Inkjet Printing of Carbon Nano-Materials

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Carbon nano materials, specifically carbon nanotubes and graphene, have been among the leading materials researched due to the display of exceptional physical and chemical properties. Yet these potentially revolutionizing materials have not yet crossed the bridge into the mainstream due to limiting techniques in efficient synthesis and large-scale production. Inkjet printing of carbon nano materials proposes a viable method for large-scale production of flexible electronics. Dimensional patterns can be controlled for micro precision dispersion. The purpose of this research was to effectively print single wall carbon nanotubes (SWCNT) and graphene as Field Effect Transistors (FET) and conductive thin films. In order to properly print our SWCNT and graphene, each was dispersed in their own respective suspension, the former in a Dimethylfolmamide suspension and latter in a Dichloroethane (DCE)/ poly (m-phenylenevinylene-co-2,5-dioctoxy-p-phyenylene) (PmPV) suspension. After proper sonication and centrifugation to remove heavy particles, each suspension was effectively printed on a SiO2/Si substrate for either line or spot printing. The printed graphene solution was analyzed for density via Scanning Electron Microscopy (SEM) and showed many thin sheets of graphene. Further Raman spectroscopy analysis confirmed the presence of graphene. For each printed transistor, a random SWCNT network was dispersed across 2 electrodes effectively creating the transistor channel. Various thicknesses were printed on each substrate to be able to characterize with relation to channel thickness. Semiconductor parameter analysis was then executed to observe drain current and on/off ratio characteristics. Results of the analysis showed an on/off ratio of 10 and mobility of 3.08cm^2/Vs among the 14 to 30 layer transistors. In conclusion, we were able to successfully print functional nanotube transistors and create a viable method for producing graphene and printing thin films.

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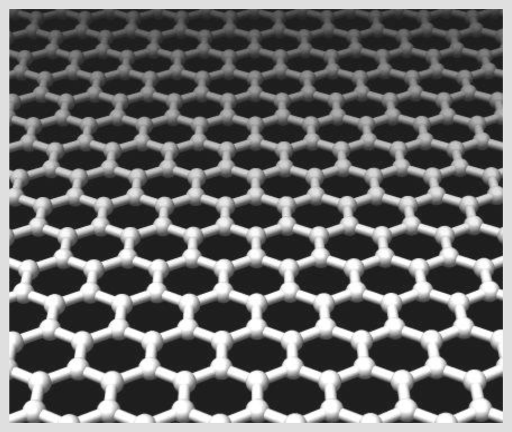
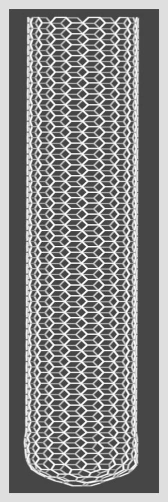
Introduction

Carbon nano materials have been among the leading materials researched due to the display of exceptional physical and chemical properties. Inkjet printing of single wall carbon nanotubes (SWCNT) and graphene proposes a viable method for large-scale production of flexible electronics. Our purpose was to effectively print SWCNT and graphene as field effect transistors (FET) and conductive thin films.

Materials Used

Graphene is 1 atomic layer of carbon. Graphene is a zero-bandgap semiconductor, or semi-metal, that demonstrates exceptionally high mobility at room temperature.

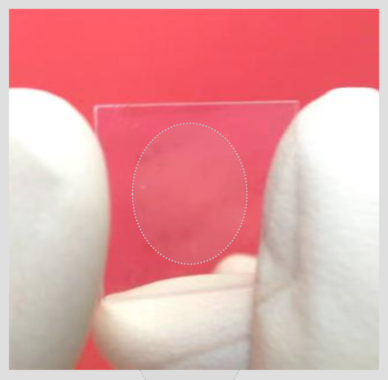


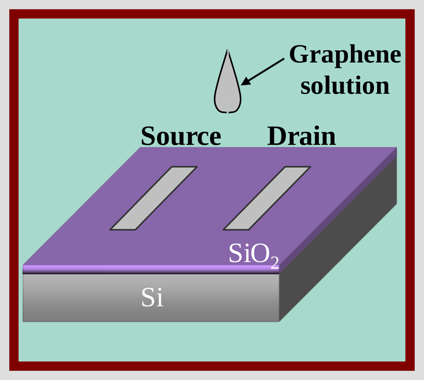


Single wall carbon nanotubes (SWCNT) are sheets of graphene rolled into a tube. They can display either metallic or semiconducting characteristics depending on the roll of the lattice.

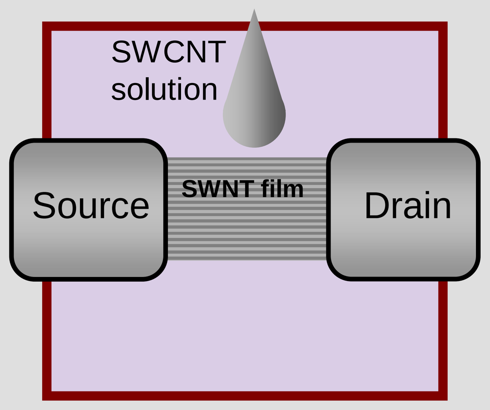
Inkjet printing

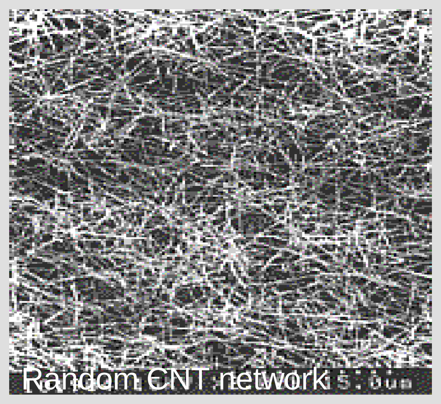
Graphene can be printed to create large area conductive thin films and transistor electrodes.





SWCNT can be printed in random networks to create Field Effect Transistors.

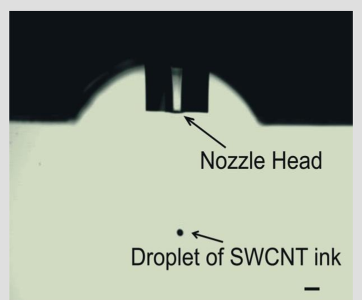




Why Inkjet printing?

- Large scale production
- Spot or line patterning
- Micro precision
- Fast

(MICROJET printer)



- Nozzle head diameter: 50 µm
- Low viscosity designed nozzle head
- Drop diameter: 200-300 µm
- Dispersion in single "shots"

Procedures

Graphene Solution

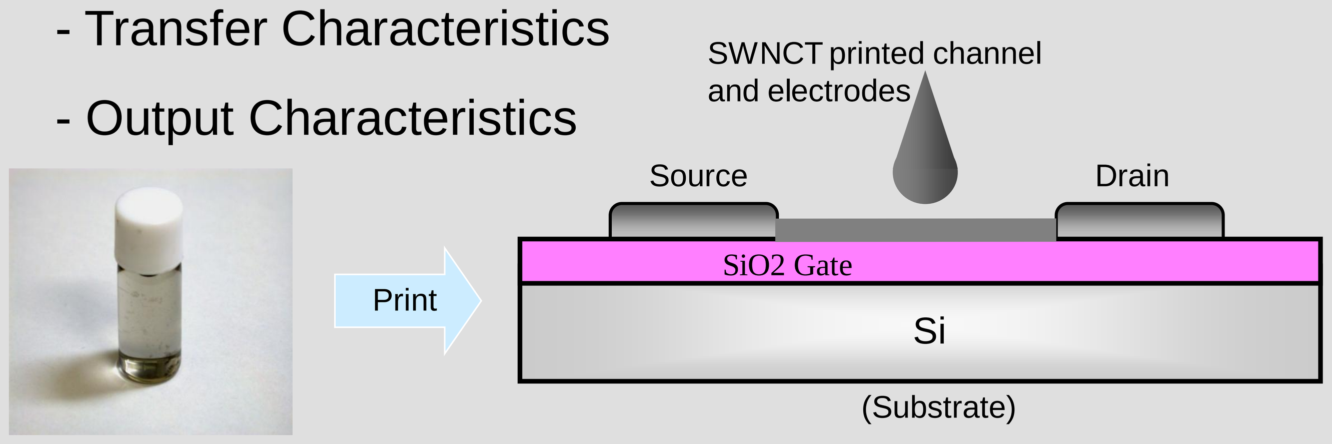
- Thermal exfoliation of GRAFguard graphite @ 1000℃ in Ar/He gas
- Dichloroethane (DCE)/ poly (m-phenylenevnylene-co-2,5-dioctoxy-p-phenylevinylene) (PmPV)/ Exfoliated graphite solution
- Ultrasonic probe sonication – 10 minutes
- 12000 RPM Centrifugation – 30 minutes
- Supernatant solution separation
- DCE open air evaporation
- Printable graphene solution

(Exfoliated graphite) (Final solution)

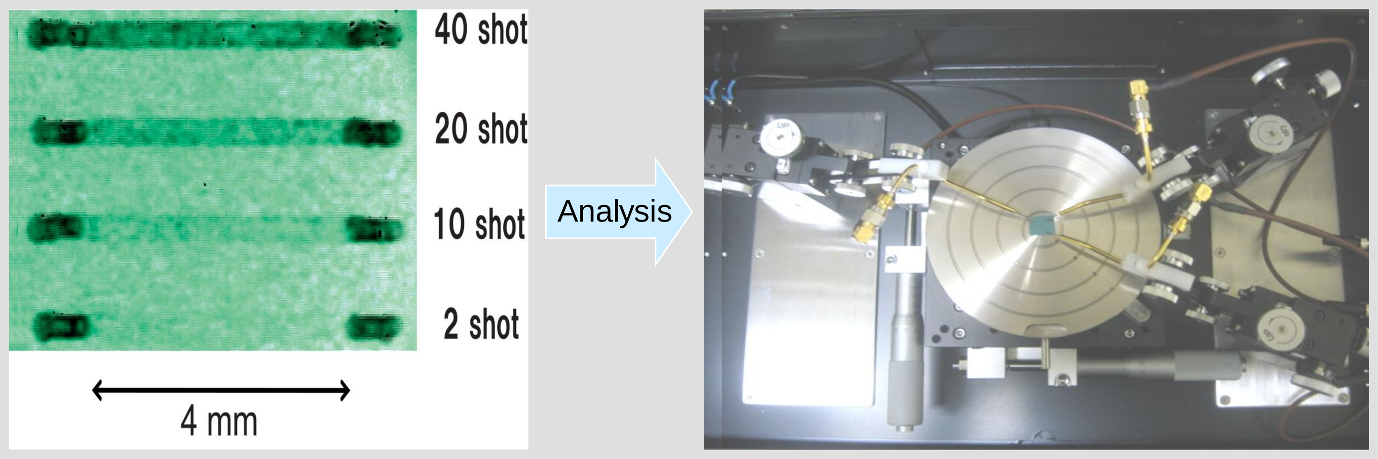
The graphene solution is then printed on an Si substrate and calcinated at 590℃ to remove excess PmPV polymer netting a high concentration of graphene sheets. High densities were observed between 1000 to10,000 printed shots.

SWCNT Field Effect Transistors

- SWCNT Dimethylfolmamide (DMF) suspension
- Inkjet printing on SiO_2 substrate
- Transistor Parameter Analysis
  - Transfer Characteristics
  - Output Characteristics



(DMF SWCNT solution) (Substrate)

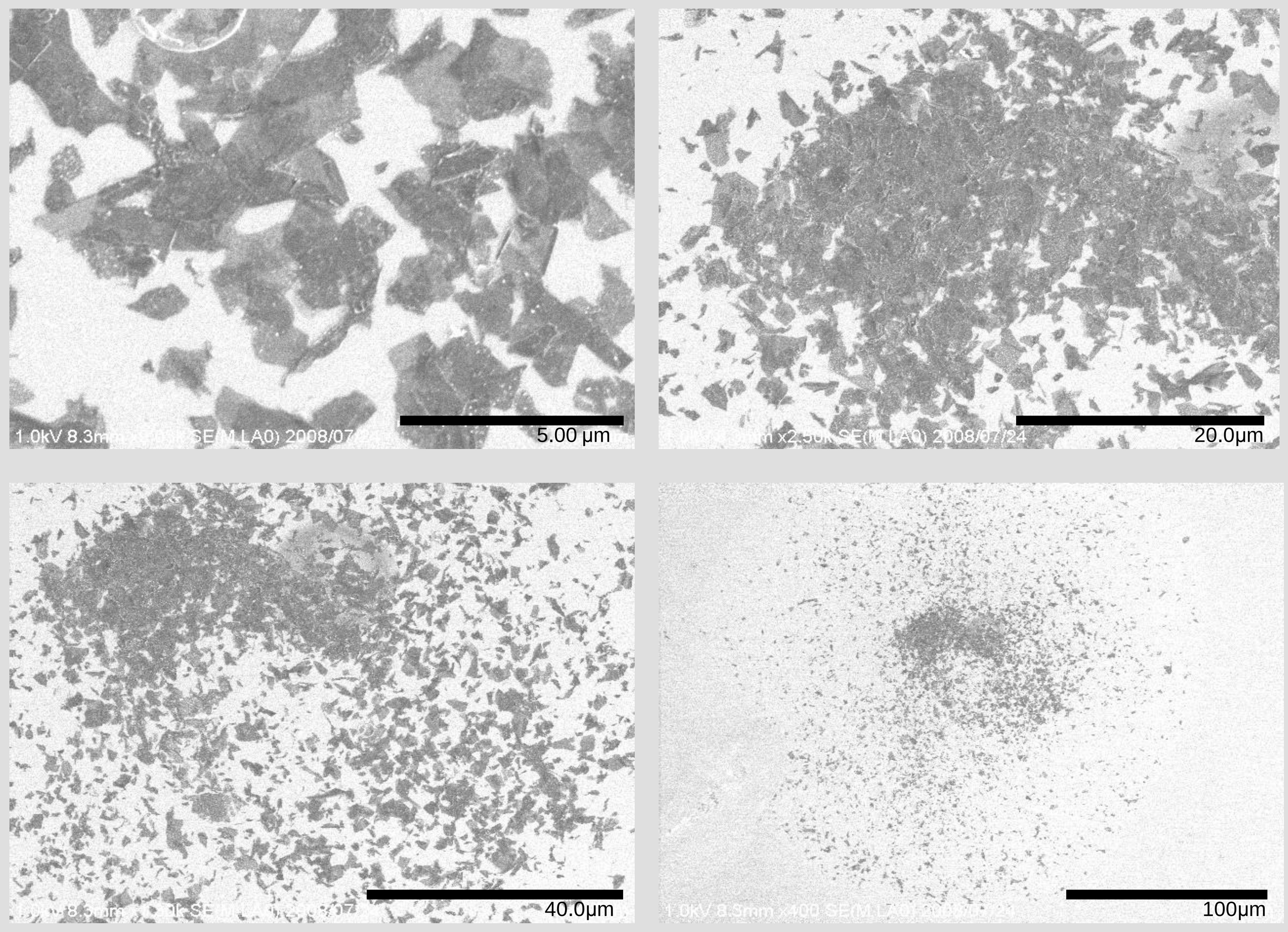


(Printed FETs) (Transistor Parameter Analyzer and substrate)

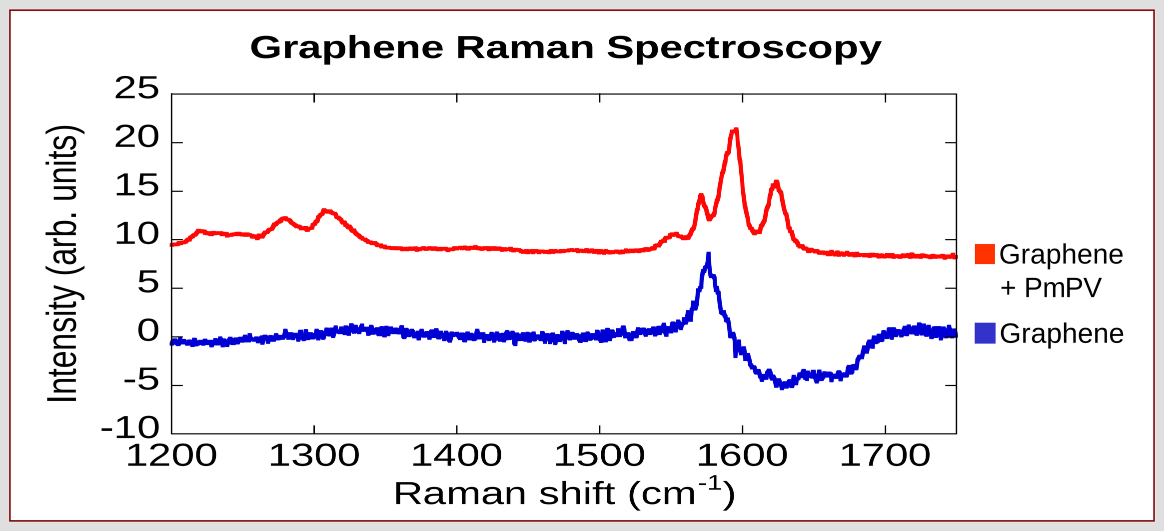
Transistor length varied between 3mm and 4mm while channel thickness varied between 2 and 40 shots. Densely printed SWCNT were also used for the transistor electrodes.

Results

Scanning Electron Microscope (SEM) images of Inkjet printed graphene from 5µm to 100µm

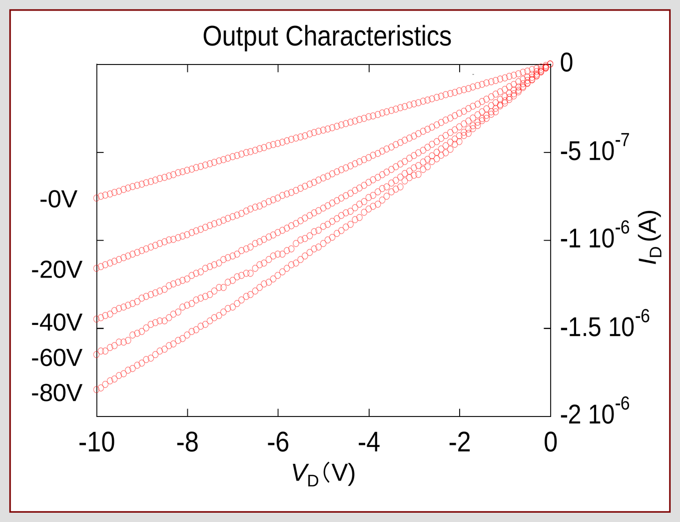


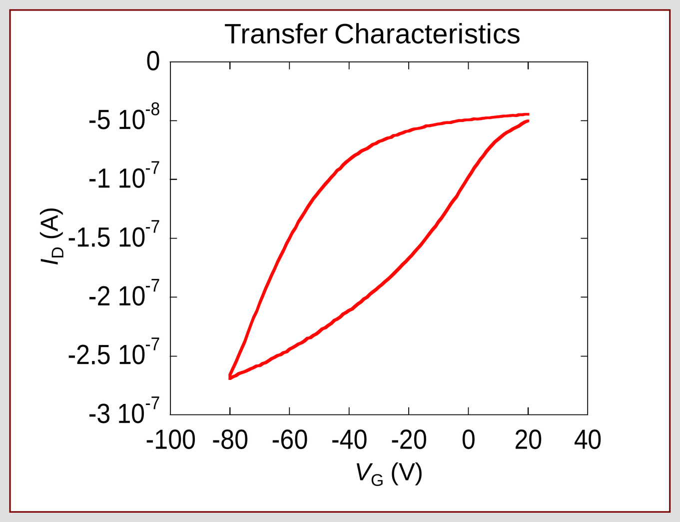
High concentrations of graphene were observed on the SEM.



Raman Analysis further characterized the graphene with a peak intensity at 1580 cm^{-1} as usually seen.

Characteristics of Inkjet Printed SWCNT transistor





Mobility: 3.06 cm^2/Vs On/Off ratio: 10

The transistors showed either good mobility with more shots or good on/off ratio with less shots but never both.

Conclusion

We were able to successfully print nanotube transistors and create a viable method for producing and printing graphene thin films. Although the graphene process is not yet completely uniform, we obtained high concentrations of graphene thus making it possible to further analyze conductivity of printed networks. SWCNT transistors were a compromise between good mobility or good on/off ratio. Further experimenting with layer thickness and electrode material could net better transistor results.

Research conducted at Tohoku University as a participant in the Rice University NanoJapan 2008 program sponsored by an NSF-PIRE grant.