Dispersive and dissipative optomechanical coupling in heterogeneously integrated 2D photonic crystal system

V. Tsvirkun\textsuperscript{1,†}, A. Surrente\textsuperscript{1}, G. Beaudoin\textsuperscript{1}, F. Raineri\textsuperscript{1,2}, R. Raj\textsuperscript{1}, I. Robert-Philip\textsuperscript{1}, and R. Braive\textsuperscript{1,2}

\textsuperscript{1}Laboratoire de Photonique et de Nanostructures, Route de Nozay, 91460 Marcoussis, France
\textsuperscript{2}Université Paris Diderot - F-75205 Paris Cedex 13, France

\textsuperscript{†}viktor.tsvirkun@lpn.cnrs.fr

Abstract — We report on optomechanical effects in 2D photonic crystal defect cavities coupled to integrated silicon waveguides of different widths. Mechanical modes are observed systematically on a chip scale. By tuning the excitation laser wavelength, we observe optical spring effects. We extract optomechanical coupling coefficients and demonstrate the dispersive and dissipative nature of optomechanical coupling. Their relative contribution can be controlled by modifying the access waveguide width, thereby paving the way for a control of optomechanical coupling on the wafer level.

In recent years, photonic crystals (PhC) have been widely employed as a platform for optomechanics [1]. The most common approach to optically address mechanical resonators consists in a tapered fiber placed in the evanescent field of the optical cavity by means of nanopositioners. While this approach enabled the demonstration of a number of optomechanical effects, it lacks the scalability required to implement optomechanical circuits on a single chip [2]. Here we report on a novel optomechanical platform, which allows for a robust and tailored coupling of suspended PhC cavities to silicon-on-insulator (SOI) waveguides [3]. Such approach is intrinsically scalable and it permits toaddress a predefined number of optical cavities coupled to mechanical resonators, thus being compatible with optomechanical arrays experiments [1].

Our mechanical resonators consist of 260 nm thick InP membranes, patterned with a 2D PhC and suspended over the substrate by employing four bridges connected to suspension pads; the waveguide-PhC cavity air gap is 230 nm [see Fig. 1(a)]. An L3 defect cavity (three missing holes in a line) in the middle of the membrane is evanescently coupled to the SOI waveguide, terminated by grating couplers at both sides for efficient light input and extraction. The cavity resonance wavelength and waveguide transmission band are centered around 1560 nm. Both waveguide width and membrane-waveguide distance allow for a precise control of the coupling between the cavity and the propagating waveguide optical modes.

The readout of the Brownian motion in the MHz range is performed in the linear optical cavity regime, at room temperature and at low pressure ($<10^{-4}$ mbar) via side-of-the-fringe detection
technique. It reveals the presence of flexural mechanical modes as seen in Fig. 1(b), associated with the whole membrane motion. The corresponding displacement field profiles are illustrated in Fig. 1(c). At higher excitation power, more mechanical modes can be read out. However, thermo-mechanical effects and optical bistability become pronounced in these experimental conditions.

In the linear optical regime, we measured the optomechanical coupling (single-photon interaction strength) $g_0$ via frequency modulation technique [4]. For the flexural modes shown in Fig. 1(b), the values of $g_0/2\pi$ ranged from 0.15 kHz for fundamental mode to a few kHz for higher order modes. Extracted $g_0/2\pi$ values are comparable to those determined via the same technique on a similar system [6].

By tuning the laser wavelength across the optical cavity resonance, dynamic backaction effects were investigated, in particular via optical spring effect [1] for the probed flexural modes. Our experimental data is fitted by the use of an analytical model considering three optomechanical coupling mechanisms (dispersive, intrinsic dissipative and external dissipative [5]). Fig. 2(a) shows a quantitative agreement with experimental data, allowing to deduce the relative contributions of the different optomechanical coupling mechanisms as shown in Fig. 2(b). These results highlight the main role played by the dispersive and external dissipative forces; these forces arise from the modulation of the PhC–SOI distance due to mechanical motion.

In summary, we propose a novel approach for the integration of optomechanical resonators (represented by PhC membranes) onto a SOI waveguide substrate. Such approach enabled us to investigate systematically the optomechanical effects occurring in the fabricated devices. By analysing the optical spring effect, we demonstrated optomechanical coupling of both dispersive and dissipative nature. The proposed technology platform has the potential to be up-scaled for the implementation of on-chip optomechanical circuits.

REFERENCES