Design and Fabrication of Piezoresistive Graphene on Nitride Accelerometer

Zachary Schaffer

Nanoscale Engineering, University at Albany SUNY

NNIN REU Site: Cornell NanoScale Science and Technology Facility, Cornell University, Ithaca, NY

NNIN REU Principal Investigator: Amit Lal, Electrical and Computer Engineering, Cornell University

NNIN REU Mentors: Ved Gund and Alexander Ruyack, Electrical and Computer Engineering, Cornell University

Contact: zschaffer@sunypoly.edu, amit.lal@cornell.edu, vvg3@cornell.edu, arr86@cornell.edu

Abstract:

Piezoresistive materials change resistance in response to strain. In a piezoresistive accelerometer, displacement of a proof mass causes strain on the proof mass support—consisting of a piezoresistive element—translating to measurable changes in resistance. In this project, an accelerometer was designed and fabricated using piezoresistive graphene on silicon nitride. Graphene is atomically thin, allowing for scalability to extremely small accelerometers for potential implementation in large arrays of sensors. In general, an atomically thin mechanical transduction element can provide new pathways to realizing nanoscale arrays of nano-electro-mechanical systems. Fabrication of the devices took place at the Cornell NanoScale Facility (CNF). Low stress silicon nitride was deposited on a wafer, followed by deep reactive ion etching to etch high aspect ratio trenches from the backside and release a silicon proof mass. The nitride layer connecting the proof mass to the substrate served as the spring for out-of-plane acceleration measurements using the device. Nickel was deposited for metallization contacts via a lift-off process, and piezoresistors made of transferred graphene patterned using oxygen plasma. Devices were successfully fabricated and tested for response. Extremely high gauge factor of graphene on nitride was measured: 17451.

Introduction:

Accelerometers are used for a broad range of applications, from image stabilization, to airbag deployment, to biomedical implants. Typical accelerometers are a multiple mm^2 in size, limiting their implementation in small scale devices. This project aimed to create a higher sensitivity to size ratio accelerometer, reducing cost of manufacture, and allowing creation of multi-sensor arrays in order to further improve signal to noise ratio and detect specific frequency accelerations.

Piezoresistive materials are characterized by gauge factor (GF), a measure of fractional change in resistance divided by strain on the material. Single crystal silicon has a GF of 200. Previous research reported an extremely high GF (17980) for graphene on nitride [1]. Displacement of a silicon proof mass causes strain on the proof mass support-consisting of a piezoresistive element-translating to measurable changes in resistance. An accelerometer's sensitivity to force increases with GF and lateral dimensions, while decreasing with piezoresistor thickness. The ultra-high GF of graphene on nitride and low thickness of graphene cause increased sensitivity without increased lateral dimensions.

Device Fabrication:

Device fabrication steps are shown in Figure 1; 350 nm of SiO_2 was grown in an oxide furnace followed by deposition of 650 nm of low-stress (~150-200 MPa) silicon nitride (Si_xN_y), then 2 µm of SiO_2 was deposited using plasma-enhanced chemical vapor deposition (PECVD) on the backside as an etch-mask for deep reactive ion etching (DRIE) of the silicon substrate (I). The backside dielectric stack of PECVD oxide, nitride and thermal oxide was etched with CHF_3/O_2 using a 10 µm thick photoresist mask (II). Next, a trench was cut around the central proof mass, through the silicon substrate, using DRIE (III). The SiO_2

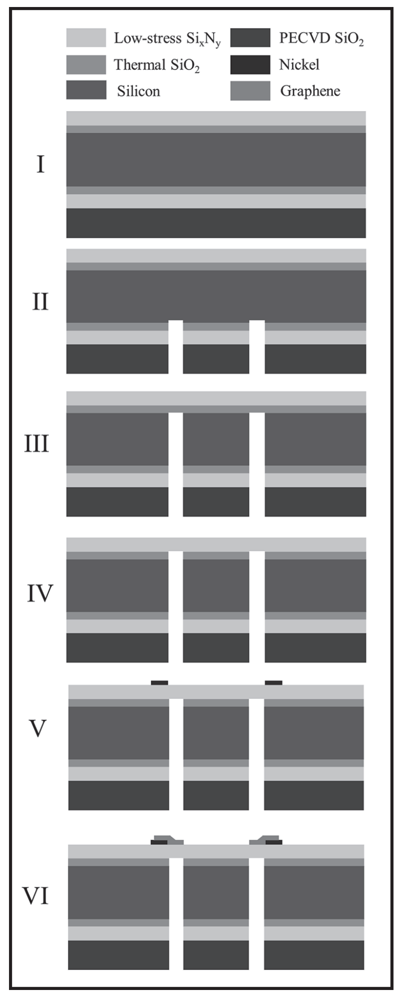


Figure 1: Process flow for accelerometer fabrication.

layer on the front side served as a DRIE etch-stop, and was subsequently removed using vapor HF etching, leaving the central proof mass connected to the bulk silicon wafer only by the Si_xN_y layer (IV). Next, a 40 nm layer of nickel was deposited and patterned using a lift-off process. A sacrificial lift-off resist layer was patterned, followed by e-beam thermal evaporation of nickel. The sacrificial resist layer was removed leaving only the patterned nickel layer (V). The graphene piezoresistors were added next. Graphene was grown via CH_4 chemical vapor deposition onto a copper foil substrate at 1000°C. A polymer layer, used for transfer handling, was spin-coated on top of the graphene. After chemical etching of the copper foil, the graphene with polymer handle layer was cleaned through serial dilution in DI water before being transferred on the device. The graphene was patterned through oxygen plasma etching with a photoresist mask (VI). Finally, remaining resist and polymer were removed chemically.

The diced device can be seen in Figure 2.

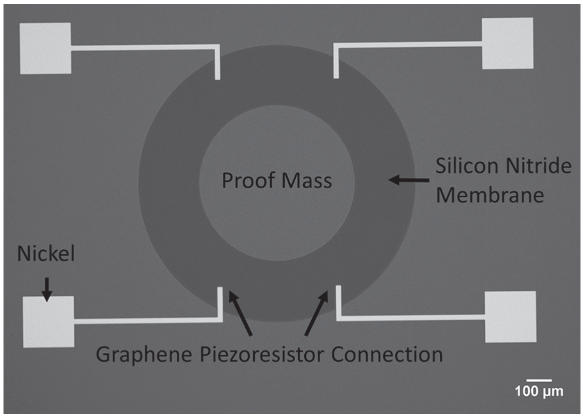


Figure 2: Optical image of topside of accelerometer.

Experiments:

The piezoresistive accelerometers were tested using a Wheatstone bridge with three off-chip resistors. The differential signal from the bridge was amplified and then filtered for 60 Hz noise. An external shaker-table was used to actuate the device at precise acceleration amplitudes and frequencies. Acceleration was translated to a strain on the graphene piezoresistor using a COMSOL model of the accelerometer. The output voltage signal was converted to a fractional resistance change of the piezoresistor, which was then divided by strain to measure GF. A linear regression of these values over a range of accelerations, as seen in Figure 4, was used to measure GF.

Conclusions and Future Work:

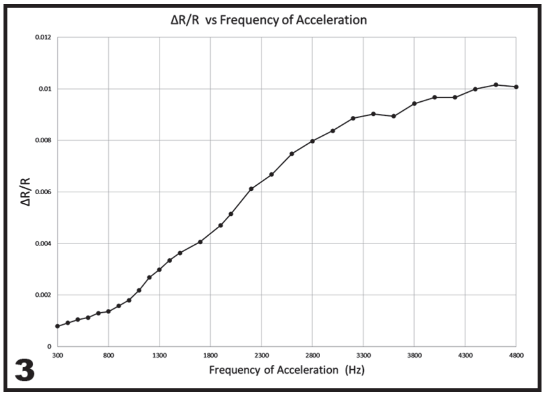
The accelerometer was successfully fabricated and showed linear response to acceleration. As seen in Figure 4, a GF of 17451 was measured, in accordance with previously reported values. Further work includes measuring the noise floor of the device piezoresistors and studying the variation of proof mass size in order to quantify its relation to resonant frequency. Response at resonance will also be examined. Extensions of this work will include downscaling of devices, fabrication of multi-sensor arrays, and 3-axis sensitivity using torsional motion of the proof-mass.

Acknowledgments:

This work was conducted through the SonicMEMS laboratory at the Cornell NanoScale Science and Technology Facility (CNF). I would like to thank Professor Lal, and my mentors Ved Gund and Alexander Ruyack, for the help and support, as well as the CNF staff. I would like to acknowledge the National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program, and the National Science Foundation, Grant No. ECCS-0335765, for funding.

References:

[1] Hosseinzadegan, et al., (n.d.). Graphene has ultra-high piezoresistive gauge factor. 2012 IEEE 25th International Conference on Micro Electro Mechanical Systems (MEMS).



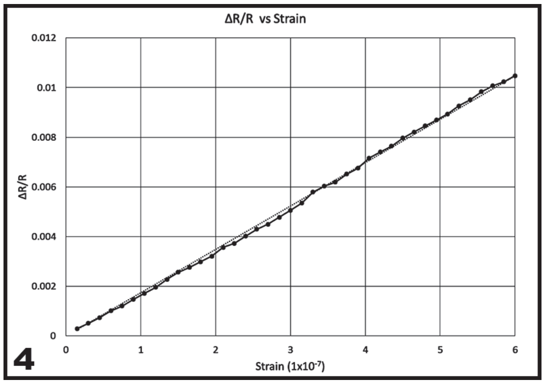


Figure 3, top: Graph of DR/R vs. Frequency of Acceleration at Force of 3 g. Figure 4, bottom: Graph of ΔR/R vs. Strain at 3000 Hz.