Optomechanical Experiments with Ultra Thin Mechanical Membranes

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Abstract and Introduction:
Manipulation and detection of the mechanical degree of freedom with light in connection with nanomechanical resonators is an emerging field with applications in the control of quantum states of macroscopic systems [1], sensing, and detection [2]. We demonstrated that a Fabry-Perot cavity between a flexural resonator and a reflecting mirror can be used to detect the motion of these resonators and a pulsed laser can be used to actuate the motion of the resonator (Figure 1) [3-6]. Detection of the resonant motion by optical means also offers advantages in terms of both optomechanical coupling experiments and sensing. In this regard there are advantages associated with using very large lightest possible membranes as the mechanical elements to achieve low spring constants and resonator mass [1, 2]. Two dimensional materials like graphene, boron nitrene and ultrathin silicon nitride membranes show promise of being used as mechanical membranes whose oscillations can be readily detected by optics [1-5]. However achieving high mechanical quality factors in these high surface-to-volume ratio resonators has been a challenge. Recently it has been observed that the mechanical quality factor of the resonators can be significantly improved by choosing appropriate resonator geometry, stress and improved fabrication techniques [2, 3, 5].

Summary of Research:
We have measured extremely high quality factors (up to 4,000,000 for 15 nm thin silicon nitride membranes [4] and up to 5,000 for graphene [6]) for large area (up to 1 mm for high stress nitride and up to 100 µm self-tensioned graphene drums, Figure 1) at room temperature. These findings pave the way for identifying optimum size and modes for achieving high mechanical $Q$ oscillators for applications in mass sensing and next generation of optomechanical coupling experiments [1, 7].
Results and Conclusions:

Preliminary results on suspended graphene resonators show that it is possible to use lasers to cool or heat a 2D material like graphene in a simple low finesse Fabry-Perot cavity formed by a graphene membrane suspended over a prefabricated trench [7] or a movable metallic mirror. An electrically driven graphene membrane’s resonant motion can be amplified or suppressed by moving the membrane within the cavity (Figure 2), wherein the resonator can be moved from regions of higher absorption to lower absorption. A phothermal back action results in resonator motion being amplified or cooled depending on the direction of the force with respect to the membrane’s motion. The strong optomechanical coupling observed in these membranes is partly due to the low mass, spring constant of these structures. The implication is that this should significantly reduce the difficulty to cool these devices to their quantum ground state from some readily accessible starting temperature or to perform sensing with self-oscillating membranes at room temperature.

References: