Graphene mechanical resonators: Direct electrical readout and magnetometry

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Radio Frequency (RF) nanoelectromechanical systems (NEMSs) are not only widely adapted in practical applications [1], but also powerful tools for exploring fundamental science [2]. Due to its tremendous mechanical strength and outstanding electrical properties, graphene makes a strong candidate for NEMS. Here we demonstrated direct actuation and detection of ultra-clean graphene mechanical resonators, and use them as magnetometer to detect their own magnetization in quantum hall regime.

Recent efforts have realized graphene mechanical resonator with optical interferometry [3] or electrical mixing technique [4], however, neither of these methods is convenient for fast readout and circuit integration. To overcome these drawbacks, we replaced the usual back gate geometry with local gate structure, hence minimizing parasitic capacitance in electrical measurement circuit to enable efficient RF signal transduction [5]. Moreover, by prepared wafers with pre-patterned trenches and electrodes, then deposited graphene by mechanical exfoliation, we approach the clean limit of sample fabrication, allowing us to study the intrinsic properties of graphene.

Figure 1 shows a false-color Scanning Electron Microscopy image of a typical graphene mechanical resonator and measurement scheme. A vector network analyzer (Agilent E5062A) was employed to achieve broadband signal processing, increasing data acquisition speed by two orders of magnitude compared to the mixing method. Figure 2 shows tunable resonant frequencies at different applied local gate voltage, V_g. At low temperatures (below 77K), most of devices showed quality factors, Q, larger than 10,000. This is important for any sensitive detection application, such as magnetometer, as described below.

Additionally, we have developed purely capacitive detection, which enables readout at zero source-drain bias and the absence of transconductance. This is crucial for low temperature experiments such as in quantum hall regime.

With the presence of applied magnetic field $\vec{B}$, there will a $\vec{\mu}\times\vec{B}$ torque exerted on the graphene sample, where $\vec{\mu}$ is the magnetic moment of graphene. This torque changes energy equilibrium hence the resonant frequency f. Performing this experiment in quantum hall regime, we observe saw-tooth-like oscillation of f, which reveals de Haas-van Alphen effect of magnetization. Additionally, frequency spikes showed up on the quantum hall plateaus. This technique provides a bulk measure of quantum hall effect and may be used for probing interacting physics, for instance, in the various symmetry-broken and fractional regime, all of which are accessible in these ultra-clean samples.

References

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Figures

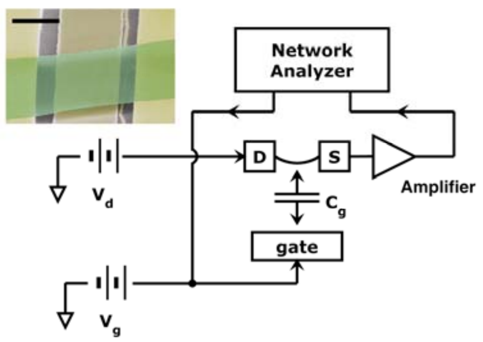

Fig. 1

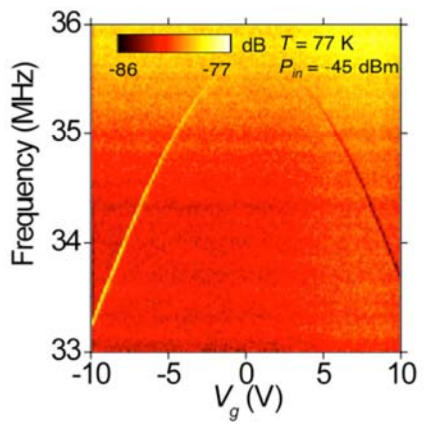

Fig. 2

Figure caption

Fig. 1. Schematic of measurement circuit. Inset, SEM image of graphene mechanical resonator, scale bar, 1 um.

Fig. 2. Resonant frequency as function of applied gate voltage, V_g.