# Marie Curie ITN cQOM
# Summary of the Scientific Achievements

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**Description of research work**

The field of cavity optomechanics seeks to create powerful new tools for the exploration of phenomenon in the quantum regime, by coupling the mode(s) of an optical cavity to the mechanical mode(s) of a mechanical oscillator. My thesis work seeks to realize a hybrid, on-chip integrated optomechanical platform that will overcome the shortcoming of current systems. The system is hybrid in the sense that it integrates a silicon nitride doubly clamped nanobeam with a silicon dioxide microdisk whispering gallery mode optical cavity. Silicon nitride nanobeams represent the state of the art in ultra-high quality factor (Q) mechanical resonators, and the research behind such systems is well established. Likewise, silicon dioxide microdisk cavities represent the highest finesse resonators that are amenable to on-chip fabrication. These two physically separate systems can be coupled by the optical gradient force, to realize a fully chip-integrated optomechanical system. Such integration allows not only minimization of the geometry (a key to achieving large coupling rates), but also avoids many experimental challenges that come with non-integrated systems – in particular acoustic noise. Moreover, integration is a requirement for any practical application in optomechanics.

**Progress made and goals achieved**

During the course of the ITN program I have successfully integrated a high-Q silicon nitride nanobeam with a high-Q optical microdisk cavity. This system now stands as the highest cooperativity – a measure of conversion efficiency between photon and phonon – system, among solid state devices. The resulting extremely high SNR readout of the fundamental mechanical mode has allowed for external feedback damping, in a cryostat, of the mode to an occupancy of just a few phonons (see Nature article in publication section). Likewise, this device has been used to observed asymmetry in the motional sideband; a signature of the zero-point energy of the mechanical mode (in preparation). Moreover, the unusually high room temperature Q provided by the nanobeam has allowed us to achieve similar performance at room temperature – a rare feature in optomechanics where cryostats are generally required to achieve high performance. We are exploiting this fact to observe quantum behavior – namely quantum back-action – at room temperature. This would be the first observation of this effect in a solid state system at room temperature. Finally, in a collaborative effort with NTT we have electrically functionalized this system, allowing for optical read-out of extremely small electrical signals, as well as electrical actuation. This implementation will be the first realization of a chip-integrated optomechanical charge sensor. Initially estimations show we may be able to achieve similar sensitivity to cryogenic charge sensors, but at room temperature. If this turns out to be the case, it would be a major step forward in demonstrating the practical utility of optomechanical sensing.

**Training received**

I attended two training events during my time in the ITN program (in the conference list below). ITN workshop that took place in Paris from 2-4 of April in 2014 included demos on laser frequency locking and 3D printing. There was also a short courses on photonic crystals, and short presentations from ITN members on their research work. I also attended the COMSOL workshop, organized by Prof. Kippenberg, that took place from 21-23 of July 2014. This three-day workshop included general tutorials from COMSOL employees, and also demonstrations of simulation methods specifically relevant to optomechanics, given by members of Prof. Kippenberg's group.

**Outreach**

I participated in the 2014 Nuit de la Science, in Geneva Switzerland. This event is a weekend-long science outreach event, open to the general public, where researchers from Swiss institutions have the chance to setup a booth, for science demonstrations. Along with three other students from the lab of Prof. Kippenberg, we designed and demonstrated several simply experiments to highlight the physics and technology relevant to our research work. One demonstration involved a guitar using an optical fiber in place of a typical guitar string. The change in polarization resulting from the fiber being plucked was read out using an interferometer. This demonstrated how light can be used as a displacement sensor, and was a big hit with young children. We also demonstrated how data can be transmitted by laser light - sending a song encoded in the light across the table (in free space), and then decoding and playing the music. Many participants were quite surprised to see they could stop and start the music simply by blocking or unblocking the light.

**Conferences attended**

| Conference Name | Location | Dates |
|---|---|---|
| Diavolezza 2013 | Diavolezza, Switzerland | 10-14 February 2013 |
| Quantum Nano- and Micromechanics | Monte-Verità, Switzerland | 21-25 July 2013 |
| Gordon Research Conference: Mechanical Systems in the Quantum Regime | Ventura, CA, USA | 9-14 March 2014 |
| ITN CQOM WORKSHOP "Laser Stabilization and high-sensitivity displacement sensing" | Paris, France | 2 - 4 April 2014 |
| ITN cQOM workshop "Finite Element Modeling" | Lausanne, Switzerland | 21.-23. July 2014 |
| Diavolezza 2015 | Diavolezza, Switzerland | 1-5 February 2015 |

**Publications**

*Measurement-based control of a mechanical oscillator at its thermal decoherence rate*, Nature, 2015