Improving Bio-sensors Using Graphene Field Effect Transistors

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Motivation

Graphene is a two-dimensional, single atomic layer of carbon whose conductance changes with external voltages. Cell activity (e.g., nerves) results in electric impulses; therefore, graphene can be used to detect cell activity. This type of device is knowns as a biological sensor. These impulses by the cell create voltage changes that can be measured. Graphene is extremely thin, using it as a biological detector should be more sensitive than traditional, bulk, detectors. The goal of this project is to study the electrical properties of graphene by modeling biological activity as an external probe in a buffered electrolyte.

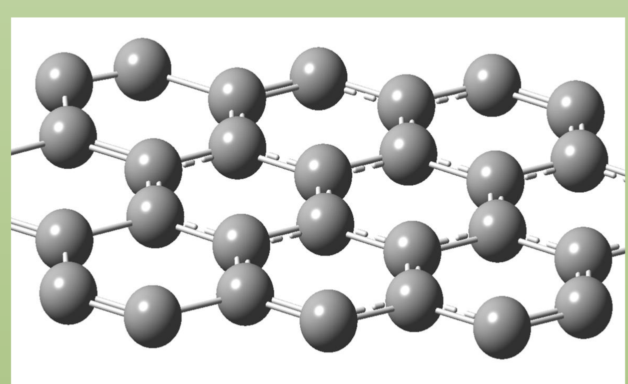


Figure 1. Atomic schematic of graphene (Taken from Wikipedia)

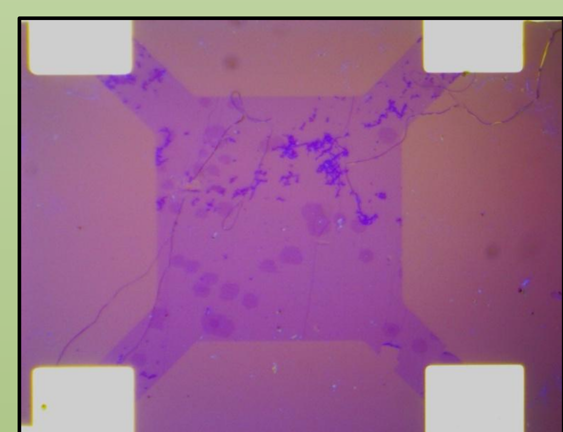


Figure 2. Actual graphene field effect transistor device

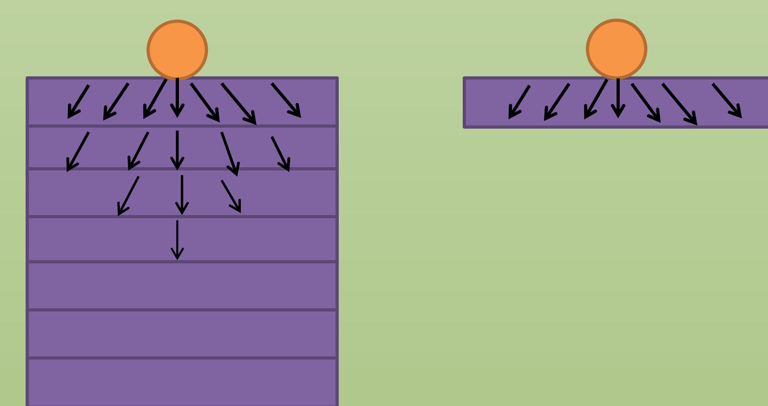


Figure 3. The resistance must be averaged over all layers in the detector. Not all layers can detect the surface interference and will bring the average down. With only a one atom thick layer to average across the sensitivity and accuracy will be much higher.

Background

- Graphene's resistance (R) changes as a result of changes in voltage (V).
  - This voltage can be due to cell activity or by a controlled voltage, called the gate voltage (V_G), that has been applied to the system

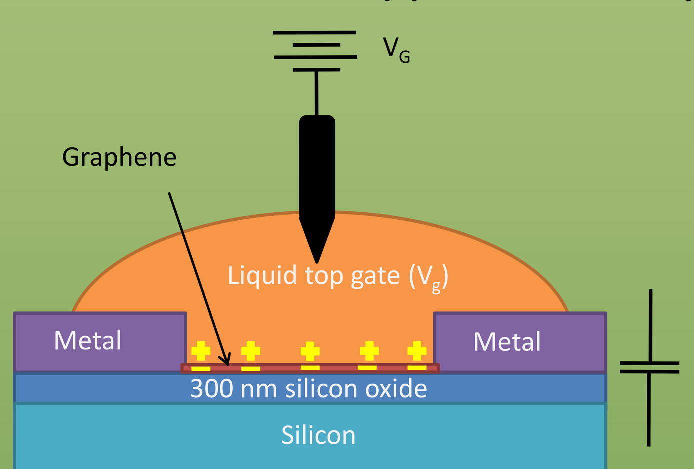


Figure 4. GFET schematic. Voltage is applied from the top into the liquid. Voltage is measured across the probes and current measured across the corresponding perpendicular probes.

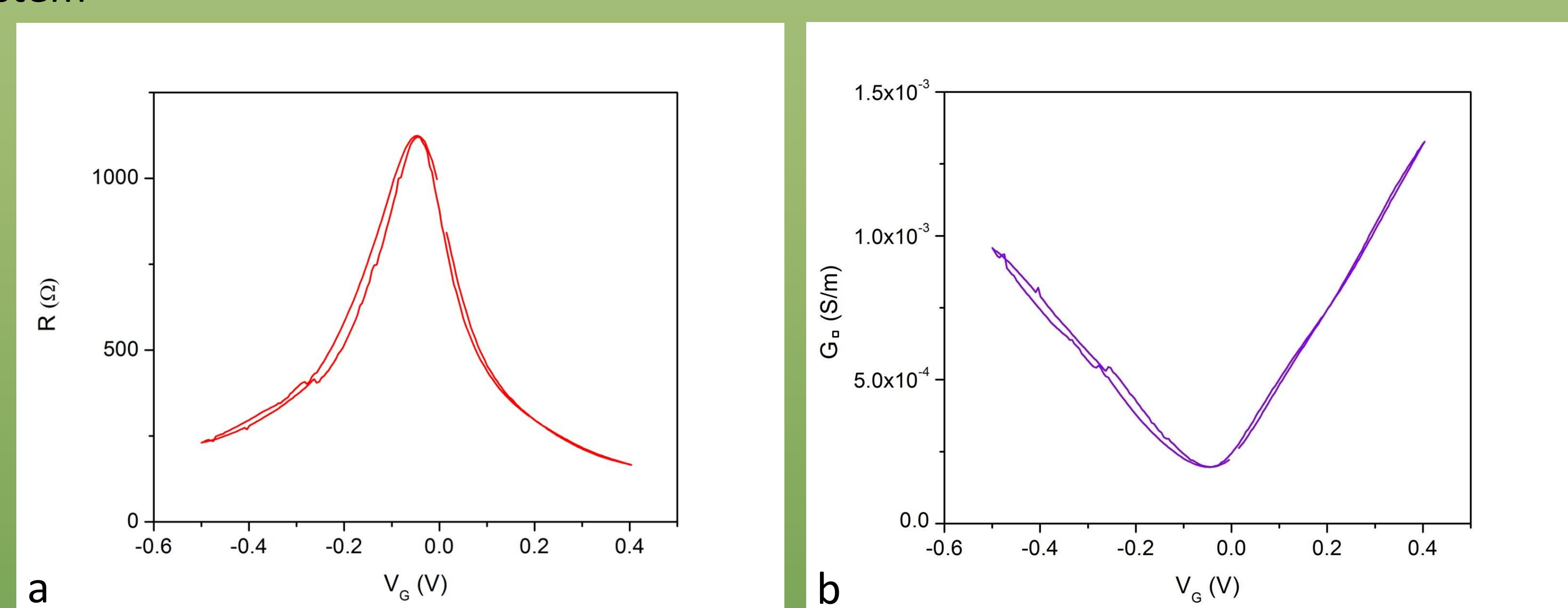
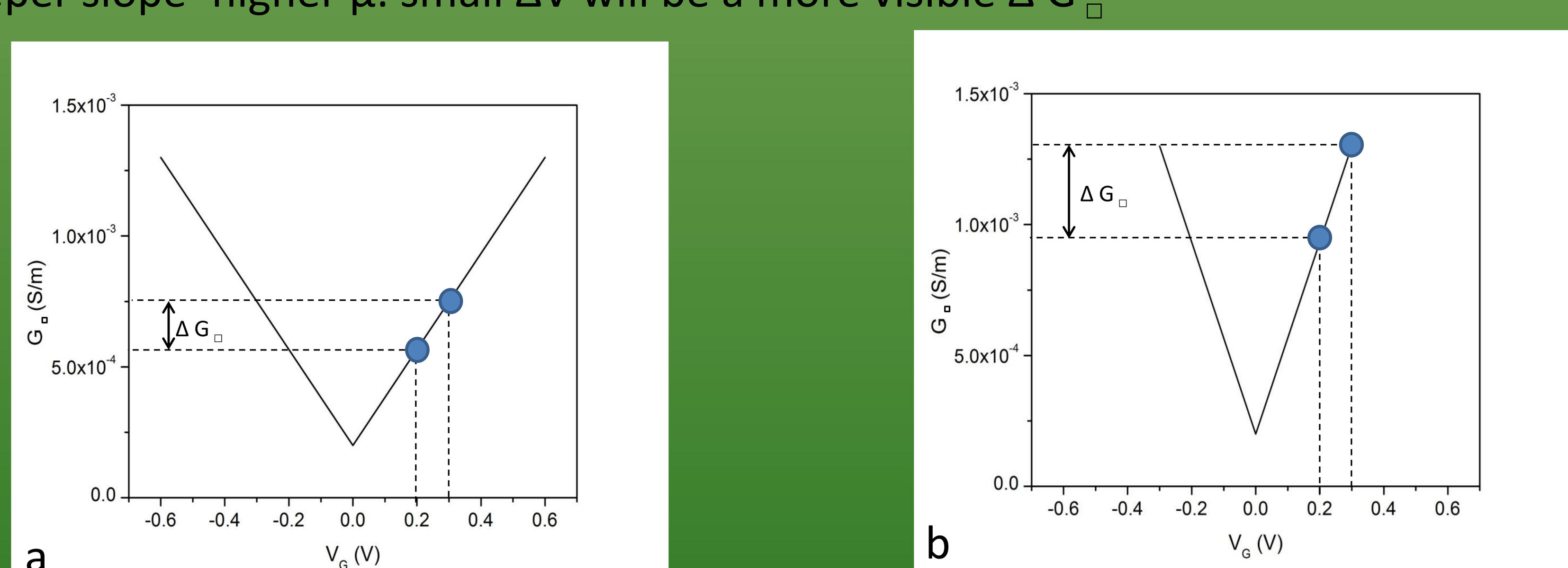


Figure 5. (a) Resistance versus gate voltage of the graphene. (b) Sheet conductivity versus gate voltage.

- To use as sensor, measure change in square conductivity ($G_{\square}$)
- $G_{\square} = 1/R$
- Device is held at a constant V which has a corresponding $G_{\square}$, cell activity causes a Δ V which results in Δ $G_{\square}$ that can be measured
- Steeper slope=higher μ: small ΔV will be a more visible Δ $G_{\square}$



$$\mu = \frac{\partial G}{\partial V_g}\frac{1}{C}$$

Figure 6. (a) Sheet conductivity versus gate voltage. Constant voltage with corresponding conductivity. Cell activity causes a change in the voltage with a resulting change in conductivity. (b) With a steeper slope (higher mobility) the same amount of voltage change results in a bigger conductivity change.

- Mobility (μ) proportionate to the slope of the conductivity
- Studies have shown mobility in liquid is diminished greatly [1]
- If there is other substances on the surface they will add to this decreased mobility. If they can be removed the mobility will improve.

Methods

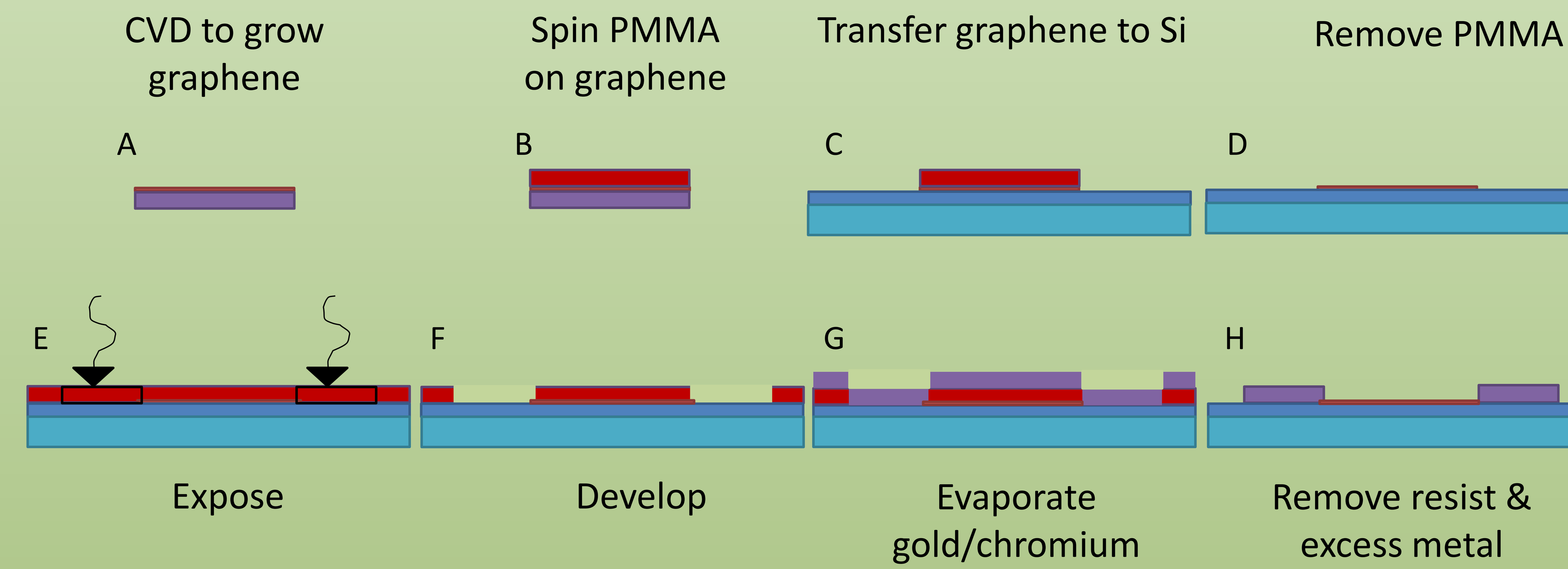


Figure 7. Process for creating a GFET. (a) Graphene is grown on copper foil, (b) a protective layer is spun onto the graphene, copper is removed from the graphene, (c) graphene is placed on a silicon chip that has a layer of silicon oxide, (d) protective layer (PMMA) is removed, (e) a layer of light sensitive material (photo-resist) is spun on the silicon chip, light is exposed on the surface in patterns that form the shape of desired circuit wires, (f) silicon chip is developed to allow the phot-resist to react and leave the surface, (g) chromium and gold are evaporated onto the chip, (h) excess photo-resist is removed and along with it the excess metal.

Van der Pauw method

Method of measuring resistance. This method was utilized because the geometry leaves a large open surface area for detecting organisms.

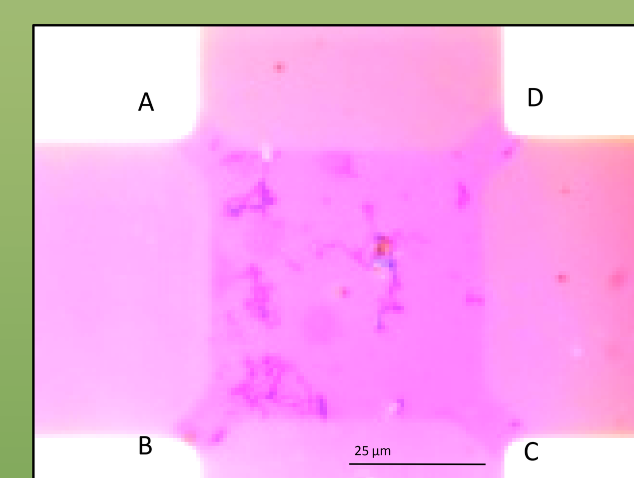


Figure 8. GFET with metal circuit contacts.

$$e^{\frac{-\pi R_{ABCD} d}{\rho}} + e^{\frac{-\pi R_{ABCD} d}{\rho}} = 1$$

$$R_{ABCD} = \frac{V_{AB}}{I_{CD}} \approx R_{CDAB} = \frac{V_{CD}}{I_{AB}}$$

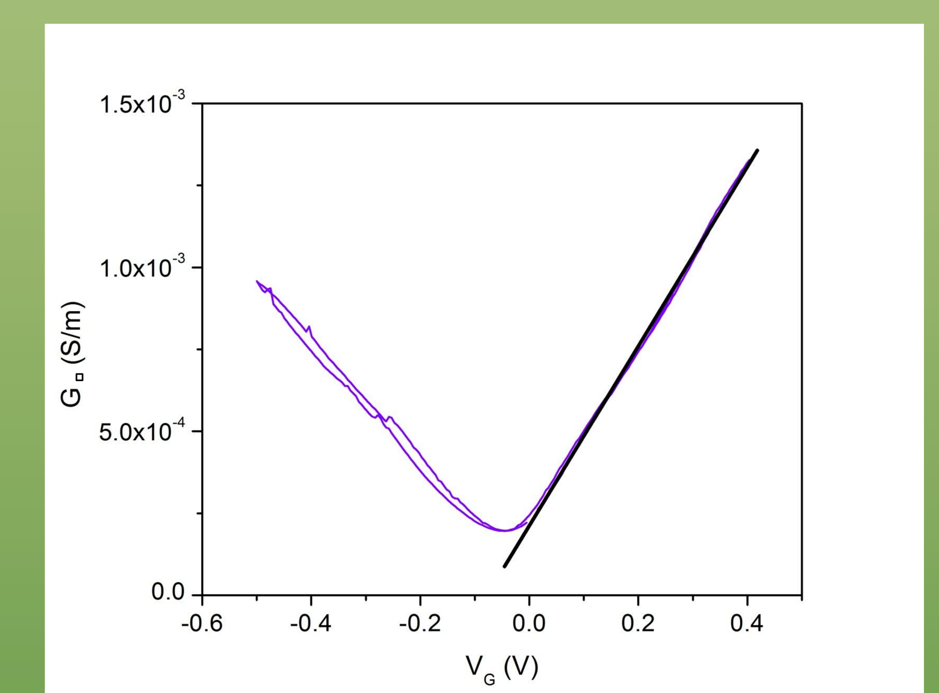


Figure 9. Sheet conductivity versus gate voltage.

Results

- Measured mobility of charge carriers in liquid gate device using van der Pauw method
- Improvement in mobility by cleaning with heat
  - Slope is steeper (higher mobility)
  - Vertex is more sharp, thus more like ideal case
  - Hysteresis reduced, molecules that cause interference removed from surface

Pre= 560 cm^2/Vs
Post= 732 cm^2/Vs

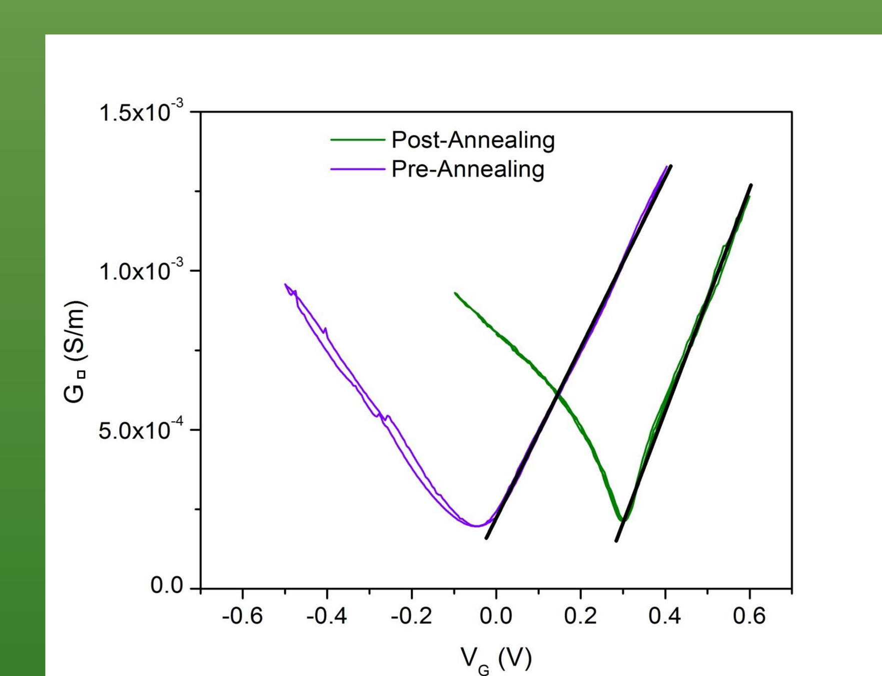


Figure 10. Sheet conductivity versus gate voltage. Post heat cleaning treatment.

Future direction

- Improve mobility
- Sense local organism activity with GFET
- Pay attention to where V probe is located in the liquid with respect to the graphene and contacts-a quick check revealed it makes a difference

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[1] Newaz, a. K. M., Puzyrev, Y. S., Wang, B., Pantelides, S. T., &Bolotin, K. I. (2012). Probing charge scattering mechanisms in suspended graphene by varying its dielectric environment. *Nature Communications*, *3*, 734. http://doi.org/10.1038/ncomms1740