Marie Curie ITN cQOM
Summary of the Scientific Achievements

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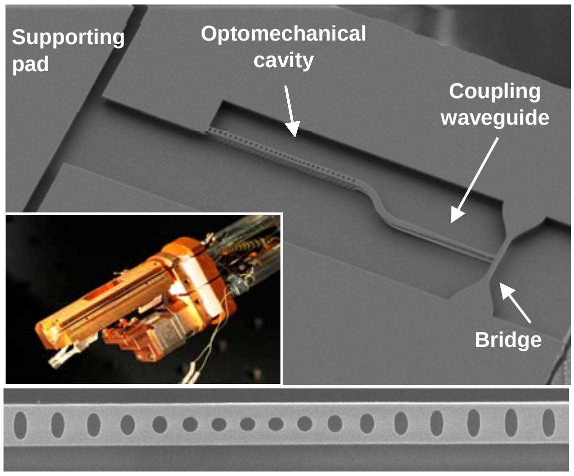
Academic / Industrial Institution: EPFL
Start Date of ITN Fellowship: 1-7-2015
End Date of ITN Fellowship: 31-5-2016
Date of Report: 14-6-2016

1. Description of research work

My research concerns realizing non-classical states in mechanical oscillators. Specifically, our research aims to create a single phonon Fock state of a mechanical mode. Such a state can be created using heralding techniques, as has been analyzed theoretically in our group: With the mechanical oscillator mode initially in the ground state, and working in the resolved-sideband regime, a single 'write' photon, tuned to the blue sideband, may leave the oscillator in a non-classical singly-excited Fock state, while generating a down-converted photon heralding the process. Subsequent reading of the mechanical state is possible via a 'read' photon tuned to the read sideband, imprinting the mechanics on up-converted photons. In analogy to early experiments in quantum optics, that demonstrated the quantum nature of light via fluorescence from single atoms, the quantum nature of mechanical oscillators is revealed in the statistical correlations of the readout light, which would violate classicality by exhibiting anti-bunching and sub-Poissoninan statistics.

We implement photonic crystal nanomechanical oscillators due to their gigahertz-scale mechanical frequency (resulting in high resolved sideband factor), high optical and mechanical *Q*-factors and excellent optomechanical coupling. The high frequency also enables reaching extremely low thermal occupation simply by cryogenically cooling the devices.

Achieving a single-phonon Fock state of a mechanical oscillator will advance the understanding of the quantum nature of macroscopic objects and facilitate using such systems for quantum information processing.



Top: Scanning Electron Micrograph (SEM) of fabricated OMC structure. The inset show the cryohead used for mounting the sample in the cryostat. Bottom: SEM of a zoom-in on the optomechanical cavity, showing the gradually-perturbed defect region which co-localizes photonic and phononic modes.

2. Goals achieved and/or progress towards them

In the 11 months period of my ITN fellowship, a major advance was made as we have acquired and installed a 3He buffer-gas cryostat in the lab. This cryostat enables reaching temperatures as low as 600mK, whereas previous measurements were performed at 4K afforded by a 4He bath cryostat. At 600mK the phonon occupation of the >5 GHz mechanical mode is already below 2 quanta. This facilitates deep ground-state cooling, as the initial stage of the heralded Fock-state generation scheme. More importantly, the 3He buffer environment (not present in other cryogenic systems) aids the thermalization of our sample. In previous studies with similar structures at cryogenic conditions, heating of the mechanical mode due to light absorption at nanosecond timescale inhibited sustained probing of the mechanical state.

Accordingly we have has set out to characterize the thermal behavior of our sample at various bath temperatures and buffer-gas pressures, We have identified the optimal working point for deep ground state cooling and subsequent pulsed quantum control. In preliminary measurements, mechanical mode occupations below 1 phonon were achieved. Further improvements are expected by using better samples (i.e. optimizing sample treatment prior to insertion into cryostat; improving the tapered-fiber coupling scheme). These promising results put achieving quantum mechanical states in this unique experimental system within reach.

In preparation for the forthcoming experiments, we have also advanced our experimental capabilities by setting up a balanced-heterodyne detection scheme, which is instrumental in observing the low mechanical signals at cryogenic temperatures. This scheme employs two additional lasers and allows observing both mechanical sidebands simultaneously. As near the ground state emission into the upper sideband is inhibited, this allows to perform, e.g., sideband asymmetry measurements as absolute calibration of the mode temperature.

3. Training received (complementary/soft skills, ITN workshops attended)

Attended several workshops (see below). As this is a new field for me, I have benefited from these opportunities to meet and network with fellow scientists and students.

4. Participation and role in dissemination and outreach activities

Since I joined the ITN for its last 11 months, I did not have the chance to participate in outreach events.

5. List of conferences attended

ITN cQOM workshop: "Taking a Research Idea to a Product"
Rüschlikon, Switzerland
30 Nov - 1 Dec

Diavolezza 2016 annual ITN cQOM Workshop
Diavolezza, Switzerland
31 Jan - 4 Feb 2016

ITN cQOM workshop "From Photonics Research to the CMOS-fab"
Ghent, Belgium
17-19 May 2016

6. Publications (with links)

A manuscript summarizing our study of our samples in a cryogenic helium-3 buffer environment, in the context of thermalization and optomechanical cooling, is in preparation.

7. Career plans after ITN

Continue my postdoc position in the host lab (as a Marie Curie Fellow) and secure a research position by the end of the contract on 31 May 2018.