# Detecting pressure changes using Graphene Field Effect Transistors

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## Abstract

Graphene is a single, atomic layer, hexagonal lattice with useful electrical properties. Discovered as a stable isolated sheet in the early 2000's, graphene field effect transistors (GFET) are an effective way to detect small changes in electrical activity. When an electrolytic fluid is placed on a GFET, a double layer capacitor can develop at the interface between the fluid and graphene. Surprisingly, this interface is sensitive to barometric pressure, making GFETs a viable device for measuring pressure changes. In this work we built a pressure vessel and placed GFETs inside to test the performance limits of graphene based on its environment.

## Theory

Graphene is sensitive to the electrical charges around it, altering its resistance in response (Fig. 1a). This is because when an external field is applied charge carriers (either electrons or holes) can be pulled into the graphene, allowing current to pass through the graphene more easily. A graphene field effect transistor (GFET) is a device that uses graphene to detect changes in voltage.

When a gate voltage is applied a double layer capacitance is formed at the surface of the graphene[1] as shown in figure 1b. Because of this the voltage seen by the graphene is reduced by

$$V_{Graphene} = V_{gate} - V_c,\quad V_c = \frac{q}{C_{dl}},\quad C_{dl} = \frac{k\varepsilon_0 A}{\lambda} \qquad (1)$$

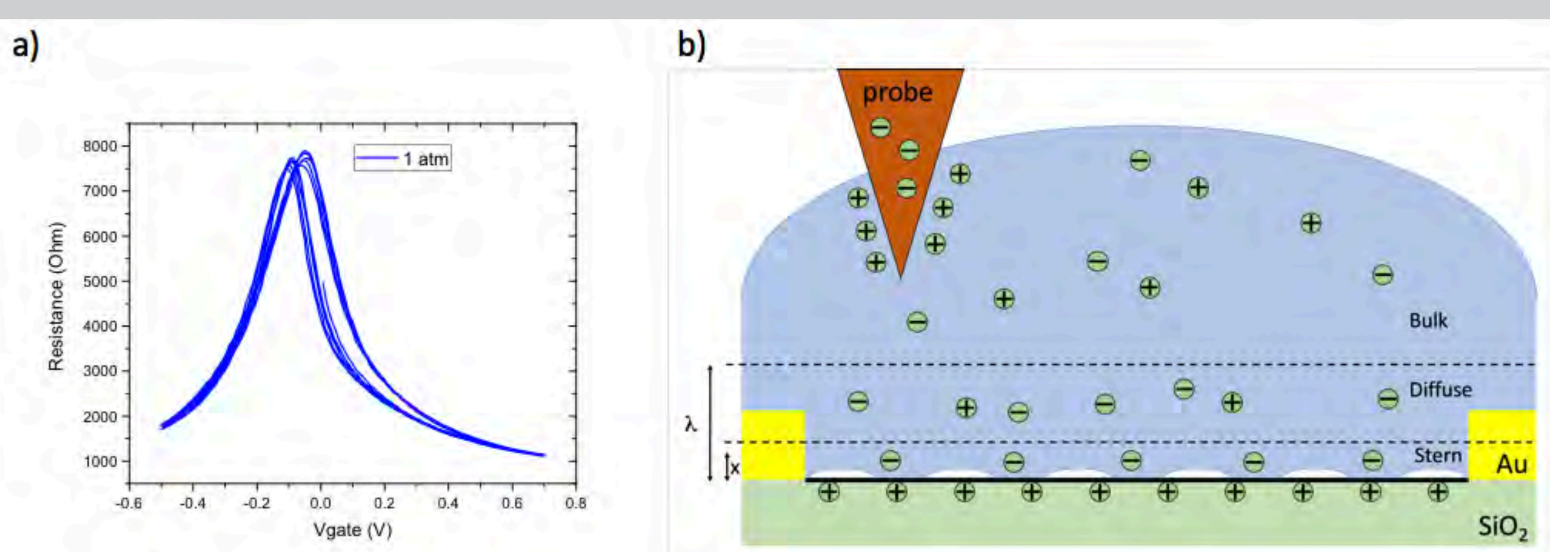


Figure 1: a) Plot of resistance within the graphene versus gate voltage. b) Schematic of a GFET in an electrolyte solution, with an external charge being applied by a probe. A double layer capacitance forms, consisting of the Stern and Diffuse layers.

Equation 1 assumes that the double layer capacitance is a parallel plate capacitor, in good contact with the surface. However, graphene is an extremely hydrophobic material which likely causes the graphene to liquid interface to not be continuous.

Therefore, if there are spaces where the liquid is not in contact, it is possible that changes in air pressure around the device could reduce these spaces and could affect the measurement.

## Methods


Figure 2: Image of the pressure vessel with A) the air input and output assembly , B) Removable cap flange, C) Electrical feed through leads.

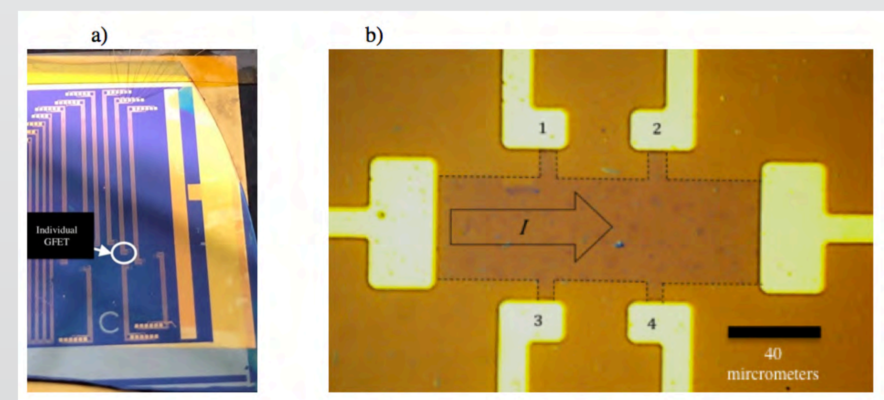


Figure 3: a) Photo of a GFET chip with nine individual GFETs. b) zoomed in view of a GFET wired for use. Current flows from the farthest left contact to the farthest right. Contacts 1 and two or 3 and 4 are used to measure resistance.

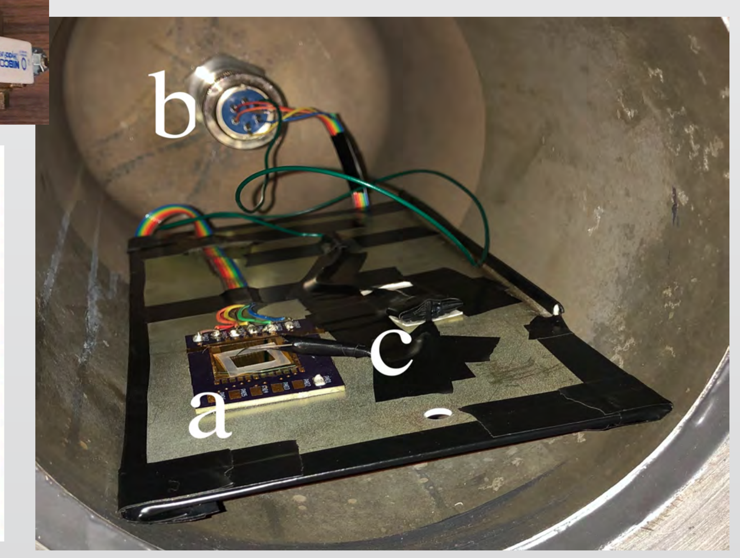


Figure. 4: Image of the inside of the pressure vessel; a) GFET chip with parafilm enclosure to contain the fluid, b) Electrical feed through set into base of tank, c) tungsten probe.

To collect data the GFET (Fig. 3) was mounted onto a removable plate (Fig. 4) and sealed inside the pressure vessel. When the program is running, a gate voltage is applied to the tungsten probe submerged into 600 mM of NaCl, while the resistance between the contacts (Fig. 3b) is measured. At this time a constant current is passed through the graphene in the direction shown in figure 3b.

## Results

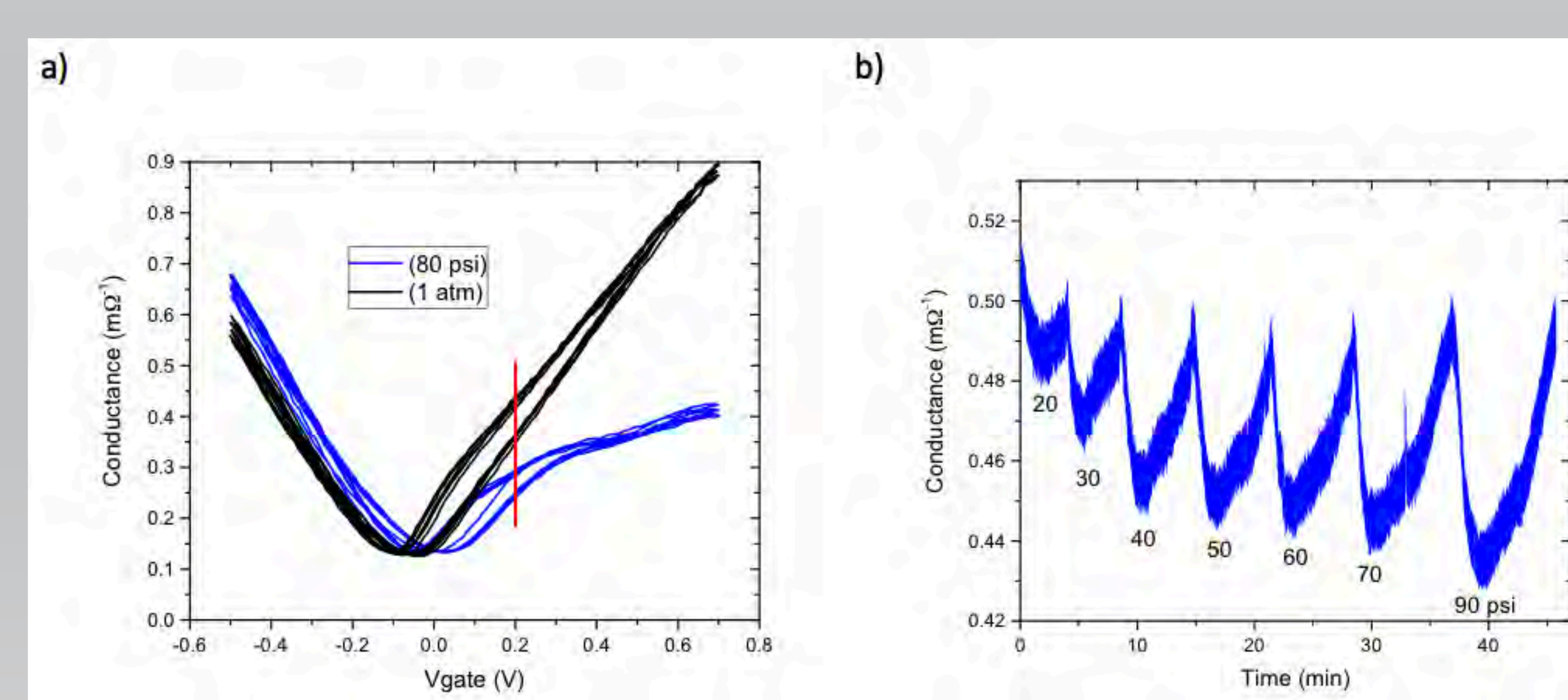


Figure 5: a) Plot of conductance vs gate voltage at two different pressures. b) The effect of pressure on the conductance of the GFET through several cycles of increasing pressure for Vg=0.2 V.

Figure 5a shows the overall effect of pressure on the conductance (G=1/R) over a wide range of gate voltages. It is worth noting that the changes are not symmetric across zero voltage. At positive voltages, the slope changes dramatically as the pressure is increased.

Maintaining a constant gate voltage allows the changes in pressure to be measured in time. Figure 5b shows how the conductance changes (for $V_g$=0.2 V) for several cycles of raising and lowering pressure. For pressures in the 40-90 psi range, the response is nearly linear. However, a slight delay was noticed between the changes in pressure and the response of the graphene.

## Conclusions

By using graphene field effect transistors in conjunction with a high pressure vessel, we were able to examine the effects of changing pressure on the performance of a GFET with an electrolytic gate. From the data collected, a clear link is established between a change in pressure and conductance of the GFET.

We speculate that this pressure dependence may be the result of graphene being a highly hydrophobic material. Because there are gaps between the liquid and the graphene, pressure changes can alter the double layer capacitance of the device.

Future research should allow more time for the system to reach its new equilibrium after each pressure change. This would allow a more definitive relationship between the variables.

In addition, only NaCl was used in this experiment. To further study the asymmetry of the voltage graph, it may be interesting to apply electrolyte solutions of different salts to see if those molecules are the cause of the asymmetry.

## Acknowledgements

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A.R.E. Manufacturing.

**References**

[1] Brown, M. A., Crosser, M. S., Leyden, M. R., Qi, Y., & Minot, E. D. (2016). Measurement of high carrier mobility in graphene in an aqueous electrolyte environment. *Applied Physics Letters*, *109*(9), 093104. https://doi.org/10.1063/1.4962141

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