Electronic Graphene Devices through Tip-Based Nanotechnology

Cassandra Todd
Electrical Engineering, University of Central Florida

NNIN REU Site: Cornell NanoScale Science and Technology Facility, Cornell University, Ithaca, NY
NNIN REU Principal Investigator: Prof. Amit Lal, Electrical Engineering, Cornell University
NNIN REU Mentor: Hadi Hosseinzadegan, Electrical Engineering, Cornell University
Contact: ctodd42@knights.ucf.edu, amit.lal@cornell.edu, hh382@cornell.edu

Abstract and Introduction:

In order to test the electromechanical properties of graphene for this project, it was necessary to build a device that would actuate a graphene film mounted on a clamped-clamped thin-film plate of silicon nitride (SiN), which was then mechanically actuated using a piezoelectric actuator (PZT). Our device was fabricated by coating Si with a 400 nm layer of low stress nitride; the backside of the nitride was patterned and etched so that the Si layer could be completely etched by potassium hydroxide (KOH) to form nitride membranes on the front of the device. A 150 nm bi-layer of gold/chromium (Au/Cr) electrodes was deposited onto the front of the device to form a four-point probe measurement system. Bond wires were attached to electrodes to interface the device to a DIP package. Graphene was transferred on top of the device, so that its electrical conductivity and piezoresistivity could be measured.

The piezoresistivity tensor elements of graphene could be extracted by putting the 4-point probes on each side of the membrane. The elements were tensor because the piezoresistivity might be different, in different directions, due to a graphene samples' lack of directional uniformity. Using an optical interferometer, the vibration profile of the graphene/Si_xN_y films, mode shapes and amplitude could be measured as well. With this knowledge, graphene could be applied to microelectromechanical systems (MEMS) for smaller and more sensitive devices.

Despite the increase in publications on graphene, there is still not much known about its electromechanical properties. By having a better understanding of the tensor elements of graphene it could be applied to various MEMS such as resonators, transistors, and cantilevers.

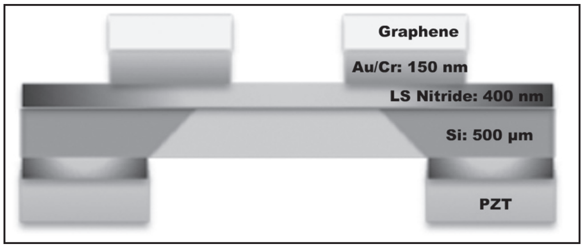

Figure 1: An illustration of the devices structure with example values for thicknesses.

Experimental Procedure:

Device fabrication consisted of nine steps.

1. About 400 nm of low stress nitride was deposited onto our Si wafers with low-pressure chemical vapor deposition (CVD).
2. Contact lithography was used to pattern the topside of the wafer in order to deposit a 150 nm bi-layer of Au/Cr electrodes.
3. Once the resist and excess metal were lifted off with 1165, the backside of the wafer was patterned and the nitride was etched to form windows in the bare Si.
4. Si was then completely etched with KOH to create nitride membranes ranging in size from 1500 μm to 50 μm squares. At this stage, the graphene was ready to be transferred onto our wafers that we diced into chips to make the process easier.
5. We used CVD-grown graphene that was deposited onto a copper (Cu) film and had poly(methyl methacrylate) (PMMA) spun onto it to make the graphene visible for transfer. A wet etch was used to remove the Cu from the graphene, and the graphene was then moved to de-ionized (DI) water to be repeatedly cleaned before it was transferred to our devices. The graphene placement was relatively easy as it was simply scooped out of the water onto a device and then left to air dry.
6. After the PMMA was removed with acetone, resist was spun onto the graphene and, using contact lithography, the graphene was patterned and then,
7. oxygen plasma etched so that only a 30 μm by 10 μm rectangle was left at the ends of our probes for our measurements.
8. A PZT was then attached to the backside of the devices followed by:
9. metal wire bonding leads, which were connected to the contact pads.

See Figure 1 for the complete layout of the design.

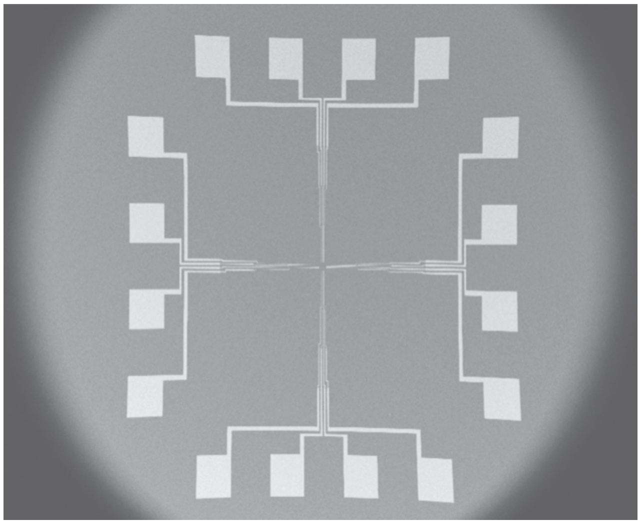

Figure 2: An illustration of the metal electrode design.

Our metal electrodes were designed specifically for a four-point probe measurement as seen in Figure 2. The pads were 200 μm squares. The actual probes extended to the center of each membrane at a final width and gap spacing of 1 μm. The PZT was connected to a function generator. We generated sine waves normally around 100 mV-500mV peak-to-peak voltage. The two outermost wire-bonded probes were connected to a current source of ~ 1 nA and the inner probes were connected to the voltmeter. To measure the amplitude at each point of a cell, the devices were placed in a vacuum under an interferometer.

Results and Conclusions:

By sweeping the frequency of the function generator attached to the PZT, the graph in Figure 3 could be obtained. The higher voltage resulted in a higher conductivity in the material. At certain frequencies, the nitride membrane was bended more, causing a peak in the conductivity. This was caused by the stress in the graphene layer, which decreased its resistivity.

Furthermore, the shape of the nitride membrane was also mapped. In Figure 4, one can see how the nitride membrane and graphene reacted when actuated at a frequency of 403 kHz.

Future Work:

At this time, not enough measurements have been completed to come up with a conclusive answer on the piezoresistivity, vibration modes and amplitude of graphene. Once this has been accomplished, the next step of the project will be to create a transistor using graphene by opening up its band gap.

Acknowledgments:

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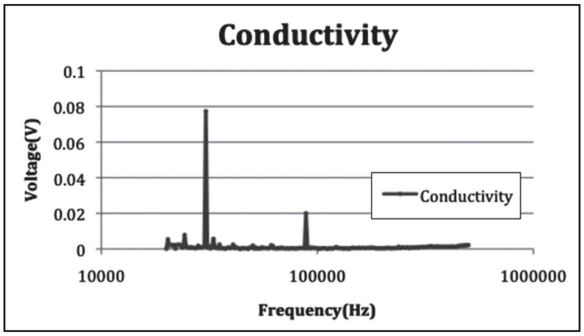

Figure 3: An analysis of the voltage when the frequency is swept and its relation to the conductivity of graphene.

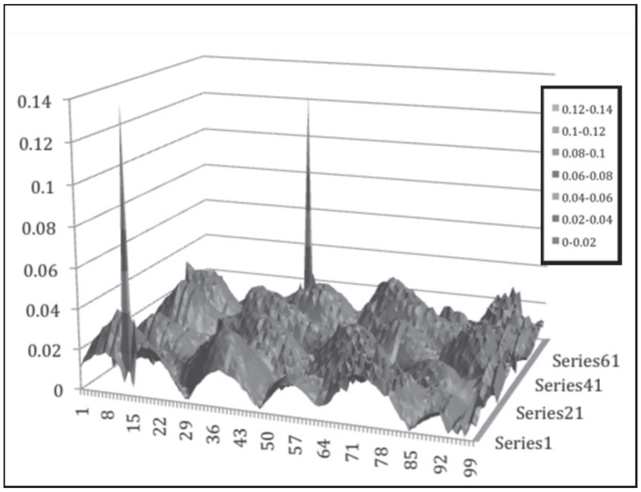

Figure 4: An illustration of the shape of a nitride membrane at 403 kHz. (See the cover for a full color version.)