Montana State University—Electrical and Computer Engineering
REU Summer 2024 Prospective Projects List

Semiconductor Process Development (Mentor: Dr. Andrew Lingley, 1 student)
Significance: The Montana Microfabrication Facility is a resource for Montana State University, external academics, and commercial entities that provides affordable access to a range of micro and nanofabrication equipment. We support applications ranging from fundamental physics to biology, microfluidics, MEMS and MOEMS, and sensors. Our mission is to accelerate and simplify the process of designing and fabricating micro and nanoscale devices for scientific research, device development, and prototyping. To better achieve this mission, we need to develop and characterize a variety of semiconductor manufacturing processes. Additionally, with the push to onshore semiconductor manufacturing, we provide opportunities to spark interest in semiconductors and microelectronics, and do so in an inclusive, supportive environment.
Objectives: This summer, our REU student will help develop a multi-user MEMS (Microelectromechanical System) process. Examples of MEMS devices are digital micromirrors that power all movie theater projectors and gyroscopes and accelerometers that determine the orientation and acceleration of smart phones. We would like to develop a MEMS course at MSU comprising one semester of design and one semester of in-lab fabrication. In this class, students would use a defined microfabrication process flow, or recipe, capable of turning a silicon wafer into a variety of microscale sensors or actuators. Although we have an outline for a basic process to create piezoresistors, cantilevers, membranes, electrodes, heaters, and other elements, this process needs to be vetted with a variety of experiments to determine the feasibility and individual process steps. ***Role of REU participant:*** The participant will work within a team of peers and will learn about cleanroom safety, operation, and etiquette, including proper dress code and gowning procedures. They will be assigned a process development task leading to a MEMS course that is commensurate with their experience, skills, and interests. Previous examples include experimenting with safer developers for photolithography, updating the texturing process for our solar cell class, and characterizing the photoresist removal rate and uniformity of several plasma ashing recipes. These projects will provide introductory experiences for motivated students to learn about micro- and/or nano-fabrication and the semiconductor industry, with a broad range of potential applications and careers. Prior cleanroom and lab experience is not required.

Long-Term Natural Soundscape Assessment and Description (Mentor: Prof. Rob Maher)
Significance: The natural acoustical environment of a park or wilderness area provides important information about the composition, diversity, and health of the natural ecosystem. The soundscape comprises biological sounds from animal communication, environmental sounds of wind, rain, and moving water, and anthropogenic sound of human activity. ***Objectives:*** The project requires (a) the creation of analytical software for automatically identifying soundscape components and performing statistical characterization of recordings that are potentially hundreds of hours in duration, and (b) experimenting with machine learning models and validation approaches to segmenting, identifying, and classifying sounds in environmental recordings. ***Role of REU participant:*** The participating student will gain a theoretical and practical understanding of environmental acoustics (the propagation, reflection, absorption, and attenuation of sound in the atmosphere), gain experience designing and conducting field

research, participate in scientific interpretation and documentation of acoustical recordings, and conceive of new means for automated acoustical processing and analysis.

Nanofabrication of Optical Devices (Mentor: Prof. Wataru Nakagawa, Prof. David Dickensheets)
Significance: Micro- and nano-fabrication technologies based on silicon have enabled a vast range of technological advances, including microprocessors, integrated systems, and optoelectronics. The Nano Optics group uses these manufacturing technologies to produce functional optical and photonic devices based on nanostructures in silicon and related materials, optimized for applications in polarimetry, optical imaging, and LIDAR. ***Objectives:*** Functional optical devices based on silicon nanostructures will be designed, fabricated, and characterized in support of ongoing projects in the group. ***Role of REU participant:*** The participating student will be given an introduction to these fabrication technologies and hands-on training in working in MSU's clean room facility. With support from team members, the REU student will be assigned a sequence of steps in the fabrication process chain to understand and optimize, and to assist in fabricating functional optical devices. The student will also be trained to use relevant characterization tools (e.g. profilometer, scanning electron microscope) to investigate the fabricated structures.

Optical Metamaterial Characterization (Mentor: Prof. Wataru Nakagawa)
Significance: The Nano Optics group is developing and testing nanostructured composite optical materials (metamaterials) with engineered polarization properties for sensing and other applications. The optical properties including polarization characteristics of these devices must be thoroughly measured and analyzed in order to understand their performance and give feedback to the design and manufacturing processes. ***Objectives:*** An optical characterization system will be used to measure the spectral and polarization properties of the metamaterials under test. As needed modifications or improvements to the system will be implemented, including laboratory automation and signal processing/analysis tools. ***Role of REU participant:*** The REU student will be trained on the operation of the optical characterization system, assist in its calibration and testing, perform measurements on fabricated metamaterial devices, and potentially assist in making improvements to the system. Prior experience with Matlab, LabView, polarimetry, and/or benchtop optical measurements desirable but not required.

River Algae Imaging (Mentor: Prof. Joseph Shaw)
Significance: The Gallatin River flows out from Yellowstone National Park and is one of three rivers that join together at Three Forks, Montana to form the headwaters of the Missouri River. One of the nation's premier fly-fishing rivers, the Gallatin is heavily used for recreation, tourism, and as a source of fresh water. It was declared in 2023 by the EPA to be an "impaired waterway" because of nuisance algae blooms that are increasing in severity and spatial extent. We are collaborating with the Montana Department of Environmental Quality (DEQ) to provide hyperspectral images from drones that fly over the river and multispectral images from fixed-location, low-cost imagers we are developing. These images are used to detect algae blooms, determine their spatial extent, and study their causes. ***Objectives***: Hyperspectral and multispectral images will be collected with drones and bridge-mounted imagers, calibrated, and processed to produce algae bloom maps and pigment concentrations to guide collaborating ecologists in understanding and addressing these algae blooms. ***Role of REU participant:*** The participating

students will participate in field experiments to collect spectral images and calibrate them to yield physical quantities such as radiance and reflectance, and then produce georectified maps of algae coverage and pigment concentrations. The students also will assist a multi-disciplinary team in collecting ground-truth algae samples that will be analyzed in our collaborators' ecology labs. Prior experience with photography or imaging is helpful, as is interest in optical systems design and calibration, and image analysis with Matlab and related software.

Optical Sensing of Prescribed Fire Smoke (Mentor: Prof. Joseph Shaw)
Significance: Because of the increasing threat of wildfire, we are studying prescribed fires and their physical and social impacts as a tool for reducing the harm done by wildfires. This multi-institutional and multi-disciplinary study includes the development of smart optical sensor systems that will be used with embedded machine learning and artificial intelligence algorithms to characterize fire fuels before and after prescribed fires and to characterize the physical properties of the smoke emitted by these fires. This will be done in partnership with studies of the societal impacts of prescribed fires and people's perceptions of prescribed fires with different levels and types of information. ***Objectives***: Smart optical sensor systems will be mounted on aerial drones, on off-road autonomous vehicles, and in a mobile sensor van to collect data that characterize the fire fuels and the emitted smoke plume and smoke aerosols. ***Role of REU participant:*** The participating students will be trained in safe operation of optical sensors during prescribed fires, then will assist graduate students and faculty in conducting field experiments and processing data from them. They will join a broadly multidisciplinary team that includes fire scientists, smoke chemists, optical and electrical engineers, computer scientists and social scientists. Their focus on this team will be helping to develop, calibrate, and operate optical sensor systems and demonstrate their effectiveness through post-experiment data processing and reporting.

Hyperspectral Signal Processing and Real-Time Classification (Mentor: Prof. Ross Snider)
Significance: Hyperspectral remote sensing can produce orders of magnitude more data than color cameras which makes it impractical/undesirable to store or transmit this voluminous data for further processing. ***Objectives:*** The Snider Lab is collaborating with the Optical Remote Sensor Laboratory (ORSL) and a local company Resonon that manufactures hyperspectral cameras to process and classify hyperspectral data in real-time. ***Role of REU participant:*** The REU participant will be expected to learn about hyperspectral signal processing and develop classification methodologies that can be applied in a real-time setting (e.g. drone-based real-time classification of hyperspectral color signatures).

Sensor modeling for biofilm application (Mentor: Prof. Stephan Warnat)
Significance: In natural and industrial environments, most microorganisms exist as organized communities known as biofilms. Biofilms are complex communities of multiple microorganisms and organic matter attached to surfaces that often cause significant changes in product quality. ***Objectives:*** The Warnat lab at Montana State University has developed a sensor technology platform using microfabricated electrochemical impedance spectroscopy (EIS) sensors. Using equivalent circuit modeling and finite element simulations are common ways to characterize changes in electrochemical systems. However, applying these modeling approaches to EIS sensors and biofilm studies is limited. ***Role of REU participant:*** The proposed work is based on the selection of a simulation tool (Comsol and RelaxIS) and the development of a biofilm model.

The developed model will be evaluated experimentally using a "synthetic" biofilm consisting of a hydrogel with incorporated microorganisms. The students will work and learn with an interdisciplinary team of biologists, physicists, and mechanical and electrical engineers at the Center for Biofilm Engineering.

Homogenous light source (Mentor: Prof. Stephan Warnat)
Significance: In natural environments, most microorganisms exist as organized communities known as biofilms. Biofilms are complex communities of multiple microorganisms and organic matter attached to surfaces that often cause microbial-induced corrosion. The study of biofilm growth is challenging due to its heterogeneous structure and diverse microbial composition. ***Objectives:*** The Warnat lab aims to develop an image recognition system that differentiates the diverse composition. The resulting database will be used in future work to determine the mechanical properties of biofilms. ***Role of REU participant:*** The lab has developed a microfluidic device that compresses cells with a constant force and an algorithm that detects deformation rates. However, the current light source is not optimal for capturing reliable images. The proposed work will develop a theoretical framework for constant illumination of the microfabricated camera system. The lessons learned are expected to be translated into an experimental setup. A possible multi-wavelength source could be an additional development during the project.

Lidar Processing and Target Identification with Machine Learning (Mentor: Prof. Brad Whitaker)
Significance: Optical remote sensing techniques have applications from environmental monitoring (detecting fish in lakes or insects in a field) to military surveillance (detecting flying drones or camouflaged materials). Unfortunately, many sensing devices produce large quantities of data that are difficult and tedious for humans to analyze completely. Machine learning techniques have the potential to assist in analyzing data collected using these sensors. ***Objectives:*** The Whitaker Lab is collaborating with the Optical Remote Sensor Laboratory (ORSL) and Spectrum Lab to develop machine learning approaches for identifying targets in cluttered lidar environments. ***Role of REU participant:*** The REU participant will be expected to learn about and use signal processing and machine learning techniques to identify targets of interest in labeled and unlabeled data collected using lidar or other optical remote sensing devices.

Underwater Machine Vision for Scene Characterization and Anomaly Detection (Mentor: Prof. Brad Whitaker)
Significance: Autonomous unmanned underwater vehicles have the potential to support many applications, including national defense, autonomous exploration and navigation, and search and rescue missions. One major problem inhibiting general robotic submarine systems is that they are often expected to be deployed in many different, and sometimes never-before-seen, environments. Such environments include human-made facilities, freshwater lakes, coastal seawater, and the deep ocean. The visual background and types of anticipated objects associated with different environments may make it infeasible for a single perception algorithm to perform well in all circumstances. ***Objectives:*** In this research project, the Whitaker Lab will create a framework for environmentally aware computer vision. Using such a framework, the algorithm will sense the current environment and rely on training data from a similar environment to make

perception inferences. We hypothesize that an adaptive perception algorithm will lead to greater success in identifying anomalous underwater objects. ***Role of REU participant:*** The REU participant will be expected to learn about machine vision and transfer learning techniques. The student will also collect and label data from multiple underwater environments in order to train different vision algorithms. This work will enable the submarine to identify targets of interest, including anomalies, in labeled and unlabeled data collected using underwater cameras.