NDnano Summer Undergraduate Research
2021 Project Summary

1. Student name & home university:

Nicholas DeLuca – University of Notre Dame

2. ND faculty name & department:

David B. Go, Department of Aerospace and Mechanical Engineering, Department of Chemical and Biomolecular Engineering

3. Summer project title:

Generating Continuous Spark Discharges Through High-Frequency Mechanical Actuation of Piezoelectric Crystals

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

I learned about traditional methods used in the production and characterization of transient sparks, along with fundamentals of piezoelectricity and its potential in the emerging field of energy conversion plasmas. I was able to further develop CAD skills to aid in the mechanical design of belt systems and crank-slider mechanisms.

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

This research explores the potential use of piezoelectric crystals for transient spark generation. Piezoelectrically induced plasmas would not require a high voltage power source, making them ideal for non-laboratory settings. For example, the rotation of high-speed components within internal combustion engines or turbomachinery can be harnessed to produce plasmas at little energetic cost. These plasmas could be used for purposes such as pollution mitigation within the larger mechanical system.

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

Plasmas are typically generated using a high voltage power supply, usually confining them to laboratory settings. The voltages induced by the mechanical deformation of piezoelectric crystals can be used to create filamentary spark discharge plasmas. This research focused on the design of a mechanical system to actuate piezoelectric crystals at high frequencies with the goal of creating usable continuous spark discharges.

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

[1]DeLuca. Generating Continuous Spark Discharges Through High-Frequency Mechanical Actuation of Piezoelectric Crystals. Poster presented at: Notre Dame Undergraduate Research Symposium; July 21, 2021; Notre Dame, IN.
[2] Jaenicke et al. Appl. Phys. Lett. (2020)
[3] Matsumoto et al. IntechOpen. (2012)
[4]Tired Tires, "Piezoelectric Effect in Quartz", https://dev.nsta.org/evwebs/2014102/news/default.html

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

Conventional methods of producing plasmas require the use of high voltage power supplies, which primarily constrain plasma devices to laboratory settings. Piezoelectric crystals have been recently explored as an alternative source for high voltages as they are relatively inexpensive and generate electric potential purely from mechanical deformation. Previous work has shown that certain piezoelectric crystals exhibit relaxation times on the microsecond scale, suggesting high frequency actuation as a feasible method for continuously generating spark discharges at atmospheric pressure. These plasmas have been shown to produce promising results in pollutant removal, specifically with regards to agriculture and water purification.

Preliminary work included the study of a piezoelectric grill ignitor. The ignitor functions by storing potential energy within a spring. When the button is pushed, the spring is released, sending a firing pin into the piezoelectric crystal causing it to deform. This deformation induces a transient high voltage that is applied across an air gap, resulting in a spark. Initial voltage measurements were taken of the discharge using an oscilloscope. The air gap distance was minimized to find the minimal breakdown voltage required to produce a visible spark. It was found that a discharge could be observed with as little as 450 V given a small enough air gap.

A mechanical system consisting of a motor, belt, and pulleys was designed and constructed to actuate a piezoelectric crystal at frequencies from 1-10 kHz. The design involves teeth on a rotating piece that strike a steel electrode pressed against a lead zirconate titanate (PZT) crystal, compressing the PZT crystal. A tungsten needle wired to the electrode routes the discharge towards a grounded copper plate. Testing consisted of spinning this toothed piece up to speed before slowly raising the electrode into its path for impact. Various tooth designs were 3D printed from PLA to best optimize impact angle and frequency. High-speed footage was taken of each design to compare these parameters. Two designs were selected and manufactured from steel using a wire EDM.

Additionally, an impact piston was designed based on a simple crank-slider mechanism. This mechanism translates rotational motion into linear motion and is driven by the previously built belt system. There were both advantages and disadvantages to this approach. A crank-slider mechanism is limited to one stroke per revolution, which drastically limits the impact frequency. The linear trajectory, however, is much more effective in transferring energy into mechanical deformation than the rotating toothed piece. Various iterations were modeled and prototyped using a 3D printer. Many parameters and challenges have been accounted for including the balance of the piston, heat due to friction, vibration, lubrication, stroke displacement, mounting, and hinge connections as well as the mounting of the crystal to ensure direct impact.

Testing showed that a continuous spark discharge could successfully be created using the piston assembly. The highest frequency achieved was 36 Hz. While this is short of the original goal, it serves as a proof of concept and as a basis for future work which will include electrically characterizing the plasma and eventually focus on further improving the current design to achieve higher actuation frequencies.