Measuring the effects of liquid environment on graphene biotransistors

Agatha Ulibarri, Dr. M.S. Crosser

Linfield College, McMinnville OR.

Abstract

Mobility is a measure of the ease with which electrical carriers pass through a material. This work studies the mobility of graphene when measured within a liquid electrolyte environment. We use two different techniques to measure their mobilities at different concentrations of the electrolyte to compare results.

Motivation

The conductivity of graphene can be altered with a change in an external potential. Thus, graphene can be used as the basis of a biosensor, detecting electrical activity of cells. Ultimately, the sensitivity of graphene biosensors depends on the mobility of the graphene itself, with higher mobilities showing greater response to V. In graphene, this mobility can be affected by external factors, such as charges trapped in the substrate or from residue left on the surface during fabrication[1].

It has been documented[2] that the mobility of graphene when measured in a liquid environment is degraded from that of a vacuum. This additional degradation is due to ions within the electrolyte scattering of charges in the graphene. However, depending on the concentration, the electrolyte might instead screen charges, improving mobility. To determine the exact behavior, we have measured graphene's response in different concentrations of NaCl dissolved in water. Data are also collected before and after a thermal anneal used to remove residue from the surface.

Theory

Mobility is often defined as $\boldsymbol{\sigma = ne\mu}$, where $\boldsymbol{n}$ is the density of charge carriers, $\boldsymbol{e}$ is the charge of the electron, and $\sigma = I/V_{xx}$ is the conductivity of the film. From this definition, it is possible to calculate mobility through two experiments:

First, if the capacitance of the gate to graphene is known, it can be defined as $\boldsymbol{\mu = \frac{1}{C}\frac{\partial\sigma}{\partial V_{Gate}}}$

For our work, capacitance is estimated from the salt concentration[3,4], assuming graphene is a metal plate.

Second, it is possible to determine the charge density from a Hall measurement, giving $\boldsymbol{\mu = \frac{V_H}{BV_{xx}}}$, where $\boldsymbol{V_H}$ is the Hall voltage, perpendicular to the current; B is the magnetic field, and $\boldsymbol{V_{xx}}$ is the voltage measured along the current path.

Methods

To improve the sensitivity of these measurements, a 4-probe Hall bar was fabricated (see Fig. 1a) by optical lithography and e-beam evaporation. Magnetic fields were directed perpendicular to the surface.

The metal leads are coated with SiO_2 in order to insulate them from the electrolyte voltages. A Keithley source-meter was used to apply current and measure voltages.

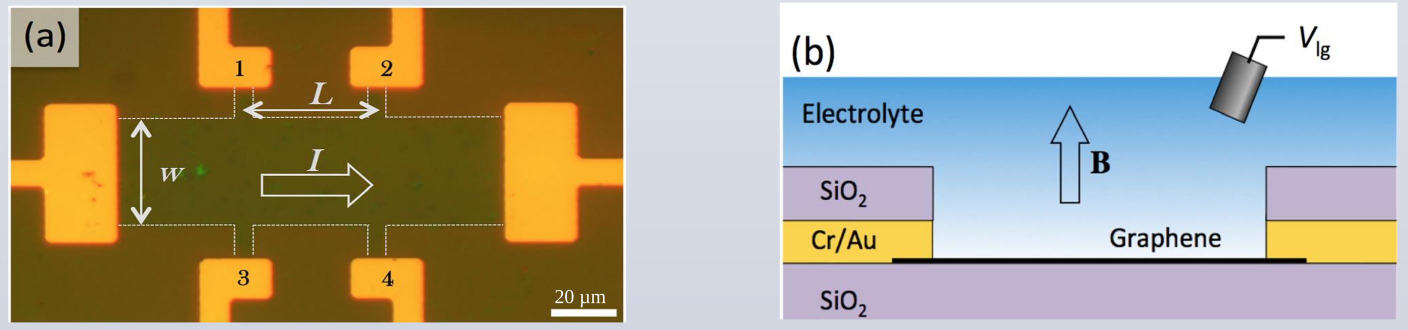

Figure 1. a) Hall bar geometry showing direction of current. White lines highlight geometry of graphene. Measurements of Vxx are measured from terminals 1 and 2; VH from teriminals 1 and 3. b) Schematic of cross section of device. A tungsten probe provides gate voltage

Data & Analysis

Measuring the conductivity before and after a thermal anneal shows that the slopes are steeper, suggesting higher mobility. Presumably, this change in slope is due to less scattering from residue on the surface.

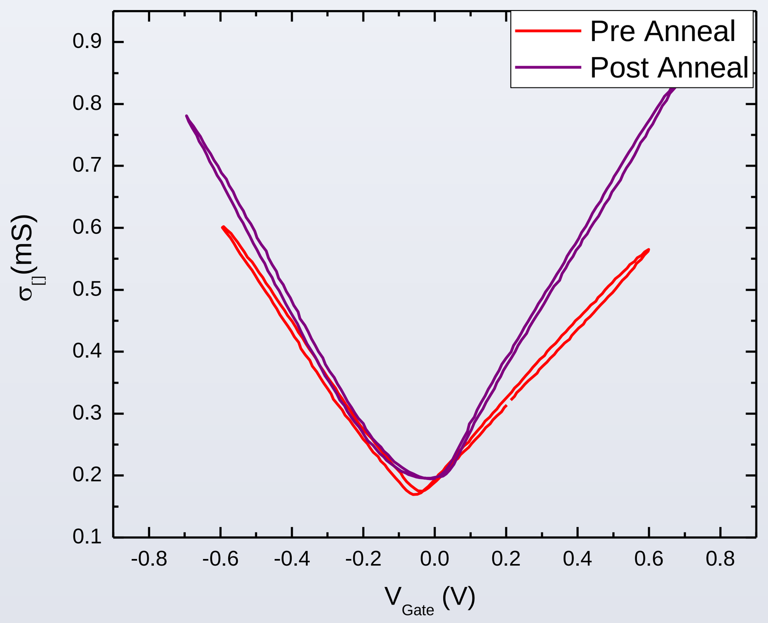

Figure 2. Square conductivity versus gate voltage for 200 mM NaCl in solution, showing change in response before and after thermal anneal.

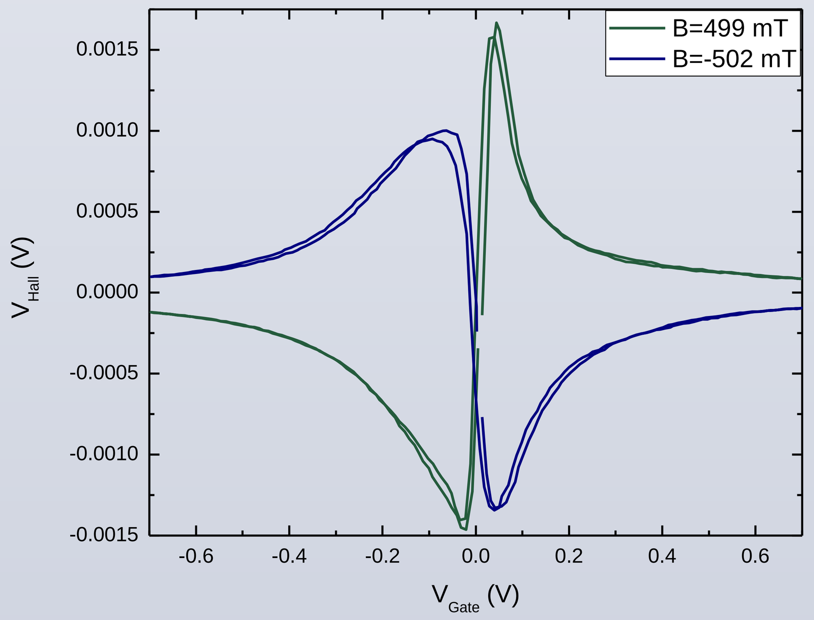

Figure 3. Hall voltage vs gate voltage of graphene sensor for positive and negative perpendicular magnetic fields in 200 mM NaCl in solution.

Hall measurements are as expected. Graphene is ambipolar, switching from electrons to holes at zero gate voltage. Reversing field changes direction of voltage.

Results

- The trends in mobility vs. concentration are seen below (Fig. 4). The two methods do not agree for the resulting mobility.
- Evidently, annealing graphene helps increase mobility by removing surface residues.
- For post anneal devices, mobility decreases as concentration increases, supporting model of increased scattering in the liquid.

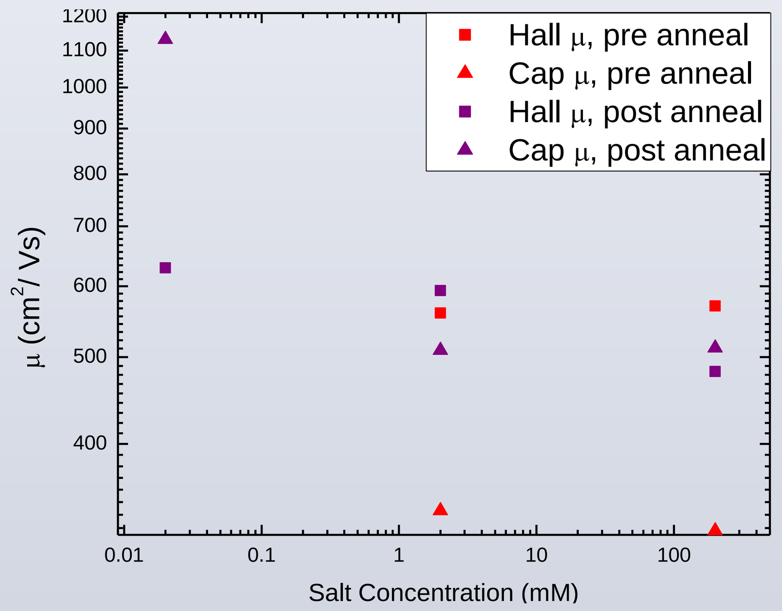

Figure 4. Mobility versus salt concentration for the hall method (square points) and capacitance method (triangle points) for both post anneal (purple) and pre anneal (red).

Further Work

- More work is necessary to determine how mobility is affected by electrolyte concentration. Firm conclusions cannot be made without more data at different concentrations.
- These calculations were made using capacitance theory based on metal probes. Independently measuring C at different concentrations would also be worthwhile.

References

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