Marie Curie ITN cQOM
Summary of the Scientific Achievements

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Optomechanical systems, in which the vibrations of a mechanical resonator are coupled to an electromagnetic radiation, have permitted the investigation of a wealth of novel physical effects. To fully exploit these phenomena in realistic circuits and to achieve different functionalities on a single chip, the integration of optomechanical resonators is mandatory.

This work aimed at the exploration and development of a fully-integrated optomechanical platform based on a suspended membrane made of two-dimensional photonic crystal suspended above an integrated silicon waveguide. Our resonator was designed to simultaneously have an optical mode at a wavelength of 1.55 microns and at the same time be able to serve as a mechanical oscillator, having two modes of families - localized modes in the core of the optical cavity (in the GHz frequency range) and modes in the MHz range, corresponding to the movement of the entire membrane. A high mode confinement and a significant overlap between the spatial localizations of photons and phonons gives rise to strong optomechanical interactions.

During these three years I developed the fabrication procedure for 3D heterogeneous integration of the described optomechanical platform onto a network of silicon waveguides. The fabrication was accomplished entirely in the cleanroom of host laboratory, where I was responsible for the majority of processing steps (wet and dry etching (plasma), substrate bonding, dielectric deposition and optical lithography). This has permitted to obtain the membranes suspended at a height of 200 nm above the integrated waveguides.

I fully settled the experimental set-up, which allowed us to perform the characterization of the optical and mechanical modes of the studied structures. The first mechanical characterizations were carried out on photonic crystal membranes (10x20 um size, thickness 260 nm) in the MHz frequency range. Brownian motion of such membranes, suspended by the means of four bridges was read out for several vibration modes within the range up to 100 MHz. By performing the characterization of the optical spring effect, which results in the change of the spring constant (and therefore of the mechanical frequency) induced by the light field, in the linear operation regime of the optical cavity, we were able to measure and understand the contributions of different kinds of optomechanical processes (dispersive and dissipative) for the intrinsic (within the membrane) and external (interaction with the external waveguide) cases. The relative and absolute strength of these effects showed to be tailorable while changing the geometrical parameters of the access waveguide circuit. Such tailored coupling pave the way to the implementation of the efficient optomechanical cooling scheme of the mechanical modes of our resonator in the case of the device operation in the so-called sideband-unresolved regime, or, when the cavity optical resonance linewidth is much larger comparing to the frequency of the mechanical mode. Eventually such technique allows to achieve a ground state cooling of the selected mode, exploring further a coupling between a quantum mechanical oscillator and a two-level system (represented in our devices by a quantum dots), quantum information processing, logical and memory elements and so on.

Alongside with the development of experimental set-up and sample fabrication procedure, different types of computer-assisted simulations were carried out in order to fully understand and characterize the system optical and mechanical parameters as well as the optomechanical couplings strengths for different types of modes and different types of effects involved into such couplings.

In addition, by accessing the non-linear regime of the optical cavity we demonstrated an important tunability of mechanical mode parameters using purely optical means. Preliminary results on system operation in such non-linear optical regime showed as well a possibility to have an optically driven mechanical switch by accessing a bi-stable region of the cavity response.

In conclusion, a novel approach to heterogeneously integrated arrays of two-dimensional photonic crystal defect cavities on top of silicon-on-insulator waveguides was developed. The optomechanical response of these devices was investigated and evidences an optomechanical coupling involving both dispersive and dissipative mechanisms. By controlling optical coupling between the waveguide and the photonic crystal, we were able to vary and understand the relative strength of these couplings. This scalable platform allows for unprecedented control on the optomechanical coupling mechanisms, with a potential benefit in cooling experiments, and for the development of multi-element optomechanical circuits in the frame of optomechanically-driven signal-processing applications.

Our system showed a step towards the fundamental studies of quantum mechanics by introducing first a possibility to reach the GS in the dominant dissipative coupling regime. The resonator embeds a two-level system, represented by the of quantum dot, opening next a way to couple a two-level system to the quantum mechanical resonator. Demonstrated integrated platform allows for easily scalable arrays of OMO, potentially allowing the implementation of QIP logic and memory elements.

An article featuring the main results of accomplished research was accepted for publishing in Scientific Reports (http://www.nature.com/srep/about).

These achievements were as well presented through several talks in some national and international conferences:

- CLEO 2015, Germany
- Frisno 2015, France
- META 2015, USA,
- OMN 2015, Israel
- OPTIQUE 2015, France