Ionic Transport Across Atomically Thin Graphene Membranes

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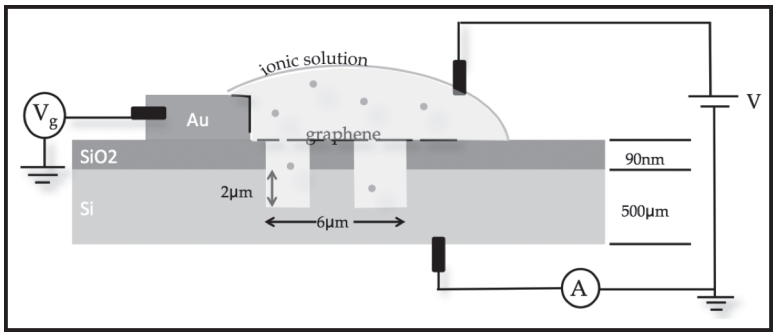


Figure 1: Side view of a completed device schematic.

Abstract and Introduction:

Membranes for ionic separation in fluids have a promising future in applications ranging from the environment to biotechnology. The mechanical robustness and atomic thinness of graphene make it an ideal candidate for such technology. Graphene, a single atomic layer of sp2-bonded carbon atoms, has the potential to achieve high levels of permeability and selectivity at low pressures, therefore making it an inexpensive alternative to current state of the art membranes. The focus of the project was to fabricate and characterize a device allowing for the electrostatic control of ions through pores in a graphene membrane.

Device Design:

The device consists of a graphene membrane suspended over a well that has been etched into a silicon/silicon dioxide substrate. The graphene is in contact with a gold electrode and supported by a post in the well. A drop of ionic solution is strategically placed so as to simultaneously cover the suspended graphene and contact the electrode (Figure 1). Slight imperfections in the graphene, attributed to induced tears and defects from the transfer process and voids between grain boundaries, should allow the ionic solution to pass through the graphene and fill the well.

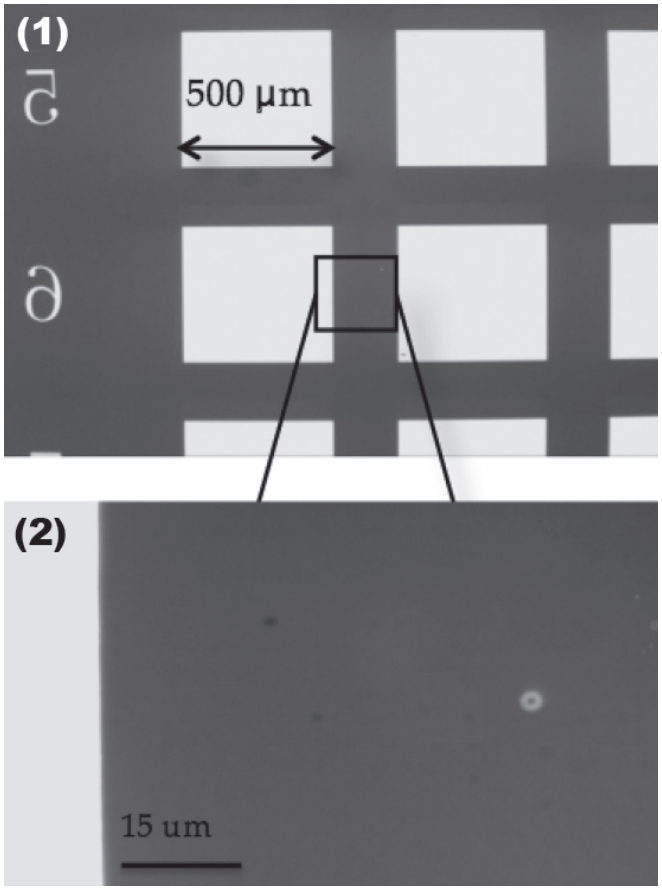
A voltage applied to the ionic solution serves as a driving current for ions passing through pores in the graphene membrane [1]. An additional level of control may be introduced by applying a voltage to the electrically contacted graphene. Such a design may allow one to alter the electric field at the membrane interface, and therefore selectively control the flow of ions in solution.

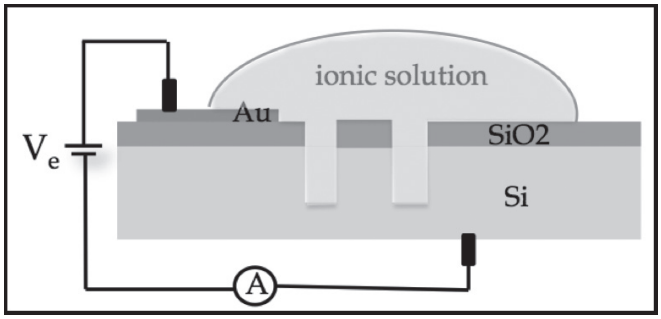
Fabrication:

The device was fabricated using a bilayer photolithography process. A 500 μm Si wafer with a 90 nm silicon dioxide layer served as the substrate. Gold electrodes were first patterned onto the wafer using evaporation (10 nm chromium, 50 nm gold) and lift off techniques. Circular wells containing structural post supports were then patterned onto the wafer and etched using standard lithography methods and reactive ion etching. An optical image showing a completed device is shown in Figure 2. The etched annular ring is shown next to the gold electrode (Figure 2, lower). Atomic force microscopy was used to ensure that the wells were etched sufficiently deep into the silicon layer of the wafer. Graphene grown through chemical vapor deposition was then transferred onto the wafer using a dry transfer technique [2], and atomic force microscopy was used to check for suspended graphene.

Results and Conclusions:

A device without graphene was characterized to ensure that a current was capable of passing through an ionic solution to the silicon back gate. A drop of ionic solution was first placed onto the device using a micropipette. The drop was positioned in a way such that the solution could fill the well and contact the underlying silicon layer. It was also necessary for the drop to contact an adjacent electrode (Figure 3). A two point probe test was used to sweep the voltage applied to the electrode, and the current associated with the silicon back gate was recorded (Figure 4). The voltages applied to





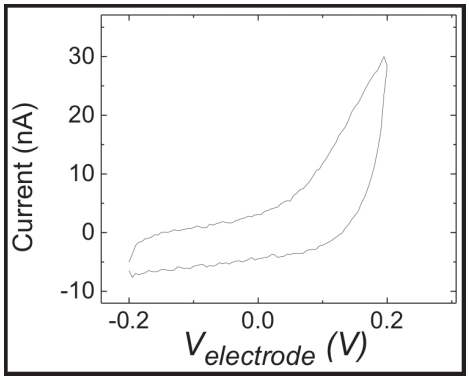


Figure 2, left: Optical image of a device before graphene transfer. (1) Patterned gold electrode. (2) Etched annular ring.

Figure 3, top: Schematic of a two point probe test used to characterize the device before graphene transfer.

Figure 4, bottom: IV curve for a two point probe test characterizing the device before graphene transfer.

the electrodes varied between -200 mV and 200 mV and the associated currents were in the ~ -10 to 30 nA range. The hysteresis in the graph may be attributed to a capacitance in the solution created by an uneven distribution of ions when the voltage is flipped from negative to positive. The diode like behavior is attributed to the silicon-ionic solution contact. This characterization process will be used in future electrical testing in which a graphene membrane has been incorporated into the device.

Future Work:

Future work will include two point probe tests in which a graphene membrane has been suspended over the well. Three point probe testing in which a constant voltage is applied to the ionic solution and a gated voltage is applied to the graphene will also be conducted.

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References:

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