QUALITY FACTOR DETERMINATION FOR A MWNT USING THE HARMONIC DETECTION OF RESONANCE METHOD

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Introduction

A decade ago, carbon nanotubes were first being electrostatically driven to resonance as a way of measuring their mechanical properties [1,2]. More recently, self-sustaining oscillations have been observed in multi-walled carbon nanotubes, again subject to an electrostatic bias [3]. While these resonances have been confirmed using electron microscopy, confirmation of the electrical signal has not been achieved due to the parasitic capacitance from the driving voltage. We present here a method for observing the cantilever-like resonance of a MWNT electrically. By using a fully electrical detection schema, we can more accurately determine the resonant behavior of the nanotube, including resonant frequency and quality factor.

Experimental

A schematic of our experimental setup is shown in Fig. 1. The MWNT we intend to monitor is part of an aligned fiber grown using chemical vapor deposition techniques. Since the fiber is conducting, we insure good electrical and mechanical contact between the nanotube and the attached electronics. As can be seen in the figure, the nanotube is aligned with a stationary counterelectrode to create a parallel plate geometry between the two. The variable electrical signal on the counterelectrode drives the nanotube to resonance which creates an electrical output at this frequency. This output is then amplified using an FET and a commercial Op-Amp (A250). The entire setup has been constructed with several piezoelectrically controlled degrees of freedom so that the nanotube can be aligned near the counterelectrode, and the system was placed in a Scanning Electron microscope so that the mechanical resonance could be confirmed visually.

Theory

In order to successfully observe the electrical signal generated by the physical resonance of our cantilevered structure, the dynamic signal must be separated from the parasitic one due to the driving voltage. To accomplish this, we use the Harmonic Detection of Resonance method (HDR). A more comprehensive treatment of the theory behind the HDR is given elsewhere [4,5], but it will be briefly summarized here.

Our driving signal, which consists of an alternating voltage with a dc offset, changes the energy of our parallel plate capacitor, made up of a fixed counterelectrode, and our nanocantilever, in this case a MWNT. This creates a force gradient which effectively drives the cantilever, nonlinearly, at 2 frequencies; ω, the frequency of our ac signal, and 2ω. This means that if the driving frequency is half of the resonant frequency of the MWNT, the nanotube will still resonate. Normally, when trying to observe this resonance electrically, the driving signal, proportional to ω, dominates the output, obscuring the dynamic signal from the resonance. However, since the driving signal only occurs at a frequency, ω, if we observe the output though a lock-in amplifier, and look only at higher harmonics of the input frequency, there will be no parasitic signal. The dynamic signal, however, will still be present, thanks to the nonlinear nature of our system and the multiple excitation frequencies.

Results and Discussion

Several MWNTs were analyzed as described above. Results agree with the previous rough measurements taken using electron microscopy alone to observe the resonance. Electrical observation allows not only a more detailed and precise analysis of the resonant behavior, it also allows, in principle, integration into MEMS and NEMS systems, allowing the resonant signal to be handled digitally. Also, our more precise detection may allow us to see the effects of dissipation mechanisms in our MWNT, since the amplitude dependant introduction of new mechanisms (induced by changing the strength of the driving signal) will change the quality factor.

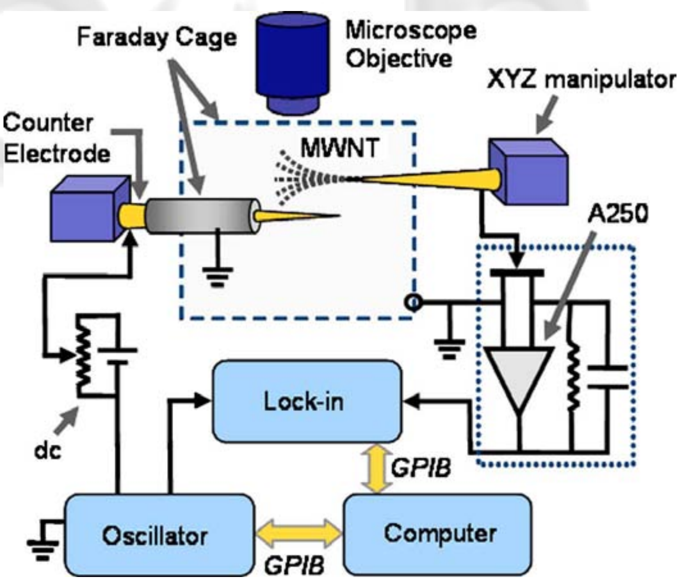

Fig. 1 HDR schematic

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