Measuring van der Waals Forces in Graphene

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Abstract:

The focus of this project was to suspend thin layers of graphene over circular wells to test how the graphene interacted with substrates in connection with a nanomechanical switch. Van der Waals forces adhered the graphene to the substrate. Through pressurization, graphene was disconnected from the center post of the annular ring, and attractive van der Waals forces could then be observed as the graphene was pulled back to the center post. This relates to a switch as graphene can be released and reattached to the annular ring post multiple times. Rings with suspended graphene both attached and not attached to the annular ring post were observed with a tapping atomic force microscope (AFM).

Introduction:

Graphene, a single atomic layer of graphite, is one of science's newest materials. Graphene layers are bonded together by van der Waals forces, weak dipole-dipole bonds that also bond graphene layers to substrates. The long range van der Waals force can be expressed by the Casimir equation:

$$F_C = \frac{-\pi^2 \hbar c A}{240 d^4} \quad (1)$$

where $\hbar$ is Planck's constant, c is the speed of light, A is the area of contact, and d is the distance between the two materials. Since graphene is impermeable, a gas must diffuse through the substrate and not the graphene. Therefore, creating pressurized graphene balloons with a permeable substrate such as silicon dioxide aids in uncovering properties of graphene, such as adhesion energies.

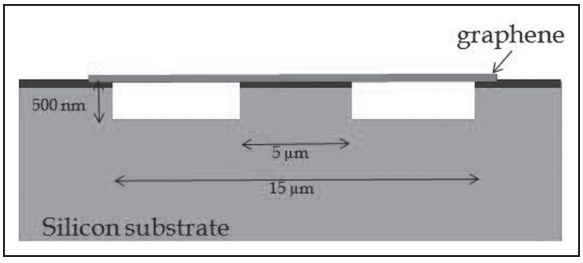

Figure 1: Cross-section view of SiO_2 wells with exfoliated graphene covering the wells.

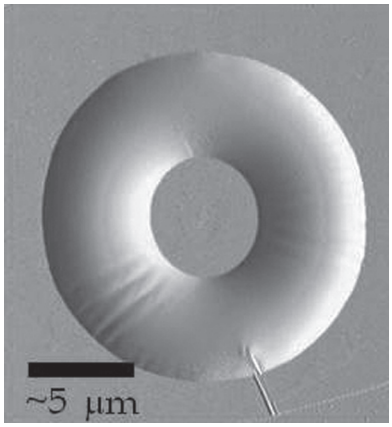

Figure 2: AFM of a pressurized annular ring at 500 kilopascals.

Experimental Procedure:

A silicon wafer with a 90 nm silicon oxide (SiO_2) thickness was used throughout this process. Chip geometry consisted of 15 μm outer diameter and 5 μm inner diameter wells, which created hollow wells with a post in the center. The pattern was etched using a reactive ion etcher to obtain a well depth of 500 nm. A cross section of this geometry can be seen in Figure 1.

A second set of chips was made with a slightly different geometry: a 3 μm outer diameter and 1 μm inner diameter with a 100 nm depth. These chips were covered with 3 nm of chromium and then 3 nm of gold via vacuum evaporation.

Graphene was applied using the scotch tape method. In this method, graphite is separated into thinner layers by peeling using scotch tape. Applying pressure to the tape against the wafer transferred graphene flakes that fully covered some wells. Placing the chip in a chamber at a pressure greater atmosphere allowed

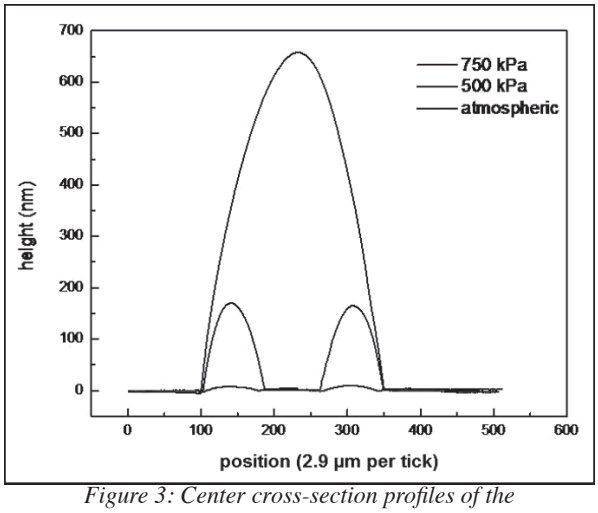

Figure 3: Center cross-section profiles of the graphene at each stage of pressurization.

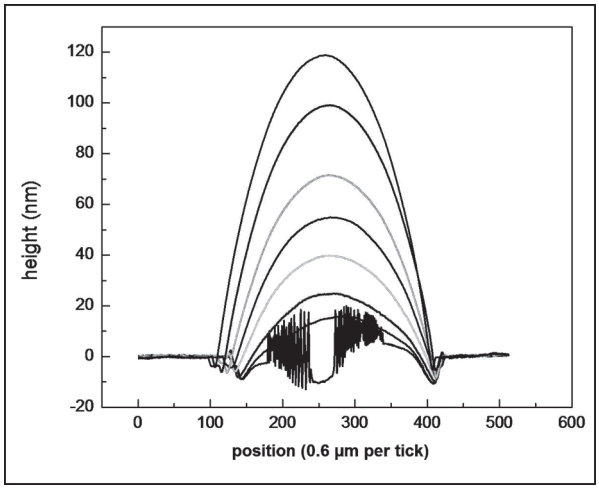

Figure 4: Center cross-section of the gold well graphene balloon. The top curve is the balloon profile almost immediately after leaving the pressure chamber. Each subsequent line is 11 minutes after the previous.

high-pressure helium gas to diffuse into the well through the substrate. Once the chamber had reached equilibrium and the internal pressure was greater than atmospheric, the chip could be removed back to atmospheric pressure and the graphene bulged upward from the pressure difference, creating a graphene balloon as is demonstrated by Figure 2. A tapping-mode AFM was used before pressurization and at various pressure steps to check the height of the graphene balloon and to see if the graphene was peeling from the substrate.

Results and Conclusions:

We observed delamination of the graphene from the substrate during various stages of pressurization. Figure 3 shows the cross-section profile of a graphene balloon as it became pressurized. The flat line represents the graphene at atmospheric pressure. The line with two modes is the profile after the cavity has come to 500 kPa equilibrium.

As the internal cavity was pressurized, but not enough to delaminate from the post, the graphene bulged over the cavity. The cavity was pressurized further until it reached the critical pressure, at which point the graphene snapped off of the center post and became one large graphene balloon. This is represented by the one tall curve.

We also observed deflation of the fully pressurized balloon. Figure 4 shows the cross-section profile of a graphene balloon on a gold-covered well. The top curve represents the balloon at the highest internal pressure, immediately after it was taken out of the pressure chamber. Each subsequent curve is the profile of the balloon 11 minutes after the previous curve. Notice that despite the noise to the left and right of the post on the final profile, the graphene snapped back to the post due to the van der Waals forces that become more significant at shorter distances. The gold-graphene adhesion energy was calculated to be ~ 0.01 J/m^2, while the SiO_2-multilayer graphene adhesion is 0.31 J/m^2. We believe this significant difference is due largely to the surface roughness of the gold.

The graphene behaved as we expected. It detached from the center post of the substrate once it reached the critical pressure. It was also drawn to the post once the distance between the two was short enough to allow van der Waals attraction. The switch-like connection was achieved.

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