Fabricating Nanostructures to Modulate Local Potential in Graphene

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Abstract and Introduction:

Graphene is an atomically thin allotrope of carbon with unique electrical properties. Its high carrier mobility at room temperature and ultra-high thermal conductivity make it a promising material for nanoscale circuit applications. One way to study the nanoscale transport properties of ballistic graphene p-n junctions is to modulate the local potential with lithographic gates that are several tens of nanometers in scale. Lithography can also be used to build graphene nanoribbon (GNR) arrays, which lead to a method to build radio frequency amplifiers.

Our efforts were directed at fabricating GNR arrays and gold split-gates with length scales less than 100 nm. After performing electron-beam lithography, we developed our patterns at low temperatures using an ice bath. Oxygen reactive ion etching (RIE) was employed to etch the graphene into nanoribbon arrays, and electron gun evaporation was used to deposit the gold split-gate electrodes, followed by a lift-off process. In order to optimize the recipe, variables such as resist type, electron beam dose, developer type, and development time were systematically tested. We successfully fabricated nanoribbon arrays with a period of 100-180 nm using poly(methyl methacrylate) (PMMA) as the e-beam resist, and arrays with a period of 60-80 nm using ZEP. We successfully fabricated split-gates separated by 50-90 nm using PMMA/MMA bilayer resist.

Procedure and Results:

We fabricated our nanoribbon arrays with a layer of graphene grown using chemical vapor deposition (CVD). The CVD graphene was transferred onto a silicon wafer with a thin layer of thermally grown silicon oxide. Our first batch of samples was made with PMMA 950K A3 as resist. Electron-beam lithography was used to pattern arrays of nanoribbons using doses ranging from 300-400 μC/cm^2. The nanoribbons we patterned were 20-90 nm wide, separated by a distance equal to their width.

Both MIBK: IPA 1:1 and MIBK: IPA 1:3 were used as developers to test the influence of concentration on feature resolution. Developer with a higher concentration of IPA requires a longer time to develop, but provides finer control. We developed our samples at temperatures below 10°C by immersing our developer in an ice bath. Cold development is known to increase the resolution of nanostructures [1]. Finally, oxygen RIE was employed to etch the graphene into nanoribbons.

With PMMA as a resist, we successfully formed GNR arrays with periods from 100-180 nm at a dose of 400 μC/cm^2. However, arrays with periods from 40-80 nm were either over-etched or completely gone, revealing a fundamental limit of our process using PMMA. We also found that a higher concentration of IPA did not increase the resolution of our nanoribbons; it only slowed down the process, and our samples were underdeveloped.

Electron scattering during e-beam lithography produced exposed stripes that were wider than the intended size, resulting in the overetching of graphene. Reducing this effect was critical at scales less than 100 nm. In order to obtain nanoribbons narrower than 50 nm, we chose ZEP 520a as our resist for the second batch of GNR arrays because of its high contrast and resolution [2]. We also wrote our features smaller than the intended size to compensate for the scattering effect. Doses from 270-390 μC/cm^2 were tested. We developed the arrays in cold n-amyl acetate. With ZEP as the resist, we successfully formed GNR arrays with periods from 60-80 nm at doses of 270-350 μC/cm^2.

We fabricated our gold split-gates on a silicon wafer, and used electron beam lithography to pattern gates that were separated by 50-200 nm. ZEP 520a, which is known to have an inherent undercut [3], and conventional PMMA/MMA bilayer resist were tested.

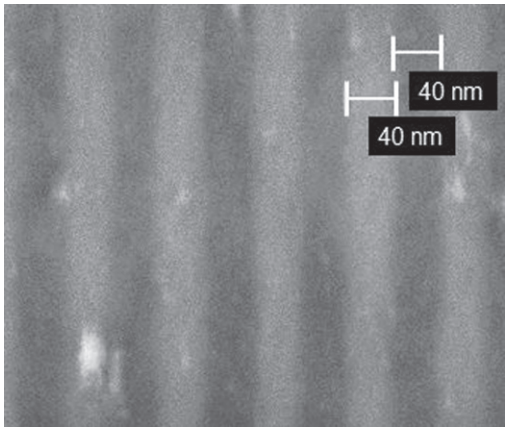

Figure 1: 80 nm period nanoribbon array made with ZEP.

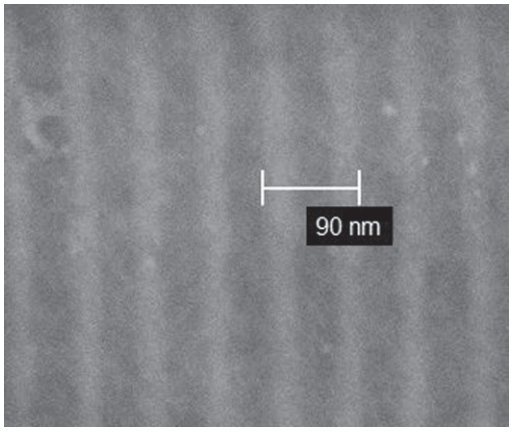

Figure 2: 60 nm period nanoribbon array made with ZEP.

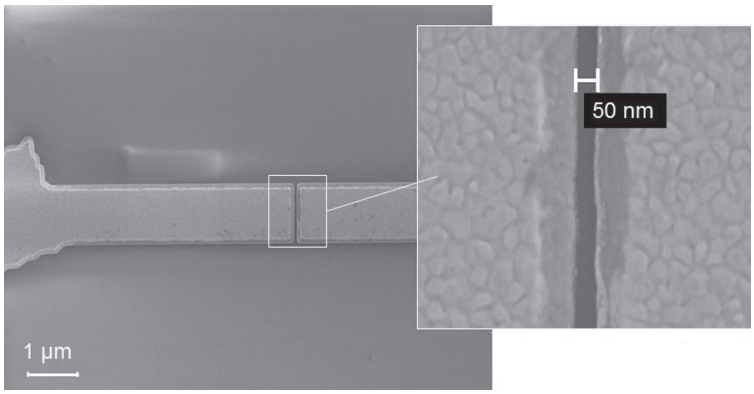

Figure 3: 50 nm split-gate made with a PMMA/MMA bilayer.

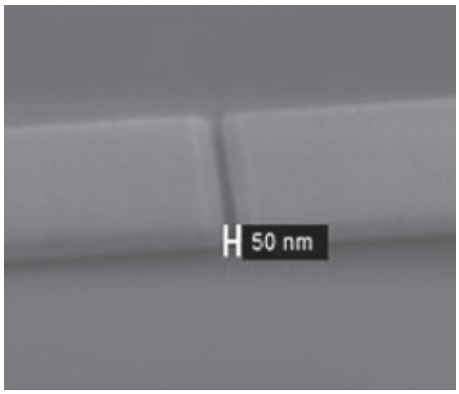

Figure 4: 50 nm split-gate made with a PMMA/MMA bilayer.

The split-gates fabricated using ZEP were written with doses from 250-390 μC/cm^2, and developed in n-amyl acetate below 10°C. We deposited 50 nm of gold with e-gun evaporation, and performed metal lift-off in a heated bath of Remover PG (75-85°C). Scanning electron microscope images and resistance measurements revealed that split-gates 90 nm wide and above were successful, but smaller gates either shorted or had very rough edges.

PMMA/MMA bilayer resist yielded much cleaner results. We wrote the patterns with doses from 300-450 μC/cm^2, and developed in cold MIBK: IPA 1:1. Metal lift-off was performed using acetone. Because of electron scattering, the split-gates were much thinner than the pattern size. This was the desired effect, and split-gates written at 70-90 nm had a final size less than 50 nm.

Conclusions:

It is possible to fabricate nanoscale GNR arrays and local gate structures using our processes. We achieved 30 nm ribbons using ZEP, correcting for electron scattering, and developing in an ice bath. Split-gates with a separation of 50 nm were achieved by writing 70-90 nm gate structures in PMMA/MMA bilayer resist. With these structures and techniques, researches can further study the transport properties of graphene by locally modulating the potential.

Acknowledgments:

I would like to thank Professor Jun Zhu for her advice and the use of her lab. I would also like to thank Jing Li for putting in many hours to teach me and help me with this project. I also greatly appreciate the Zhu Group and the Penn State Nanofab Staff for all the advice, and the National Nanotechnology Infrastructure Network REU Program, along with the National Science Foundation, for providing funding.

References:

[1] Cord, B., et al., "Optimal temperature for development of poly(methylmethacrylate)." Journal of Vacuum Science and Technology B, 25, 2013-2016 (2007).

[2] Chapin, C., et al., "Optimization Studies of ZEP520." Georgia Institute of Technology, Nanotechnology Research Center, 2010. PowerPoint.

[3] Conway, J., "E-beam Process for ZEP-520A to be used for Metal Liftoff and RIE." Stanford University, SNF, 2005. Web.