Impact of Edge Roughness On Graphene Nanoribbons

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Graphene as an electronic material has been receiving much attention as a possible replacement for Silicon CMOS technology [1]. In addition to its use as a switching device, Graphene can also be used as an interconnect material – a truly monolithic system can be constructed using graphene for both transistors and interconnects. An understanding of the edge effect in graphene systems is indispensable for realization of graphene-based electronics. In patterned graphene, the edge effect encompasses chirality, critical dimension (CD) variation, and line edge roughness (LER). In this study, it is shown how LER can affect transport properties of graphene nanoribbons (GNR).

Numerous theoretical calculations have been able to assess the impact of edge roughness and chirality on GNR transport properties. Edge defects act as random point scatterers and induce strong backscattering. Armchair ribbon conduction is mostly through edge states, whereas zigzag ribbons mostly conduct through bulk states. Thus, it is found that a transport gap is formed more rapidly for armchair ribbons due to Anderson localization [2]. Both ribbon types are found to be ballistic even with edge disorder [3]. For low edge disorder, zigzag GNRs are metallic whereas archmair GNRs can be semiconducting. As edge disorder increases, all GNRs, irrespective of chirality, start showing a transport gap [4]. Simulations reveal that edge-roughness causes gated GNR transistors to show more than a 10X variation in their on-current [5]. STM provides information on the atomic-scale roughness and has shown that the edge roughness is about 10 unit cells deep [6]. There has been no previous experimental work on the impact of edge roughness on GNR properties.

Using flaked few-layer graphene as the starting material, graphene ribbons of various dimensions have been fabricated with 15 nm<W<40 nm, 150 nm<L<730 nm. Electron-beam lithography (using the 100 kV JEOL 9300FS) is used to pattern narrow features, and HSQ (XR-1541) is used as the resist. Using dry-etch in oxygen plasma (in an ICP system), the HSQ patterns are transferred to graphene. Electrical testing using standard lock-in techniques reveals that the contact resistance is 10 ohm-μm^2 (Pd/Au is used as the contact metal). Fig. 1 shows a fabricated device with a set of ten GNRs between each electrode-pair.

To isolate the impact of edge roughness, GNRs of the same chirality, line-width, and length are compared. Fig. 2a shows the resistance of a set of GNRs with W=30 nm. It can be seen that there is a 20X variation in resistance between the GNRs. This experiment was repeated on two other samples and the resistance variation was found to be 22X and 45X. Substrate in-homogeneity can induce charge puddles in GNRs and could cause significant variation in resistance. To remove the substrate effect, the GNRs are suspended by etching away the SiO_2 substrate in a buffered-oxide-etch solution. The variation in resistance is now reduced to 8X, Fig. 2b. A similar resistance variation is seen in another sample once the substrate is etched away. With a LER of 1.8 nm, this study shows that edge roughness in GNRs contributes to significant variability in device properties. If Graphene is to become main-stream technology, methods for edge-passivation and low LER will need to be explored to obtain controlled and repeatable device behavior.

References:
[1] C. Berger et al, *J. Phys. Chem. B* 108, 19912 (2004).
[2] E. R. Mucciolo et al, arXiv:0806.3777.
[3] D. A. Areshkin et al, *Nano Letters* 7 (1), pp 204–210 (2007).
[4] D. Querlioz et al, *Appl. Phys. Lett*. 92, 042108 (2008)
[5] D. Basu et al, *Appl. Phys. Lett*. 92, 042114 (2008).
[6] L. Tapaszto et al, arXiv:0806.1662.

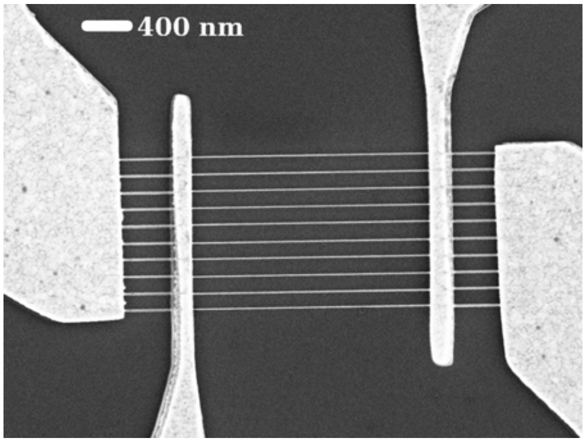
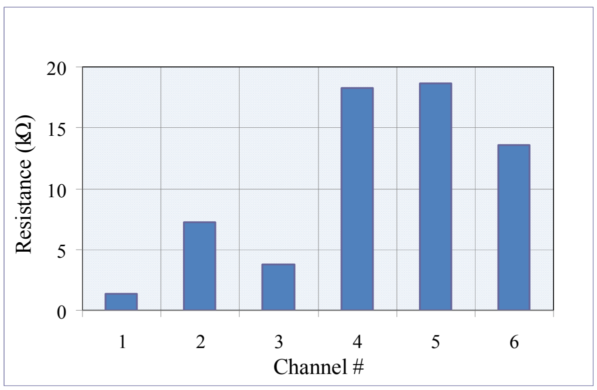
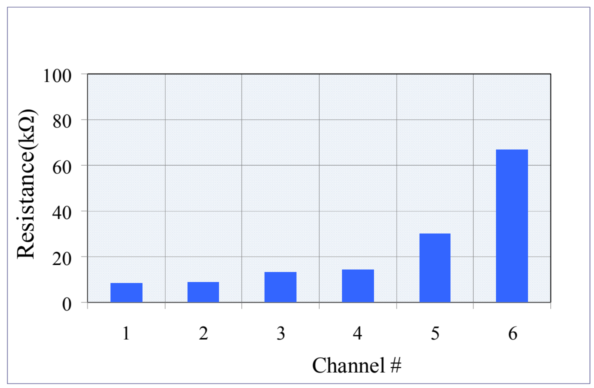


Figure 1: Sub 20 nm graphene ribbons (underneath HSQ resist); the edge roughness is on the order of 2 nm.



(a)



(b)

Figure 2: (a) Resistance of six GNRs with the same chirality, width, and length. Substrate induced in-homogeneity along with edge-roughness causes more than a 20X variation in resistance between the GNRs; (b) Resistance of GNRs from a different sample after the substrate is etched away by a BOE solution; the variation between devices now reduces to 8X.