Approaching the stress-free limit in ultrathin doubly-clamped nanomechanical resonator

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Nanomechanical resonators created from ultrathin or low-dimensional materials have demonstrated high potential for applications in the areas of sensing, signal processing and quantum physics[1-8]. Significant research has been directed toward the study of the mechanical properties of these low-dimensional films when used in resonant structures. Unfortunately, as the thickness of the vibrating structures is reduced, the built-in strain of the structural materials plays an increased role in determining the mechanical performance of the devices[5-9]. As a consequence, it is very challenging to fabricate resonators working in the modulus-dominant regime, where their dynamic behavior is exclusively determined by the device geometry.

In this work, we demonstrate the realization of ultrathin (nm thickness) doubly clamped nanomechanical resonators with aspect ratios as large as L/t ∼5000 and working in the modulus-dominant regime[9]. We observed room temperature thermomechanically induced motion of multiple vibration modes with resonant frequencies closely matching the predicted values of Euler–Bernoulli beam theory under an axial strain of 6.3×10^{-8}. The low strain of the devices enables a large responsivity ($\langle x \rangle = \sqrt{k_B T/k}$) and a record frequency tuning ratio of more than 50 times. These results illustrate a new strategy for the quantitative design of nanomechanical resonators with unprecedented performance.

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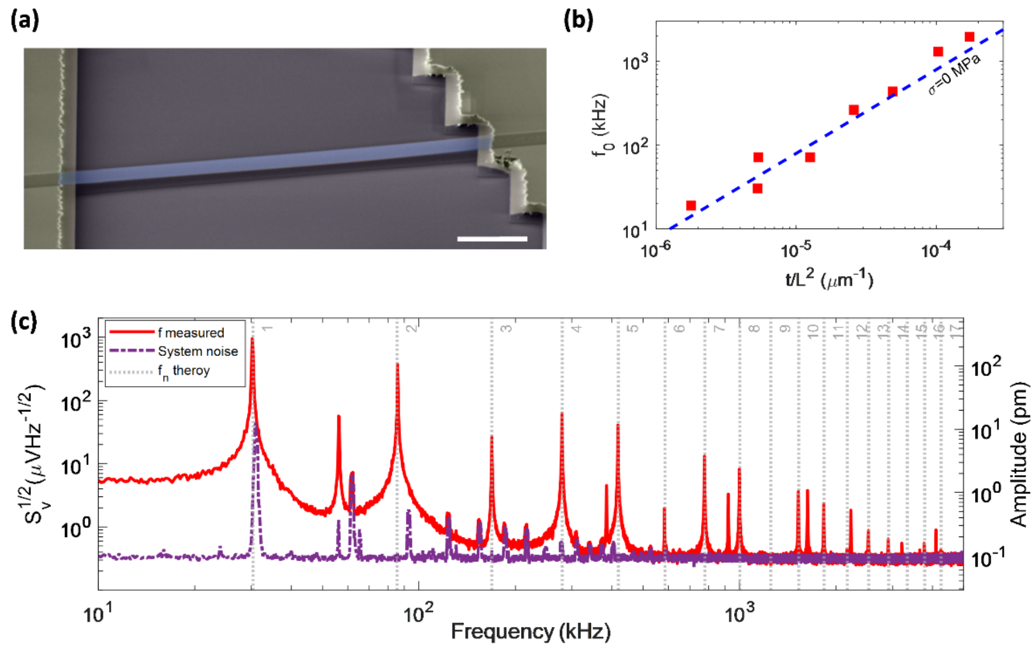

Figure 1: Ultrathin doubly clamped Al_2O_3 resonators near the modulus-dominant regime. (**a**) False colored scanning electron image of a representative device. Scale bar, 10 µm. (**b**) Thermomechanical resonance frequencies at the fundamental mode f_0 of resonators with different geometric parameters (Devices 1–8, L~17–111 µm; t ~ 22 and 50 nm). The inserted line is the theoretical value f_M of free-of-tension doubly clamped bridges (Young's modulus E = 180 GPa, volume density $\rho = 3000\ kg/m^3$). (**c**) Thermomechanical noise spectra of a 97 µm long Al_2O_3 resonator (w ~ 3 µm, t ~ 50 nm, measured nearby x ~0.4 L). The gray dotted lines are the estimated resonance frequencies $f_n(\epsilon)$ of a Euler–Bernoulli doubly clamped beam under a slight strain of $\epsilon \sim -6.3 \times 10^{-8}$.