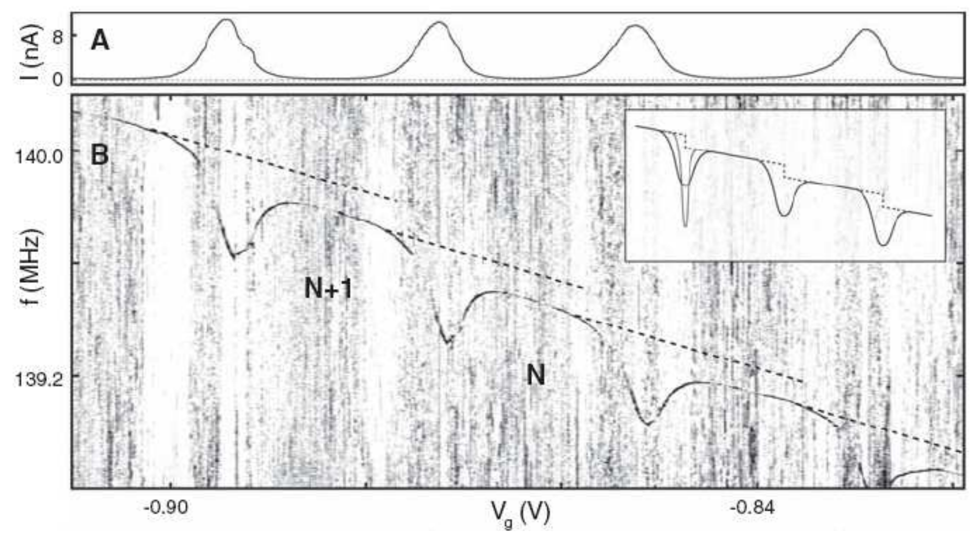
Strong coupling in carbon nanotube mechanical resonators

Herre S.J. van der Zant
Kavli Institute of Nanoscience, Delft University of Technology, the Netherlands

Nano-electromechanical systems (NEMS) make use of electrically induced mechanical motion and vice versa. Carbon nanotubes are ideal building blocks of NEMS because of their unique (mechanical) properties and their low mass. This puts them in an unexplored regime of motion which approaches the fundamental detection limit set by quantum mechanics. At room temperature, we use mixing techniques to probe the bending-mode vibration of a suspended carbon nanotube in a three-terminal device configuration -the gate voltage strains the carbon nanotube and thereby tunes its frequency [1]. At low temperatures, mechanical vibrations are actuated by a nearby antenna and a record high Q-value of 150000 at a resonance frequency of a few hundred MHz is achieved [2]. Electron tunneling and mechanical motion are strongly coupled resulting in single-electron tuning oscillations of the mechanical frequency and in energy transfer to the electrons causing mechanical damping [3]. Furthermore, the nanotubes are easily driven into the non-linear regime, showing a complicated response to the external drive. Recent progress includes the observation of GHz resonance frequencies in shorter nanotubes.



Top (A): Current through the carbon nanotube quantum dot as a function of gate voltage showing single-electron tunnelling at the peaks and Coulomb blockade in the valleys. Bottom (B): Mechanical tuning oscillations of the resonant frequency as a function of gate voltage. The tuned mechanical resonance shows up as the darker curve with dips at the Coulomb peaks. The offsets between the dashed lines indicate the frequency shift due to the addition of one electron to the nanotube. The dips in the resonance frequency are caused by a softening of the spring constant due to single-electron charge fluctuations [3].

[1] *The bending mode vibration of a suspended nanotube oscillator*
B. Witkamp, M. Poot and H.S.J. van der Zant, Nano Lett. **6** (2006) 2904.
[2] *Carbon nanotubes as ultra-high quality factor mechanical resonators*
A.K. Hüttel, G.A. Steele, B. Witkamp, M. Poot, L.P. Kouwenhoven and H.S.J. van der Zant, Nano Lett. **9** (2009), 2547-2552.
[3] *Strong coupling between single-electron tunnelling and nano-mechanical motion*
G.A. Steele, A.K. Hüttel, B. Witkamp, M. Poot, H.B. Meerwaldt, L.P. Kouwenhoven and H.S.J. van der Zant, Science **325** (2009) 1103.