# Transfer Procedures of Graphene Nanoribbon Powders onto $SiO_2$ Substrates for Device Fabrication

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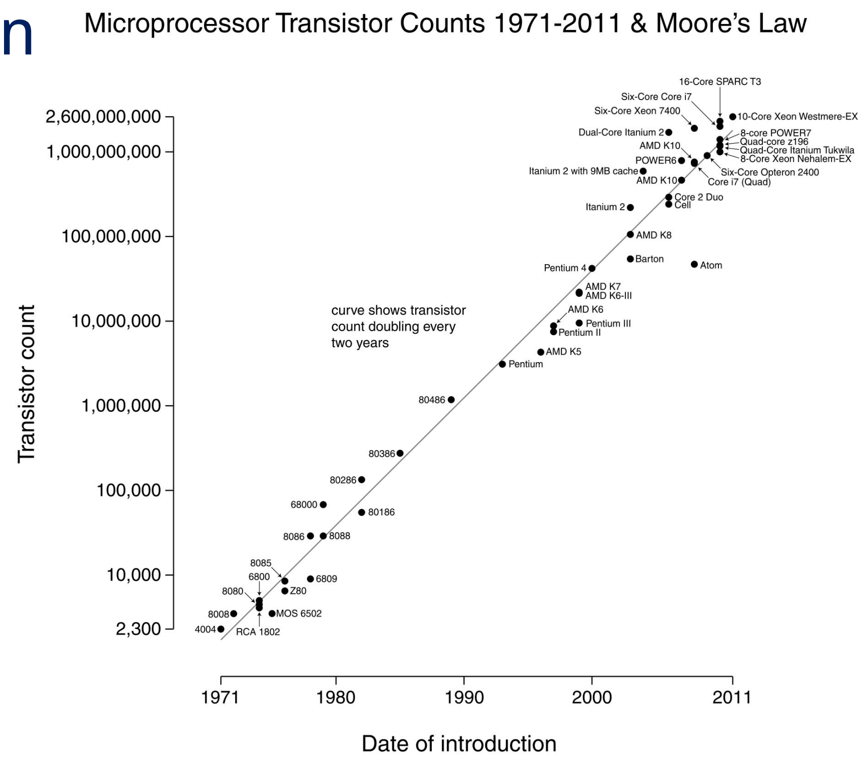
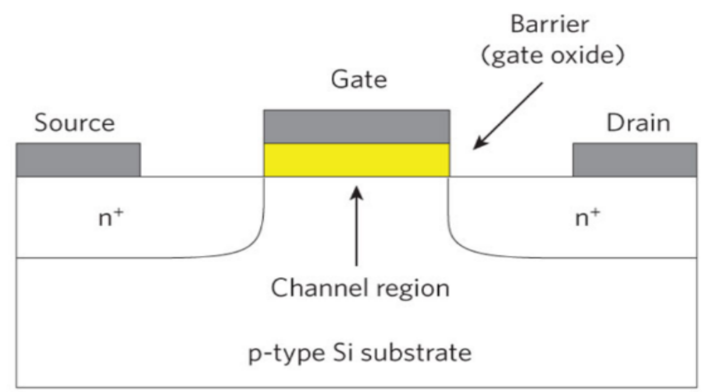
# Background

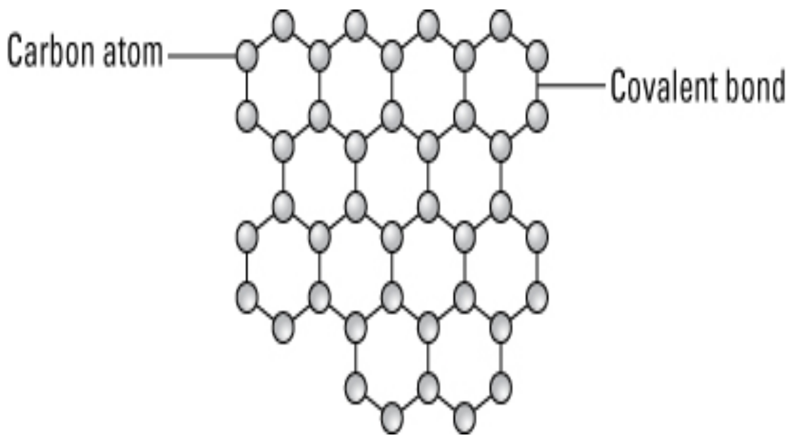
- Moore's law: Number of transistors on an IC chip doubles every 18-24 months
- Silicon is approaching a fundamental scaling limit
- International Technology Roadmap for Semiconductors (ITRS) predicts that new materials will be needed
- Graphene is a principle candidate for post-silicon electronics

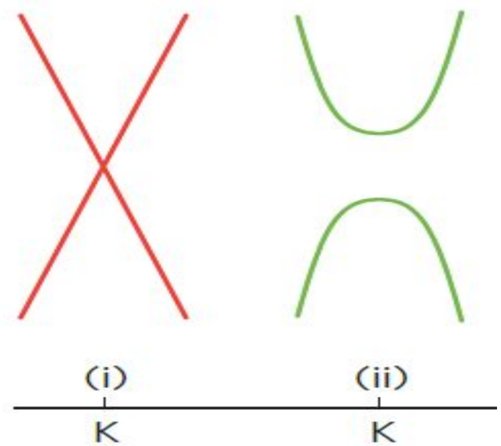


# Graphene & Graphene Nanoribbons (GNRs)

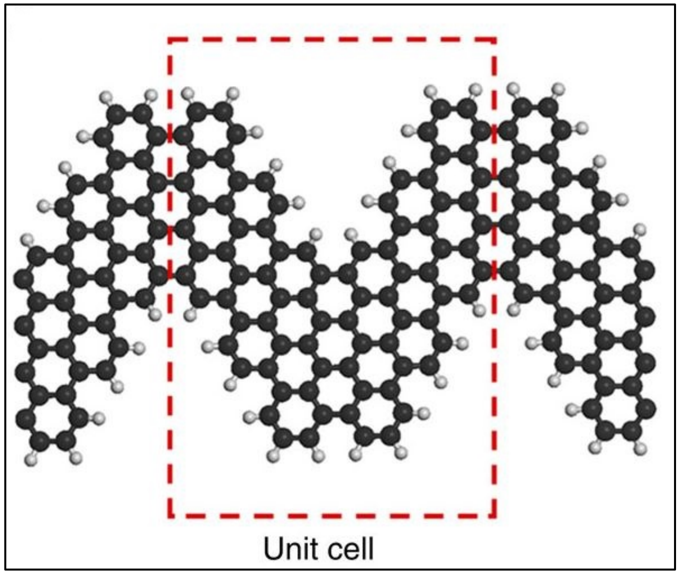
- Graphene is a two dimensional atomically thin sheet of $sp^2$ bonded carbon atoms
- High carrier mobility: (10,000 – 15,000 $cm^2\ V^{-1}s^{-1}$); 1400 $cm^2\ V^{-1}s^{-1}$ for Si
- Graphene lacks a bandgap and is not suitable for logic applications
- A bandgap opens up in narrow sheets (<20nm) resulting in a graphene nanoribbon (GNR)

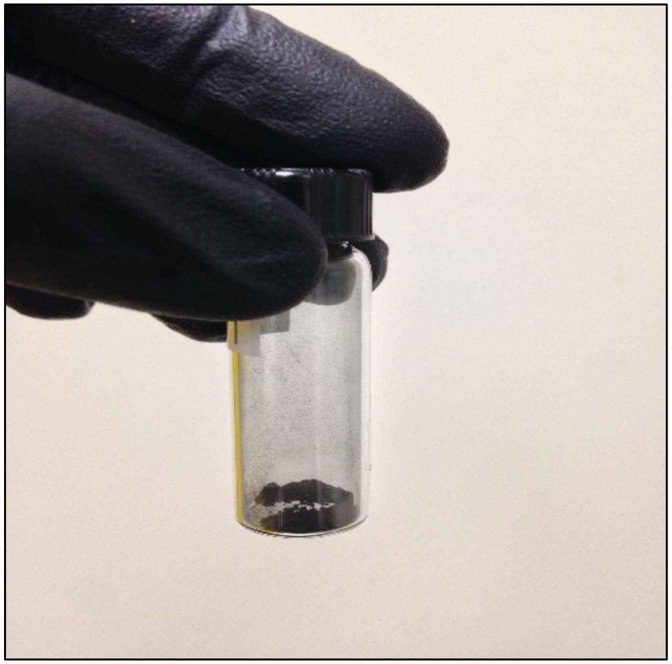


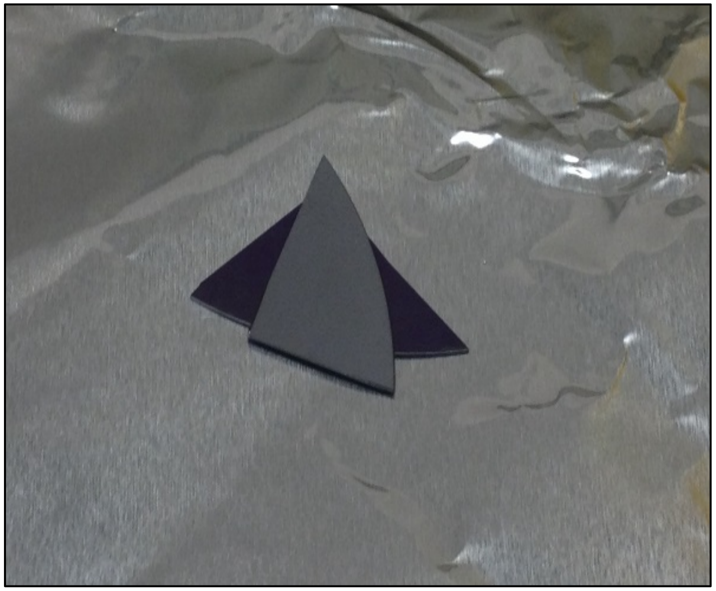
# Proposed Work

- The larger project: GNR field effect transistor
- Thesis: Transferring GNRs onto an $SiO_2$ substrate; (1$^{st}$ step)
- GNRs used are powdered form: 1nm width and lengths > 100nm (Prof. A. Sinitskii)
- Transfer Procedure: Dry Contact Transfer, Toluene solution, Dimethylformamide (DMF) solution

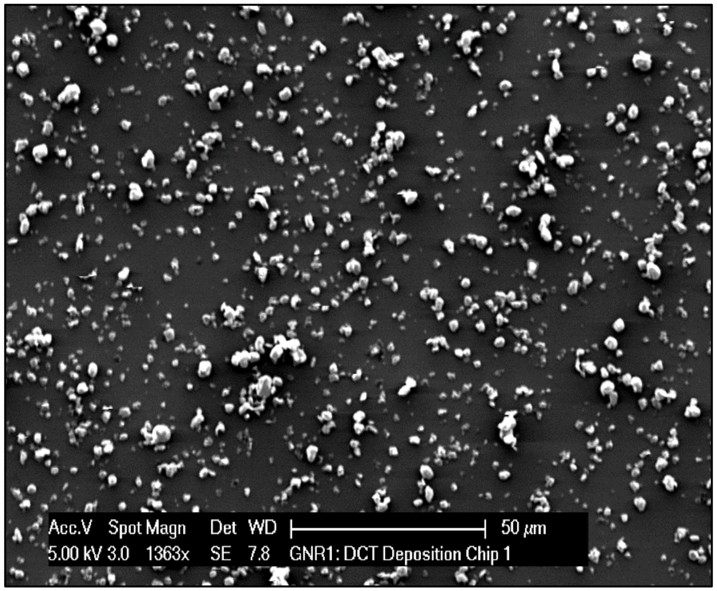


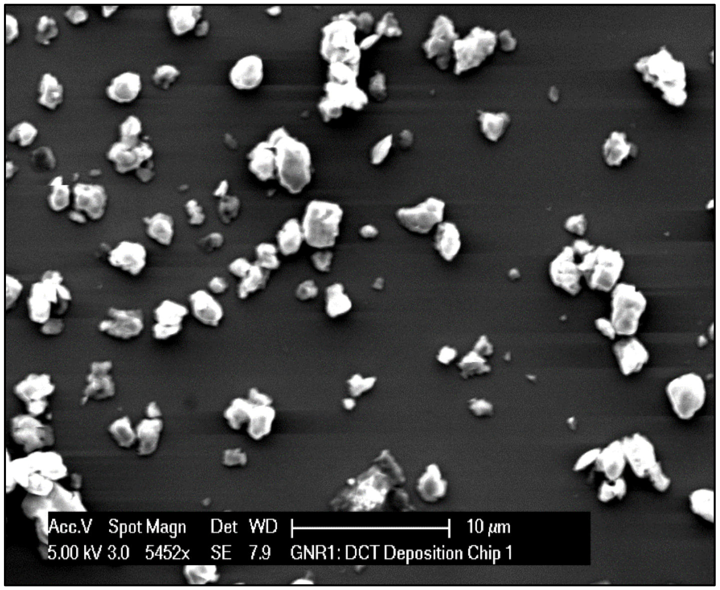



# Experiments & Results (Dry Contact Transfer)



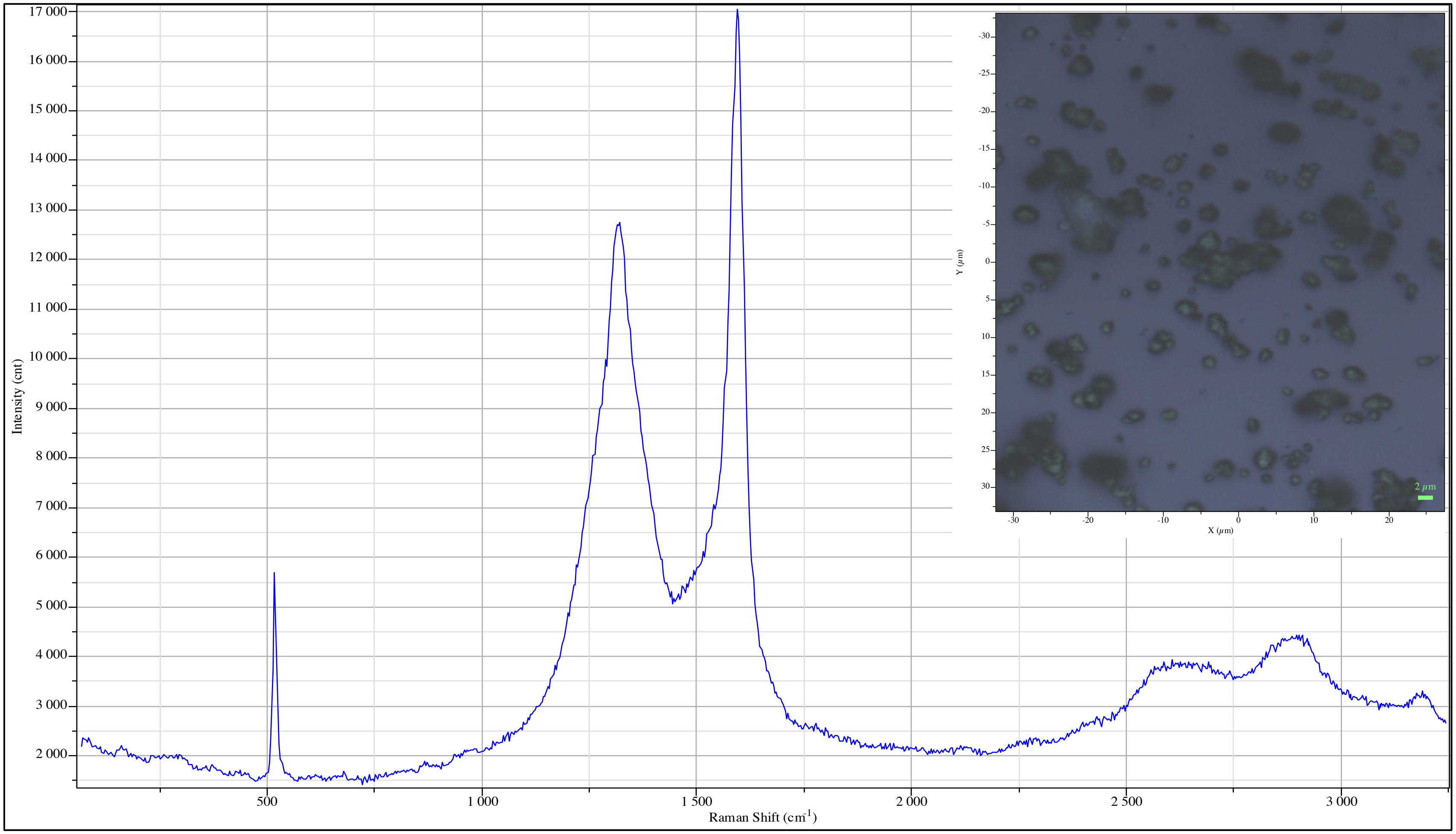
- 1mg of GNR powder was added to the bottom substrate and another substrate was placed on top
- Both substrates were rubbed against each other for 1 minute
- SEM images show big particles, but they did not exfoliate
- The powders did not form a continuous region; we can see spaces between giant particles



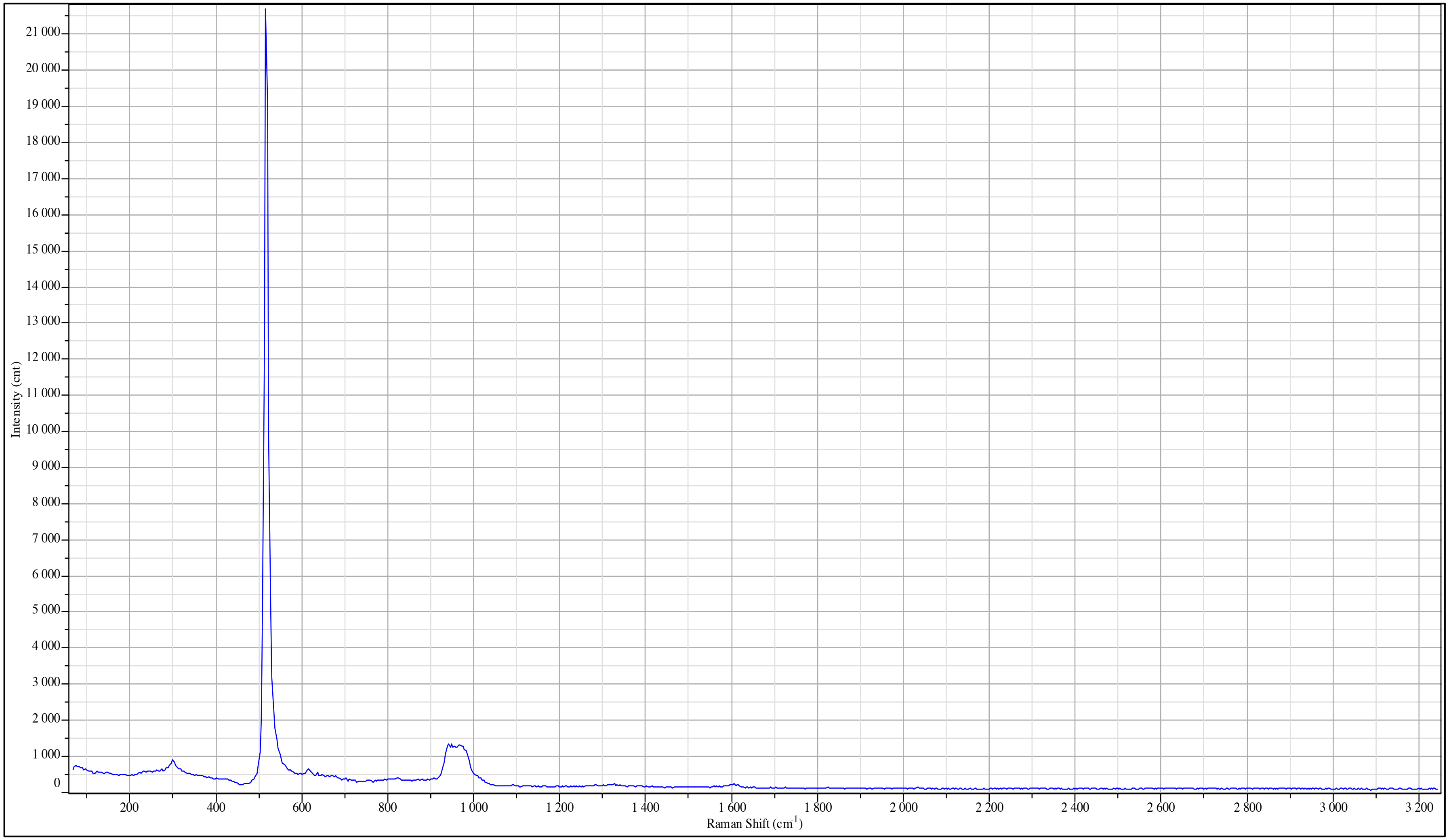
# Experiments & Results (Dry Contact Transfer)

- Raman Spectroscopy: Peaks at ~1300 and 1600 $cm^{-1}$ (D and G bands)

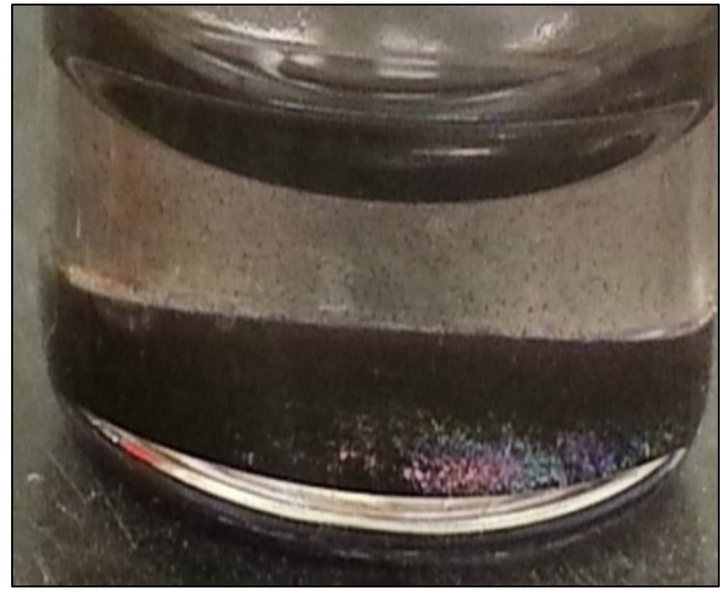


# Experiments & Results (Dry Contact Transfer)

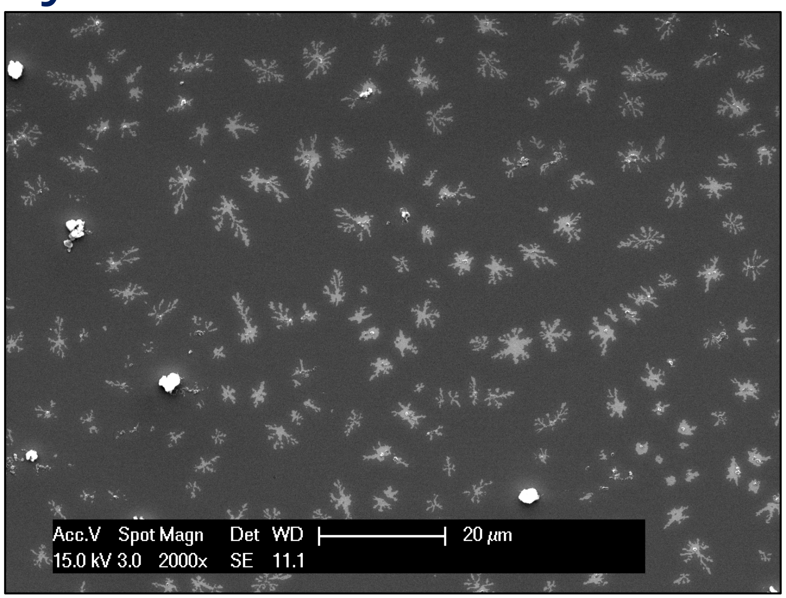
- Raman Spectroscopy

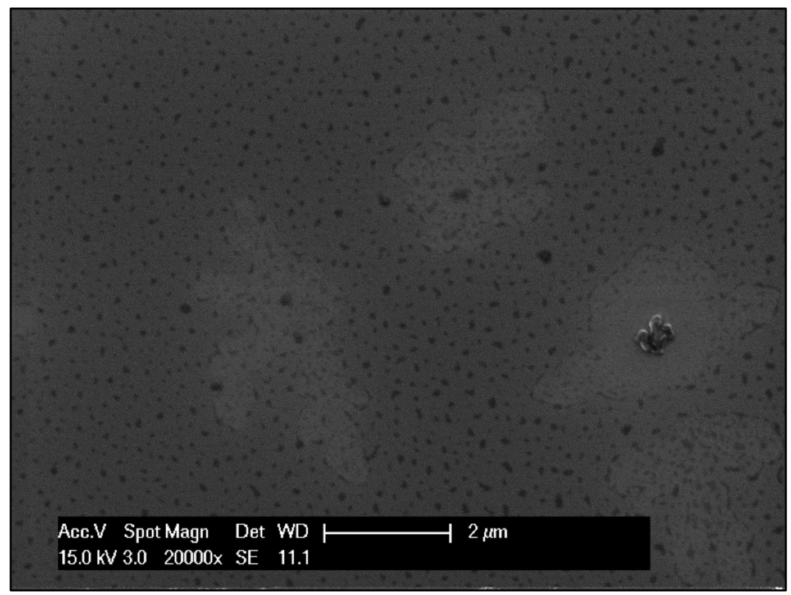


# Experiments & Results (Toluene Solution)



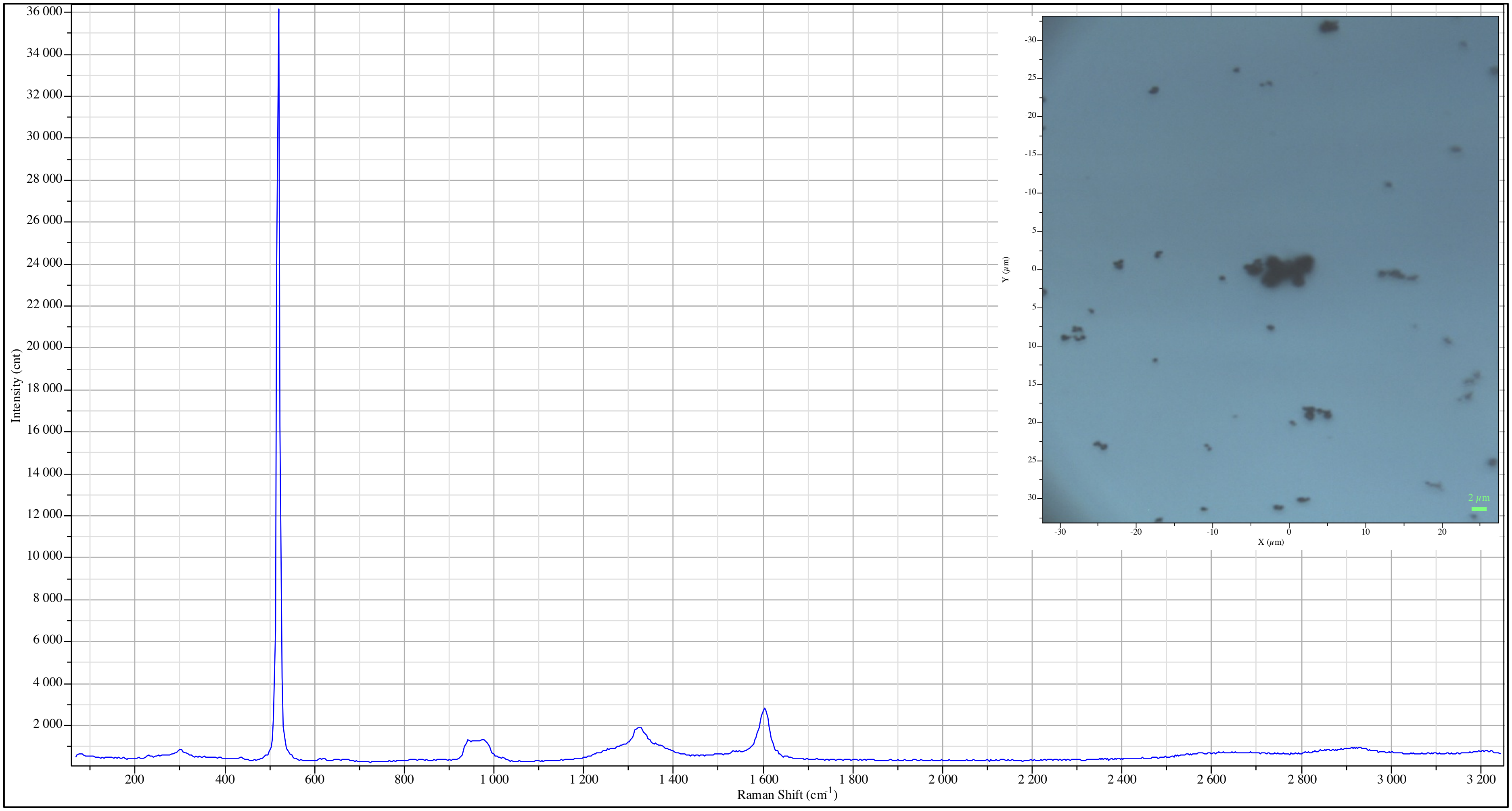
- Added 2mg of GNR powder to 4mL of Toluene and sonicated for 20 minutes
- After 10 days solution separated into two parts (purple and black)
- Pipetted the purple solution, dropcasted it onto substrate and did an $N_2$ dry.
- SEM images show drying patterns
- The powders did not form a continuous film, but they seem to have exfoliated



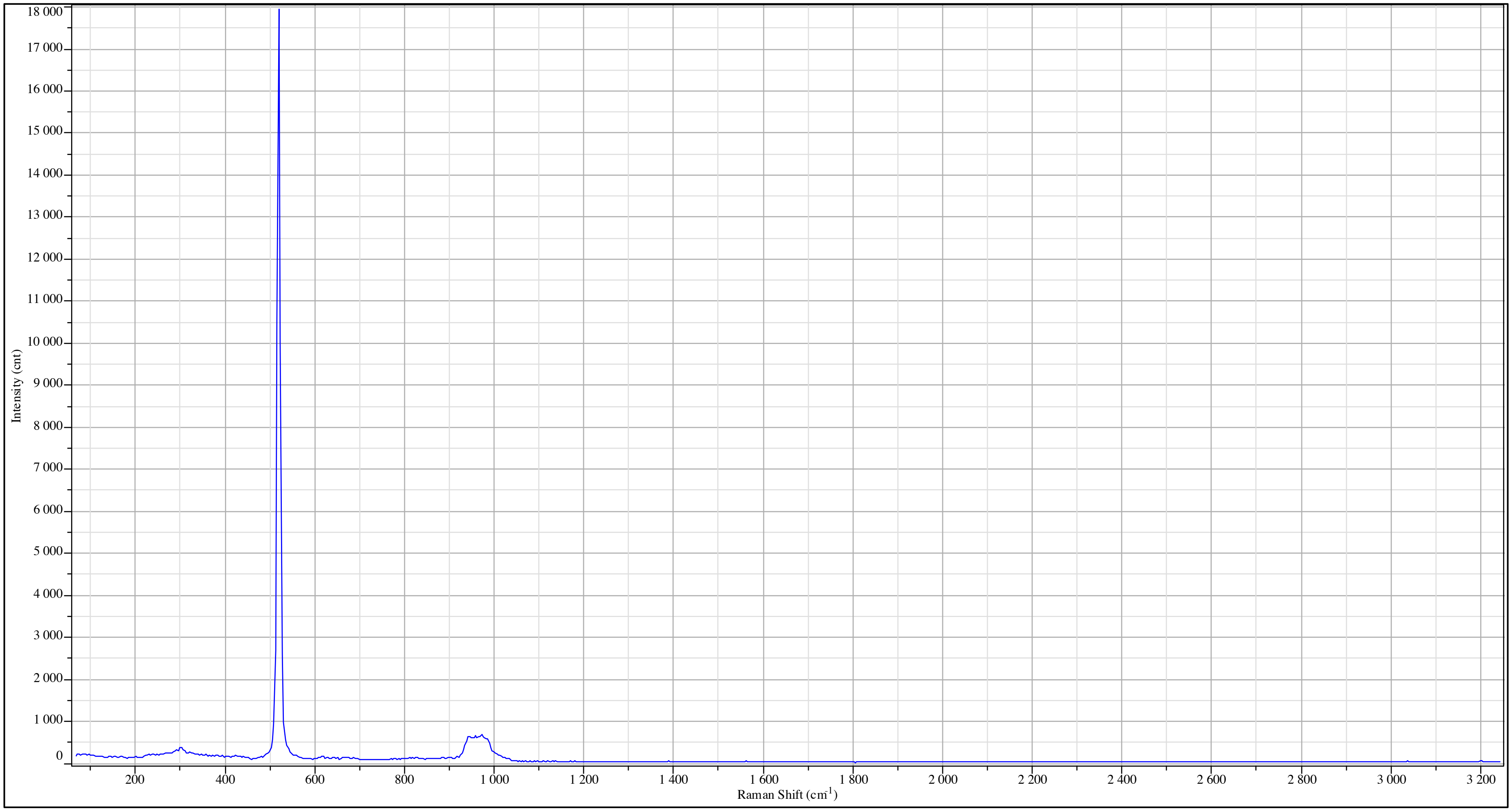
# Experiments & Results (Toluene Solution)

- Raman Spectroscopy: small peaks at ~1300 and 1600 cm$^{-1}$ (D and G bands)



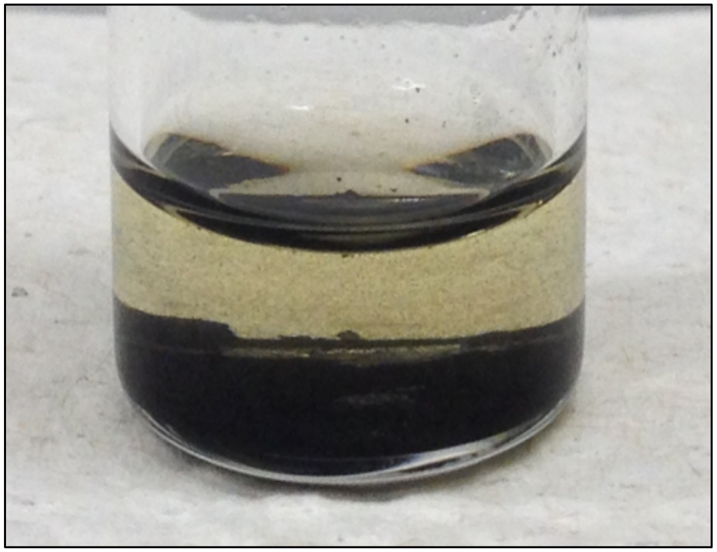
# Experiments & Results (Toluene Solution)

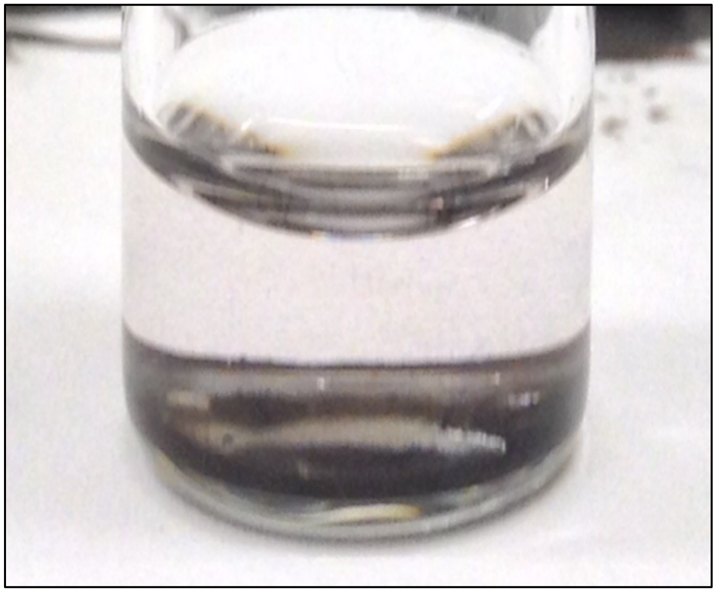
- Raman Spectroscopy
- No GNRs in areas where we can't see anything



# Experiments & Results (DMF Solution)

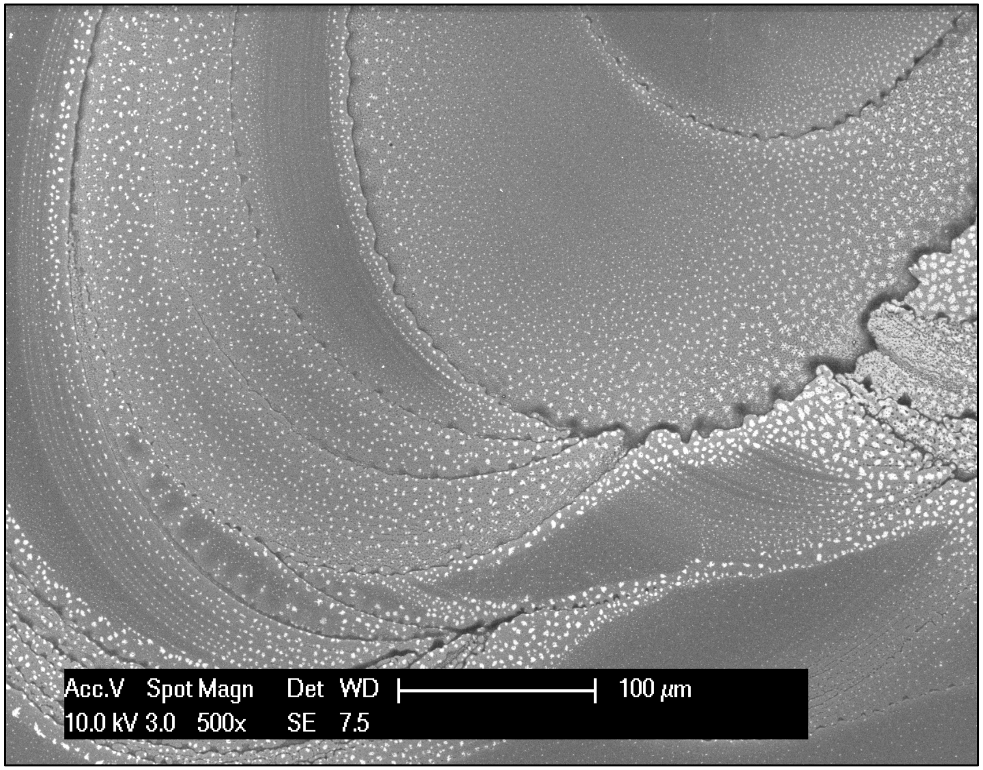
- Added 0.2mg of GNR powder to 2mL of DMF and sonicated for 3 minutes
- Heated for 10 min. at 60°C
- 10 min. sonication
- Heated for 10 min at 80-90°C
- Allowed to settle overnight
- Removed the liquid with a pipette and added new DMF to the vial
- The solution was shook by hand and sonicated for 5 minutes
- After settling, there was a purple hue
- Dropcasted purple solution onto substrate and placed it on a hotplate until solution evaporated

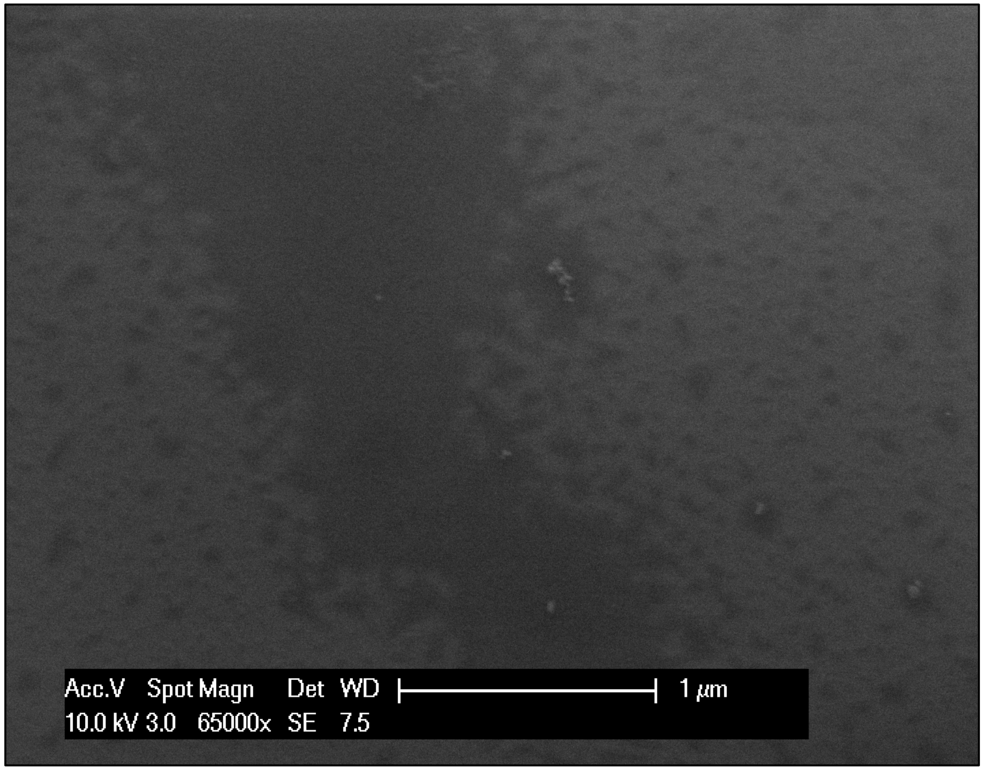




# Experiments & Results (DMF Solution)

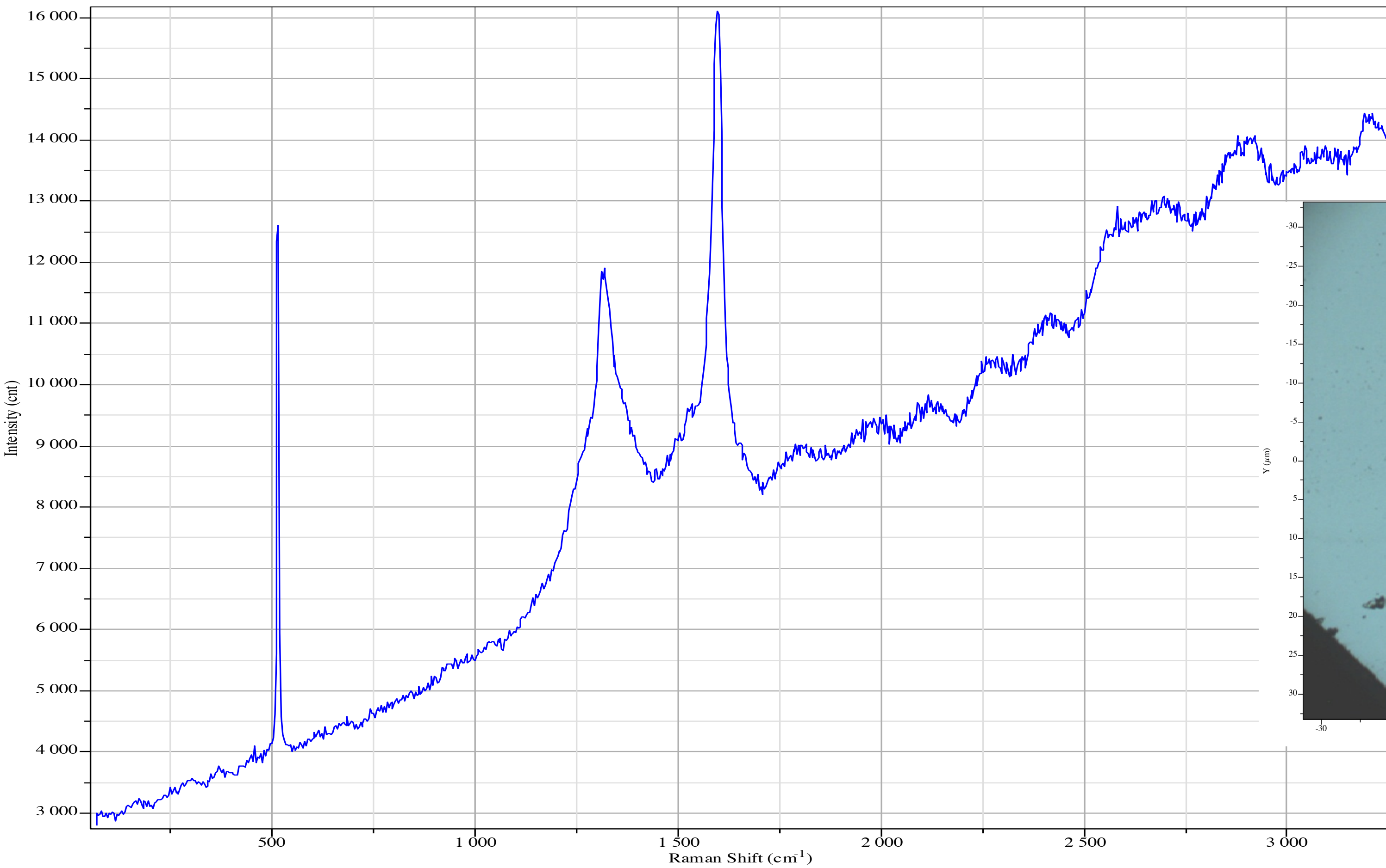
- SEM images show drying patterns
- The powders did seem to form a continuous region, and no giant particles were observed

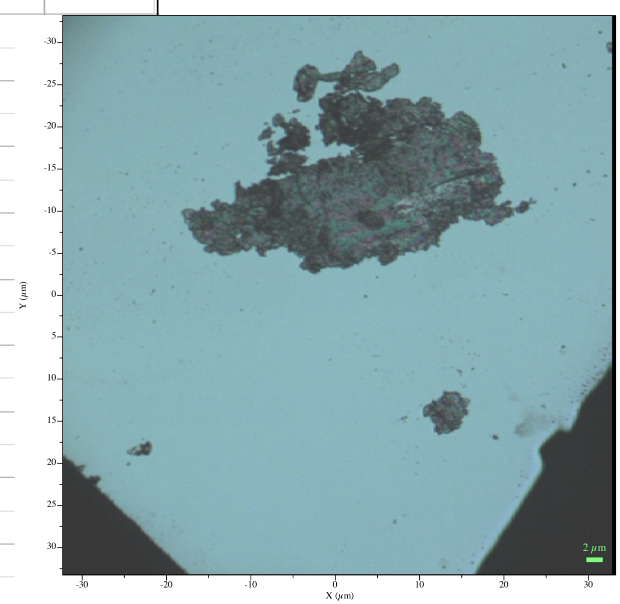


# Experiments & Results (DMF Solution)

- Raman Spectroscopy: Observed a continuous region at one portion of the substrate
- Large Peaks at ~1300 and 1600 cm$^{-1}$ (D and G bands)



# Conclusions & Future Work

- We attempted various transfer procedures to create a high performance GNR-FET
- The DMF solution shows the greatest promise as we were able to create a continuous region
- Will also continue to perfect the DMF procedure
- Next steps include full wafer-scale coverage and device fabrication