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Ultra-high frequency optomechanical resonators sensing submicron liquid droplets

Samantha Sbarra[a*], L. Waquier[a], S. Suffit[a], A. Lemaître[b] and I. Favero[a]

a. Matériaux et Phénomènes Quantiques, Université de Paris, CNRS, UMR 7162
b. Centre de Nanosciences et de Nanotechnologies, CNRS, UMR 9001, Université Paris-Saclay

* email : samantha.sbarra@u-paris.fr

Thanks to their small dimensions, nanomechanical systems are extremely responsive to the mass measurement of small/nanoscale objects [1,2]. Their limit of detection can be enhanced by driving them to large motion amplitude, within the linear dynamic range, while ensuring that the detection noise is set by fundamental noises such as the thermomechanical noise. All-optical operation of nanomechanical systems enables approaching such optimal regime: optical driving, under modulation of the input laser, combined with optical measurement and demodulation [3], allow both efficient actuation and detection at ultimate limits. It is the natural way to go for optomechanical sensors.

Here, the all-optical actuation and detection of ultra-high frequency radial breathing modes of an optomechanical disk resonator is shown, employing light modulation/demodulation with an ultra-high frequency lock-in instrument (100-600MHz). A new optomechanical model, encompassing canonical radiation-pressure optomechanics, photothermal interactions, as well as non-linear photon absorption, is introduced and validated by systematic experiments. It enables the accurate extraction of relevant physical signals from the demodulated signal, of practical interest for optomechanical sensing experiments [4].

As a first example of such sensing experiment, we report here on the detection of sub-micron liquid droplets landing on a resonator. The droplets are sprayed, and deposit one by one on the resonator while being visualized by an ultra-fast camera. Through the interpretation of the dual optical and mechanical output signals, the size and the shape of the droplets can be investigated. The extreme sensitivity of such optomechanical approach enables analyzing the droplet evaporation dynamics down to a volume of liquid of a few tens of attoliters only, where the canonical picture of a sessile droplet on a surface collapses. Such small volume of liquid had only been analyzed by invasive Transmission Electron Microscopy techniques, where the intrinsic dynamics was perturbed and non-accessible.

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[2] M. S. Hanay et al.," Nat. Nanotechnol., 7, 9, 602, (2012).
[3] C. Metzger et al., Phys. Rev. B, 78, 3, 035309, (2008).
[4] S. Sbarra et al., arXiv:2103.09509 (2021).

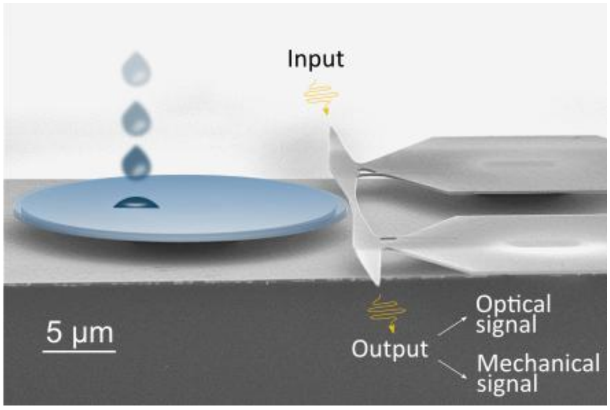

Figure 1 : SEM image of a Gallium Arsenide resonator (blue) with a fully suspended optical waveguide (grey) and anchoring structures (grey paddles at right). The resonator is perturbed by the landing of a sub-micron droplet on its surface. The time evolution of the droplet is studied by analysing the optical and mechanical output signals.