CVD Graphene Nanoribbons by Silver Nanowire Shadowmasking

Benjamin Piazza,[1,2] Aoki Kensuke,[3] and Aoki Nobuyuki[3]

[1]*Dept. of Physics, The Pennsylvania State University, University Park, Pennsylvania, United States of America*
[2]*Nakatani RIES: Research & International Experiences for Students Fellowship in Japan, Nakatani Foundation, Tokyo, Japan*
[3]*Dept. of Materials Science, Chiba University, Inage, Chiba, Japan*

The aim of this project is to determine if CVD graphene nanoribbons are a plausible candidate for FET (Field-effect Transistor) devices. Owing to its remarkably high mobility, a CVD graphene FET would boast better performance and energy efficiency than any conventional transistor device. However, graphene in its natural, sheet form lacks a band gap, which is a prerequisite to device applications. By fabricating graphene in nanoribbon structures, a band gap is induced that is inversely proportional to nanoribbon width. Using photo-lithography and thin film deposition techniques, gold electrodes are built over thirty nanometer diameter silver nanowires on CVD graphene. Silver nanowires provide a shadowmask for CVD graphene from oxygen plasma etching and are subsequently removed via nitric acid treatment, leaving CVD graphene nanoribbons as confirmed by AFM and electrical transport measurements. These results may serve as the precursor to fabrication of ultra-fine, large band gap CVD graphene nanoribbons by ultra-thin nanowire shadowmasking.

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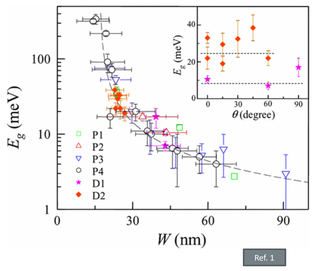
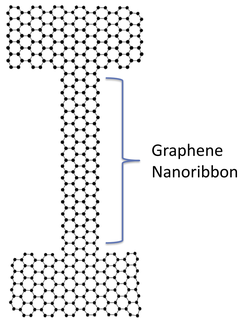
[1]*The Eberly College of Science, Pennsylvania State University,* [2]*Nakatani-RIES: Research and International Experiences for Students Fellowship, Rice University,* [3]*Department of Materials Science, Chiba University*

Contact: bsp139@psu.edu

Graphene as a MOSFET Device

Graphene Energy Band Gap vs. Width





- **Graphene boasts highest electric mobility of all materials**
- **High utility for device applications**
- **Requires a band gap to be usable in MOSFET transistor devices**

- **Thin nanoribbon structures of graphene have band gaps**
- **Size of band gap inversely proportional to width**

Electron Beam Lithography

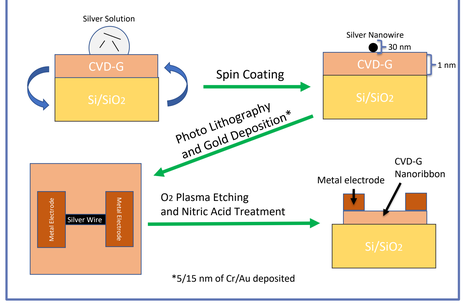
Can be used to fabricate specific patterns.

Difficult to fabricate and edges are rough.

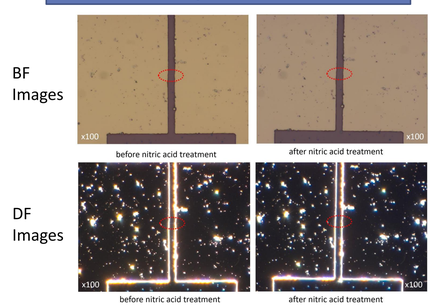
Nanowire-based Fabrication

Can produce nanoribbons at a less than 20 nm width with fewer edge defects and easier fabrication.

Sample Fabrication



Sample Surface



*Images taken via optical microscopy

Nanoribbon Fabrication Methods

Silver Nanowires

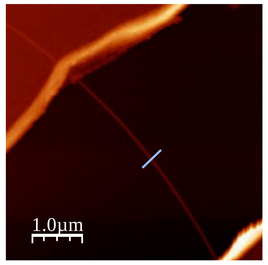
- Size ranges from 20-30 nm
- Act as shield for CVD Graphene in O_2 plasma etching
- Easily removed via nitric acid treatment

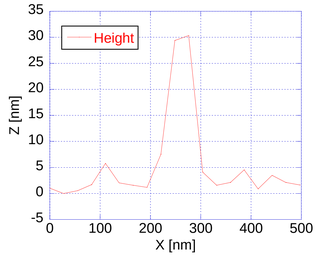
Photolithography

- Enables precise patterning of electrode via positive lithography and chrome/gold nanolayer deposition.
- Can quickly and easily build electrodes around nanowires (compared to EBL)
- Can etch two terminal patterns for conductivity measurements

Material Properties

AFM Data and Height Profile

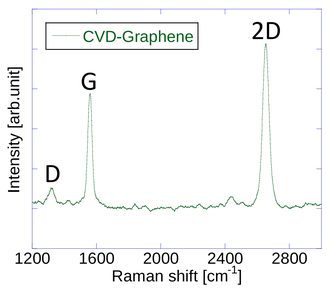


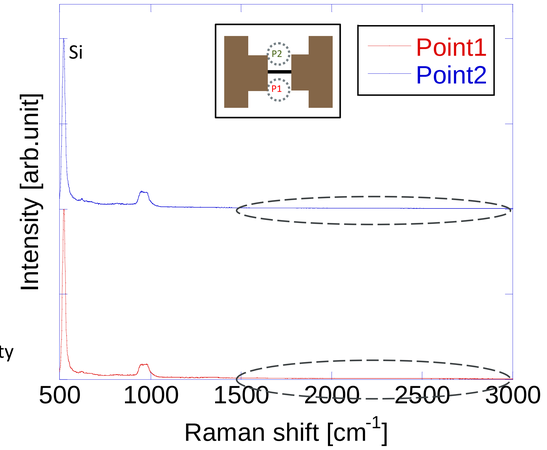


- Silver nanowire height profile
- Width measurement is unreliable owing to AFM tip curvature
- Confirmed to be about 30nm in radius via height profile
- Therefore fabricated CVD graphene nanoribbon should also be about 30 nm

Results and Analysis

Raman Spectroscopy





- Via Raman Spectroscopy, characteristic intensity peaks of CVD graphene are confirmed prior to O_2 plasma etching (20 W for 3 seconds)
- Post-treatment, characteristic peaks are lost, indicating loss of CVD graphene near channel

*Raman Spectroscopy performed in two regions near but not including silver nanowire

Conductance

*Both plots taken at 297 K in a vacuum environment

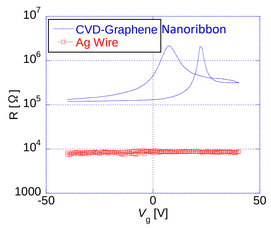


Fig. 1 Resistance vs. Gate Voltage Across Electrode

Post nitric acid treatment, gate leak occurred due to reaction with Si substrate, and so data is unreliable in this region

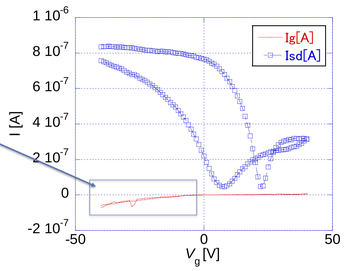
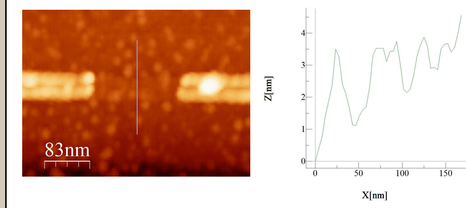


Fig. 2 Current vs. Gate Voltage Across Electrode

- CVD graphene normally exhibits a resistance of kiloohm order, so the large increase in resistance is indicative of CVD graphene. Ref. 2
- Resistance is constant regardless of gate voltage before nitric acid treatment, indicating metallic transport, hence the presence of the silver nanowire. (Figure 1 Red Profile)
- Owing to the gate voltage dependent current post nitric acid treatment, DOS effects are exhibited. This indicates the removal of the silver nanowire. The resistance pattern is characteristic of CVD graphene. (Figure 1 & 2 Blue Profile)

Conclusion

AFM Image and Height Profile Post Nitric Acid Treatment



- The AFM, Raman, and Conductance data indicates the presence of a graphene nanoribbon
- Could be used to realize a graphene MOSFET device

Future Work

- Determine whether thinner nanoribbons can be fabricated from thinner nanowires
- Measure energy band gap against temperature for nanoribbons

References

1. Han, Melinda Y., "Ozyilmaz, Barbaros, Zhang, Yuanbo & Kim, Philip (2007). Energy Band-Gap Engineering of Graphene Nanoribbons. *Phys. Rev. Lett., 98*, 206805.
2. Lin, Wei-Hsiang & Chen, Ting-Hui & Chang, Jan-Kai & Taur, Jieh-I & Lo, Yuan-Yen & Lee, Wei-Li & Chang, Chia-Seng & Su, Wei-Bin & Wu, Chih-I. (2014). A Direct and Polymer-Free Method for Transferring Graphene Grown by Chemical Vapor Deposition to Any Substrate.

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