

Figure 2: Changes in volume in response to applied backgate voltage.

-30V to 39V both qualitatively in the AFM images as well as quantitatively in the flooded volume measurements. As the applied voltage increased, the bubble pulled into contact with the substrate along its edges, as shown in Figure 2. Modeling the bubble as a parallel plate capacitor, the electrostatic force initially required to pull graphene into contact with the substrate was approximately 19.6 pN, corresponding to 3V.

In response to the constant backgate voltage applied over an extended time (48 hrs), there was evidence of the graphene bubble deflating. Before and after images reveal the occurrence of mass transport beneath the graphene film (Figure 3). The proximity of the deflated graphene bubble to the edge of the graphene film is an indication that the contents of the bubble may have escaped out the edge. Additionally, several graphene bubbles ruptured under the force of the AFM tip due to shear forces present during contact mode imaging.

Force-distance measurements taken on the bubble show that the bubble is deformed by the AFM tip  $\sim 12$  nm before tip deflection occurs (Figure 4). Upon deflection, the slope of the curve is consistent with the slope of an AFM tip interacting with graphene on the substrate, indicating that after initial deformation the tip is deflected as if it were on a hard substrate. The applied force necessary to deform the bubble was calculated to be 300 nN.

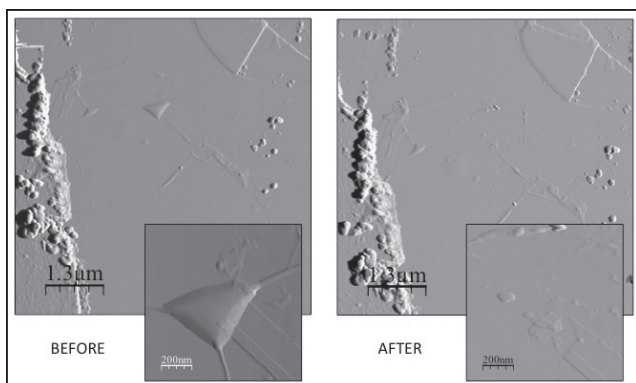


Figure 3: Deflated bubble after constant voltage applied for 48 hours.

**Conclusions:**

The measurements and observations gathered do much in helping us to characterize these graphene bubbles. The deformation of the bubbles reveals that the contents are a compressible substance. While further study is necessary to fully understand these bubbles, the ability to rupture, move, deflate and control the shape of the bubbles by applying shear, normal and electrostatic forces make graphene bubbles an exciting prospect for future applications of the material.

**Future Work:**

Measurements should be repeated to confirm the above observations. Additionally, puncturing a graphene bubble via focused ion beam will give insight as to the contents of bubble.

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**References:**

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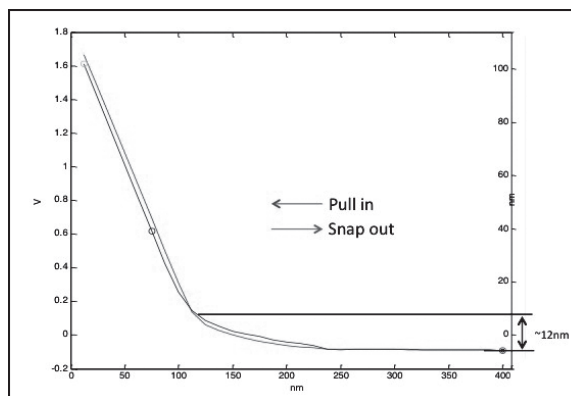


Figure 4: Force-distance curve produced on graphene bubble.