Research Update

Graphene Radiation Sensor
Gd$_2$O$_3$ Film Simulation

Edward Cazalas

12/12/11
Graphene Project

Objectives

If possible, create a radiation detection device utilizing graphene that rivals traditional detection architectures.

Study the electrical properties of graphene

Characterize response to irradiation

Artistic impression of a corrugated graphene sheet: Jannik Meyer
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Background

2010 Nobel prize in Physics

3000 publications, 400 patents in 2010 alone

Exploding field of potential applications and research

Applications from high sensitivity chemical sensors, faster than silicon based transistors, thin touch screens...

One of the strongest materials in the world².
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Background

2-D single atomic layer of carbon

Interplanar spacing of 0.335 nm... 1 mm → 3 million sheets\(^1\)

High electrical conductivity and carrier mobility

Charge type and density can be tuned with electric field (through gate voltage)

Low electronic noise (increased single to noise)

Fabrication through mechanical exfoliation, epitaxially, graphite reduction oxide.
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Physics of interest

Charge Neutrality Point (Dirac peak)
Electrons induced as carrier above Dirac point, holes below.
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Construction

Where the resistance of graphene between terminals 2 and 3 is $V_1/I_1$. Also note: terminals 1 and 2 or 3 and 4 can be combined for a 2- or 3-terminal measurement.
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Previous Testing
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Latest Testing
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Testing

Are we observing the field effect? Or doping? e- beam irradiation show reversed resistance changes as compared to Alpha irradiation

Experiments completed:
-Voltage sweeps of different devices
-Alpha source irradiation with backgate at different voltages for different devices
-Repeatability of Dirac peak
-Testing effects of visible light
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Future Work

- Install Lock-in amplification to reduce noise in resistance reading (perhaps possible in labView).

- Test 'dummy' device

- Fourier analysis of data

- Alpha 'pulsing'

- Automate alpha source shutter system and testing

- Alpha irradiation with backgate far from Dirac peak. No effect → previous changes in resistance due to doping, not field effect.

- Alpha source position testing. Gradually move source away from graphene. Ultimately, want to cause field effect without alpha bombardment on graphene (air ionization).

- Test alpha source through back side of chip.

- Neutron source testing (far future)
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References


3) ARI Project Website
Gd$_2$O$_3$ Film Simulation

Collaboration with Dr. Joshua Robinson, Material Science and Engineering.

Goals:
Understand growth and material properties of Gd$_2$O$_3$ film.
Understand electrical properties of film during irradiation with various radiation types (radiation induced conductivity)

Current status:
Developed Gd$_2$O$_3$ film solid state device to perform neutron detection
Beam port irradiation in Penn State Breazeale reactor
Understanding radiation induced conductivity
Gd$_2$O$_3$ Film Simulation

Device Structure

Film structure/density dependent on growth properties such as oxygen content and temperature. Film density can vary from 7.62 to 8.35 g/cm$^3$.
Gd$_2$O$_3$ Film Simulation

Experiment

<table>
<thead>
<tr>
<th>Power [KW]</th>
<th>Flux [n/cm$^2$/sec]</th>
<th>Gamma [mR/hr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>3.0E+07</td>
<td>31250</td>
</tr>
<tr>
<td>100</td>
<td>3.0E+06</td>
<td>3125</td>
</tr>
<tr>
<td>10</td>
<td>3.0E+05</td>
<td>313</td>
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<tr>
<td>1</td>
<td>3.0E+04</td>
<td>31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Dep. Temp. (°C)</th>
<th>O$_2$ Flow (sccm)</th>
<th>Oxide thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>D110727</td>
<td>250</td>
<td>200</td>
<td>1.07</td>
</tr>
<tr>
<td>D110726</td>
<td>350</td>
<td>200</td>
<td>0.9</td>
</tr>
<tr>
<td>D110725</td>
<td>450</td>
<td>200</td>
<td>0.85</td>
</tr>
<tr>
<td>D110722</td>
<td>550</td>
<td>200</td>
<td>0.89</td>
</tr>
<tr>
<td>D110802</td>
<td>650</td>
<td>200</td>
<td>0.67</td>
</tr>
<tr>
<td>D110811</td>
<td>250</td>
<td>50</td>
<td>1.11</td>
</tr>
<tr>
<td>D110810</td>
<td>350</td>
<td>50</td>
<td>1.08</td>
</tr>
<tr>
<td>D110805</td>
<td>450</td>
<td>50</td>
<td>1.06</td>
</tr>
<tr>
<td>D110804</td>
<td>550</td>
<td>50</td>
<td>1.1</td>
</tr>
<tr>
<td>D110803</td>
<td>650</td>
<td>50</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Research update presentation – Nov. 8, 2011. Zachary Hughes and Joshua Robinson
Gd$_2$O$_3$ Film Simulation

Experimental results

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GEANT4 Simulation

Device geometry
Gd$_2$O$_3$ Film Simulation

GEANT4 Simulation

Gamma Source modeling

Modeled in MCNP from reactor simulation

GEANT4 input

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GEANT4 Simulation

Neutron Source modeling

From reactor simulation and experiment

GEANT4 input

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GEANT4 Simulation

Geometry scenarios

<table>
<thead>
<tr>
<th>Density Thickness (DT) (mg/mm$^3$)</th>
<th>Density (g/cm$^3$)</th>
<th>Thickness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>52.6</td>
<td>7.62</td>
<td>0.69</td>
</tr>
<tr>
<td>57.6</td>
<td>8.35</td>
<td>0.69</td>
</tr>
<tr>
<td>91.4</td>
<td>7.62</td>
<td>1.2</td>
</tr>
<tr>
<td>100.2</td>
<td>8.35</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 1: Density thicknesses (DT) simulated. Density and thickness of each DT is given.
Gd$_2$O$_3$ Film Simulation

GEANT4 Simulation

Energy deposition to Current for neutrons

\[ I_n [pA] = \left( \frac{E \text{[eV]}}{W \text{[eV/ip]}} \right) \times \phi_n \left[ \frac{n}{cm^2 s} \right] \times \left( \frac{1 \times 10^{12} \text{[pA/A]}}{6.24 \times 10^{18} \text{[ip/C]} \times A \text{[cm^2]}} \right) \]

where,

- \( E \) is the energy deposition in a volume per particle
- \( W \) is the work function of the material
- \( \phi_n \) is the neutron flux incident on the device
- \( A \) is the area of irradiation

Energy deposition to Current for gammas

\[ \phi_g = \frac{S}{\left(1 - \left(\frac{1}{t_c}\right) \frac{t}{A}\right)} = 170 \left[ \frac{\gamma}{(mR/hr)cm^2 s} \right] \]

where \( S \) is the sensitivity, \( t \) is the time conversion from cpm to cps (\( t = 60 \text{ s/min} \)),

\[ I_g [pA] = \left( \frac{E \text{[eV]}}{W \text{[eV/ip]} \times \frac{\gamma}{(mR/hr)cm^2 s}} \right) \times \frac{\gamma}{(mR/hr)cm^2 s} \times E X \left[ mR/hr \right] \times \left( \frac{1 \times 10^{12} \text{[pA/A]}}{6.24 \times 10^{18} \text{[ip/C]} \times A \text{[cm^2]}} \right) \]
# Gd$_2$O$_3$ Film Simulation

## GEANT4 Simulation

### Results for Neutrons

<table>
<thead>
<tr>
<th>Current</th>
<th>Film</th>
<th>Contact</th>
<th>Substrate</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>DT ($mg/mm^3$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52.6</td>
<td>2.2E-7 ± 2.4E-7</td>
<td>4.0E-8 ± 3.5E-8</td>
<td>0.27 ± 0.01</td>
<td>0.27 ± 0.01</td>
</tr>
<tr>
<td>57.6</td>
<td>7.7E-4 ± 9.7E-4</td>
<td>8.4E-5 ± 1.0E-4</td>
<td>0.29 ± 0.05</td>
<td>0.29 ± 0.05</td>
</tr>
<tr>
<td>91.3</td>
<td>4.1E-4 ± 4.5E-4</td>
<td>3.6E-5 ± 6.2E-5</td>
<td>0.26 ± 0.03</td>
<td>0.26 ± 0.03</td>
</tr>
<tr>
<td>100.2</td>
<td>4.0E-4 ± 3.9E-4</td>
<td>4.6E-5 ± 4.4E-5</td>
<td>0.29 ± 0.08</td>
<td>0.29 ± 0.08</td>
</tr>
</tbody>
</table>

### Results for Gammas

<table>
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<tbody>
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<td>DT ($mg/mm^3$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52.6</td>
<td>1.3E-6 ± 8E-7</td>
<td>4.8E-7 ± 5.1E-7</td>
<td>1.19 ± 0.03</td>
<td>1.19 ± 0.03</td>
</tr>
<tr>
<td>57.6</td>
<td>2.4E-6 ± 4E-7</td>
<td>9.5E-7 ± 3.4E-7</td>
<td>1.20 ± 0.03</td>
<td>1.20 ± 0.03</td>
</tr>
<tr>
<td>91.3</td>
<td>1.3E-6 ± 2.0E-6</td>
<td>3.9E-7 ± 6.2E-7</td>
<td>1.20 ± 0.02</td>
<td>1.20 ± 0.02</td>
</tr>
<tr>
<td>100.2</td>
<td>5.4E-6 ± 1.2E-6</td>
<td>8.8E-7 ± 5.3E-7</td>
<td>1.18 ± 0.03</td>
<td>1.18 ± 0.03</td>
</tr>
</tbody>
</table>

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Zachary Hughes and Joshua Robinson
Gd$_2$O$_3$ Film Simulation

GEANT4 Simulation

Creation of Charge (e-) due to gammas
Gd$_2$O$_3$ Film Simulation

GEANT4 Simulation

Creation of Charge (e-) due to Neutrons
$\text{Gd}_2\text{O}_3$ Film Simulation

GEANT4 Simulation

Creation of Charge (e-) due to Neutrons, edge of film
Gd$_2$O$_3$ Film Simulation

Summary

- Neutrons interact strongly with film.
- Gammas interact uniformly with device
- Film thickness and density rather unimportant in simulated current estimation
- Simulated current estimations match reactor at 1 kW but no clear explanation of power law performance