UNIVERSITY OF NOTRE DAME
NDnano
CENTER FOR NANO SCIENCE AND TECHNOLOGY

ND*nano* Undergraduate Research Fellowship (NURF)
2013 Project Summary

1) Student name: Buchanan Bourdon
2) Faculty mentor name: Professors Alan Seabaugh and Susan Fullerton
3) Project title: Electrostatic Doping of 2D materials via Polymer Electrolytes: Using COMSOL to Simulate Ion-electron Transport

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

This research allowed me the opportunity to learn how to use the probe station and operate the automation feature using the Nucleus automation software. In addition, I learned how to use the Wavevue software via GPIB communications to interconnect the autoprober's and semiconductor parameter analyzer's operations. The goal of my project was to simulate ion-electron transport and this allowed me the opportunity to learn how to utilize COMSOL Multiphysics software to model physical phenomena.

5) Please briefly share a practical application/end use of your research:

To reduce power dissipation in electronics, we must reduce the operating voltages of the individual components, including memory. By using COMSOL Multiphysics software to model ion transport, we can gain insight on how to better develop low-voltage nanoionic memory devices that could lead to more efficient electronic devices.

Project Summary:

The development of increasingly smaller electronic devices necessitates the development of low-voltage components, including memory.[1] Recent ion-based memory concepts have focused on the formation and destruction of a conductive filament formed by the migration of ions; however, one drawback to this approach is that it requires a high-voltage forming step.[2] The long-term goal of this project is to develop a low-voltage nanoionic memory based on electrostatic doping that implements graphene and a polyethylene oxide (PEO) and LiClO4 as a solid polymer electrolyte with an ether oxygen to lithium ratio of 20:1. Graphene is used because (1) it has a high electrical conductivity in which electrons move at 1/300th the speed of light[3], (2) a surface at which ions will not react, and (3) it is a two-dimensional material that is only one atomic layer thick, allowing us to approach the limits of scaling[4]. The memory will operate by moving ions in the polymer towards and away from the graphene surface, thereby modulating its conductivity, which will be sensed to indicate the state of the memory. The goal of this summer's research was to use COMSOL Multiphysics software to simulate ion transport in a simplified architecture comprising a source, drain, and backgate to model how the ions respond to an electric potential.

We simulated systems with a continuous graphene channel and ones that had a gap (figure 1). The back gate voltage controls the electric potential through the channel between the source and drain. Using the dielectric constants and electrical conductivities derived from experimentation, we determined that the ions take up to five seconds to reach a homogeneous concentration profile for a back gate voltage of -5 V – a timescale longer than preconceived (figure 2). Specifically, a p-n-p junction is formed in the channel when the back gate voltage is positive, and an n-p-n junction is formed when it is negative (figure 2). When relaxing the system by instantaneously changing the back gate voltage from -5 V to 0 V, we determined that it can take up to 20 seconds for the anions and up to 35 seconds for the cations to return to a homogeneous concentration profile. These results will inform decisions on how to gate the device experimentally. Future work will include adding a top gate to generate a uniform electric potential, and accounting for non-idealities such as electrochemistry to more accurately represent the experimental system.

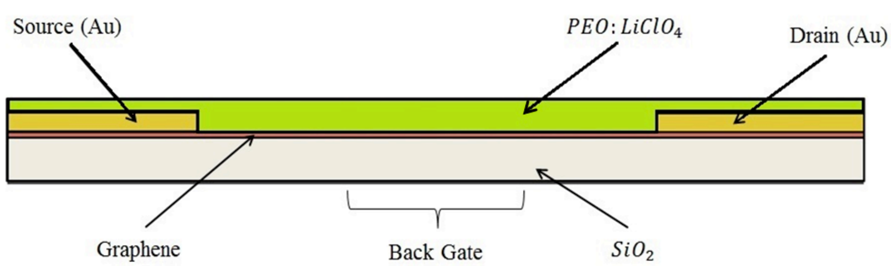
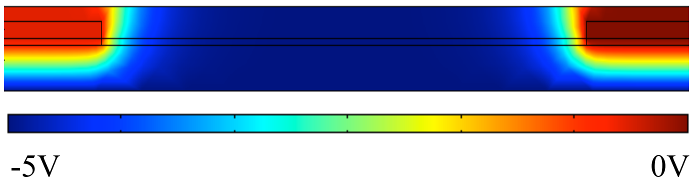


Figure 1. Device with Continuous Graphene Between Source and Drain

1 Guo. Y., *et al.* **Organic Electronics** (2012), 1969-1974
2 Wu, S., *et al.* **Adv. Funct. Mater.** (2007), 93-99
3 Meric, I. *et al.* **Nature Nanotechnology** (2008) 654-659
4 Geim, A. K. and Novoselov, K. S. **Nature Materials** (2007), 183-191

Electric Potential



$V_{BG} = -5V$
$V_{SD} = 0.5V$
Source/Drain Channel = 5 µm

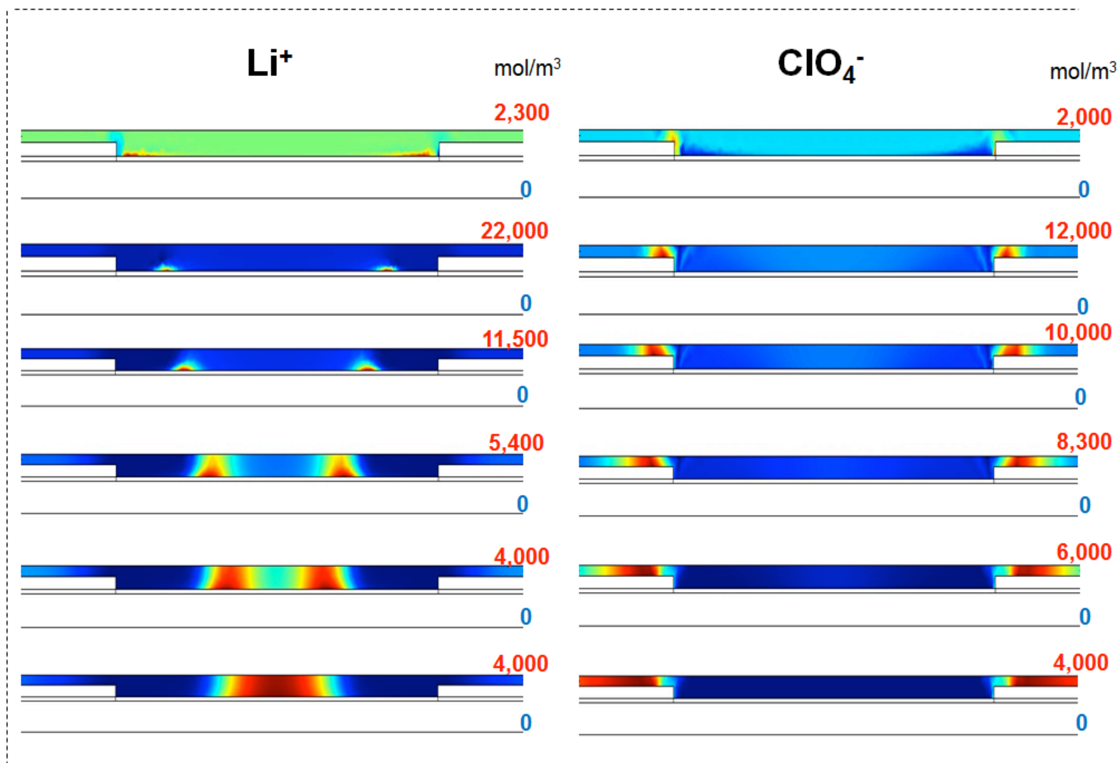


Figure 2. Ion concentration profiles as a function of time for continuous graphene model

Publications (papers/posters/presentations):
I presented a poster at the 2013 Summer Undergraduate Research Symposium. The poster was titled "Electrostatic Doping of 2D materials via Polymer Electrolytes: Using COMSOL to Simulate Ion-electron Transport" and was coauthored by Joshua Vahala, Alan Seabaugh, and Susan Fullerton