HIGH FREQUENCY NANO-OPTOMECHANICAL DISK RESONATORS OPERATING IN LIQUIDS FOR SENSING APPLICATIONS

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Optomechanical resonators have been the subject of extensive research in a variety of fields, such as advanced sensing, communication and novel quantum technologies. We present our work towards the development of nano-optomechanical semiconductor disks as ultrasensitive mass sensors. In particular, we focus on one family of mechanical modes: the radial breathing modes. With micrometer radius disks, these modes possess high mechanical Q even in liquid (>10), low mass (pg) and high mechanical frequency (GHz) (see Figure 1). In this work, we develop novel analytical and numerical models in order to predict their capabilities as sensors (see Figure 2). Nano-optomechanical disks appear as probes of rheological information of unprecedented sensitivity and speed. Minimum mass detection of $14\cdot10^{-24}$ g, density changes of $2\cdot10^{-7}$ kg/m^3 and viscosity changes of $5\cdot10^{-9}$ Pa·s, for 1s integration time, are extrapolated from our measurements in liquids (see Figure 3). While putting miniature disk fluidic sensors on a firm ground, our recent investigations also provide a solid picture of nano-optomechanical dissipation in liquids [1].

The use of multiple optomechanical cavities is essential to further improve their sensing capabilities, as it enlarges the sensing area while keeping their individual assets. Here we present new collective configurations where optomechanical disk resonators, each supporting its own localized optical and mechanical mode, are placed in a cascaded configuration and unidirectionally coupled through a common optical waveguide (see Figure 4). In collective configurations, overcoming fabrication imperfections and allowing spectral alignment of resonators is essential. Here we present a new simple and scalable tuning method to achieve this in a permanent manner. The method introduces an approach of cavity-enhanced photoelectrochemical (PEC) etching in a fluid. This resonant process is highly selective and allows controlling the resonator size with pm precision, well below the material's interatomic distance. The technique is illustrated by finely aligning up to five resonators in liquid and two in air (see Figure 5). This technique opens the way of fabricating large networks of identical resonators [2]. As an example of a possible application, we finally demonstrate the all-optical light-mediated locking of multiple spatially distant optomechanical oscillators (see Figure 6). We inject light simultaneously in all the resonators using a single laser, eventually locking their very high-frequency mechanical oscillations [3].

Word Count: 365

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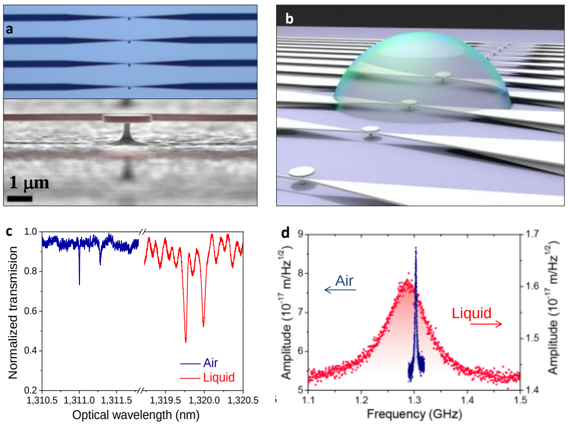

Fig. 1.a. Upper panel: optical microscope top view of four tapered waveguides and disk resonators. Lower panel: scanning electron microscope side view of a GaAs disk resonator. b. Schematic representation of resonators immersed in a liquid droplet. c. Optical transmission spectra of a 1 μm radius disk in air (dark blue) and in liquid (red). d. Thermomechanical spectra of the disk vibrating in air (dark blue) and in liquid (red).

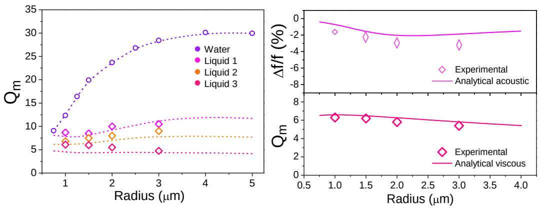

Fig. 2. Left panel: Radius-dependent mechanical quality factor measured in liquids (open diamond symbols) and calculated by FEM (dashed lines). The FEM results for water are shown in open violet circles linked by a dashed line. Right-Upper panel: Radius-dependent mechanical frequency shifts measured in a low viscous liquid and fitted by the analytical acoustic model. Right-Bottom panel: Radius-dependent mechanical quality factor measured in a highly viscous liquid and fitted by the analytical viscous model

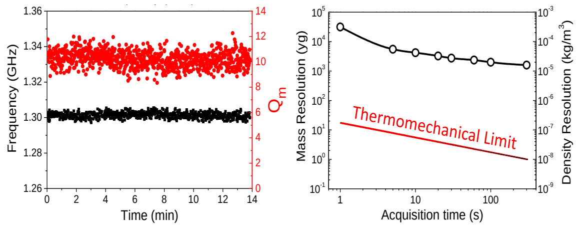

Fig. 3. Left panel: Measured mechanical frequency and mechanical quality as a function of time. Right panel: Theoretical mass and density resolution, obtained from the previous frequency stability measurement (black line) and thermomechanical limit (red line), as a function of the acquisition time.

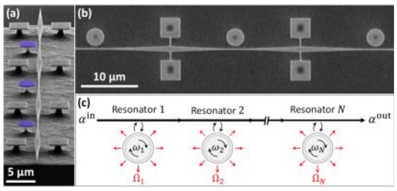

Fig. 4.a. Side view and, b. top view, scanning electron microscope (SEM) images of a device consisting of three GaAs optomechanical disk resonators with identical nominal dimensions (radius of 1.5 micron and thickness of 320 nm) c. Sketch of the unidirectional cascaded configuration containing multiple optomechanical disks along a common waveguide.

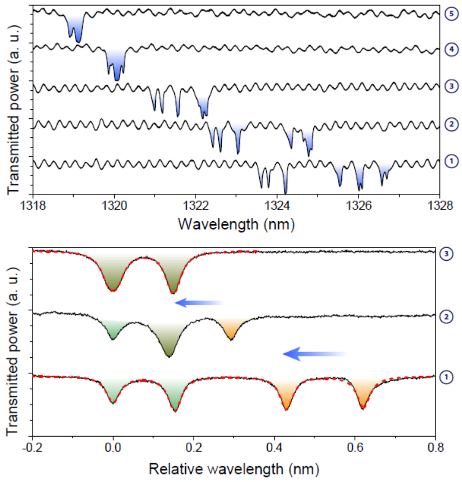

Fig. 5.a. Five optical spectra corresponding to step-by-step spectral alignment of five optical resonators in water. b. Three optical spectra corresponding to step-by-step spectral alignment of two optical resonators in air.

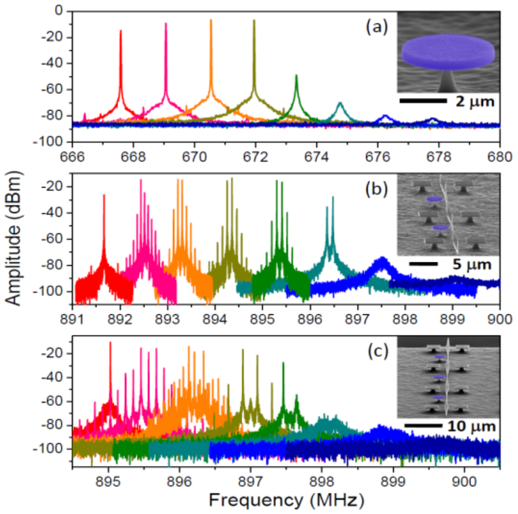

Fig. 6. From right (blue curve) to left (red curve), power spectral densities of: a. a single optomechanical oscillator (2 μm radius and 320 nm thickness), b. two and c. three optomechanical oscillators (1.5 μm radius and 320 nm thickness), as a function of increasing the laser wavelength λ.