Nanoscience - Nanomechanics (MCC026)

Exercise - 2
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1 Mechanical dissipation

In the lecture we got to know different mechanical dissipation mechanisms. Overall, the total quality factor Q_m of a mechanical resonator is given as a sum of all relevant dissipation sources as

$$\frac{1}{Q_m} = \sum_{i \in \{\text{dissipation mechanisms}\}} \frac{1}{Q_i}. \tag{1}$$

Question 1: Mechanism 1
In the work of G. D. Cole et al. [Nature Comm. 2, 231 (2011)] mechanical dissipation in dependence of tether position for the free-free-type oscillation mode of a micromechanical resonator (with a size of $130 \times 40 \times 7\,\mu$m) was analyzed, see Fig. 1. The theoretical prediction is shown in panel (a), the experimentally measured values are shown in panel (b).

(i) Explain the origin of the minimum in $1/Q$ for the free-free-type oscillation mode in dependence of the position of the tethers. What is this type of dissipation mechanism called?

(ii) The experimentally measured values follow to a good degree the theoretical prediction, see panel (b). However, there is a constant offset in $1/Q$ between theory and experiment in panel (b). Explain possible reasons for this offset.

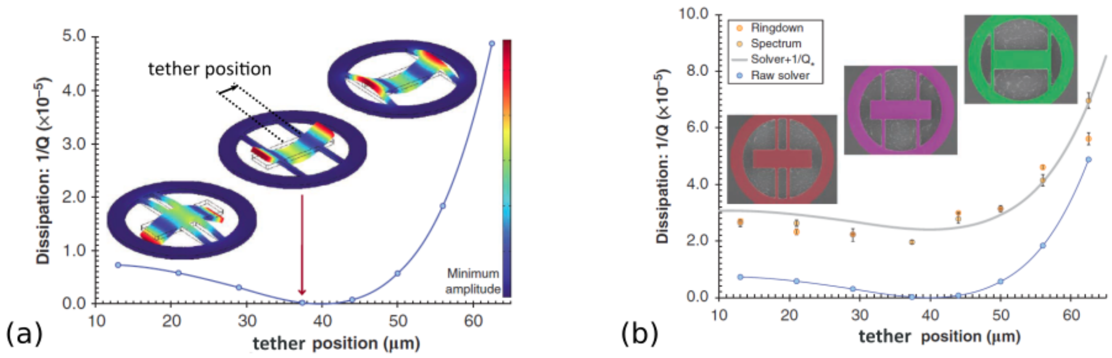

Figure 1: Mechanical dissipation in dependence of tether position, from G. D. Cole et al. [Nature Comm. 2, 231 (2011)]. (a) FEM simulation results, (b) comparison experiment and simulation results.

Question 2: Mechanism 2
In the work of A. Naesby et al. [Appl. Phys. Lett. 111, 201103 (2017)] mechanical dissipation of a tensile-strained $500 \times 500 \times 0.09\,\mu$m SiN membrane was measured in dependence of pressure, see Fig. 2.

(i) Explain the mechanism that determines the behavior of Q_m between $(10^{-1} - 10^{1}\,)$mbar.

(ii) Which mechanism might determine Q_m below 10^{-4} mbar?

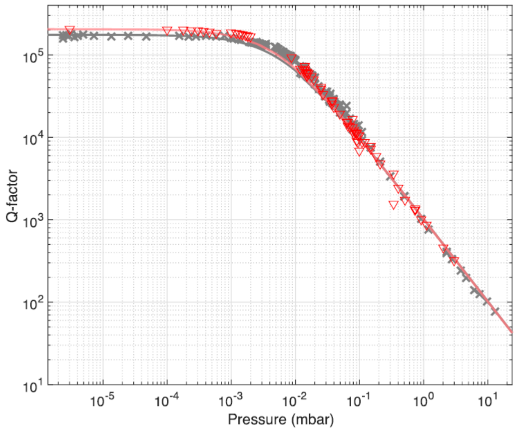

Figure 2: Mechanical quality factor in dependence of pressure, from A. Naesby et al. [Appl. Phys. Lett. 111, 201103 (2017)]

2 Mass sensing

In the lecture we saw that the responsivity of a mechanical resonator's resonance frequency ω_m to a mass change is given as

$$\mathcal{R} = \frac{\partial \omega}{\partial m} = -\frac{\omega_m}{2m_{\text{eff}}}, \tag{2}$$

with m_{eff} the effective mass of the resonator.

Question 3: Which molecule?
J. Chaste et al. [Nature Nanotech. 7, 301 (2012)] demonstrated mass sensing of Yoctogram resolution with a carbon nanotube mechanical resonator. Look at Fig. 3, which shows the frequency change of the nanotube once a particular molecule attaches.

(i) Calculate the adsorbed mass for each individual molecule that is attached. The resonance frequency of the nanotube is $f_m = 1.85\,\text{GHz}$ and its effective mass is $m_{\text{eff}} = 3 \cdot 10^{-19}\,\text{g}$.

(ii) What kind of molecule could that be? Hint: it is an organic molecule of the kind C_xH_y with x, y are even numbers.

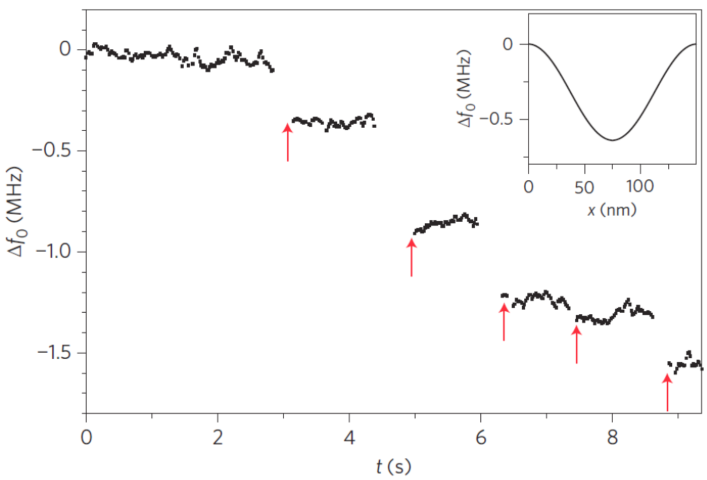

Figure 3: Yoctogram mass sensing with a nanotube, from J. Chaste et al. [Nature Nanotech. 7, 301 (2012)]. The red arrows mark the event when a single molecule attaches to the nanotube.