Nanomechanical Friction: a source of nonlinear damping in CNT resonators
- Nanomechanical manipulation experiments and modeling-

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Task rationale: Design of devices that are amenable to manipulation in TEM and SEM based microfabrication systems and in AFM [2]

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:
- Gun damping
- Defect scattering
- Intermolecular phonon-phonon dissipation
- Thermoelectric losses
- Clamping/anchor losses

Target: Develop nanomanipulation techniques for in situ determination of mechanical properties of SWCNTs and evaluation of the clamping quality for different contacts.

TEM manipulation
A special holder was designed for in situ device testing

Manipulation sequence: probe-CNT contact by EBD, applied tensile strength by retraction of probe

SEM manipulation
Manipulation set-up in SEM 10% of the tip is mounted on a solid block with carbon tape. The trench is freely accessible.

With clamping: Failure at the CNT

SEM microfabrication (Nanolink Nanoetcher) The probe consists of a sharp tungsten wire attached to a 1mm thick copper shaft.

Modeling of Damping by Slippage

Lateral AFM deflection

Lateral force calibration using diamagnetically levitated graphite

General force deflection equation:

\[ F_y = \frac{1}{3} \frac{d^4 u_y}{dx^4} + \frac{1}{2} \frac{d^2 u_y}{dx^2} \]

Solution:

\[ u_y = \frac{F_y}{EI} \]

Decoupling into 2 problems:

A: Longitudinal response

\[ \tau_m(t) = \sum_{n=1}^{\infty} \left( \frac{P}{n \pi^2} \right)^{1/2} \frac{\cos(n \pi \theta)}{n \pi} \]

B: Transverse response

\[ \delta_m(t) = \sum_{n=1}^{\infty} \left( \frac{P}{n \pi^2} \right)^{1/2} \frac{\cos(n \pi \theta)}{n \pi} \]

Conclusions

- Experimental Results:
  Additional clamping reduces slipping as shown qualitatively and quantitatively by SEM, TEM and AFM manipulation methods, and hence should help achieve high Q-factors.

- Analytical model:
  - Slipping friction equivalent to linear damping
  - Transition from sticking to slipping friction leads to decreasing quality factors with increasing forces, as most prominent characteristic of nonlinear damping

References

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