Optomechanics with 2D photonic crystals membrane

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Abstract: Cavity optomechanics exploits the coupling of mechanical oscillators to the light field via the optical force. In our work, the optomechanical resonator is a suspended 2D photonic crystal structure. We investigate experimentally the mechanical behavior exhibited by a conventional two dimensional photonic crystal acting as a mirror or including a cavity of diffraction-limited size. Due to their geometry and very small scales, the optomechanical mirrors sustain mechanical modes in the MHz frequency range; these modes exhibit a very strong nonlinear behavior. The optomechanical cavities also sustain in the GHz frequency localized mechanical modes, which are confined in the cavity core. In this paper, we will present our work towards fully integrated optomechanical platforms combining the optomechanical resonator and external actuation tools, either by electrostatic actuation via interdigitated electrodes or by optical actuation via an integrated silicon waveguide below the optomechanical resonator.

1- Introduction

Optomechanics utilizes the coupling between light and the geometry of a mechanical oscillator to read or tailor the mechanical motion of the oscillator. Optomechanical coupling can be enhanced by use of an optical cavity. This coupling is also stronger at the nano-scale because of the very small mass of nano-mechanical oscillators. In our work, we investigate the nano-optomechanics of suspended photonic crystal membranes. These structures may combine cavity enhancement and low mass and thus exhibit strong mechanical coupling to light. Optomechanical coupling in 1D photonic crystal cavities has been observed in patterned single and dual nanobeams (zipper cavities). In this work, the mechanical oscillator consists of a suspended nano-scale InP membrane pierced with a regular array of holes constituting a two-dimensional photonic crystal. Depending on the arrangement of holes, it can either act as a deformable end-mirror in a conventional Fabry-Perot cavity or include a cavity of diffraction-limited volume that simultaneously confines both phonons (i.e. mechanical vibrations) and photons.

2- Optomechanical photonic crystal cavities

We first investigated experimentally the mechanical behavior exhibited by a conventional two dimensional photonic crystal including a cavity of diffraction-limited size[1]. This cavity sustains a single optical mode at a telecommunication wavelength with a cold-cavity quality factor of around ten thousand. In our experiment the mechanical modes of the suspended membrane are observed by measuring the frequency noise spectrum obtained by evanescently coupling a laser into the optical cavity and locking it on a side of the resonance. We observe more than 20 mechanical modes in the frequency range between 10 MHz and 1 GHz. These modes can be assigned to two different mode families. Low-frequency modes (below 200 MHz) are flexural modes corresponding to the movement of the whole membrane. The second mode family consists of localized modes corresponding to mechanical displacement of the membrane localized in the cavity core. Due to the strong confinement and colocalization of the optical and mechanical modes within the defect cavity, strong optomechanical coupling is observed for the localized modes.

The observation and actuation of these modes, exploited up to now light coupling to the resonator via a tapered optical fiber placed in the evanescent field of the resonator, restraining the possibility to combine various optomechanical functionalities on the same chip. An integrated platform has been developed by replacing the usual tapered fiber by a silicon waveguide underneath the suspended photonic crystal membrane (see Figure 1. left). This approach opens the possibility to integrate an extra functionality on the top surface of the planar membrane. The use of this fully-intergrated circuitry on a single planar setting opens the way to their use for RF photonics (microwave oscillators, RF filters...) or chip-scale optomechanical signal processing (wavelength conversion, delay lines...).

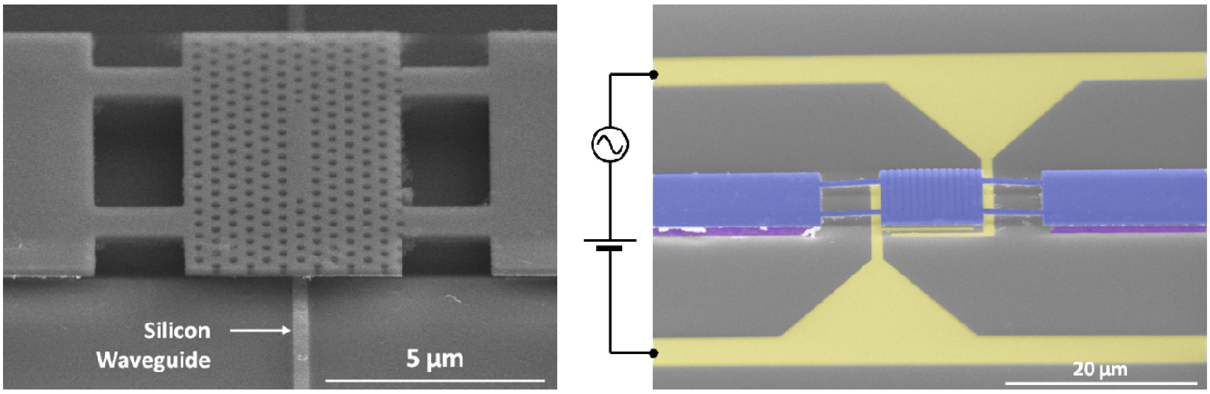

Figure 1: Scanning electron image of (Left) a suspended photonic crystal cavity bonded over an integrated silicon waveguide and (Right) a suspended photonic crystal mirror bonded over interdigitated electrodes.

3- Optomechanical photonic crystal mirrors

Photonic crystal slabs with a square lattice of holes have been used as mirrors operating at normal incidence in active (VCSEL) and passive optical resonators. We extended their use to optomechanics[2], by demonstrating experimentally that such slabs sustain vibrational modes in the MHz range while their reflectivity at normal incidence at 1064 nm is higher than 95 %. These two features, combined with their very low mass, open the way to the use of such periodic structures as deformable end-mirrors in Fabry-Perot cavities for the investigation of cavity optomechanical effects.

Due to their geometry and very small scales, these resonators exhibit a very strong nonlinear behavior, in particular mechanical bistability[3]. This feature turns out to have a dramatic impact on the dynamics of a mechanical mode, as well as an intermodal effect observed on the frequency shift of a second mode when a first mode is actuated in its nonlinear regime. We also observed in particular the emergence of a phase conjugate mechanical response to a weaker probe actuation; the mechanical response exhibits both a resonance at a frequency above the pump frequency and a spontaneously generated mechanical motion at a lower frequency symmetrically located below the pump frequency.

Most of these experiments used an external piezoelectric actuation of the mechanical motion. Such actuation scheme could be strongly enhanced by using integrated electrostatic actuation tools. Such scheme can be achieved by integrating interdigitated electrodes below the membrane (see figure 1 right). Applying an AC voltage (superimposed to a DC voltage) on the electrodes, induces an electrostatic force that is applied on the membrane and thus that actuates mechanical motion. In our preliminary experiments, we observe that the increase of the applied DC voltage (an thus of the force) induces a parabolic shift of the mechanical frequency, as predicted by our numerical simulations.

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