Fabrication of a Three Terminal Nanomechanical Graphene Switch

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Abstract and Introduction:

Nanomechanical switches can be used in a variety of applications, such as memory design or computational elements. Due to their temperature and radiation resistance, nanomechanical switches are advantageous over semiconductor switches in some applications, such as extreme environments where computational devices would need to withstand large amounts of radiation or extreme heat.

Graphene, a single atomic sheet of graphite, has superior electrical, mechanical and thermal properties. The high Young's Modulus, extremely low mass, low resistivity and planar surface make suspended graphene ideally suited for the active component of a nanomechanical switch. Thus, the objective of this project was to fabricate and test a graphene based nanomechanical switch.

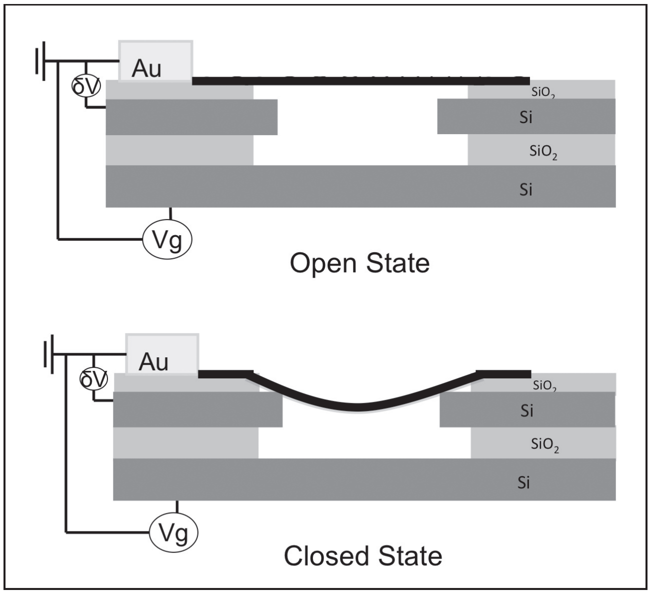

Figure 1: Three terminal switch design.

Device Design and Operation:

The device geometry consisted of a graphene sheet suspended over a silicon/silicon dioxide substrate and in electrical contact with a gold electrode. Voltage applied to the underlying silicon substrate was used to actuate the switch. By applying a voltage, the graphene was brought into physical contact with the underlying silicon step and was in the closed state. By removing the voltage, the graphene was no longer in contact, and returned to the open state, as seen in Figure 1.

The three terminal design can adapt to transistor logic and allows for separate gate and circuit voltages, resulting in a low voltage drop across the graphene during the On State. Additionally, the mechanical nature of the switch allows for a high On/Off ratio.

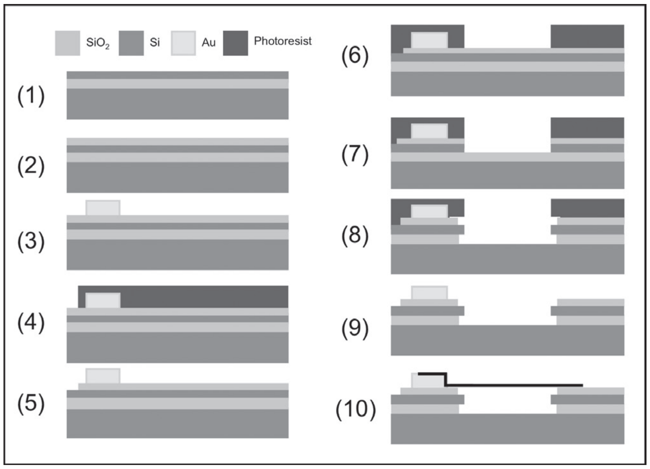

Figure 2: Fabrication process outline.

Fabrication:

The switch was fabricated using standard photolithography (Figure 2). Starting with a bare silicon-on-insulator (SOI) wafer (top silicon [Si] layer 2 μm, SiO_2 0.5 μm) (Step 1), a 65 nm oxide was grown on the top surface through thermal oxidation (Step 2). Gold electrodes were deposited using evaporation and lift-off techniques (Step 3). A pattern was formed with photoresist for probe access windows (Step 4), which were then etched into the top layer of Si by buffered oxide etching (Step 5). The switch cavities were patterned onto the substrate with photoresist (Step 6), and etched into the bottom layer of SiO_2 with reactive ion etching (~ 2.5 μm depth) (Step 7).

This was followed by buffered oxide etching to remove the excess SiO_2 and form the Si step (~ 1 μm wide) to which the graphene would make contact (Step 8). Photoresist was then removed (Step 9). Additionally, a trench, surrounding each device, was etched down to the bottom layer of Si in order to electrically isolate the top and bottom layers of Si. This was done in order to prevent electrical shorts between the two layers.

The final geometry of the substrate can be seen in Figure 3.

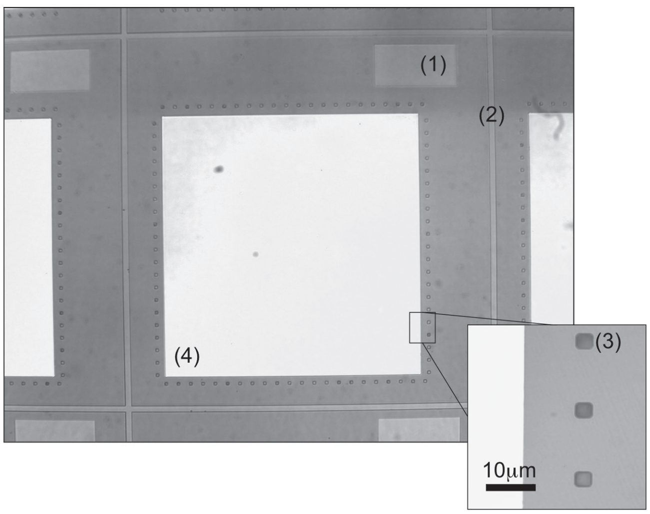

Figure 3: Overhead view of final substrate geometry. Access window to top layer of silicon (1), electrical isolation trench (2), switch cavity (3), gold electrode (4).

The final step in the fabrication process was to suspend a graphene sheet over the cavity by way of mechanical exfoliation (Step 10). Figure 4 shows an overhead view of the final switch with each cavity 5 μm in diameter and ~ 2.5 μm deep.

Results and Conclusions:

The graphene nanomechanical switch was successfully fabricated to the desired geometry. Electrical testing using a probe station is currently in progress. By sweeping the voltage and measuring the current associated with the graphene in physical contact with the underlying silicon substrate, one is able to read out the open and closed states of the switch. The distance between the suspended graphene and the bottom layer of silicon to which the actuation voltage is applied is fairly large, thus requiring a much greater voltage than desired to pull down the graphene sheet into physical contact with the sense electrode. Future designs will incorporate a smaller gap between the graphene and underlying silicon substrate to lower the actuation voltage of the switch.

Future Work:

Future work includes the continuation of electrical testing with the current graphene switches and alterations in the geometry of the substrate to reduce the required actuation voltage. Alterations include reducing the overall depth of the cavity as well as experimenting with the width of the top silicon step.

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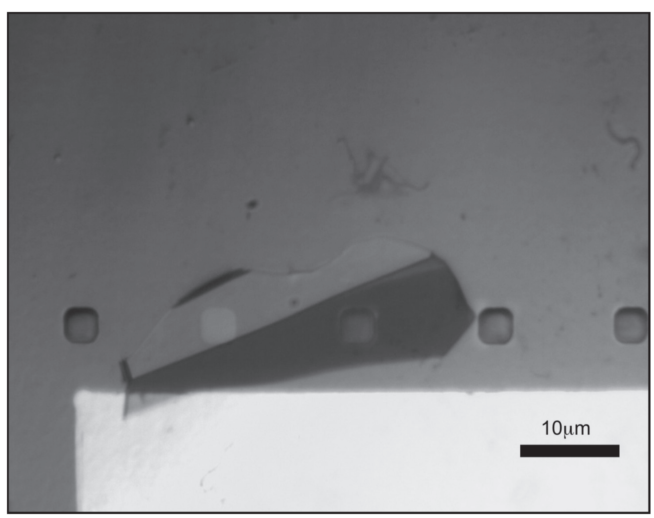

Figure 4: Image of completed switch.