/2021	11/30/2022	62,000.00
DARPA/HRL FOCII PROGRAM PHASE II	BELLOTTI ENRICO	HRL Laboratories, LLC	08/24/2021	11/30/2022	63,000.00

AWARD TITLE (FULL)	PI	SPONSOR	PROJECT START DATE	PROJECT END DATE	ADDITIONAL FUNDS THIS BUDGET PERIOD (TOTAL OBLIGATED)*
OPTIMIZATION AND VALIDATION OF QUANTITATIVE BIREFRINGENCE MICROSCOPY FOR ASSESSMENT OF MYELIN PATHOLOGIES ASSOCIATED WITH COGNITIVE IMPAIRMENTS AND MOTOR DEFICITS IN YOUNG AND OLD AGING MONKEY BRAIN	BIGIO J IRVING	NIH/National Institute on Aging	01/01/2022	11/30/2026	569,055.00
VALIDATION OF LIGHT SCATTERING SPECTROSCOPY FOR INTRA-OPERATIVE MARGIN GUIDANCE DURING ORAL CANCER RESECTION	BIGIO J IRVING	Boston Medical Center Corporation	07/07/2020	06/30/2025	180,322.00
PERSONNEL AGREEMENT FOR RESEARCH SERVICES OF A'AMAR OUSAMA	BIGIO J IRVING	VA Boston Healthcare System	07/01/2021	08/31/2021	24,272.00
NANOSYSTEMS ENGINEERING RESEARCH CENTER FOR DIRECTED MULTISCALE ASSEMBLY OF CELLULAR METAMATERIALS WITH NANOSCALE PRECISION: CELL-MET	BISHOP DAVID	National Science Foundation	10/01/2017	09/30/2022	4,250,000.00
NANOSYSTEMS ENGINEERING RESEARCH CENTER FOR DIRECTED MULTISCALE ASSEMBLY OF CELLULAR METAMATERIALS WITH NANOSCALE PRECISION: CELL-MET	BISHOP DAVID	National Science Foundation	10/01/2017	09/30/2022	110,000.00
INTERPOSER TECHNOLOGIES FOR QUANTUM COMPUTING	BISHOP DAVID	IBM	11/15/2021	07/15/2023	200,000.00
THE NEUROSCIENCE OF EVERYDAY WORLD- A NOVEL WEARABLE SYSTEM FOR CONTINUOUS MEASUREMENT OF BRAIN FUNCTION	BOAS DAVID	NIH/National Institute of Biomedical Ima	09/22/2020	05/31/2025	164,734.00
THE NEUROSCIENCE OF EVERYDAY WORLD- A NOVEL WEARABLE SYSTEM FOR CONTINUOUS MEASUREMENT OF BRAIN FUNCTION	BOAS DAVID	NIH/National Institute of Biomedical Ima	09/22/2020	05/31/2025	1,208,495.00
THE NEUROSCIENCE OF EVERYDAY WORLD- A NOVEL WEARABLE SYSTEM FOR CONTINUOUS MEASUREMENT OF BRAIN FUNCTION	BOAS DAVID	NIH/National Institute of Biomedical Ima	09/22/2020	05/31/2025	1,358,265.00
THE IMPACT OF MICROVASCULAR (DYS)REGULATION ON CEREBRAL FLOW AND OXYGEN HETEROGENEITY	BOAS DAVID	NIH/National Institute of Neurological D	09/01/2018	05/31/2023	620,265.00
IMAGING AND ANALYSIS TECHNIQUES TO CONSTRUCT A CELL CENSUS ATLAS OF THE HUMAN BRAIN	BOAS DAVID	Massachusetts General Hospital	08/22/2018	05/31/2023	295,122.00
MULTISPECTRAL AND HYPERSPECTRAL PRECLINICAL IMAGER SPANNING THE VISIBLE, NIR-I AND NIR-II	BOAS DAVID	NIH/Office of the Director	09/01/2021	08/31/2022	404,300.00
TIME-GATED DIFFUSE CORRELATION SPECTROSCOPY FOR FUNCTIONAL IMAGING OF THE HUMAN BRAIN	BOAS DAVID	Massachusetts General Hospital	09/21/2019	06/30/2024	125,795.00

AWARD TITLE (FULL)	PI	SPONSOR	PROJECT START DATE	PROJECT END DATE	ADDITIONAL FUNDS THIS BUDGET PERIOD (TOTAL OBLIGATED)*
COMPARING LASER SPECKLE CONTRACT AND DIFFUSE CORRELATION SPECTROSCOPY MEASUREMENTS IN HUMAN BRAIN FUNCTION	BOAS DAVID	Facebook Technologies, LLC	04/20/2021	02/22/2022	23,000.00
DESIGN OF HELMET PAD STRUCTURES USING AUTONOMOUS EXPERIMENTAL RESEARCH	BROWN KEITH	Department of Defense/ Natick Soldier Res	05/13/2020	05/12/2023	75,000.00
DESIGN OF HELMET PAD STRUCTURES USING AUTONOMOUS EXPERIMENTAL RESEARCH	BROWN KEITH	Department of Defense/ Natick Soldier Res	05/13/2020	05/12/2023	65,000.00
CRACKING GENETICALLY DEFINED NEOCORTICAL CIRCUITS ACROSS LEARNING AND BEHAVIOR	CHEN JERRY	NIH/National Institute of Neurological D	09/30/2018	05/31/2023	62,698.00
UNVEILING THE MECHANISMS OF ULTRASOUND NEUROMODULATION VIA SPATIALLY CONFINED STIMULATION AND TEMPORALLY RESOLVED RECORDING	CHENG JI-XIN	NIH/National Institute of Neurological D	09/30/2018	06/30/2023	151,961.00
UNVEILING THE MECHANISMS OF ULTRASOUND NEUROMODULATION VIA SPATIALLY CONFINED STIMULATION AND TEMPORALLY RESOLVED RECORDING	CHENG JI-XIN	NIH/National Institute of Neurological D	09/30/2018	06/30/2023	654,740.00
SENSING VULNERABLE PLAQUE IN VIVO BY AN ALL-OPTICAL INTRAVASCULAR ULTRASOUND AND PHOTOACOUSTIC CATHETER	CHENG JI-XIN	NIH/National Heart, Lung, and Blood Inst	09/01/2020	08/31/2024	634,489.00
METABOLIC ASSESSMENT OF ANTI-MICROBIAL SUSCEPTIBILITY WITHIN ONE CELL CYCLE	CHENG JI-XIN	NIH/National Institute of Allergy & Infe	12/01/2018	11/30/2022	518,480.00
HIGH-CONTENT HIGH-SPEED CHEMICAL IMAGING OF METABOLIC REPROGRAMMING BY INTEGRATION OF ADVANCED INSTRUMENTATION AND DATA SCIENCE	CHENG JI-XIN	NIH/National Institute of Biomedical Ima	04/01/2022	12/31/2025	459,171.00
HIGH-CONTENT HIGH-SPEED CHEMICAL IMAGING OF METABOLIC REPROGRAMMING BY INTEGRATION OF ADVANCED INSTRUMENTATION AND DATA SCIENCE	CHENG JI-XIN	NIH/National Institute of Biomedical Ima	04/01/2022	12/31/2025	61,222.00
MAPPING CANCER METABOLISM BY MID-INFRARED PHOTOTHERMAL MICROSCOPY	CHENG JI-XIN	NIH/National Cancer Institute	09/20/2021	08/31/2024	398,440.00
TARGETING LIPID UNSATURATION IN OVARIAN CANCER STEM CELLS	CHENG JI-XIN	Northwestern University	08/01/2018	07/31/2023	173,600.00
AN INFRARED PHOTOTHERMAL PHASE MICROSCOPE FOR HIGH-RESOLUTION CHEMICAL IMAGING IN FINGERPRINT REGION	CHENG JI-XIN	Leonardo DRS Daylight Solutions	10/01/2019	09/30/2022	216,972.00
IMAGING BREAST TUMOR BY A COMPACT SRS MICROSCOPE	CHENG JI-XIN	Hologic, Inc.	11/15/2021	04/30/2023	300,000.00
ADVANCEMENT OF A POXVIRUS INHIBITOR	CONNOR H JOHN	NIH/National Institute of Allergy & Infe	03/12/2020	02/28/2025	593,447.00

AWARD TITLE (FULL)	PI	SPONSOR	PROJECT START DATE	PROJECT END DATE	ADDITIONAL FUNDS THIS BUDGET PERIOD (TOTAL OBLIGATED)*
DETERMINANTS OF COVID19-INDUCED VENOUS THROMBOSIS AND TARGETED THERAPY ASSESSED WITH BIOENGINEERED VEIN-CHIP	CONNOR H JOHN	NIH/National Heart, Lung, and Blood Inst	05/01/2021	04/30/2025	665,322.00
DEVELOPMENT OF A RVSV VECTORED VACCINE FOR LASSA VIRUS: NONHUMAN PRIMATE EFFICACY AND IMMUNOGENICITY STUDIES	CONNOR H JOHN	University of Texas Medical Branch at Ga	09/01/2021	08/31/2022	423,390.00
CULTURE OF SARS-COV-2 VARIANTS OF INTEREST FROM THE MASSACHUSETTS REGION	CONNOR H JOHN	President & Fellows of Harvard College o	10/01/2021	09/30/2022	178,250.00
GEOSENTINEL THE GLOBAL SURVEILLANCE NETWORK OF ISTM AND CDC	CONNOR H JOHN	International Society of Travel Medicine	05/01/2022	04/30/2023	120,540.00
DEEP SEQUENCING OF PATHOGENS TO PRECISELY DEFINE TRANSMISSION NETWORKS USING RARE VARIANTS	CONNOR H JOHN	President and Fellows of Harvard College	06/01/2021	05/31/2022	110,731.00
MODULAR POINT-OF-CARE PLATFORM FOR DIFFERENTIAL DIAGNOSIS OF VIRAL HEMORRHAGIC FEVERS	CONNOR H JOHN	RedBud Labs	02/14/2022	06/01/2022	80,342.00
COLLABORATIVE RESEARCH: ENGINEERING FRACTIONAL PHOTON TRANSPORT FOR RANDOM LASER DEVICES	DAL NEGRO LUCA	National Science Foundation	09/15/2021	08/31/2024	350,000.00
LINEAR AND NONLINEAR OPTICAL CHARACTERIZATION OF CARBON QUANTUM DOTS (CQDS) AND METAL HYBRID CQDS	DAL NEGRO LUCA	Em-Tech	03/15/2022	11/15/2022	29,999.00
NEURAL CIRCUITS FOR REGULATING SOCIAL BEHAVIOR IN RODENTS	DAVISON IAN	NIH/National Institute on Deafness & Com	03/01/2019	02/28/2024	33,325.00
NEURAL CIRCUITS FOR REGULATING SOCIAL BEHAVIOR IN RODENTS	DAVISON IAN	NIH/National Institute on Deafness & Com	03/01/2019	02/28/2024	299,927.00
MULTIPLEXED IMAGING IN THE NEAR INFRARED WITH INDIUM PHOSPHIDE QUANTUM SHELLS	DENNIS ALLISON	NIH/National Institute of General Medica	07/01/2019	07/31/2023	462,000.00
IN VIVO MAPPING OF ENZYME ACTIVITY USING SWIR-EMITTING, SELF-ILLUMINATING QUANTUM DOT SENSORS	DENNIS ALLISON	NIH/National Institute of Biomedical Ima	04/01/2022	01/31/2024	222,750.00
DEEP TISSUE PHOTOACOUSTIC IMAGING WITH DEGRADABLE INORGANIC NANOPARTICLES (SCIALOG-DENNIS)	DENNIS ALLISON	Silicon Valley Community Foundation	08/01/2021	07/31/2022	57,500.00
LOCAL NEURONAL DRIVE AND NEUROMODULATORY CONTROL OF ACTIVITY IN THE PIAL NEUROVASCULAR CIRCUIT	DEVOR ANNA	NIH/National Institute of Neurological D	08/16/2021	05/31/2026	2,774,791.00
LOCAL NEURONAL DRIVE AND NEUROMODULATORY CONTROL OF ACTIVITY IN THE PIAL NEUROVASCULAR CIRCUIT	DEVOR ANNA	NIH/National Institute of Neurological D	08/16/2021	05/31/2026	854,726.00

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LOCAL NEURONAL DRIVE AND NEUROMODULATORY CONTROL OF ACTIVITY IN THE PIAL NEUROVASCULAR CIRCUIT	DEVOR ANNA	NIH/National Institute of Neurological D	08/16/2021	05/31/2026	1,862,582.00
EFFECTS OF INTRINSIC AND DRUG-INDUCED NEUROMODULATION ON FUNCTIONAL BRAIN IMAGING	DEVOR ANNA	NIH/National Institute on Drug Abuse	08/01/2020	05/31/2025	382,450.00
MICROSCOPIC FOUNDATION OF MULTIMODAL HUMAN IMAGING	DEVOR ANNA	NIH/National Institute of Mental Health	06/01/2020	05/31/2022	134,300.30
INTEGRATION OF HIGH DEFINITION DISPLAY TECHNOLOGIES WITH PLATINUM NANOROD MICROELECTRODES FOR LARGE SCALE IN-VIVO RECORDING AND STIMULATION	DEVOR ANNA	University of California, San Diego	09/01/2021	08/31/2024	636,423.00
UNDERSTANDING THE RELATIONSHIPS BETWEEN FUS-BBB OPENING, NEUROINFLAMMATION, AND THE NEUROVASCULAR RESPONSE	DEVOR ANNA	The Brigham and Women's Hospital, Inc.	09/02/2020	06/30/2023	78,776.00
LINKING MOTOR CORTEX ACTIVITY AND MOVEMENT IN THE MOUSE OROFACIAL SYSTEM.	ECONOMO NICHOLAS MICHAEL	NIH/National Institute of Neurological D	02/01/2022	01/31/2027	412,498.00
HIGH-THROUGHPUT MAPPING OF SYNAPTIC CONNECTIVITY BETWEEN TRANSCRIPTOMICALLY DEFINED CELL TYPES	ECONOMO NICHOLAS MICHAEL	NIH/National Institute of Mental Health	05/01/2022	04/30/2025	1,423,833.00
REVERSE ENGINEERING THE BRAIN STEM CIRCUITS THAT GOVERN EXPLORATORY BEHAVIOR	ECONOMO NICHOLAS MICHAEL	University of California, San Diego	06/01/2020	05/31/2023	95,124.00
THE DESCENDING CONTROL OF MOVEMENT INITIATION BY THE MOTOR CORTEX	ECONOMO NICHOLAS MICHAEL	The Esther A. & Joseph Klingenstein Fund	07/01/2020	06/30/2023	75,000.00
INVESTIGATING THE CONTROL OF MOVEMENTS BY SUBSPACES AND CELL TYPES IN THE MOUSE OROFACIAL SYSTEM	ECONOMO NICHOLAS MICHAEL	Whitehall Foundation, Inc.	03/01/2021	02/28/2024	75,000.00
MODULATION OF CELLULAR METABOLISM TO MAXIMIZE NEURONAL REGENERATION	GABEL V CHRISTOPHER	Comm. of Mass./ Department of Public Heal	07/17/2019	06/30/2023	450,112.00
GADOLINIUM DISTRIBUTION IN RAT BRAIN AFTER SYSTEMIC ADMINISTRATION OF GADOLINIUM-BASED CONTRAST AGENTS	GOLDSTEIN E LEE	GE Healthcare, Inc.	10/01/2016	10/01/2019	30,707.35
EVALUATION OF LATENT NEUROLOGICAL EFFECTS OF HYPOBARIC PRESSURE FLUCTUATIONS IN PHYSIOLOGICAL EPISODES	GOLDSTEIN E LEE	Advanced Technology International	10/27/2021	09/25/2023	1,000,000.00
MULTIDIMENSIONAL OPTIMIZATION OF VOLTAGE INDICATORS FOR IN VIVO NEURAL ACTIVITY IMAGING	HAN XUE	NIH/National Institute of Mental Health	03/01/2020	01/31/2025	70,109.00
MULTIDIMENSIONAL OPTIMIZATION OF VOLTAGE INDICATORS FOR IN VIVO NEURAL ACTIVITY IMAGING	HAN XUE	NIH/National Institute of Mental Health	03/01/2020	01/31/2025	630,981.00

AWARD TITLE (FULL)	PI	SPONSOR	PROJECT START DATE	PROJECT END DATE	ADDITIONAL FUNDS THIS BUDGET PERIOD (TOTAL OBLIGATED)*
VOLTAGE IMAGING ANALYSIS OF STRIATAL NETWORK DYNAMICS RELATED TO VOLUNTARY MOVEMENT AND PARKINSONS DISEASE	HAN XUE	NIH/National Institute of Neurological D	04/01/2020	08/31/2025	88,100.00
VOLTAGE IMAGING ANALYSIS OF STRIATAL NETWORK DYNAMICS RELATED TO VOLUNTARY MOVEMENT AND PARKINSONS DISEASE	HAN XUE	NIH/National Institute of Neurological D	04/01/2020	03/31/2025	389,050.00
COLLABORATIVE RESEARCH: DYNAMIC INTERACTIONS OF INDIVIDUAL NEURONS IN SUPPORTING HIPPOCAMPAL NETWORK OSCILLATIONS DURING BEHAVIOR	HAN XUE	National Science Foundation	10/01/2020	09/30/2025	71,496.00
TARGETING PATHOLOGIC SPIKE-RIPPLES TO ISOLATE AND DISRUPT EPILEPTIC DYNAMICS	HAN XUE	The General Hospital Corporation d/b/a M	01/01/2021	11/30/2025	313,280.00
CIF: MEDIUM: DISCOVERING CHANGES IN NETWORKS: FUNDAMENTAL LIMITS, EFFICIENT ALGORITHMS, AND LARGE-SCALE NEUROSCIENCE	HAN XUE	National Science Foundation	07/01/2020	06/30/2024	320,192.00
WABOSH - WASHINGTON AND BU DO OPEN SOURCE HARDWARE	JOSHI JAYANT AJAY	University of Washington	06/06/2018	06/05/2022	27,885.00
WABOSH - WASHINGTON AND BU DO OPEN SOURCE HARDWARE	JOSHI JAYANT AJAY	University of Washington	06/06/2018	06/05/2022	60,000.00
WABOSH - WASHINGTON AND BU DO OPEN SOURCE HARDWARE	JOSHI JAYANT AJAY	University of Washington	06/06/2018	06/05/2022	39,963.00
ELECTRO-PHOTONIC COMPUTING (EPIC) FOR ON-PREMISE APPLICATIONS	JOSHI JAYANT AJAY	Lightmatter, Inc.	11/12/2021	11/11/2023	295,828.00
SHF: SMALL: ARCHITECTING THE COSMOS:A COMBINED SYSTEM OF OPTICAL PHASE CHANGE MEMORY AND OPTICAL LINKS	JOSHI JAYANT AJAY	National Science Foundation	10/01/2021	09/30/2024	500,000.00
CAREER: PROBING AND MANIPULATING ELECTRONIC AND SPIN DEGREES OF FREEDOM IN PARAMAGNETIC SINGLE MOLECULE CIRCUITS	KAMENETSKA MARIA	National Science Foundation	01/01/2022	01/31/2027	390,000.00
MRI: ACQUISITION OF A UNIVERSAL OPTICAL TWEEZER PLATFORM TO PROBE NANOSCALE STRUCTURE AND FUNCTION OF SINGLE POLYMERS USING FORCE AND OPTICAL SPECTROSCOPY	KAMENETSKA MARIA	National Science Foundation	09/01/2021	08/31/2024	255,850.00
THE BUTTERFLY EFFECT IN CELLULAR PHASE SEPARATION: FROM MOLECULAR INTERACTIONS TO EMERGENT BEHAVIOR	KAMENETSKA MARIA	Research Corporation for Science Advance	01/01/2022	12/31/2022	55,000.00
NOVEL BIOSENSORS BASED ON MINING BACTERIAL TRANSCRIPTION FACTORS	KLAPPERICH M CATHERINE	NIH/National Institute of Biomedical Ima	07/01/2020	03/31/2025	655,799.00

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FLIPPED BIOMEDICAL GRAND ROUNDS: CREATING A CLINICAL IMMERSION CLASSROOM	KLAPPERICH M CATHERINE	NIH/National Institute of Biomedical Ima	06/04/2018	03/31/2023	21,600.00
RAPID ASSESSMENT OF ILLEGAL DRUGS IN WASTEWATER	LING XI	Giner Inc.	03/01/2022	02/29/2024	12,500.00
MULTI-LAYER NEURONAL IMAGING WITH REVERBERATION MULTIPHOTON MICROSCOPY	MERTZ JEROME	NIH/National Institute of Neurological D	03/15/2020	12/31/2024	40,050.00
MULTI-LAYER NEURONAL IMAGING WITH REVERBERATION MULTIPHOTON MICROSCOPY	MERTZ JEROME	NIH/National Institute of Neurological D	03/15/2020	12/31/2024	360,466.00
FAST, LARGE-SCALE NEURONAL IMAGING WITH MULTI-Z CONFOCAL MICROSCOPY	MERTZ JEROME	NIH/National Institute of Biomedical Ima	02/01/2020	11/30/2023	400,395.00
FAST, LARGE-SCALE NEURONAL IMAGING WITH MULTI-Z CONFOCAL MICROSCOPY	MERTZ JEROME	NIH/National Institute of Biomedical Ima	02/01/2020	11/30/2023	44,490.00
ULTRAFAST HIGH-CONTRAST VOLTAGE IMAGING IN FREELY MOVING ANIMALS	MERTZ JEROME	NIH/National Institute of Neurological D	03/15/2022	02/28/2024	655,123.00
RAMPS: RING-BASED ANALOG MILLIMETER-WAVE PHOTONIC-ELECTRONIC SYSTEMS-ON-CHIP	POPOVIC MILOS	University of California, Berkeley	07/09/2021	04/08/2022	246,750.00
AIM ACADEMY DESIGN/TEST EDUCATION	POPOVIC MILOS	Aim Photonics	02/15/2020	07/09/2021	50,000.00
LIGHT-MATTER INTERACTIONS WITH A TWIST	RAMACHANDRAN SIDDHARTH	Department of Defense/ ONR	09/01/2019	08/31/2024	600,563.00
HIGH CAPACITY DATA CENTERS WITH ORBITAL ANGULAR MOMENTUM (OAM) SUPPORTING FIBERS	RAMACHANDRAN SIDDHARTH	Brookhaven National Laboratory	11/06/2018	12/31/2021	118,500.00
LOW SWAP SOURCES FOR HIGH-POWER BLUE COMMUNICATIONS	RAMACHANDRAN SIDDHARTH	Department of Defense/ ONR	05/01/2020	04/30/2023	56,739.00
LOW SWAP SOURCES FOR HIGH-POWER BLUE COMMUNICATIONS	RAMACHANDRAN SIDDHARTH	Department of Defense/ ONR	05/01/2020	04/30/2023	43,261.00
ARTIFICIALLY MODULATING MEMORIES TO ALLEVIATE PSYCHIATRIC DISEASE-LIKE STRESS	RAMIREZ STEVE	NIH/Office of the Director	07/01/2017	08/31/2022	412,500.00
SINGLE-CELL AND TARGET SPECIFIC RESOLUTION OF MULTIPLE MEMORIES ACROSS THE BRAIN	RAMIREZ STEVE	Research Foundation for Mental Hygiene	09/13/2019	08/31/2022	385,494.00
RESTORING ACCESS TO MEMORIES 'LOST' AS A RESULT OF SLEEP DEPRIVATION	RAMIREZ STEVE	Department of Defense/ AFOSR	09/01/2021	08/31/2024	241,136.00
RESTORING ACCESS TO MEMORIES 'LOST' AS A RESULT OF SLEEP DEPRIVATION	RAMIREZ STEVE	Department of Defense/ AFOSR	09/01/2021	08/31/2024	115,100.00
RESTORING ACCESS TO MEMORIES 'LOST' AS A RESULT OF SLEEP DEPRIVATION	RAMIREZ STEVE	Department of Defense/ AFOSR	09/01/2021	08/31/2024	118,800.00

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CAROL AND GENE LUDWIG AWARD FOR NEURODEGENERATION RESEARCH	RAMIREZ STEVE	Ludwig Family Foundation	09/24/2021	09/23/2023	175,000.00
GM3 NANOPARTICLES FOR SUSTAINED DELIVERY OF ANTI-RETROVIRALS TO LYMPHATIC TISSUES	REINHARD M BJOERN	NIH/National Institute of Allergy & Infe	11/08/2017	10/31/2022	624,640.00
ILLUMINATING DYNAMIC RECEPTOR CLUSTERING IN THE EPIDERMAL GROWTH FACTOR RECEPTOR SIGNAL TRANSDUCTION PATHWAY USING PLASMON COUPLING	REINHARD M BJOERN	NIH/National Cancer Institute	04/01/2020	03/31/2025	384,038.00
ILLUMINATING DYNAMIC RECEPTOR CLUSTERING IN THE EPIDERMAL GROWTH FACTOR RECEPTOR SIGNAL TRANSDUCTION PATHWAY USING PLASMON COUPLING	REINHARD M BJOERN	NIH/National Cancer Institute	04/01/2020	03/31/2025	56,869.00
ILLUMINATING DYNAMIC RECEPTOR CLUSTERING IN THE EPIDERMAL GROWTH FACTOR RECEPTOR SIGNAL TRANSDUCTION PATHWAY USING PLASMON COUPLING	REINHARD M BJOERN	NIH/National Cancer Institute	04/01/2020	03/31/2025	72,153.00
PLASMONIC INACTIVATION OF VIRUS AND MYCOPLASMA CONTAMINANTS	REINHARD M BJOERN	NIH/National Institute of General Medica	08/01/2021	05/31/2025	330,000.00
PLASMONIC INACTIVATION OF VIRUS AND MYCOPLASMA CONTAMINANTS	REINHARD M BJOERN	NIH/National Institute of General Medica	08/01/2021	05/31/2025	330,000.00
PLASMONIC INACTIVATION OF VIRUS AND MYCOPLASMA CONTAMINANTS	REINHARD M BJOERN	NIH/National Institute of General Medica	08/01/2021	05/31/2025	0.00
EARLY BREAST CANCER TREATMENT RESPONSE MONITORING WITH REAL-TIME DIFFUSE OPTICAL IMAGING	ROBLYER DARREN	Department of Defense/ Army Medical Resea	09/01/2021	08/31/2024	821,340.00
LABEL-FREE MEASUREMENT OF BLOOD LIPIDS WITH HYPERSPECTRAL SHORT-WAVE INFRARED SPATIAL FREQUENCY DOMAIN IMAGING TO IMPROVE CARDIOVASCULAR DISEASE RISK PREDICTION AND TREATMENT MONITORING	ROBLYER DARREN	NIH/National Institute of Biomedical Ima	07/01/2020	03/31/2023	188,289.00
EFRI CEE: OPTICALLY CONTROLLED LOCALIZED EPIGENETIC CHROMATIN REMODELING WITH PHOTOACTIVATABLE CRISPR-DCAS9	ROBLYER DARREN	Beth Israel Deaconess Medical Center, In	09/01/2018	08/31/2022	122,343.00
FREQUENCY DOMAIN SHORTWAVE INFRARED SPECTROSCOPY (FD-SWIRS) FOR VOLUME STATUS MONITORING DURING HEMODIALYSIS IN END STAGE KIDNEY DISEASE	ROBLYER DARREN	NIH/National Diabetes & Digestive & Kidn	03/01/2022	01/31/2024	223,986.00
FREQUENCY DOMAIN DIFFUSE OPTICAL SPECTROSCOPY AND DIFFUSE CORRELATION SPECTROSCOPY FOR ASSESSING INSPIRATORY MUSCLE METABOLISM IN MECHANICALLY VENTILATED PATIENTS	ROBLYER DARREN	NIH/National Institute of Biomedical Ima	09/15/2021	06/30/2023	215,000.00

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ESTIMATING BLOOD PRESSURE CHANGES USING LASER SPECKLE CONTRAST MEASUREMENTS ON THE WRIST AND HAND	ROBLYER DARREN	Facebook Technologies, LLC	12/07/2021	07/31/2022	369,263.75
A WEARABLE PROBE FOR DEEP TISSUE IMAGING OF HEMODYNAMICS IN BREAST TUMORS	ROBLYER DARREN	American Cancer Society, Inc.	01/01/2022	06/30/2023	360,000.00
PEAK POWER, SPECTRAL BANDWIDTH AND X(3) NONLINEARITIES CHARACTERIZATION IN SPECIALTY FIBERS	SANDER MICHELLE	Department of Defense/ ONR	11/10/2020	11/09/2021	25,000.00
PEAK POWER, SPECTRAL BANDWIDTH AND X(3) NONLINEARITIES CHARACTERIZATION IN SPECIALTY FIBERS	SANDER MICHELLE	Department of Defense/ ONR	11/10/2020	11/09/2022	32,888.00
INVESTIGATING MECHANISMS UNDERLYING PERCEPTUAL INTEGRATION IN AUTISM	SCOTT BENJAMIN	Simons Foundation	12/01/2021	11/30/2024	250,000.00
FUNCTIONAL ARCHITECTURE FOR EVIDENCE ACCUMULATION IN THE RAT NEOCORTEX	SCOTT BENJAMIN	Whitehall Foundation, Inc.	07/01/2019	06/30/2022	75,000.00
COLLABORATIVE RESEARCH: ANOMALOUS PLASMA COOLING IN THE TOPSIDE IONOSPHERE: OBSERVATIONS AND MODELING OF SOLAR MODULATIONS MEASURED BY DMSP DURING SOLAR ECLIPSES	SEMETER L JOSHUA	National Science Foundation	09/01/2019	08/31/2022	54,790.00
QUANTUM SENSING AND SIMULATION FOR FUNDAMENTAL DISCOVERY	SUSHKOV ALEXANDER	Stanford National Accelerator Laboratory	03/10/2022	08/31/2024	368,042.00
CAREER: FUNDAMENTAL DISCOVERY WITH SOLID SATE SPIN ENSEMBLES	SUSHKOV ALEXANDER	National Science Foundation	12/15/2021	11/30/2026	296,201.00
QUANTUM SENSORS FOR LIGHT-FIELD DARK MATTER SEARCHES	SUSHKOV ALEXANDER	Stanford National Accelerator Laboratory	01/19/2022	09/30/2023	314,174.00
SMALL-SCALE FUNDAMENTAL PHYSICS BLOCK GRANT	SUSHKOV ALEXANDER	Northwestern University	01/01/2021	12/31/2022	67,436.00
COMPUTATIONAL MINIATURE MESOSCOPE FOR CORTEX-WIDE, CELLULAR RESOLUTION CA2+ IMAGING IN FREELY BEHAVING MICE	TIAN LEI	NIH/National Institute of Neurological D	04/01/2022	03/31/2027	412,500.00
A NOVEL METHOD FOR VOLUMETRIC OXYGEN MAPPING IN LIVING RETINA	TIAN LEI	Johns Hopkins University	03/01/2021	02/28/2025	129,897.00
A NOVEL METHOD FOR VOLUMETRIC OXYGEN MAPPING IN LIVING RETINA	TIAN LEI	Johns Hopkins University	03/01/2021	02/28/2025	77,381.00
REFLECTION-MODE COMPUTATIONAL 3D PHASE AND POLARIZATION IMAGING FOR SEMICONDUCTOR WAFER METROLOGY AND INSPECTION	TIAN LEI	Samsung	12/15/2021	12/15/2022	150,000.00
B-BIC RADX-RAD: UNLU (BU) SUBCONTRACT	UNLU SELIM M	The Brigham and Women's Hospital, Inc.	12/21/2020	08/31/2022	54,000.00

AWARD TITLE (FULL)	PI	SPONSOR	PROJECT START DATE	PROJECT END DATE	ADDITIONAL FUNDS THIS BUDGET PERIOD (TOTAL OBLIGATED)*
INTERFEROMETRIC REFLECTANCE IMAGING SENSOR FOR RAPID BACTERIAL IDENTIFICATION IN INFECTED WOUNDS	UNLU SELIM M	Physical Sciences, Inc.	05/12/2021	09/30/2021	41,933.00
LUNAR ENVIRONMENT HELIOPHYSICS X-RAY IMAGER (LEXI)	WALSH MICHAEL BRIAN	NASA	03/19/2020	03/31/2022	207,000.00
LUNAR ENVIRONMENT HELIOPHYSICS X-RAY IMAGER (LEXI)	WALSH MICHAEL BRIAN	NASA	03/19/2020	03/18/2022	45,263.00
CAREER: SPREADING OF 3D MAGNETIC RECONNECTION	WALSH MICHAEL BRIAN	National Science Foundation	06/01/2019	05/31/2024	128,948.00
REFINING PREDICTIONS OF RECONNECTION X-LINES AT EARTH'S MAGNETOPAUSE	WALSH MICHAEL BRIAN	NASA	07/22/2020	07/21/2023	112,243.00
BOSTON UNIVERSITY PARTICIPATION IN THE SOLAR WIND MAGNETOSPHERE IONOSPHERE LINK EXPLORER (SMILE)	WALSH MICHAEL BRIAN	NASA	10/01/2020	09/30/2023	44,107.80
BOSTON UNIVERSITY PARTICIPATION IN THE SOLAR WIND MAGNETOSPHERE IONOSPHERE LINK EXPLORER (SMILE)	WALSH MICHAEL BRIAN	NASA	10/01/2020	09/30/2023	42,537.20
X-RAY IMAGING FOR SPACE SCIENCE	WALSH MICHAEL BRIAN	NASA	06/10/2022	01/09/2025	208,500.00
DESIGN AND IN VIVO COMPARISON OF ALTERNATIVE STRATEGIES FOR ARTIFICIAL ZINC FINGER (AZNF) BASED REGULATABLE GENE THERAPIES	WHITE ALICE	Novartis Institutes for BioMedical Resea	03/04/2022	09/03/2023	279,190.00
TRAINING PROGRAM IN QUANTITATIVE BIOLOGY & PHYSIOLOGY (QBP)	WHITE A JOHN	NIH/National Institute of General Medica	07/01/2022	06/30/2027	520,372.00
INVESTIGATING CYCLIC DI-GMP ACCUMULATION AS A TEMPORAL FILTER IN BACILLUS SUBTILIS BIOFILM COMMITMENT	WHITE A JOHN	Howard Hughes Medical Institute	06/01/2022	05/31/2023	60,440.00
INVESTIGATING HOW BIOCHEMICAL AND MECHANICAL CUES SHAPE CALCIUM DYNAMICS IN FIBROBLAST CELLS	WHITE A JOHN	Howard Hughes Medical Institute	07/05/2022	12/31/2022	28,101.00
UNDERSTANDING THE MECHANISM OF MICROWAVE NEURON INHIBITION	YANG CHEN	Department of Defense/ ARO	05/09/2022	05/08/2023	81,000.00
UNDERSTANDING THE MECHANISM OF MICROWAVE NEURON INHIBITION	YANG CHEN	Department of Defense/ ARO	05/09/2022	05/08/2023	28,117.27
ACOUSTIC POWER HARVESTING AND COMMUNICATION FOR SENSORS IN DOWNHOLE ENVIRONMENT	ZHANG XIN	University of Texas at Austin	08/01/2021	12/31/2022	100,016.00
ULTRAFAST 2DIR STUDIES OF DYNAMICS IN DENSE GAS AND SUPERCRITICAL FLUID SOLUTIONS	ZIEGLER LAWRENCE	National Science Foundation	08/01/2021	07/31/2024	184,140.00

TOTAL: $45,761,803.56

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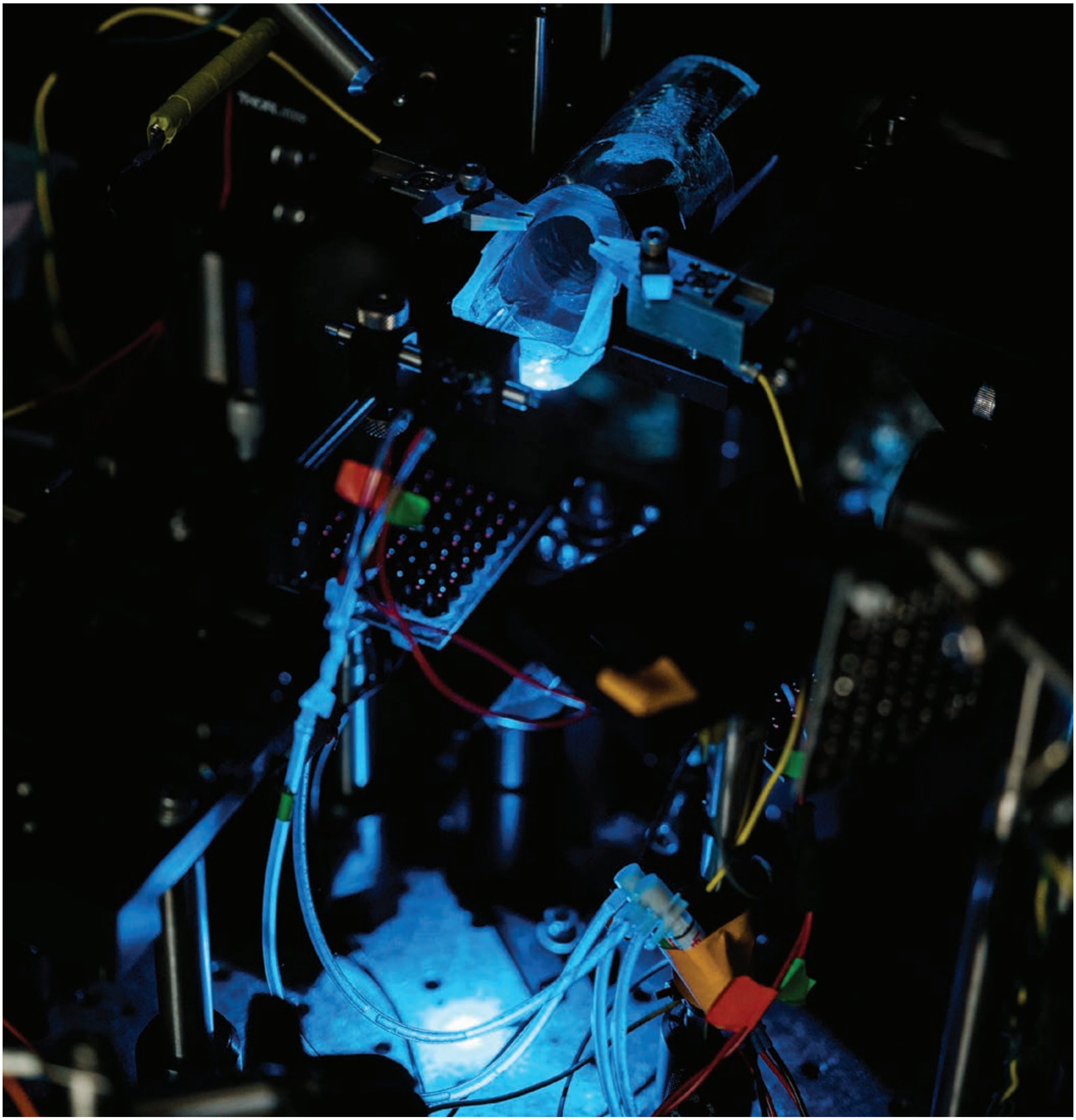

Photo taken in Mike Economo's lab. Credit: Christopher McIntosh