Atomic Layer Deposition on Single/Few Layer Graphene

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Introduction

Due to the limitations of silicon based transistors, as the dimensions are continuously scaled down, there exists the need to find materials that produce more promising electrical properties such as high mobility, nearly ballistic channel and ohmic contact. Carbon based materials, especially single-walled carbon nanotubes (SWNTs), are among the most promising materials thus far. Yet due to the uncontrollability of chirality and position of SWNTs, the large scale integration is still unachievable. Recently, single layer graphene, which is a one atom thick layer of carbon, was discovered to be stable. Due to the structure of graphene, electrons can travel through the material at the same speed, acting as if they have no mass. Graphite, from which graphene is derived, can be grown in a controlled manner leading to the possibility of large-scale integration particularly in the development of field effect transistors. Another unique advantage of graphene materials is their band gap is inversely proportional to the width of the material, as you will see in Figure 1 [1], which indicates that the smaller it is the more potential energy it has, which is a very attractive semiconducting quality. The development and fabrication of such a device however, is nontrivial. Due to graphene being hydrophobic, we must coat the surface of the graphene with a material which will allow for the bonding of the high dielectric material, aluminum oxide (Al_2O_3), serving as the top gate. We used atomic layer deposition (ALD) to deposit the Al_2O_3, and after we coated the graphene, we checked our results using atomic force microscopy (AFM).

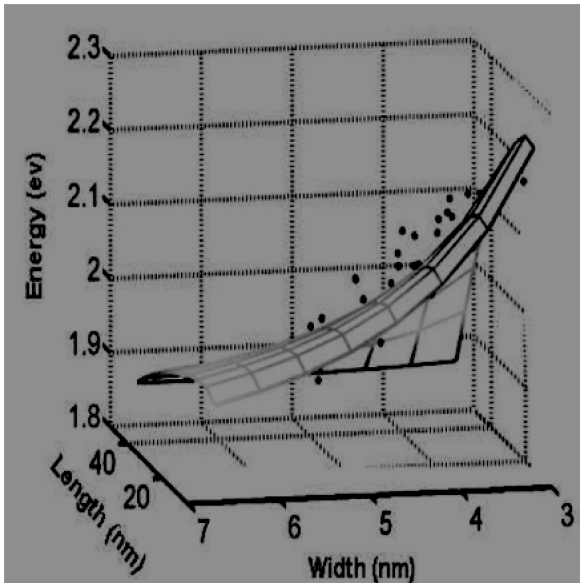

Figure 1: Energy band inversely proportional to the width of the graphene ribbon.

Experimental Procedure

The first stage of our experiment was the development of single layer graphene (SLG). This involved a process named micromechanical cleavage. In this process we cleaved off layers from a $10 \times 10 \times 2$ mm block of highly oriented pyrolytic graphite using scotch tape. Once we achieved relatively thin sheets of graphite on our tape, we contacted the tape against the substrate at varying angles. Next, we investigated our substrate under the 5x/20x optical microscope for signs of graphene which reflects a pale pinkish/purplish color when viewed under the microscope. We proceeded, from this point, by calcining our chip at 470°C for 20 minutes which burned away tape residue and any impurities on the surface. We confirmed our findings using the atomic force microscopy (AFM) system.

Our next step was to deposit the high dielectric oxide layer on the surface. However, since graphene is hydrophobic, we needed to test a control sample, with graphene only, along with a sample soaked for an hour in fluorescein (FITC) and a sample soaked for an hour in deoxyribonucleic acid (DNA), both of which are hydrophilic chemicals. By doing this, we expected the graphene to bond with the high dielectric oxide and uniformly layer over the samples. We proceeded to the atomic layer deposition system, which uses two precursor gases H_2O and tri-methyl aluminum (TMAl). The two gases pulsed respectively and reacted with the surface of the substrate to form the high dielectric, Al_2O_3 (oxide), on the surface. Each cycle put a 0.1 nm layer of Al_2O_3 on the surface and we performed 80 cycles resulting in 8 nm of Al_2O_3. After the ALD was completed, we took more AFM images of our samples to observe and conclude our results.

Results and Conclusions

We were able to conclude from our AFM images that the control sample did have some oxide on the surface however, we were uncertain as to why this would happen because we did not think that any Al_2O_3 would exist on the surface at all. We believe that

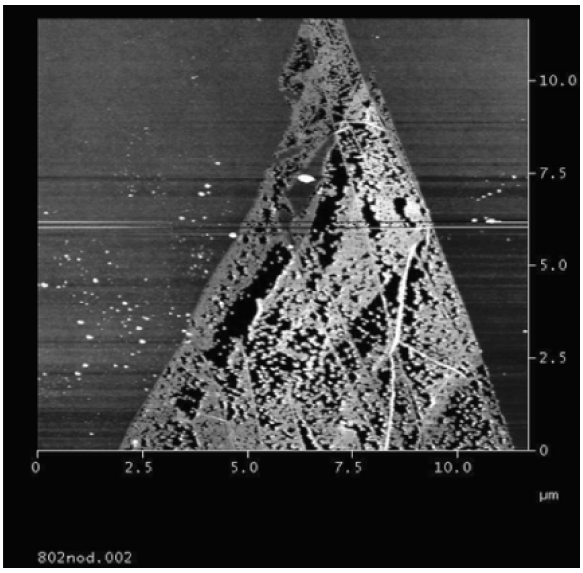

Figure 2: Control sample after ALD.

this was a result of defects in the graphene. Perhaps the dangling bonds reacted with the Al_2O_3 and caused the dielectric to form. There existed a minimal amount of oxide on the surface, as shown in Figure 2.

We then investigated the sample with the FITC coating and we noticed more Al_2O_3 build up on the surface of the graphene, however it was still not uniformly distributed on the surface as you can see in Figure 3. We also noticed that the Al_2O_3 layer was patterned in blotches which indicated to us that the FITC may have reacted with the graphene forming undesirable bonds.

Lastly, we observed the sample coated with DNA, which had produced the best results thus far. There was considerably more oxide on the surface than both of the previous experiments. The Al_2O_3 was still not uniform over the surface, however, as you can see in Figure 4. We were slightly disappointed by this outcome because our lab had successfully coated carbon nanotubes with DNA in a prior research experiment, so we believed that this would work.

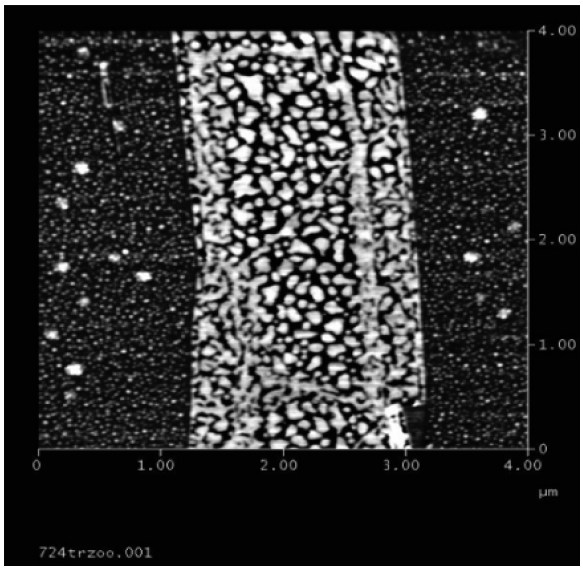

Figure 3: Graphene sample soaked in FITC for one hour after ALD.

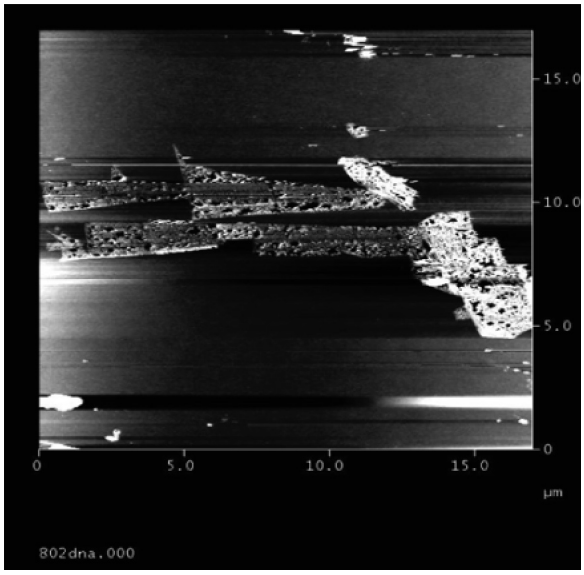

Figure 4: Graphene sample soaked in DNA for one hour after ALD.

Future Work

We will attempt to try more hydrophilic chemicals to achieve a uniform distribution of the Al_2O_3 (oxide) layer. Once achieved, we will etch the graphene down to a narrow ribbon and use the e-beam to pattern contacts on the graphene sample. Once the pattern is made, we will use metal sputtering to deposit the metal contacts on the graphene sample. We will then test the electrical properties of the device and compare with a chemistry method being tested in the lab.

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References

[1] Yang, Li. " Quasiparticle Energies and Band Gaps of Graphene Nanoribbons" Jun. 2007: arXiv:0706.1589v1. 11 Jun. 2007 <http:// cond-mat.mes-hall>.