NDnano Summer Undergraduate Research
2021 Project Summary

1. Student name & home university:
Kathleen Hart, University of Notre Dame

2. ND faculty name & department:
David B. Go, Aerospace and Mechanical Engineering

3. Summer project title:
Characterization of triple junction-enhanced thermally-driven plasma on the surface of pyroelectric crystals

4. Briefly describe new skills you acquired during your summer research:
I learned how to operate the experimental setup, including setting the power supply, running a LabVIEW code to measure current from a picoammeter, and measuring the distance between the crystals and wafer using a microscope camera. Using python, I was able to learn how to analyze the data in different ways, by adding error bands, integrating the data, and creating various plots. I developed skills in using Eagle to create prints and in printing them using the Voltera V-One PCB printer with conductive silver ink. I also learned how to operate an IR camera and use a computer application to collect temperature data. Finally, I learned how to communicate my research through designing and presenting a poster in a way that is logical and keeps the audience engaged, as well as through presentations at meetings.

5. Briefly share a practical application/end use of your research:
Plasmas require very high voltages to produce in useful amounts for real-world applications. This research could provide a way to produce plasmas in a more efficient and sustainable manner. By using pyroelectric crystals, it is possible to convert heat into plasma production. Heat is usually wasted in our everyday lives, so harnessing it as an energy source could reduce the amount of energy we waste. This research provides important insights into the behavior of triple junction-enhanced thermally-driven plasmas, which could be used in the future to create a realistic thermally-driven plasma device.

6. 50- to 75-word abstract of your project:
Low temperature non-equilibrium plasmas can be produced by pyroelectric crystals if they are exposed to a significant temperature gradient, what is termed an energy-conversion plasma source. The addition of a triple junction, a feature where a metal, dielectric and air meet, on the surface of the crystal enhances the electric field that produces these plasmas. This project focuses on characterizing thermally-driven plasmas enhanced by triple junctions by analyzing their dependence on distance and angle.

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

Hart, K. (July 2021) *Characterization of triple junction enhanced thermally-driven plasma on the surface of pyroelectric crystals.* Poster presented at: Notre Dame Summer Undergraduate Research Symposium. Notre Dame, IN.

[1] Johnson, M. J., Linczer, J., & Go, D. B. (2014). Thermally induced atmospheric pressure gas discharges using pyroelectric crystals. *Plasma Sources Science and Technology*, *23*(6), 065018.
[2] Jordan, N. M., Lau, Y. Y., French, D. M., Gilgenbach, R. M., & Pengvanich, P. (2007). Electric field and electron orbits near a triple point. Journal of Applied Physics, 102(3), 033301.

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

Plasmas are a form of ionized gas that have many useful properties for applications in medicine and sustainability, for example sterilization of medical equipment or pollution mitigation. However, they require high voltages to produce and therefore finding a way to convert other forms of energy to plasma production could make for more useful plasma devices. Pyroelectric crystals can be used to convert heat into electrical energy, and have been shown to produce plasmas when exposed to a significant temperature gradient [1]. This occurs because of a change in polarization that occurs when the temperature of the crystal changes, creating an electric field that is sufficient enough to break down the surrounding gas molecules.

Previous work has shown that a triple junction, a feature where a metal, a dielectric, and air meet at one point, on the surface of a dielectric enhances the local electric field [2]. The addition of a triple junction on the surface of a pyroelectric crystal would therefore enhance the formation of a thermally-driven plasma, however the physics of this feature still need to be studied. The goal of this project was to gain a deeper understanding of the fundamental physics behind a triple junction-enhanced thermally-driven plasma. This was achieved by investigating the role of distance and junction angle in the production of a plasma.

The experiment involved placing the crystals on a heater attached to a DC power supply. The crystals were lithium tantalate, with a layer of silver printed on one side in various configurations (Figure 1). The power supply was set to 6 V and turned on for 30 s, allowing the crystal to reach a maximum temperature of about 120℃, then turned off to allow the crystal to return to room temperature. A silicon wafer was mounted just above the crystal, allowing a plasma to form between them. The plasma induced a current in the wafer which was measured with a picoammeter at a sampling rate of 2-3 Hz.

We started the project by exploring various distances between the crystal and collecting silicon wafer. We implemented a microscope camera into the experimental setup in order to accurately measure the distance between the crystal and the wafer. To visualize the relationship between the plasma and distance, we integrated the current to obtain charge, which showed a clear relationship. The next step was to explore how the angle of the triple junction impacts the plasma. We did this by finding the charge as a function of distance for 30, 90, 150 and 180 degree triple junctions, and then plotting them all together. Although the total charge did not present a clear trend, the charge density did. The total charge was divided by the area of exposed crystal, indicating that there is a relationship between the angle of the triple junction and the charge density produced by the plasma. Our findings indicate that increasing both the distance and angle results in a decrease in charge density (Figure 2).

Another part of this project was developing a method to print our own silver onto crystals, making the process of producing different triple junctions more efficient and convenient. Using a Voltera V-One PCB printer, we were able to print conductive silver on lithium tantalate crystals. We designed prints for 30, 60, 90, 120, 150, and 180 degree triple junctions. We were able to repeat the same experimental procedure to the new crystals, and found a similar trend for both distance and angle. However, the angle of the silver we have printed is not as precise as we would like, therefore future work will need to focus on refining the method of printing to improve triple junction quality.

We were also able to incorporate an IR camera into the setup to accurately measure the temperature of the crystal and analyze its relationship with the plasma. Since it is not possible to measure the temperature of the crystal directly while measuring the current due to the silicon wafer, which is not 100% transparent to

IR radiation, future work will be needed to create a process of converting between the temperature of the silicon wafer and the crystal.

Additional future work will focus on characterizing the effect of other angles, for example those greater than 180 degrees, to investigate whether there is a symmetry in the enhancement. It would also be possible to explore different shapes in the silver layer and study how much of an enhancement is possible.

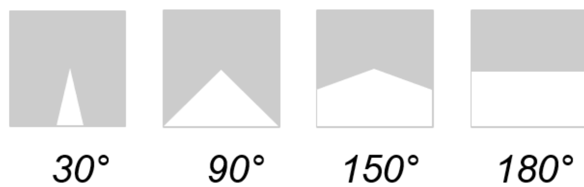

Figure 1: Schematic representation of silver printed on crystals at various angles

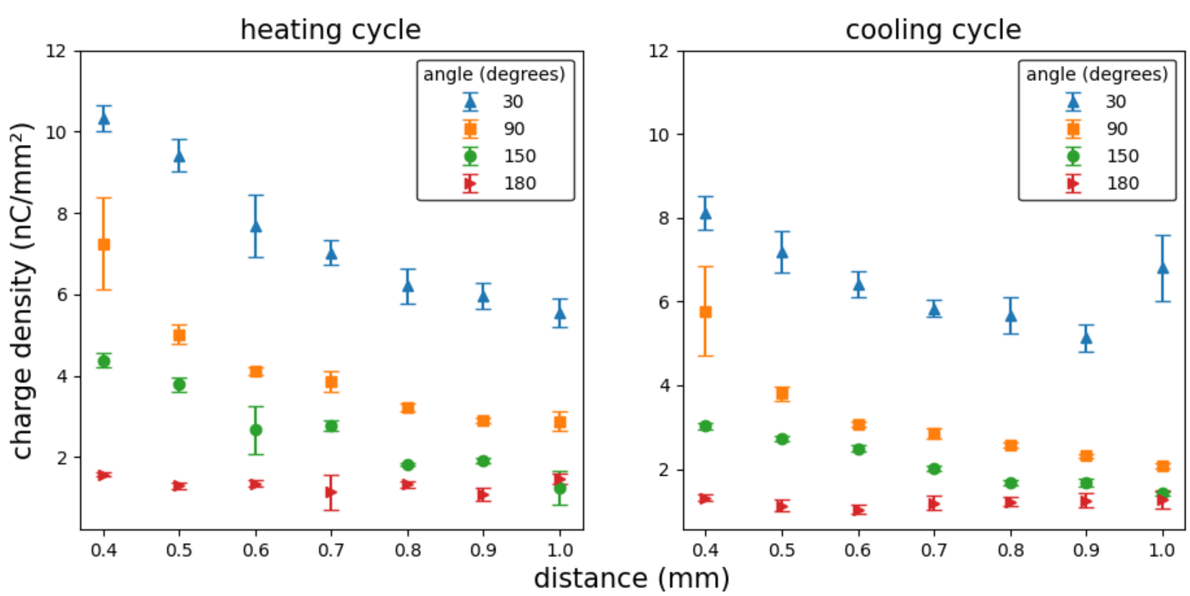

Figure 2: Charge density as a function of distance for various angles between 30- and 180-degrees