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FNSNF

Force deflection study on suspended nanotubes: Electrode/metal contact improvement

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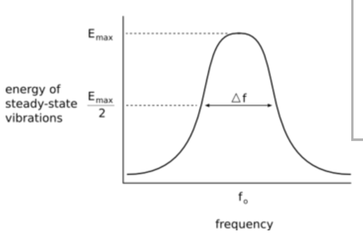
Motivation

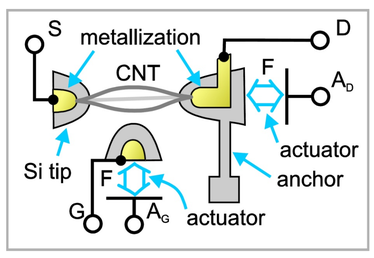
Mechanical properties of single walled carbon nanotubes (SWCNTs) and nanowires are critical for various nanoelectromechanical systems such as Giga Hertz resonators for ultra-low mass and chemical sensing, high sensitivity pressure sensing and low-power wireless communication

Major limiting so far: poor Q-factor at ambient conditions

Possible sources of dissipation:

- Gas damping
- Defect scattering
- Intrinsic phonon-phonon dissipation
- Thermoelastic losses
- Clamping/anchor losses



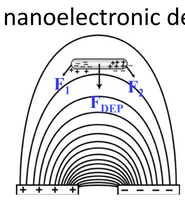


Target: Develop atomic force microscope (AFM) based nanomanipulation techniques for in situ determination of mechanical properties of nanowires without damaging them

Nanotube integration: Dielectrophoresis

Bottom-up approach:

- Grow nanotubes in LPCVD reactor and form their dispersion
- Use dielectrophoresis (DEP) for nanowire and nanotube assembly onto nanoelectronic devices



An inhomogeneous electric field acting on a polarizable particle exerts a dielectrophoretic force on it, which equals

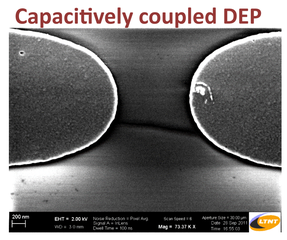
$$F_{DEP} = \frac{\pi d^2 l}{8}\varepsilon_m \,\mathrm{Re}\left(\frac{\varepsilon_t^* - \varepsilon_m^*}{\varepsilon_m^* + \left(\varepsilon_t^* - \varepsilon_m^*\right)L}\right)\nabla E^2$$

with $\varepsilon^* = \varepsilon + \frac{\sigma}{j\varpi}$

as complex and frequency dependent permittivity.

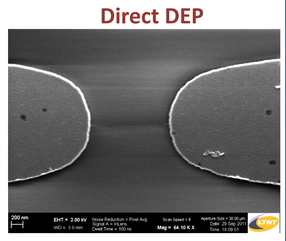
CNT suspension:
CNTs are dispered by sonication in suspension containing a surfactant.

Capacitively coupled DEP



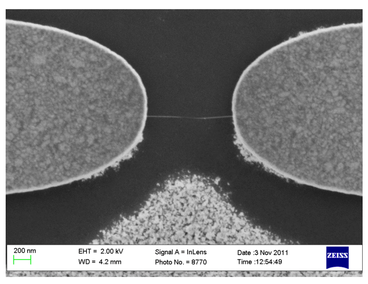
High frequencies necessary
f = 10 MHz, Vp = 3-3.5 V

Direct DEP

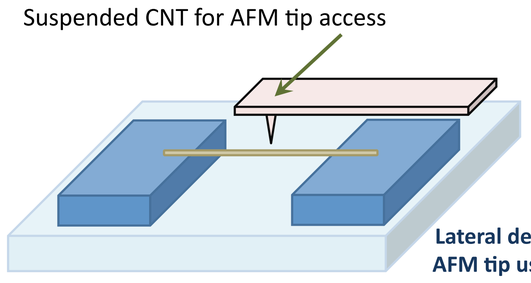


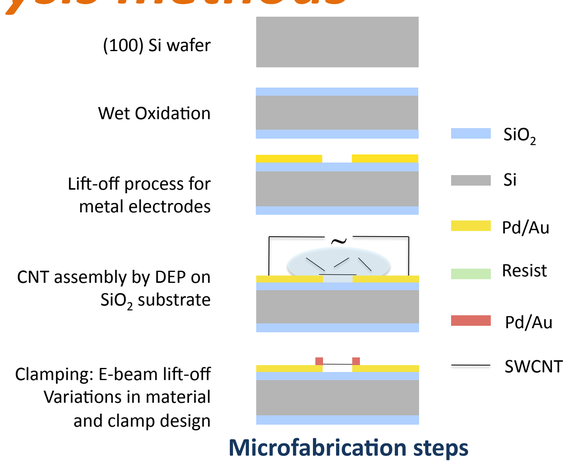
lower frequencies work too
f = 100 kHz-10 MHz, Vp = 2-3 V

Fabrication and analysis methods



Suspended CNT for AFM tip access

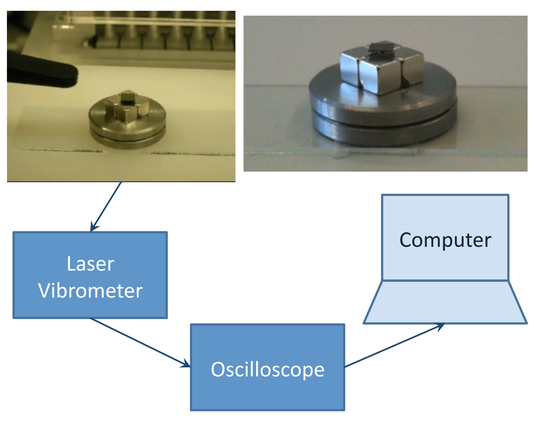




Microfabrication steps

Lateral deflection of suspended nanowire/nanotube with AFM tip using nanomanipulation strategy in MFP-3D AFM

Diamagnetic lateral force calibration



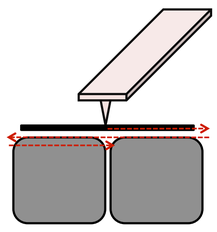
Scheme for determining spring constant of levitated graphite

Introduced by Li et al. Rev. Sci. Inst. 77, 065105 (2006).

Frequency (Hz)	Mass (mg)	Spring constant (nN/ nm)
60.95	16.5	6.130×10^{-3}
58.59	7.1	2.437×10^{-3}
58.53	6.2	2.124×10^{-3}
55.26	5.8	1.771×10^{-3}
62.67	3.0	1.178×10^{-3}

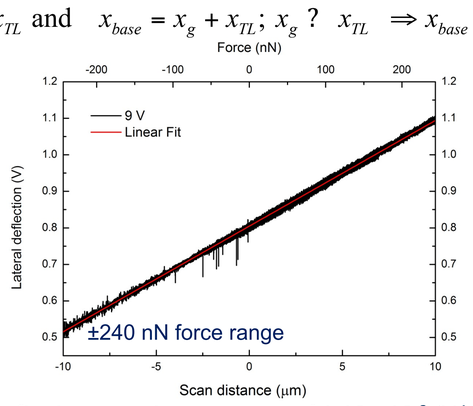
Approximately 4 mm x 4 mm graphite sheets with different thickness

AFM tip lateral calibration

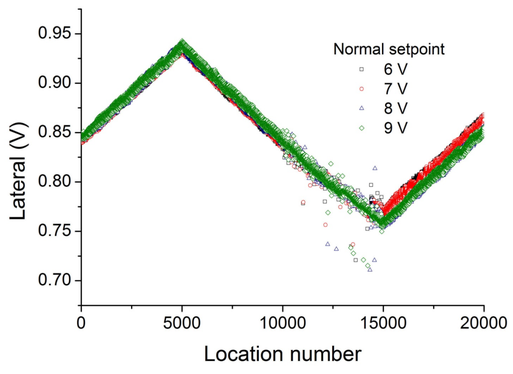


Lateral force calibration using diamagnetically levitated graphite (D-LFC)

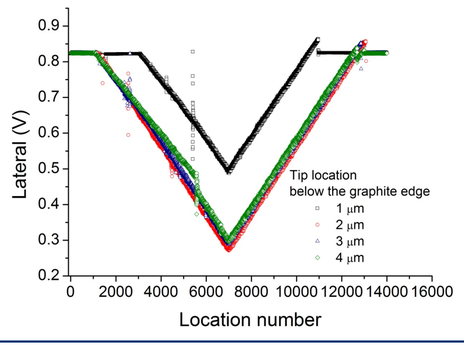
$$k_g x_g = k_{TL} x_{TL} \text{ and } x_{base} = x_g + x_{TL};\ x_g \ ?\ x_{TL} \Rightarrow x_{base} \approx x_g$$



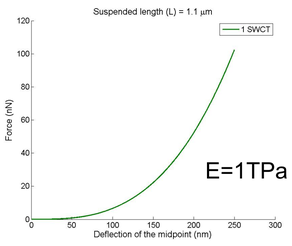
Linear fit gives a spring constant of 1.19×10^{-3} (V/nN)



coated graphite sheet ±5 μm scan distance



Lateral force deflection results



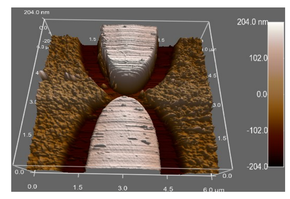
General force deflection equation:

$$EI\frac{d^4w}{dx^4} - T\frac{d^2w}{dx^2} = F_{center}\delta(x-(L/2))$$

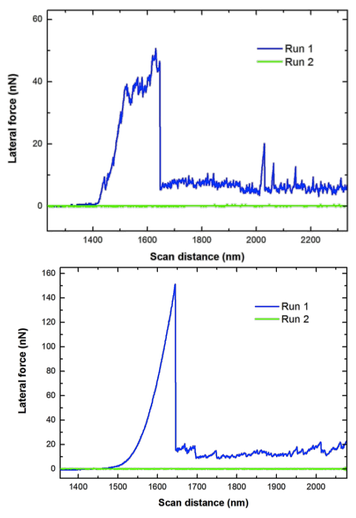
Solution:

$$F_{center} = \frac{192EI}{L^3}\Delta z_{center}\left(1+\frac{A}{24I}\Delta z_{center}^2\right)$$

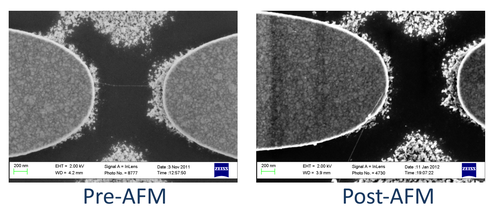
Simplified form in Heidelberg et al. Nano Lett., 6(6), 1101-1106, 2006.



Post nanomanipulation topography (AFM)



Au electrode without clamp



Pre-AFM Post-AFM

- Nearly ~85 nm deflection is sustained before slippage
- ➡ **About 1.4% stretching of the SWCNT before failure** (suspended length: ~1μm)

Au electrode with Pt-clamp

Pre-AFM Post-AFM

- Nearly ~150 nm deflection is sustained before failure
- ➡ **About 4.4% stretching of the SWCNT before failure** (suspended length: ~1μm)

Future study

- Establish the damage free property determination principle
- Evaluation of different metals as clamp material
- Evaluation of different clamp patterns and thicknesses
- Dynamic measurements and determination of paramters affecting the Q-factor

References

1. V. Sazonova, Y. Yaish, H. Üstünel, D. Roundy, T.A. Arias, P.L. McEuen, *Nature*, 431, 284, 2004.
2. S. Schürle, M. K. Tiwari, K. Shou, D. Poulikakos and B. J. Nelson, *Microelectronic Eng.*, 88, 2740-2743, 2011.
3. A. Heidelberg et al. *Nano Lett.,* 6(6), 1101-1106, 2006.
4. Q. Li, K.-S. Kim, and A. Rydberg, *Rev. Sci. Inst.,* 77, 065105, 2006.

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ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

EMPA Materials Science & Technology

CabTuRes Carbon nanoTube Resonators