Development of Fabrication Process on Strainable Polyimide Substrate

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Primary CNF Tools Used: Heidelberg Mask Writer - DWL2000, GCA 6300 DSW 5X g-line Wafer Stepper, Nabity System for Supra SEM, SC4500 Evaporator, Trion Etcher

Abstract:

In this project, we make bilayer graphene devices with a metal gate and electrical contacts on strainable polyimide substrates. We developed a procedure for doing photolithography with the resolution of 2.5 µm on polyimide substrate and using electron beam lithography along with etcher to pattern devices. Currently, we have achieved about 1% of strain on a graphene device and over 1% of strain on bare chip.

Summary of Research:

Theoretical calculation has shown that net orbital magnetization would appear in uniaxially strained bilayer graphene with broken inversion symmetry and current bias [1]. Similar magnetization has been observed in exfoliated single layer MoS_2 device [2].

To induce orbital magnetization in bilayer graphene, the device has to be dual gated, strained, and have electrical contact. We chose strainable polyimide substrate and used photolithography to pattern the prepattern, which includes a bottom gate, metal contacts to the device and a meander strain gauge. A picture of the prepattern is shown in the figure section. Then we transfer a boron nitride (BN) flake to the prepattern and pattern the flake so that it covers the bottom gate with electron beam (e-beam) lithography and reactive ion etching (RIE). Lastly, we transfer the rest of the stack on the chip with the conventional dry transfer technique. The polyimide substrate is soft and often has a curvature, making lithography difficult. It also has a non-negligible thermal expansion rate, making baking resist tricky.

By using nLOF negative tone photo resist, instead of bilayer photo resist, we managed to reduce the effect of substrate curvature on uniformity of resist thickness. Then we experimented with both a contact aligner and a stepper and found that a stepper gives better resolution. The substrate curvature making it hard for the mask to have uniform contact with the substrate. By the end, we were able to achieve 2.5 µm resolution with over 90% yield rate.

The difficulty we encountered when doing e-beam lithography is mostly related to baking resist (PMMA 495 A4 495). Since the substrate expand and shrink as temperature changes, the BN flake on it often gets wrinkles after baking, resulting in defective devices. We figured that by baking at a lower temperature (90°C) with longer time (20 min), we managed to reach our resolution requirements without making the BN flake wrinkle.

With the improved fabrication process, we have made several single gated devices. They could be strained to 0.5-0.7%, confirmed with Raman spectroscopy. We could induce an even larger strain on the substrate (over 1%) but could not transfer this strain onto the device. The strain on substrate is confirmed by both optical image and resistance measurements of the strain gauge.

Conclusions and Future Steps:

As we have successfully strained single gated bilayer graphene device, our next step would be to fabricate dual gated devices, which has an extra layer of graphite on top of the stack compared to our current stack. We also plan to try to increase clamping force on our device. Our current devices start to lose strain at 0.5-0.7% and we hope to increase the maximum strain we can induce on the device. One possible improvement we plan to try is to evaporate a layer of metal on the contact region on top of the device, thus clamping the device from both top and bottom.

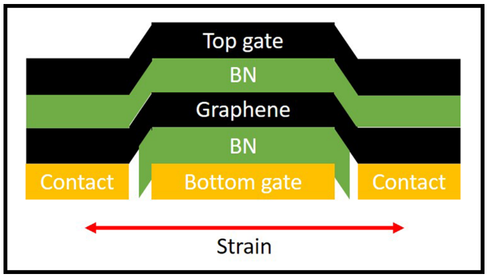

Figure 1: Cartoon picture of the structure of our final device. The red double headed arrow indicated the orientation of strain. We rely on the adhesion between the metal contact and graphene to transfer the strain from substrate to graphene. Currently, we have fabricated and strained several devices without the top graphite gate layer.

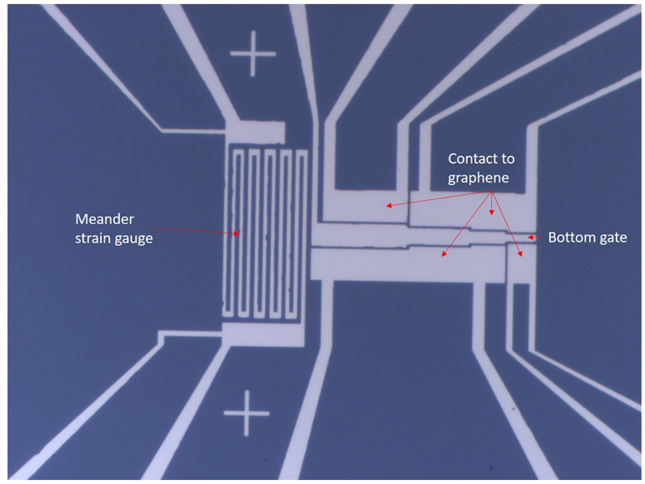

Figure 2: Prepattern that was made with photolithography and metal evaporation.

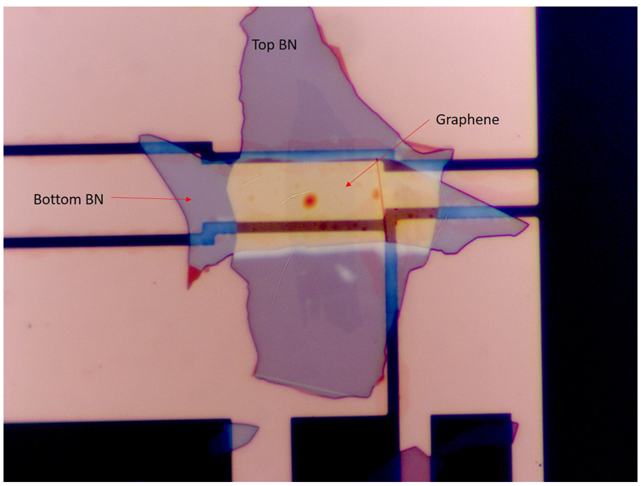

Figure 3: Fabricated device. This device does not go through the e-beam pattern step because the BN flake has the same width as the bottom, not requiring any patterning.

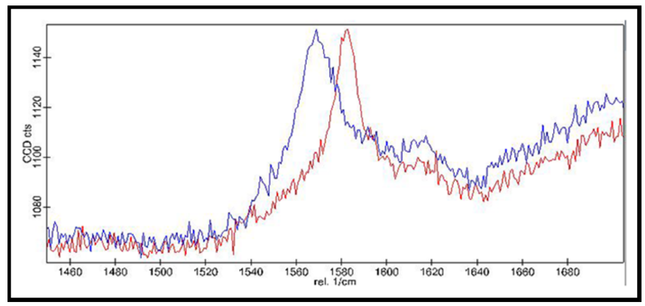

Figure 4: Raman spectrum of the device in Figure 3. The red spectrum was taken when the substrate was not strained and the blue spectrum was taken when the substrate was strained. The shift of the peak in the spectrum indicate that we have achieved ~0.7% of strain on graphene.

References:

[1] B. Schaefer, Phys. Rev. B. 103, 224426 (2021)

[2] Lee, J., Wang, Z., Xie, H., et al. Valley magnetoelectricity in single-layer MoS2. Nature Mater 16, 887-891 (2017).