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| **2025 Boston University ECE Summer Research Projects** | | | |  |
| Project title | Project Description | Mentor | openings | Applicants and email address |
| Patterned Illumination for Retina Stimulation | Modulating neural activities in damaged retina is essential for restoring vision in blind patients. In our work, we have developed novel photoacoustic retinal stimulation. In this study, students will participate in design the programmable optics to enable a patterned illumination for retina stimulation.  Reference: https://www.biorxiv.org/content/10.1101/2024.09.03.611068v2 | Chen Yang  <https://sites.bu.edu/yanglab/> | 2 |  |
| Brain imaging for understanding photoacoustic stimulation in animal brain | Brain stimulation is important for non-drug treatment for neurological disorders and for brain machine interface. In this project we will further develop an in vivo fluorescence brain imaging platform to under photoacoustic brain stimulation. Students will design and setup the optic setup for the imaging platform and perform in vivo imaging in animal model develop.  Reference: *Nat. Comm*, 11, 881 |  |
| Single molecule vibrational photothermal imaging | Based on mid-infrared, stimulated Raman, or shortwave infrared absorption, vibrational photothermal microscopy is rising as a highly sensitive chemical imaging technology. Yet, single molecule imaging sensitive remains to be reached. In the project, we will explore the use of fluorescence as a novel and highly sensitive sensor of temperature to reach photothermal imaging single biomolecules such as single proteins.  **References:** Yeran Bai, Jiaze Yin, Ji-Xin Cheng, Bond-Selective Imaging by Optically Sensing the Mid-Infrared Photothermal Effect, **Science Advances**, review, 2021, 7: eabg1559 | Ji-xin Cheng  <https://sites.bu.edu/cheng-group/> | 3, 1 for each |  |
| Super-resolution photothermal modulation of neurons via stimulated Raman | Our recent work on stimulated Raman photothermal microscopy shows energy deposition into a volume of less than 1.0 femtoliter via the stimulated Raman gain and loss processes. This energy deposition creates an unprecedented opportunity of performing nanoscale photothermal modulation of single axons or organelles.  **References:** Yifan Zhu**,** Xiaowei Ge, Hongli Ni, Jiaze Yin, Haonan Lin, Le Wang, Yuying Tan, Chinmayee V. Prabhu Dessai, Yueming Li, Xinyan Teng, Ji-Xin Cheng, Stimulated Raman photothermal microscopy towards ultrasensitive chemical imaging, **Science Advances**, 2023, 9: eadi2181. |  |
| Killing drug-resistant superbugs with photons | Drug-resistant suberbugs has become a big burden and threat to human health. Recently, we showed that by blue light photobleaching of the intrinsic chromophores in MRSA, one can sensitize a drug-resistant bug causing skin infections in human, to low-concentration hydrogen peroxide.This works well to surface infections, but not to infections under the skin. The summer project aims to overcome this limitation by using a second beam at short-wave IR window to convert ground state oxygen into singlet oxygen to synergize with the blue light, towards the gold of eliminating MRSA infection in a drug-free manner.  **References:** Pu-Ting Dong, Haroon Mohammad, Jie Hui, Leon G. Leanse, Junjie Li, Lijia Liang, Tianhong Dai, Mohamed N. Seleem\*, Ji-Xin Cheng\*, “Photolysis of Staphyloxanthin sensitizes methicillin-resistant *Staphylococcus aureus* to reactive oxygen species”, **Advanced Science**, 2019, 6: 1900030 |  |
| Elucidating Multiphoton Excitation with Quantum State of Light | Multiphoton microscopy (MPM) is the workhorse for deep-tissue imaging for its ability to acquire 3D fluorescent images through highly scattering biological tissues -- a property indispensable for minimizing invasiveness for in vivo imaging. The ability of MPM to image through biological tissue relies on multi-photon excitation (MPE) of fluorescence, a nonlinear process that favors high light intensity for fluorescence generation. However, as a trade-off, the nonlinear excitation is often accompanied by weak fluorescent signals, which in turn limits imaging speed. More recently, there has been a resurgence of interest in investigating the possibility of enhancing MPE through quantum coherent control [1]. In molecular systems with multiple energy levels, it's possible to significantly boost MPE probability by using intermediate energy levels as “springboards” to reach the final energy level. This process can be controlled by shaping the excitation pulses' spectrotemporal structure with a high-resolution pulse shaper. With advancements in machine learning and high-dimensional optimization techniques, the pulse shaper can be trained *in situ* to adjust the amplitude and phase of the excitation pulses for maximum fluorescence. The goal of this summer project is to contribute to designing and building a high-resolution pulse shaper and programming it to optimize its performance using fluorescence signal feedback.  [1] Silberberg, Y. Quantum coherent control for nonlinear spectroscopy and microscopy. *Annual review of physical chemistry*, **60**, 277-292 (2009). | Tianyu Wang  <https://tyw-lab.github.io/> | 1 |  |
| Metasurface computational image sensors | In this project, we are developing a new type of image sensors that are uniquely sensitive to the direction of propagation of the incident light, based on the integration of specially designed metasurfaces with standard photodetectors.  By virtue of their unconventional angular response, these devices can enable novel imaging capabilities such as lensless compound-eye vision with ultrawide field of view, quantitative phase-contrast imaging, and edge enhancement for image classification.  Therefore, they have significant potential for applications ranging from endoscopy and biomedical microscopy to autonomous navigation and computer vision.  The required metasurfaces are designed with full-wave electromagnetic simulations and fabricated on the illumination window of a photodetector using a variety of nanofabrication techniques.  The device imagining capabilities are then extrapolated from the angle-resolved photocurrent measurement results.  The summer REU project will focus on the metasurface design and development to provide increased performance or to create new computational imaging functionalities. | Roberto Paiella  <https://www.bu.edu/paiella/> | 1 |  |
| Physics & Applications of Singular Light | When we think of light, we think of a Gaussian-shaped spot, usually traveling in a straight line except when it encounters interfaces. This is, however, only the first, fundamental solution of the wave equation – much as a guitar string can have many modes (and frequencies) of vibrations, so can light also exist in different eigenstates. These peculiarly shaped light beams are characterized by singularities – i.e., regions in which some quantity does not have a well-defined value – in polarization, phase or amplitude. The physics of propagation of such beams reveals exotic effects, such as the ability of the beam to self-heal past obstructions (**Bessel beams**), the ability to carry **orbital angular momentum (OAM)** that makes light travel in helical paths rather than a straight line, or even the possibility of retaining **memory** of the paths that it takes. Analogous to the physics of tornadoes as well as electron orbitals, these beams reveal several unique **classical**and **quantum** properties not normally observed with conventional Gaussian beams. We study these fundamental properties and also apply them to varied applications such as **high-capacity classical communications** that consume **low energy per bit**, high-speed metrology including object sensing for **autonomous systems** as well as **spectrometry**and**imaging**. | Siddharth Ramachandran  <https://sites.bu.edu/ramachandranlab/> | 1-2 |  |
| Nonlinear & Quantum Photonics | Nonlinear optical phenomena represent the interaction of light with the material in which it propagates, resulting in myriad effects such as the ability to controllably alter its color and shape in both time and space. Because such effects perturb the principle of superposition in linear optics, nonlinear optics is one of the best known means of generating **quantum entanglement**. We study new nonlinear optical phenomena enabled by singular and structured light beams, such as new modal selection rules for **Raman & Brillouin scattering** and the ability to obtain **hyper-**or **hybrid-quantum entanglement**. We then exploit these unique effects for applications such as single-photon frequency conversion for **quantum networks**, and for developing **high-power lasers** in the long-pulse as well as **ultra-fast** regime, for myriad uses ranging from **biomedical imaging** to **LIDAR-based sensing**and**underwater communications**. |  |  |