Electrically and Optically Obtaining *Q* of High Stress SiN Devices

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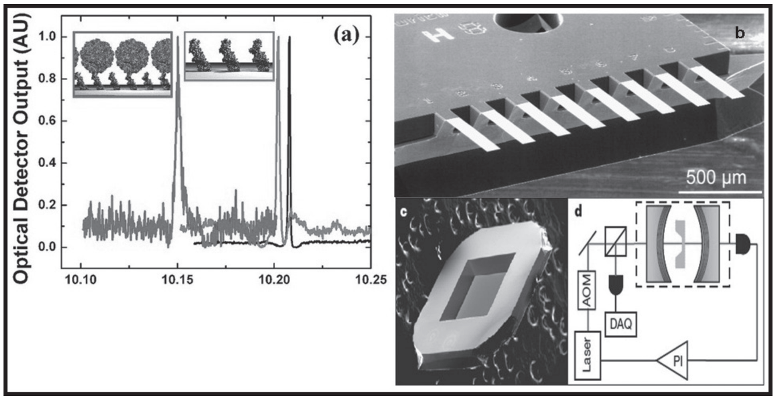

Figure 1: (a) Virus detection method [1]. (b) Chemical sensor [2]. (c) Device used in (d) an optomechanical experiment [3].

Abstract:

High-stress silicon nitride (SiN) membranes show extremely high mechanical quality factors (*Q* of up to 4 million) and are useful for applications in resonant sensors, oscillators and optomechanical experiments. Here we fabricated high *Q* stoichiometric SiN membranes by depositing SiN using a low pressure chemical vapor deposition (LPCVD) process followed by back etching of a pre-patterned Si wafer. Monolayer graphene and thin gold pads were deposited onto this suspended membrane so as to create a conductive region that would enable the capacitive readout of the resonant motion. Amplitude of motion in resonance is usually detected using interferometric means in a custom built laser setup. The optical readout is to be compared to the electrical readout where the amplitude of resonant motion is detected by passing a source-drain current through the graphene via wire-bonded gold pads. The resonant motion should modulate the resistance of the graphene. The readouts display *Q* factors of the composite resonator as high as 100,000. We concluded that electrically active SiN resonators maintained the ultra-high *Q* and therefore are useful for the above-mentioned applications.

Introduction:

Microelectromechanical (MEMS) devices are well-suited for many applications. Because of high resonance frequencies, high quality factors (*Q*), and low masses, MEMS resonators can be used to probe the limits of quantum mechanics that larger resonators cannot. In addition, MEMS devices are more effective in terms of miniaturization, power conservation, and force sensitivity [1]. Future applications of these devices include usage as signal processors, oscillators, and improved sensors in pressure, temperature, charge, spin, and mass [2].

It has been previously reported that the *Q* of high stress SiN devices has reached up to 4 million, making them ideal for the aforementioned applications [4, 5]. High stress SiN devices are often studied in optomechanical experiments due to their high *Q* factors. However, we wanted to also perform electrical experiments on the high stress SiN devices so as to read them out electrically rather than optically.

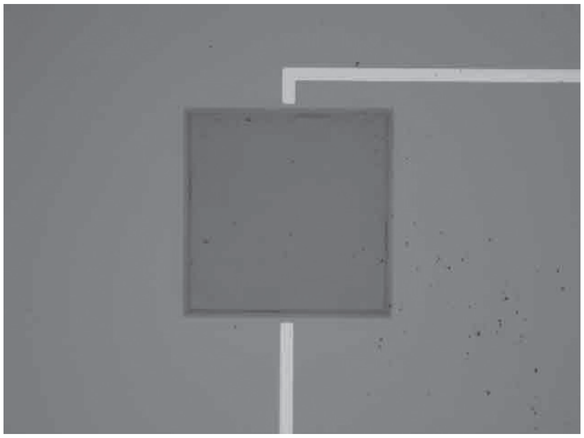

Figure 2: An optical image of a 300 µm × 300 µm membrane device on a 60 nm thick nitride layer covered with 0.3 nm of monolayer graphene with 30 nm of gold.

Fabrication Process and Methodology:

The first step in our fabrication process was to use a thermal oxidation process to grow 1 μm of silicon oxide (SiO_2) followed by a deposition of 60 nm stoichiometric nitride (Si_3N_4), using a LPCVD process. We created our suspended membranes using plasma and KOH etches of the back side of the wafer. Then, graphene was transferred and patterned on these suspended membranes. Electrical contacts to the graphene were achieved by gold deposition, followed by lift off. The buffered oxide etch was used to remove the oxide layer to create the high stress nitride membrane.

We used an electrical drive to actuate the resonant motion of the membrane, and detected that resonance electrically and optically. The electrostatic drive was produced using a combination of DC and AC voltages. The piezo-controlled mirror was charged with both DC and AC voltage while the membrane was grounded. In the optical setup, the amplitude of this reflectance change at resonance depended directly on the physical motion of the membrane and the position of the membrane with respect to the mirror. In the electrical setup, a DC voltage source was used to cause a source-drain current to detect the resonant motion of the membrane.

Results:

The resonant frequency decreased as the gate voltage was swept from 0 V to 30 V (or 0 V to -30 V) due to capacitive softening. In capacitive softening, as the voltage increased, the membrane was attracted to the fixed electrode encountering a larger field gradient. The field gradient resulted in a force that opposed the device's mechanical restoring force, leading to a decrease in resonant frequency. Motion of the piezo-controlled mirror towards the device also caused the electric field gradient to increase, which decreased the resonant frequency.

Oscillations in both resonant frequency and amplitude of the resonant motion are due to the absorption of the light by graphene membrane. *Q* factors of up to 100,000 were detected with our devices.

Conclusions:

We are certain that our optical and electrical experimental setups are fully operational. Now that we can optically detect resonant motion using an electrical drive, we will work on electrically detecting *Q* by passing current through gold contact pads that will act as the source and drain of the current. After successfully fabricating high-stress SiN devices using SiO_2 as a protective layer, we were able to perform optomechanical experiments with our current optical setup. In these optical mechanical experiments, we have not only been able to obtain *Q* factors of up to 100,000, but we have also seen interesting phenomena such as capacitive softening and the photothermal effect in action.

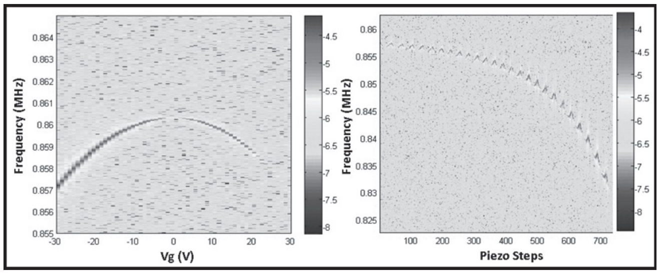

Figure 3: Both graphs depict capacitive softening, but the image on the right illustrates the photothermal effect due to optical back action.

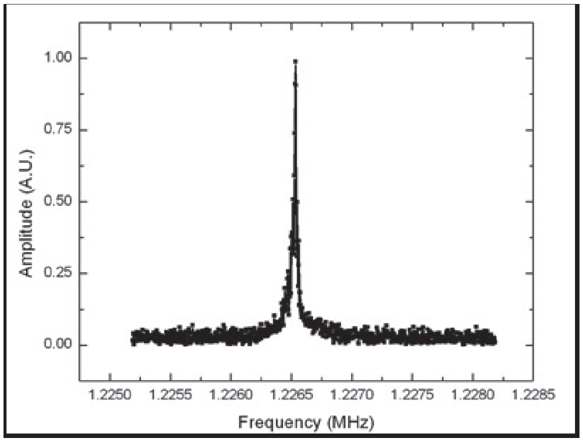

Figure 4: The Lorentzian curve of the resonant frequency is used to determine the Q factor which, in this case, is 90,000.

Future Work:

Long-term goals are to conduct *Q* measurements at near absolute zero temperatures (30-50 mK) so as to optimize *Q* for any sort of devices and to study other dissipation mechanisms caused by other factors such as clamping.

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