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 known 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.

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

• To use as sensor, measure change in square conductivity (G_s)
  • G_s = 1/R
  • Device is held at a constant V which results in G_s, cell activity causes a ΔV which results in ΔG_s that can be measured
  • Steeper slope=higher μ: small ΔV will be a more visible ΔG_s

Methods

CVD to grow graphene
Spin PMMA on graphene
Transfer graphene to Si
Remove PMMA

Expose
Develop
Evaporate gold/chromium
Remove resist & excess metal

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 photo-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.

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\frac{-\Delta R_{ABCD}}{\rho} + \frac{-\Delta R_{ABCD}}{\rho} = 1
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R_{ABCD} = \frac{V_{AB}}{I_{AB}} = \frac{V_{CD}}{I_{CD}} = \frac{V_{CD}}{I_{AB}}
\]

Figure 8. GFET with metal circuit contacts.

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

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—quick check revealed it makes a difference

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Acknowledgements:
• M. A. Brown, Dr. Ethan D. Minot from Oregon State University
• Linfield College Faculty/Student Collaborative Research Grant

Figure 9. Sheet conductivity versus gate voltage.

Pre= 560 cm²/Vs
Post= 732 cm²/Vs

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

http://doi.org/10.1038/ncomms1740