National Institute for Nanotechnology

Luminescence Properties of Graphene

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Graphene Canada

Montreal

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Outline

1. Background
2. Experiment
3. Results
4. Conclusions & Future Work

1. Background

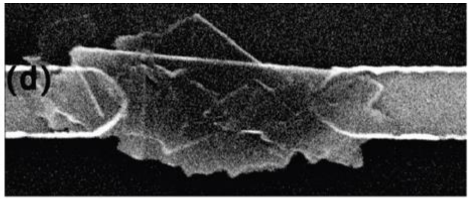
Introduction: Light and graphene

- Unique optical, electronic, and mechanical properties of graphene => many potential applications in photonics and optoelectronics, eg. solar cells

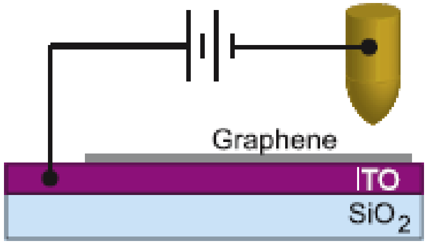
- It is important to determine the optical and optoelectronic properties of graphene => light emission of graphene

Light Emission of Graphene

- Luminescence achieved in various ways with applications such as light emitting diodes, display and lighting devices, and biological labelling
- Mainly photoluminescence has been studied, and electroluminescence (EL) of related carbon-based materials (eg. nanotubes and graphene oxide)
- Two studies so far on EL of pristine graphene



[1]: EL excited with applied source-drain voltage, due to phonon-assisted radiative decay



[2]: EL excited by electron tunneling in an STM with applied bias voltage capacitive effect, due to a hot luminescence mechanism

[1] Essig, S., Marquardt, C. W., Vijayaraghavan, A., Ganzhorn, M., Dehm, S., Hennrich, F., ... & Krupke, R. (2010). Phonon-assisted electroluminescence from metallic carbon nanotubes and graphene. *Nano letters*, *10*(5), 1589-1594.
[2] Beams, R., Bharadwaj, P., & Novotny, L. (2014). Electroluminescence from graphene excited by electron tunneling. *Nanotechnology*, *25*(5), 055206.

2. Experiment

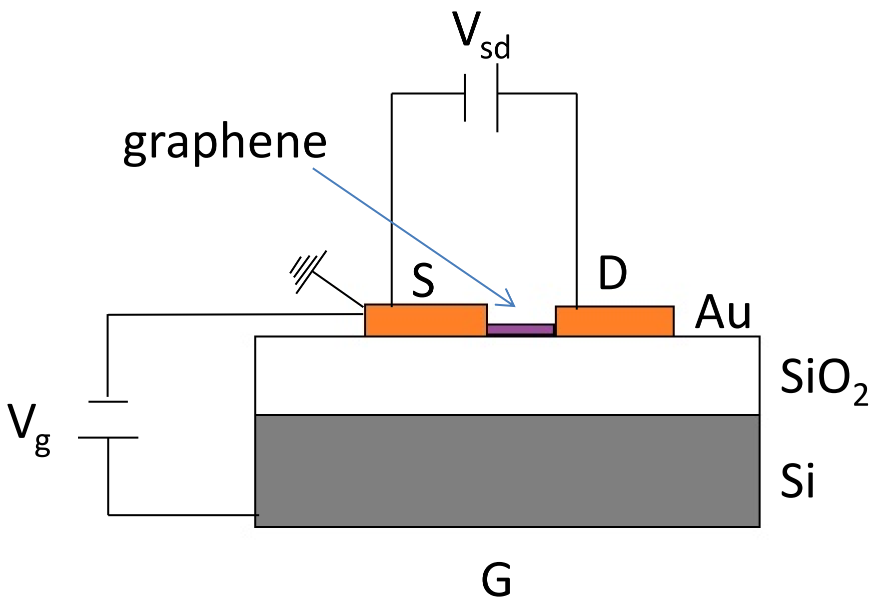
Goal:

To investigate the electroluminescence (EL) properties of a graphene field effect transistor (FET)

Purpose:

To learn about the light-emitting properties of graphene in order to further the development of its optoelectronics applications

Device for EL Excitation: Graphene Field Effect Transistor (FET)



S = Source (COM)

D = Drain

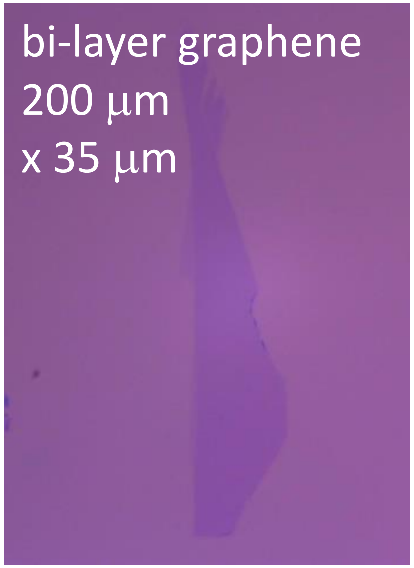
G = Gate

V_g = Gate voltage

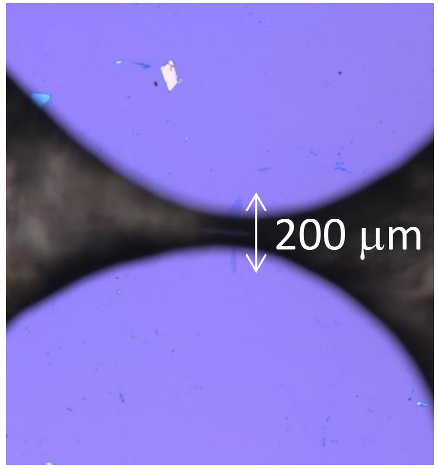
V_{sd} = Source-Drain voltage

- Gate voltage and source-drain voltage are simultaneously applied to excite EL

Sample and Device Preparation

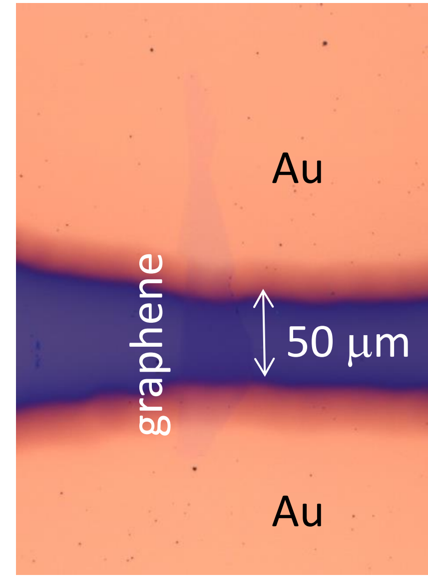


Exfoliation



Mask

E-beam

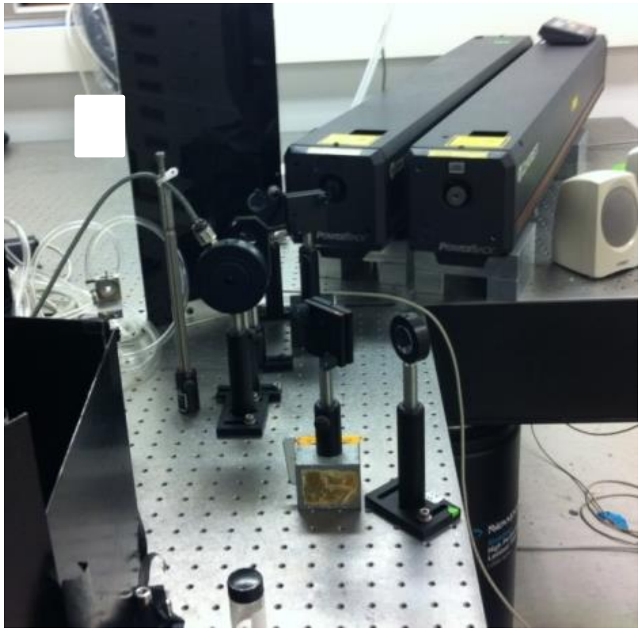


Electrodes

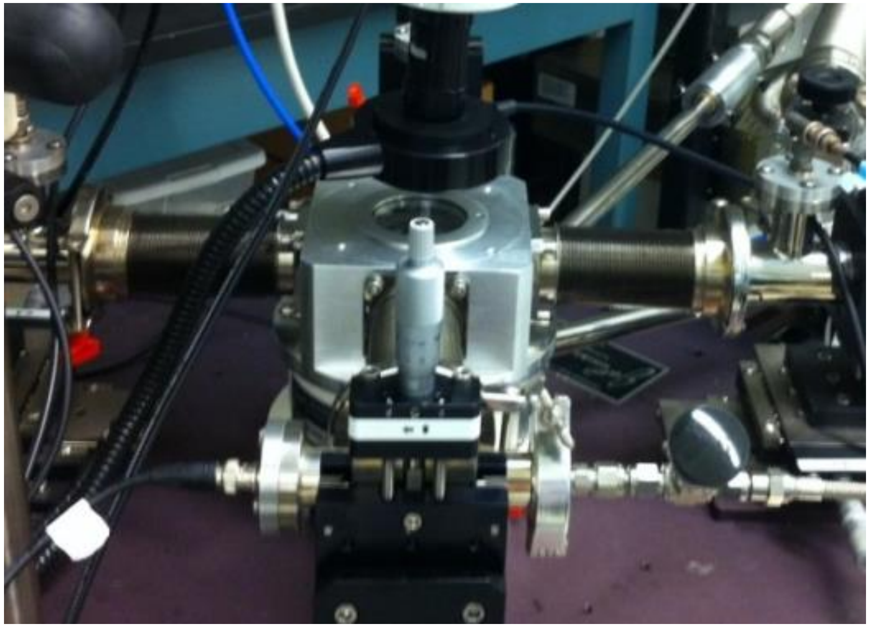
- Samples of various thickness prepared on Si/SiO_2 substrates by mechanical exfoliation and identified by optical microscopy
- Gold electrodes deposited onto the samples via shadow mask and electron beam evaporation (E-beam)
- Silver epoxy used to attach wires to the electrodes

Sample and Device Characterization

- Samples characterized by Raman Spectroscopy to determine the number of layers and quality
- FET devices characterized by electronic measurements
- Current-Voltage (I-V) and transport measurements determine the quality of the electrodes, the resistivity of the graphene, and the doping level

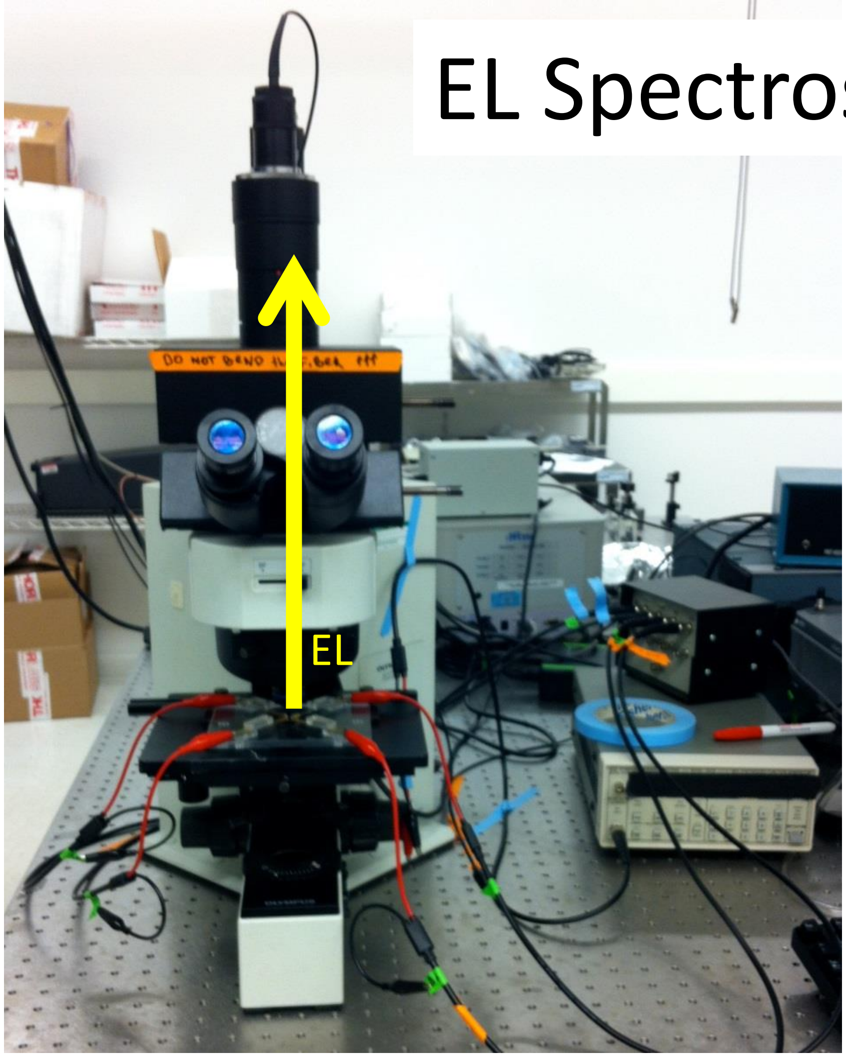


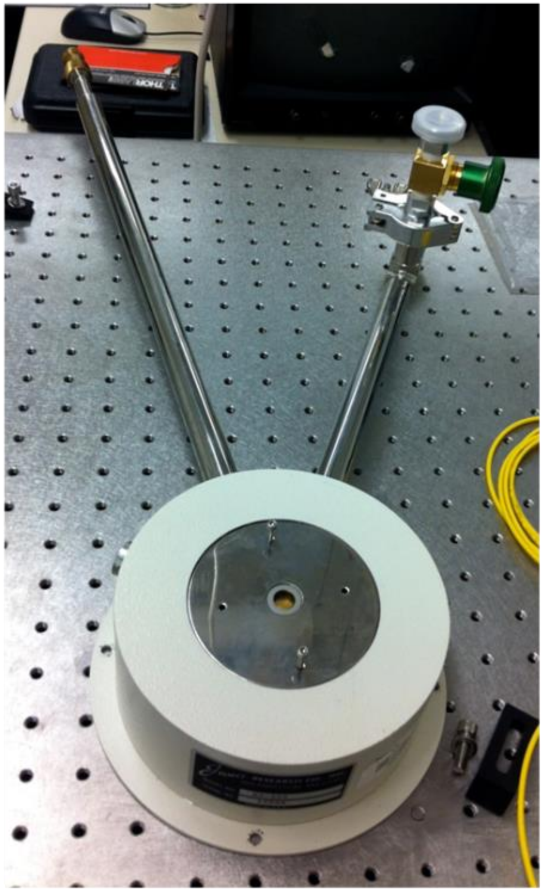
Raman Spectroscopy



Electronic measurements

EL Spectroscopy



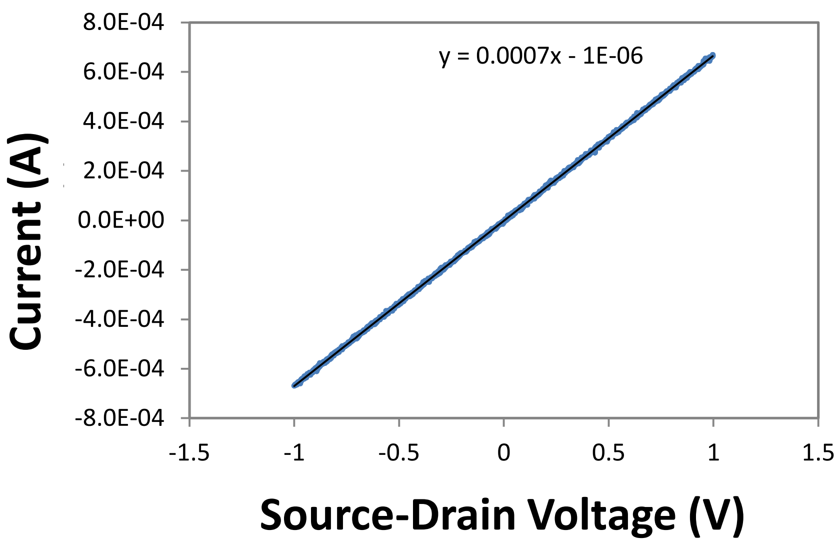


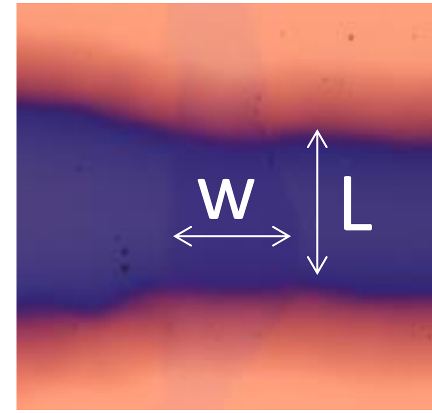
- EL spectroscopy was carried out on a home-built set-up through an optical microscope and Spectrograph/CCD
- A source meter with two channels was used to apply voltages V_{sd} and V_g

- Samples were measured in an air and vacuum environment (using optical cryostat and turbo vacuum pump)

3. Results

Electronic: I-V and Transport Measurements





Linear I-V curve

⇒ ohmic contacts

⇒ functioning device

w = 35 μm

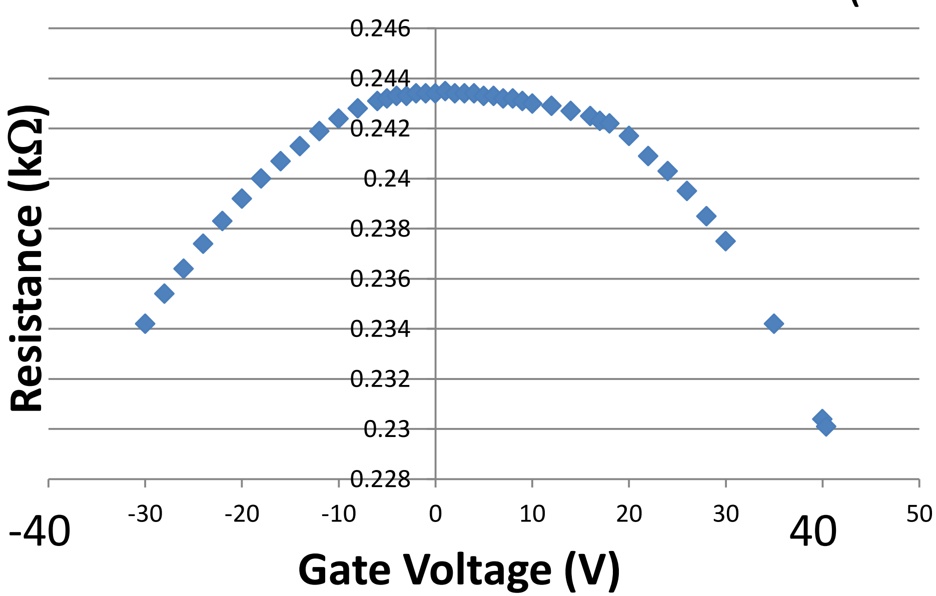
L = 50 μm

t = 0.6 nm

Resistance R =1/slope = 1428 Ω

Resistivity ρ ≈ Rwt/L = 6E-5 Ω cm

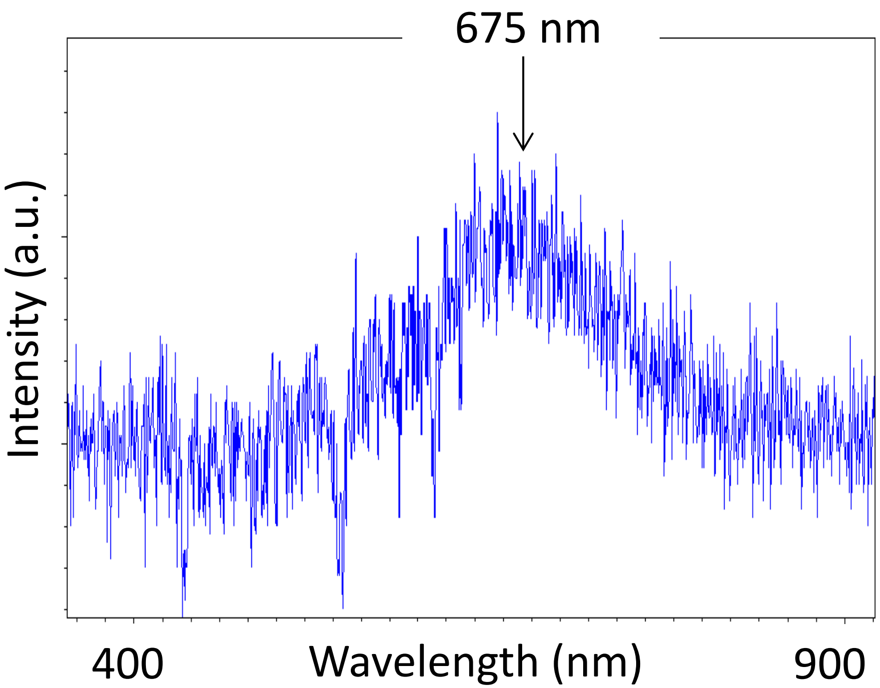
(comparable to known values)



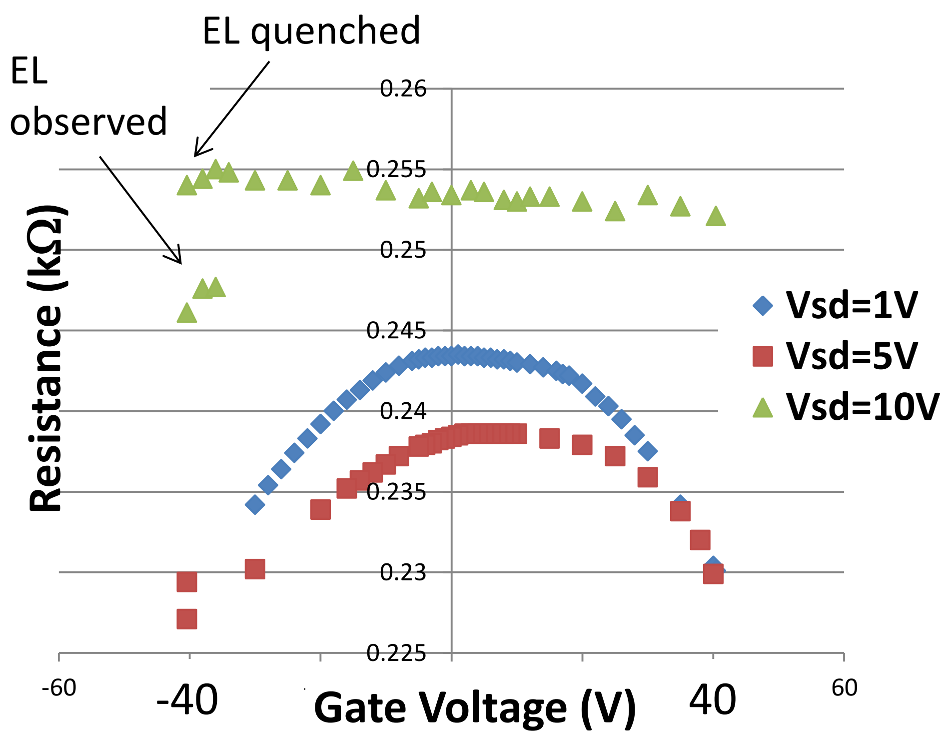
- Transport measurements were simultaneously carried out with EL to relate the data to the electronic properties of the material
- Shows electronic doping level of sample

EL of Graphene FET in Air

- We observed EL in air under certain voltage conditions
- Thresholds of Vg and Vsd were apparent
- The EL was quenched after several minutes=> effect of humidity

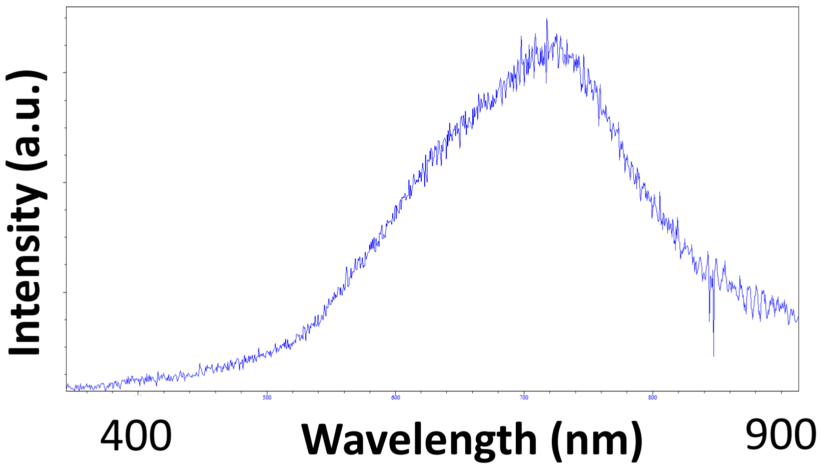


Typical EL spectrum in air



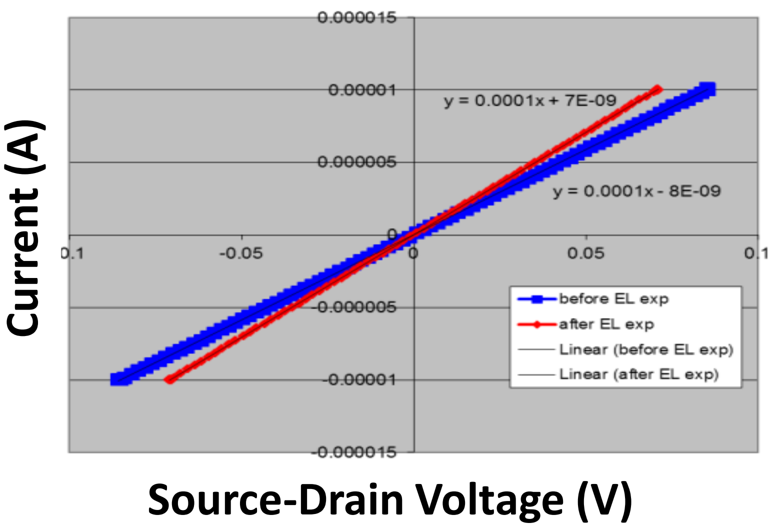
Corresponding Transport Characteristics

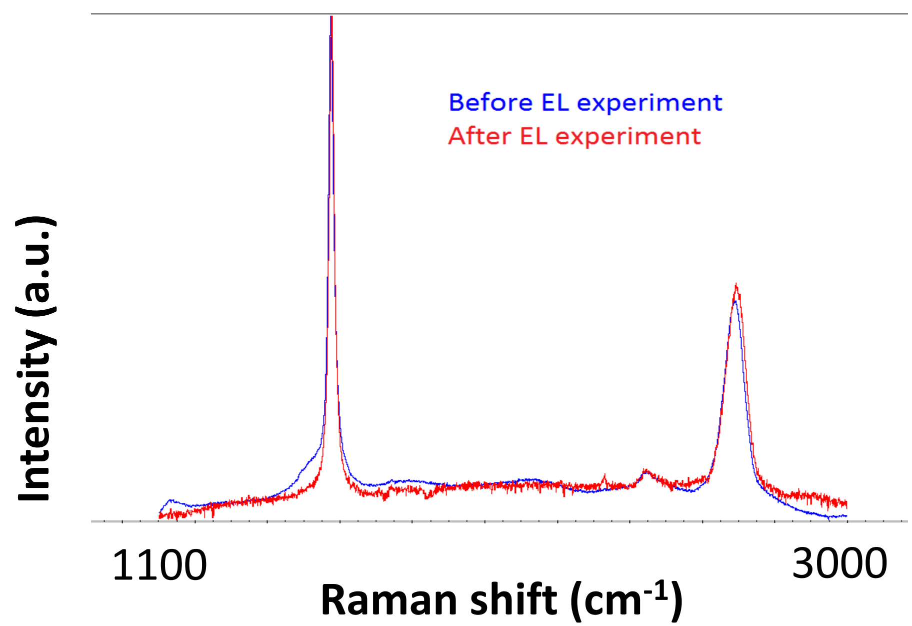
EL of Graphene FET in Vacuum



Typical EL spectrum in vacuum

- The EL had better signal-to-noise ratio (~100 times more intense than in air)
- The EL lasted much longer (quenched after ~40 min upon device breakdown)
- Raman characterization and electronic measurements confirmed the quality of the sample after the EL experiment





I-V curves and Raman spectra: before and after EL

4. Conclusions & Future Work

Conclusions

- EL of a graphene FET was demonstrated for the first time (to our knowledge), peaking at ~700 nm wavelength
- In air the EL was weak and quenched after a few minutes, likely due to humidity in the air
- In vacuum the EL was much brighter and lasted up to 40 minutes
- The EL was excited for various gate voltages
- Excitation thresholds for gate voltage and source-drain voltages are apparent

Future Work

- EL study at different temperatures using an optical cryostat
- FET device packaging for protection from ambient
- Photoluminescence

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Thank you!

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