Development of Near-field Microwave Methods for Graphene NEMS Resonators

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Abstract
As electromechanical devices become smaller, approaching the nanoscale, the oscillation displacement amplitude scales down in proportion to size. Thus new ultra-sensitive transducer techniques and low dissipation excitation schemes are needed to operate NEMS sensors. Microwave measurement using high Q resonators becomes attractive due to the high sensitivity of frequency measurement and the very low phase noise from synthesized microwave sources, in contrast with optical systems. We have developed a novel near-field microwave probe system which is able to simultaneously excite and readout the oscillation of a range of mechanical resonators, from hundreds of microns to sub-micron size. By using a quarter wave microwave coaxial resonator with the open end connected to a sharp tip we can produce a very localized intense microwave field in a very limited region close to the tip. The spatial range of this high field region is on the order of the radius of curvature of the tip, which can be, comparable to the smallest mechanical resonator dimensions.

In this paper we discuss fabrication and measurement of a number of different graphene mechanical resonators based on transferred material onto different lithographically patterned substrates. CVD grown graphene films are of increasingly good quality and, following growth on a metal thin film catalyst, can then be transferred to any arbitrary supporting substrate. The transfer process is critical. The quality and performance of the graphene mechanical resonators depend on how fully the polymer support layer has been removed from the graphene, following transfer. AFM scanning has been used to investigate the purity of the graphene and the strain in the transferred films and to test the breaking stress of the material.

The main result of this paper is to present experimental data on graphene mechanical resonators using a variety of microwave excitation and readout methods, including a novel self-sustaining microwave interrogated oscillator with excellent frequency stability. An important issue is that there is strong coupling between graphene and microwave fields. This relates to the relatively close matching of the impedance of free space, or a confined geometry like a microwave resonator, and the sheet resistance of high quality graphene [1]. This fact makes the microwave method particularly suitable for application to graphene NEMS resonators.

We have modelled the performance of single graphene layer drumhead membrane mechanical resonators and compared these results with those of experiments as a further means of determining the strain present in the NEMS systems. An SEM image of one of our graphene NEMS resonators is shown in Fig. 1a. The microwave method seems to be particularly suitable for implementation in an array of sensors. As a start towards development of this technique we show, in Fig. 1b, an array of various sized circular graphene drum resonators on a Si_3N_4 membrane. We present designs for a scanned array system which allows a single microwave source to interrogate a range of membrane resonators. This has potential for biosensor and other future applications. Further details will be provided at the conference. In our latest results, in order to try to increase the mechanical Q factor of the graphene NEMS resonators we have begun to move away from the use of drilled Si_3N_4 membranes as support, towards more rigid SiO_2 or Si support structures.

References

[1] L. Hao, J. Gallop, S. Goniszewski, O. Shaforost, N. Klein and R. Yakimova, ‘ Non-contact method for measurement of the microwave conductivity of graphene’, Appl. Phys. Lett. Vol. 103, 123103 (2013)

Figures

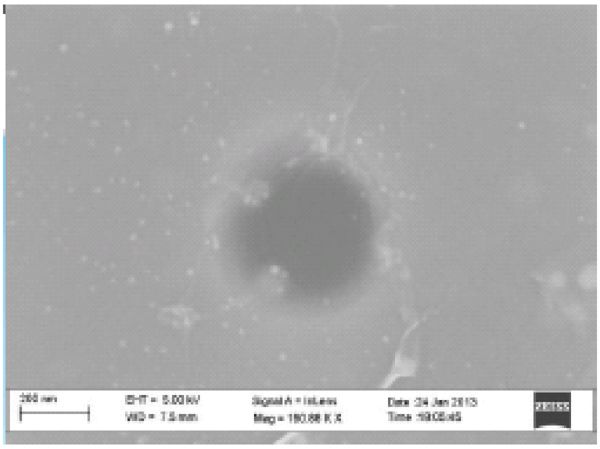

Fig. 1a. A SEM image of CVD graphene covering one hole in the Si_3N_4 membrane.

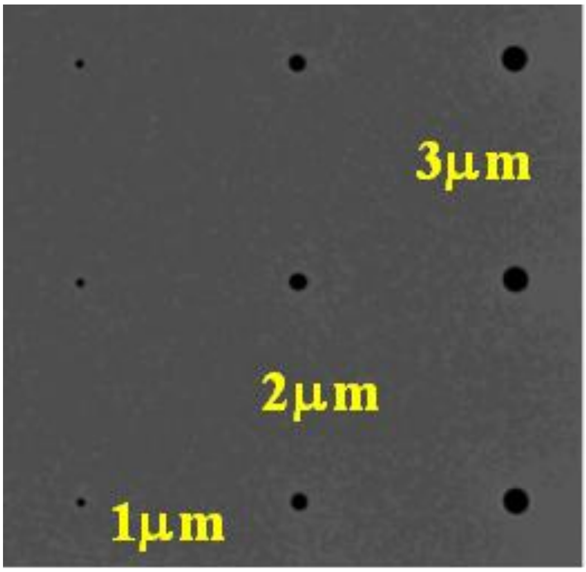

Fig. 1b. SEM image of Si_3N_4 membrane drilled with array of holes with diameter from 1 µm to 3µm.