NDnano
Notre Dame Nanoscience and Technology

NDnano Summer Undergraduate Research
2022 Project Summary

1. Student name & home university: Luke Strachan - University of Notre Dame

2. ND faculty name & department: Dr. Gergo Szakmany, Department of Electrical Engineering

3. Summer project title: Far-Field Characterization of Infrared Nanoantenna Detectors

4. Briefly describe new skills you acquired during your summer research:

Throughout the summer, I have gained lots of experience working in a lab environment and had the opportunity to create my own tests on differently fabricated nanoantennas. The skills utilized included lab safety when working with a class IV laser, coding skills in MATLAB for generating motor position recipes, and creating custom GUIs in LabView. I have also gained experience working with published research papers to help aid my understanding of the background material of the project I was joining.

5. Briefly share a practical application/end use of your research:

In the future, this research project will aid the use of nanoantennas sensitive to long-wave infrared light in solar observations. Currently, studying phenomena such as solar flares can be difficult as mid to far infrared frequencies have a low spectral irradiance meaning more sensitive instruments are needed. Additionally, directional, polarization, and wavelength selective properties allow for additional functionality such as motion tracking.

6. 50- to 75-word abstract of your project:

Semiconductor based IR detectors, bolometers, and traditional thermocouples used for measuring infrared radiation either need to be cooled or their response time is slow. A new alternative is the use of thermo-electrically coupled nanoantennas (TECNAs) that utilize the Seebeck effect to generate a response to a signal that can have directional, polarization, and wavelength selective properties all while being an uncooled, sensitive device. Further testing of these TECNAs will allow for improved measurement devices in areas such as solar research.

7. References for papers, posters, or presentations of your research:

1. Szakmany, G.P., Bernstein, G.H., Kinzel, E.C. et al. Nanoantenna-based ultrafast thermoelectric long-wave infrared detectors. Sci Rep 10, 13429 (2020). https://doi.org/10.1038/s41598-020-70062-6
2. Gergo P. Szakmany, Alexei O. Orlov, Gary H. Bernstein, and Wolfgang Porod , "Fabrication of suspended antenna-coupled nanothermocouples", Journal of Vacuum Science & Technology B 37, 052201 (2019) https://doi.org/10.1116/1.5113506
3. G. Bernstein. (2022). Thermoelectrically Coupled Nanoantennas (TECNAs) for Circularly-Polarized IR Light and Angle-of-Incidence Detection [PowerPoint slides].

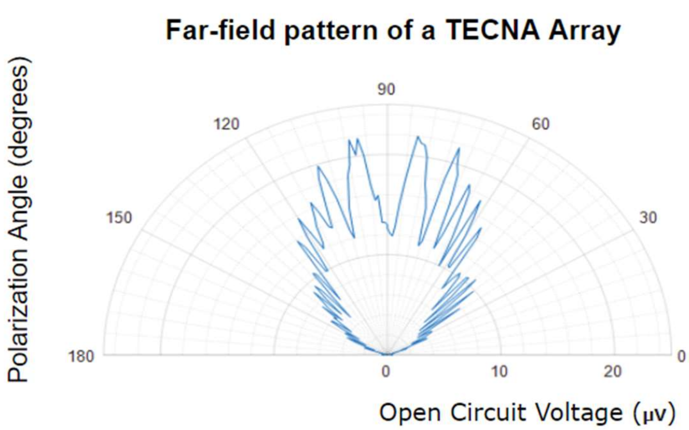
Note: These were reference materials that I used in my project. A report utilizing some of the data I collected is being submitted this week.

One-page project summary that describes problem, project goal and your activities / results:

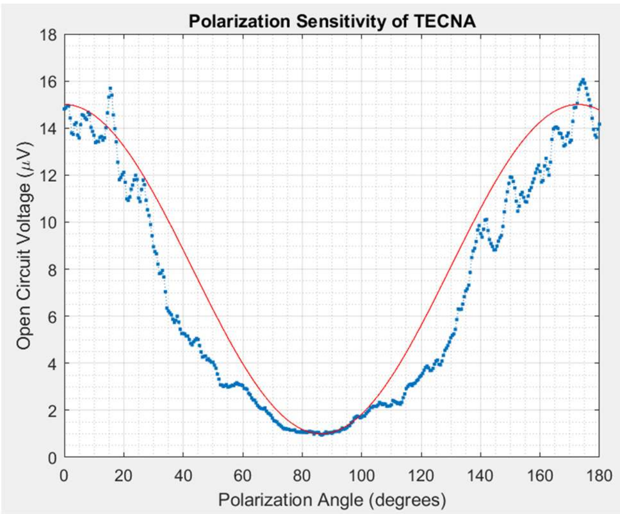
The main objective of this project is to characterize the response of various thermoelectrically coupled nanoantennas (TECNAs). These TECNAs are suspended over a spherical cavity in a silicon substrate and utilize the Seebeck effect to generate a signal when exposed to infrared light from a CO_2 laser. The incident light on the nanoantennas is absorbed creating radiation-induced antenna currents that heat the hot junction of a nanothermocouple by Joule heating. A temperature difference between hot and cold junctions creates a thermo-electric voltage that is proportional to the intensity of the incident infrared radiation and the difference between the absolute Seebeck coefficients of the metals. This process holds potential application as uncooled, highly sensitive infrared detectors that have differing properties from traditional bolometers and thermocouples.

At the start of the project, the main task was automating the testing process to allow for faster, higher resolution graphs detailing the response of the antennas when different parameters such as angle of incidence and polarization of the light were varied. Two testing apparatus were programmed using stepper motors to control the position of the antennas. The first setup uses two stepper motors to control the two-dimensional position of the antenna chips allowing for scans of the antenna response. A second setup using six motors including three translational and three rotational motors is used to control the three-dimensional position of the antenna in space. I used LabView to automate the process of collecting data from a lock-in amplifier and created a GUI for the two-dimensional sweep. Next, MATLAB was used to generate a recipe of positions to be given to the motors in a sequence to obtain a relationship between antenna response and position. These scripts accounted for geometric corrections when rotating a chip not at the center of rotation.

Once the testing process was automated, I was tasked to collect data from several different antenna chips each with different devices. By rotating the antenna chip along its Euler angles, a different property is tested. The first test was the angle of incidence sensitivity for both singular devices and antenna arrays by rotating the roll and yaw of the devices. Light hitting the antenna at an angle would result in less of a response that can be characterized. When changing the roll, the E-field (Electric Field) of the antenna is measured as the E-field of the light is no longer aligned with the antenna. Similarly, rotating the yaw measures the H-field (Magnetic Field) of the antenna. The results of H-field sensitivity for an array are below:



The signal peaks around 90 degrees which is where the H-field of the antenna is aligned with the magnetic field of the light (perpendicular angle). The surrounding 'fringes' of peaks are the result of constructive and destructive interference when light is reflected by the silicon substrate back to the antenna. Tests were also conducted with arrays where the antenna was off-centered from the cavity such that the peak would occur at other angles. When multiple of these antennas are placed over a cavity, the devices will have more directional capabilities. The second type of test I conducted was the polarization test. Instead of changing the polarization of the incident light, we opted to rotate the device along the pitch angle instead, ultimately changing the polarization of the light hitting the antenna. The following is one device's polarization sensitivity:



The result was an approximate cosine squared relationship which is consistent with antenna theory. The next steps are to continue building a dataset of these tests for different antennas with varying fabrication methods and in different environments such as a vacuum to continue to improve the sensitivity of the detectors.

One last component of my project was to characterize the CO_2 laser beam that was used in testing. The laser was a gaussian beam of about 0.150 W at a 10.6 micron wavelength. I conducted a knife edge test to determine the shape of the laser beam that will be needed to further analyze the results. The result was a net magnitude difference in the x and y axes and a slight rotation making the beam a rotated oval shape. This added analysis was needed as the size of the antennas is smaller than the beam used to scan the devices.

Each test showed the antennas were operating as expected and showed the future capabilities of utilizing the properties of the TECNAs. Future work will need to be done to minimize the fringes by potentially adding a reflective surface to the cavities to prevent the substrate effect as well as increasing the sensitivity of the devices.