NDnano
Center for Nano Science and Technology

ND*nano* Summer Undergraduate Research 2019 Project Summary

1. Student name & home university:

Se Hwan Jeon, University of Notre Dame

2. ND faculty name & department:

David B. Go, Seong-Kyun Im, Aerospace and Mechanical Engineering

3. Summer project title:

Development of a pyroelectric-driven plasma generation testing rig.

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

For my summer research, I needed to build a setup capable of generating plasma and then measure the resultant current. In order to do so, I first needed to learn how to assemble an experimental setup that could would generate a plasma from a thermally-cycled pyroelectric, and then determine which parts were necessary to actually build the rig. Then, I was taught how to operate a magnified Nikon camera over long exposure times to image the plasma formed on the pyroelectric and counter-electrode of the testing rig. A mechanical micropositioner was also attached to the mount of the pyroelectric, and controlled with my computer so that an exact distance between the counter-electrode and crystal could be determined. To measure the current of the plasma, I had to learn how to create a program using LabView software and how to connect it to a Keithley 6487 picoammeter to take measurements. Our lab had noticed that the pyroelectric crystal would often produce spark discharges, and to try and measure the current of the transient spark, a 10 MΩ resistor was connected to a Tektronix oscilloscope that recorded the voltage drop across the resistor in the pyroelectric circuit.

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

Potentially, using heat as the only energy source, a substantial plasma could be generated for use in non-laboratory (field) settings. Traditional methods of generating plasma require using power supplies at extremely high voltages and frequencies. This research investigates unconventional methods of generating gas discharges for practical use. For example, sources of waste heat are often present in the environment. Most electronics, industrial processes, and the sun itself produces heat that could be harvested to generate useful plasma. A specific application that could be explored is the purification of exhaust from motor vehicles. By capturing the waste heat of an engine, plasmas could potentially nullify the most harmful products emitted from automobiles and other transportation vehicles.

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

In this study, a lithium tantalate pyroelectric crystal was thermally cycled with a resistance heater to produce an atmospheric pressure gas discharge. A copper plate parallel to the crystal and a picoammeter were used to determine the current of the plasma. By coating the crystal with silver paint, “triple points” were created that significantly enhanced the current of the discharge. Time-integrated visualization showed the formation of surface discharges on both crystals during the thermal cycling.

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

1. Johnson, Michael & Linczer, John & Go, David. (2014). Thermally induced atmospheric pressure gas discharges using pyroelectric crystals. Plasma Sources Science and Technology. 23. 065018. 10.1088/0963-0252/23/6/065018.
2. Kemp, Mark & Kovaleski, Scott. (2006). Ferroelectric plasma thruster for microspacecraft propulsion. Journal of Applied Physics. 100. 113306-113306. 10.1063/1.2399886.
3. Jordan, Nicholas & Lau, Yue-Ying & French, D & Gilgenbach, R.M. & Pengvanich, P. (2007). Electric field and electron orbits near a triple point. Journal of Applied Physics. 102. 033301 - 033301. 10.1063/1.2764211.
4. L. Sullivan, Dustin & Kemp, Mark & Kovaleski, Scott. (2007). Characterization of a Ferroelectric Atmospheric Pressure Plasma Source. Plasma Science, IEEE Transactions on. 35. 1480 - 1485. 10.1109/TPS.2007.905952.
5. Yoshida, Keiichiro & Johnson, Michael & Go, David. (2017). Enhancement of thin air jets produced by ring-shaped dielectric barrier discharges using an auxiliary electrode. Journal of Electrostatics. 87. 293-301. 10.1016/j.elstat.2017.06.004.

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

Traditional methods of generating non-equilibrium gas discharges have involved using electrodes at hundreds to thousands of volts, but by taking advantage of the material properties of non-centrosymmetric crystals, a plasma can be generated with alternative sources of energy such as vibration or heat. Due to the intrinsic properties of the crystal, a change in temperature with respect to time creates a significant electric potential at the crystal surface, leading to the breakdown of the nearby air molecules and the formation of plasma. Potentially, these atmospheric-pressure plasmas could be generated with no electrical power source and be integrated into portable plasma devices for use in the field. With a substantial discharge current, the devices could then be used in a variety of possible applications, such as air or water purification, propulsion technology, and surface treatment.

While the concept of using pyroelectric crystals to thermally drive plasma generation has been demonstrated previosuly[1], the resultant discharge current was too weak to have any significant practical application as it was on the order of nA. The goal of this project over the summer was to recreate the experimental testing rig, and then characterize strategies to enhance the plasma generation from the surface of the crystal.

For this study, optical parts were assembled to recreate a similar, if not identical, setup as the one previously built to generate an atmospheric pressure gas discharge. By adhering a pyroelectric crystal (lithium tantalate) to the surface of a resistance heater and positioning a needle counter-electrode over it, plasma was observed around the tip of the needle and the surface of the crystal as the crystal was thermally cycled. A magnified Nikon camera was used to image the plasma with exposure times of 15 and 30 seconds in a dark room, and a clear corona discharge can be seen around the counter-electrode.

Having visually confirmed the discharge, the next step was to characterize the current of the generated plasma. By attaching the counter electrode to a Keithley 6487 picoammeter and using LabView to control data collection, current measurements of 20-50 nA were obtained, which confirmed earlier findings[1]. Occasionally, visible sparks were noticeable from the crystal to the counter-electrode, a Tektronix oscilloscope with a 10 MΩ resistor was also used to try and determine the current of the spark discharge, but was unfortunately unable to capture the current, possible due to the setup or geometry of the counter-electrode.

After successfully recreating the thermally-driven pyroelectric testing rig, methods were explored to enhance the current of the plasma to significant levels (on the order of at least 1 μA). The main strategy investigated was modifying the surface of the pyroelectric to create triple points that theoretically would create much higher localized electric fields, aiding in plasma formation and propagation[2, 3]. By coating the surface of the crystal with a variety of patterns of silver paint, there was a noticeable increase in the current measured. As shown in Figure 1, the needle electrode was exchanged for a copper plate electrode placed parallel to the crystal in order to cover the entire surface of the crystal. The measured current for an unmodified crystal was around 2-3 nA, and around 25-30 nA for the painted crystal, nearly a tenfold increase, as shown in Figure 2.

Currently, methods for enhancing the current even further are being explored. Metal electrodes in a variety of configurations and materials were attached to the crystal surface as was explored in other works[4, 5]. The surface of the crystal has been modified with varying geometries of copper tape, mesh, and silver paint, but a current near the target of 1 μA has not been obtained yet. Furthermore, a variety of crystal materials have also been tested. Lithium niobate as well as lead zirconium titanate were tested as alternative pyroelectric crystals, and further work is required to determine the optimal crystal material for thermally-drive plasma generation.

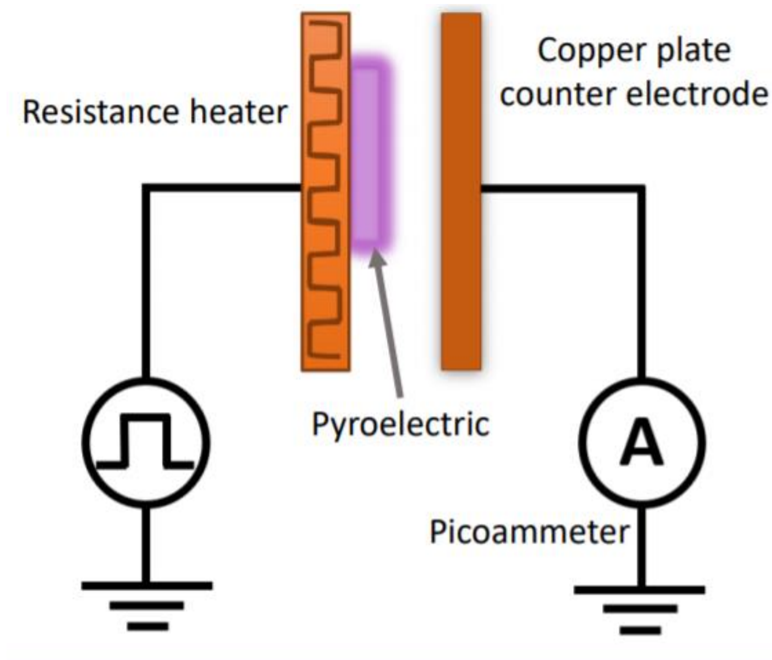

Figure 1. Pyroeletric thermally-driven plasma generation testing rig schematic.

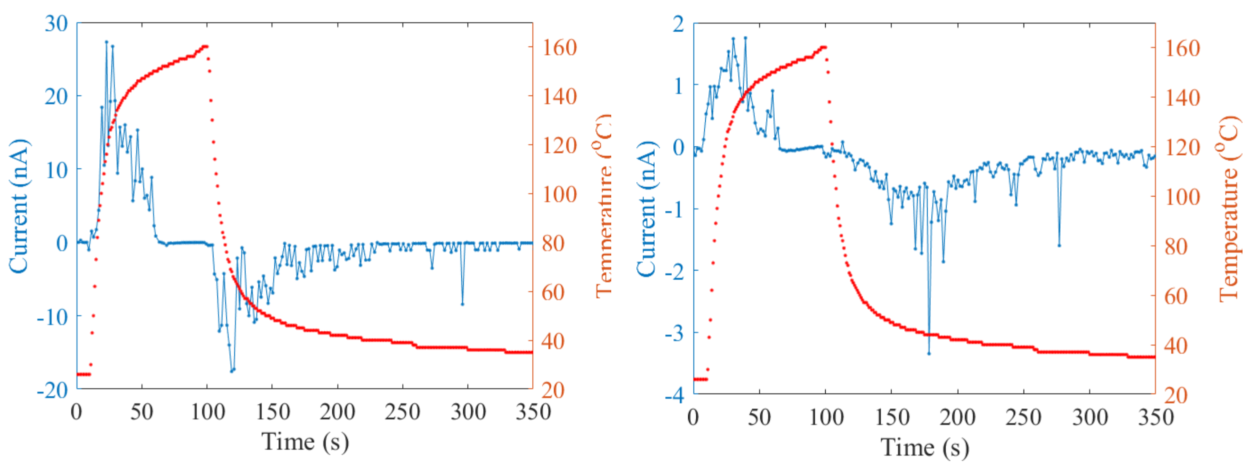

Figure 2. Plot of current and temperature vs. time for modified (left) and unmodified (right) pyroelectric crystal.