NDnano
Center for Nano Science and Technology

ND*nano* Summer Undergraduate Research
2019 Project Summary

1. Student name & home university:
Alfred Chang
Carnegie Mellon University

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

3. Summer project title:
Development of a Flowing Thin-Film Plasma-Liquid System

4. Briefly describe new skills you acquired during your summer research:
From my research this summer, I have gained a myriad of new skills. I have learned to be a better presenter and public speaker. I have become a better researcher by learning to view my research project as a personal undertaking and to complete my research as I would a personal project. I have learned to think more outside the box as a problem solver, learned to work together with others, learned how to self-learn, and learned to write abstracts and create research posters.

5. Briefly share a practical application/end use of your research:
Although this project is still in its early stages, a flowing thin-film plasma liquid system has applications in high-throughput wastewater treatment, nanoparticle synthesis, and catalyst-free chemical synthesis.

6. 50- to 75-word abstract of your project:
Recent experiments from the Go Research Group using a batch reactor plasma electrolytic cell observed a significantly lower faradaic efficiency, the ratio of product molecules to incident electrons, than that expected from theoretical predictions. This reduced value is consistent with the intended reaction being limited by reactant depletion at the plasma-liquid interface. To mitigate this effect, the aim of this work is to construct a microfluidic flowing thin-film plasma system to examine the effects liquid film thickness, on the order of the size of the depletion region, has on faradaic efficiency, using flow to refresh processed liquid and inhibit evaporation.

7. References for papers, posters, or presentations of your research:
Chang, A. (July, 2019). *Development of a Flowing Thin-Film Plasma-Liquid System*. Poster Presented at: Notre Dame Summer Undergraduate Research Symposium. Notre Dame, IN.

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

Plasma electrolysis is an electrochemical process where one of the metal electrodes is replaced with a plasma (a cloud of ionized gas molecules). In such a system, the electrons from the plasma dissolve into the solution and act as the primary chemical reaction driver. Because of electrons' highly reactive nature, they are able to produce chemistry that lends plasma-liquid systems to have applications in medical therapy, wastewater treatment, nanoparticle synthesis, and catalyst-free chemical processing. The measure for the quality of these systems is evaluated by the faradaic efficiency, calculated by dividing the number of product molecules by the number incident electrons. Previous research conducted within the Go Research Group has found that the faradaic efficiency in batch reactor systems is significantly lower than that expected from theoretical predictions (Figure 1). This is believed to be a function of reactant transport limitations to the plasma-liquid interface.

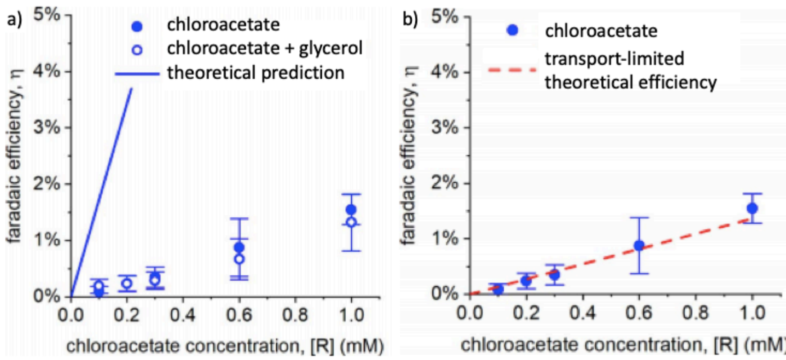

Figure 1: Faradaic efficiency in batch reactor plasma electrolytic cell is significantly lower than previous predictions
Source: Delgado, et al., J. Electrochem. Soc. 166.6 (2019): 181-186.

The aim of this work is to study the effect a flowing thin-film plasma liquid system has on faradaic efficiency. The reason for choosing such a system is two-fold. First, a thin-film, on the order of magnitude of the reactant depletion region, allows plasma-chemistry to reach a greater percentage of the fluid thickness. Second, flowing the fluid refreshes processed fluid and mitigates the effects of evaporation. To achieve such a system, the initial approach was using a falling-film (unbounded) on an inclined surface. Initial tests with the system were successful in obtaining a stable plasma on the flowing liquid. However, the thickness of the liquid film was not sufficiently small to study the role of transport on the faradaic efficiency. For this reason, a microfluidic channel design was utilized (Figure 2). In this configuration, fluid flows in from the left, passes underneath the plasma cathode (situated in the middle of the channel), and exits from the rightmost outlet.

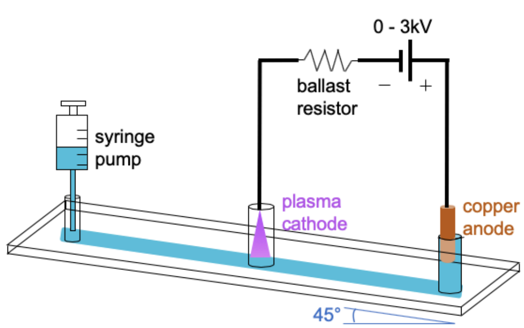

Figure 2: Microfluidic channel setup using a three layered polycarbonate channel 70 x 2 x 0.3 mm

The microfluidic channel presented an unforeseen challenge. The moment plasma formed at the liquid surface, air pockets appeared within the channel, disrupting the connection between the plasma cathode and the copper anode through the solution, and caused the plasma to become unstable or even extinguish. Without a stable plasma, the plasma-liquid system would be unable to continuously process fluid. To address this problem, a matrix of flow rates and plasma currents were tested to identify potentially stable conditions (Table 1).

Table 1: Tests for a Stable Plasma Configuration

Flow rate $[\frac{mL}{hr}]$	Current [mA]: 1	Current [mA]: 3
0.02		
0.10	X	
1.00	X	X
10.00		
47.60	X	

Salt Concentration: 20 mM $NaClO_4$

Although no configuration of parameters that forms a stable plasma has been found, these results suggest that the effects of evaporation and electrostatic Maxwell pressure may have a larger effect on microfluidic systems than previously thought, especially when considering that the falling-film setup formed stable plasma. This project is still in the early stages of its study. More experiments with higher flow rates, different currents, and higher salt concentrations need to be tested as well as alternate channel designs and electrode placements. Once a stable plasma is formed, the system can be used to degrade methylene blue dye for faradaic efficiency measurements.