ND*nano* Undergraduate Research Fellowship (NURF)
2015 Project Summary

1. Student name: **Jorge Ramirez.**

2. Faculty mentor name: **David B. Go.**

3. Project title: **Plasma jets for nanomaterials synthesis.**

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

I was in an environment that allowed me to think critically, take ownership of my project, collaborate with lab mates, and acquire new knowledge on plasma science and nanotechnology.

I learned to characterize silver nanoparticles using the technologies of UV/vis spectroscopy, scanning electron microscopy, and dark field microscopy.

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

The controlled synthesis and deposition of silver nanoparticles has significant applications in the advanced manufacturing of photonic and electronic technologies.

Project summary to describing problem and project goal and activities / results:

Metallic nanoparticles (NPs) are currently attracting attention for a wide range of applications. In particular, the controlled and uniform deposition of colloidal silver NPs has significant applications in the advanced manufacturing of photonic and electronic technologies as well as environmental and medical devices. Therefore, a deep understanding of the spatial control over the deposition of NPs in a drying solution is vital in many industrial and scientific processes. Plasma electrochemical synthesis is a promising new approach to this need. This project targets using plasma electrochemistry to synthesize silver nanoparticles. Furthermore, using plasma electrochemical synthesis to process droplets and control *in situ* deposition of colloidal NPs creates new opportunities for the fast manufacturing of NP-based technologies.
Typically, when NPs are deposited from colloidal solutions, they are drop-cast onto a substrate, but form a 'coffee stain'-like ring, which is not useful for most applications. Two conditions are necessary for ring formation of a drying drop: contact line pinning and evaporation form the edge of the drop. When either of these conditions is relaxed the final deposit is uniform[4]. Using the power deposition of a plasma, we aim to control the ring formation of colloidal silver NPs. Given the high complexity of these physical and chemical phenomena, detailed fundamental studies are necessary for effective use of this procedure.

Experiments to study novel plasma configurations for plasma/liquid interactions in a plasma electrochemical cell were performed. These studies consist of holding a metal capillary tube at high electric potential relative to an aqueous droplet breaking down the gas between the capillarity tube and liquid interface into a plasma and injecting electrons into the solution. These electrons electrochemically reduce silver cations (Ag^{+}) in the solution to silver (Ag^{0}) to form colloidal silver NPs. Simultaneously, the plasma evaporates the droplet leaving behind the silver NPs directly on a flat substrate where they can easily be used or integrated into a device.

Using a systematic experimental approach, and microscopy and spectroscopy technologies, we studied the control that processing properties have over the synthesis and ultimately the self-organization of NPs on the surface of the substrate/anode. Acquired optical micrographs showed that plasma power deposition can be used to homogenize the solute deposition. In other words, the typical 'coffee stain' – like ring formed when a droplet evaporates on a substrate was prevented using a plasma power deposition and the final pattern of the solute on the substrate was more uniform and evenly distributed.
In order to confirm the formation of silver nanoparticles in the plasma electrochemical cell, absorption spectroscopy techniques were utilized. Silver nanoparticles exhibit a surface plasmon resonance effect when they interact with light of a specific wavelength. Several liquid solutions with colloidal particles synthesized from a metal salt using plasma electrochemistry were analyzed using UV/vis spectroscopy. A surface plasmon resonance peak was observed at around 425 nm indicative of the presence of nano-sized silver particles.
To confirm the presence of nanosized particles on a substrate surface after synthesis and deposition process UV/vis spectroscopy and dark field microscopy techniques were utilized. Plasmonic particles were observed in the dropcast deposition of colloidal particles using dark field microscopy.

In summary, the manipulation of the deposition of solute in a drying droplet using a plasma jet as well as the formation of silver nanoparticles in a plasma electrochemical cell were confirmed using optical microscopy, UV/vis spectroscopy and dark field microscopy.

Publications (papers/posters/presentations):

NDnano Undergraduate Research Fellowship (NURF) oral presentations. Wednesday, July 22nd, 2015. The University of Notre Dame.

Undergraduate summer research symposium. Friday, July 31th, 2015. The University of Notre Dame.