Giant increase in mechanical Q-factor of SWCNT induced by external voltage

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Individual Single Wall Carbon Nanotubes (SWCNT) were grown *in-situ* by Field Emission (FE) assisted Chemical Vapor Deposition (CVD) at the apex of etched tungsten (W) tips using a procedure presented in previous work [1]. Mechanical flexural resonances were afterwards excited in Ultra High Vacuum (UHV) by bringing a nearby electrode at an oscillating potential V_{AC} at the mechanical eigenfrequency (f) while a constant negative voltage V_{DC} is applied on the W tip with SWCNT in order to extract electrons by FE, as presented on Fig.1. This FE current is then amplified by a Micro-Channel Plate (MCP) and sent to a phosphor screen where it forms a FE pattern. Mechanical motion of the nanostructure is detected either by the broadening of the FE pattern [2] or by lock-in downmixing in the amplified FE current of a low frequency component added in the AC signal by frequency modulation (FM) [3].
The FE voltage V_{DC}, on the order of 100V, induces an important axial stress on the SWCNT and therefore increases the eigenfrequencies, like on a guitar string [4] (Fig. 2). The novelty of this study made on four different SWCNT samples is that this high stress also induces a dramatic increase of the room temperature resonances' quality factor Q as presented on Fig. 2. Q factors superior to 25000 were obtained, exceeding by two orders of magnitude typical room temperature values in literature [5]. We attribute such high Q factors to the relative isolation of our sample, minimizing therefore external energy decay channels. Moreover, the relative increase in the Q factor with V_{DC} highly exceeds the eigenfrequency relative increase, therefore indicating an important reduction in dissipation.
Eigenfrequencies' and Q factors' tuning with V_{DC} can be described by a simple theoretical model based on viscoelastic behavior of the SWCNT (*i.e.* complex Youngs' modulus) and complex mechanical impedance at the clamping. The reason of the dramatic Q factor increase is that axial stress strongly decreases the rod's curvature, and therefore viscoelastic losses, and localizes this curvature at the clamped end increasing the impedance mismatch for acoustic waves radiated in the supporting tip.
We achieve here Q*f products exceeding 17THz, which opens new perspectives in extremely localized force sensing at room temperature.

References

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Figures

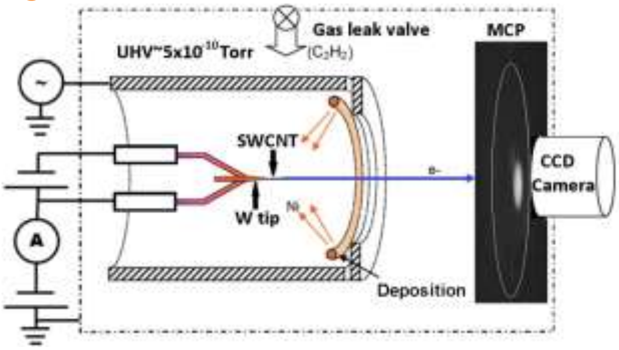

Figure 1. Experimental UHV setup.

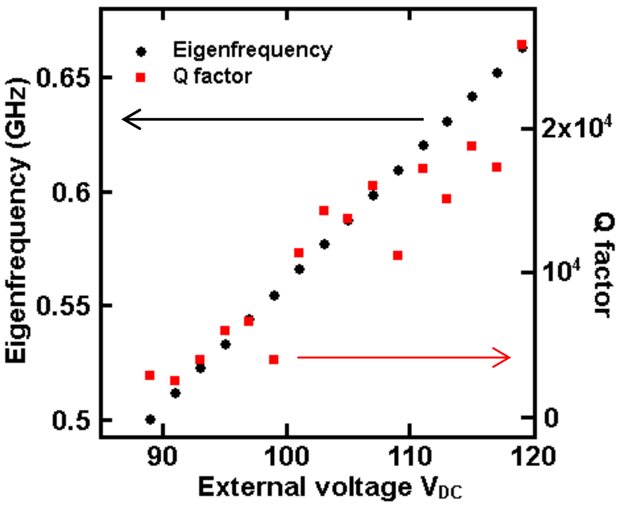

Figure 2. Evolution of the mechanical eigenfrequency and of the Q factor with the applied voltage.