

Marie Curie ITN cQOM

Summary of the Scientific Achievements

Name of Fellow: Iman Moaddel Haghghi
Principal Investigator: Prof. David Vitali
Academic / Industrial Institution: University of Camerino
Start Date of ITN Fellowship: 10.12.2013
End Date of ITN Fellowship: 31.05.2016
Date of Report: 20.06.2016

1. Description of research work

Recent developments in quantum information and communication have proven the need for quantum coherent interfaces. The main role of these coherent interfaces is for the coherent transfer of the quantum state of photons between different wavelengths, for example between optical-radio frequency photons. We know that Radio Frequency photons are frequently used in quantum information and quantum memory experiments especially for reading out the qubits in atomic or solid state systems. Introducing a coherent hybrid interface would enable one to manipulate and transfer these qubits to optical fields.

The objectives of my research project are:

- (i) Understanding of the RF to optical connection on the basis of cavity electro-optomechanical set up.
- (ii) Implementing a mechanical oscillator like thin membrane as an interface between optical and RF photons.

Based on these targets we are going to develop an opto-electro mechanical transducer in which a thin membrane as a nano-mechanical oscillator is strongly coupled to an optical field and simultaneously coupled to an LC circuit. The nano mechanical membrane as well as LC circuit should have High Q. The candidate material for making the membrane is SiN which is proven to have high Q factors of the order of millions. Placing this membrane inside a high finesse cavity causes the vibrational modes of the membrane to be coupled capacitively to RF field and via radiation pressure with optical field.

2. Goals achieved and/or progress towards them

- **Measurement power spectrum and Q factor of assembled metalized membrane**

We designed and built a metalized membrane with a specific pattern, and then measured the Q factor of the system.

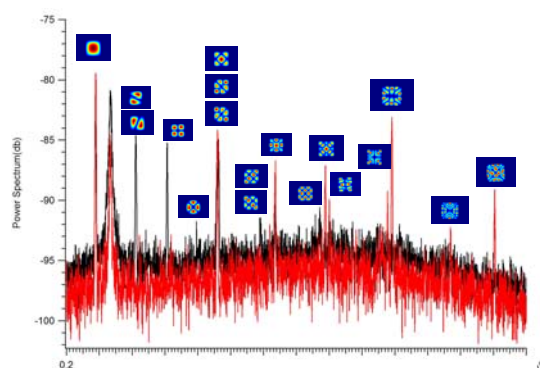


Figure 1. Power spectrum of the metalized membrane

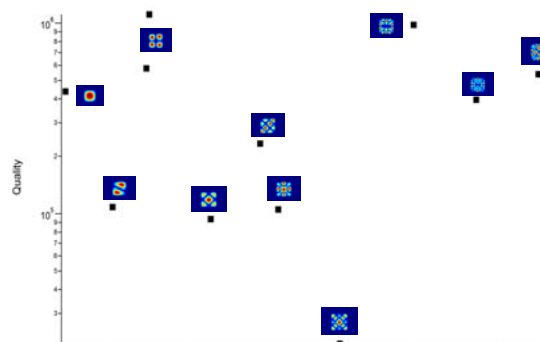


Figure 2. Quality factor of the different modes of the metalized membrane.

- **Observation of Mechanically induced transparency.**

We could observe MIT which is a signature of electromechanical coupling. As is shown in the figure below, by increasing the dc voltage resonance frequency of the membrane shifts and MIT effect is more clear. In the figure the LC response is depicted.

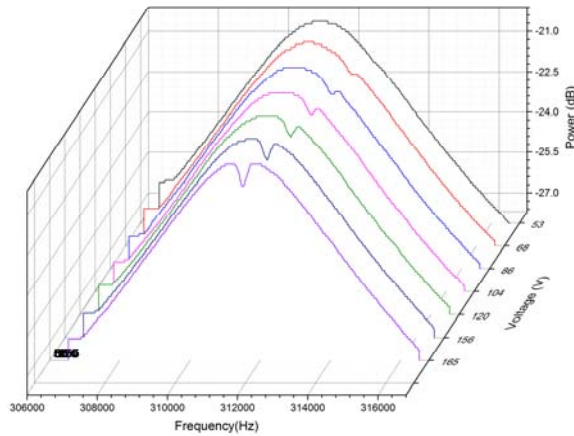


Figure 3. Observed MIT for different dc bias voltages. Shift of the mechanical resonance frequency due to the dc bias is clear.

- **Optical/Electrical readout of electromechanical coupling.**

There are several means for measuring electromechanical coupling, including the measurement of mechanical and optical resonance frequency shift. We did several measurements of these types. The figure below depicts the mechanical resonance frequency shift when the dc voltage is applied.

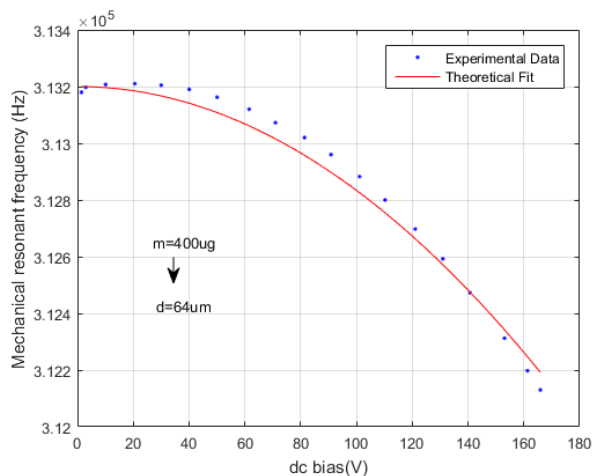


Figure 4. Mechanical resonance frequency shift. By applying different dc voltage across the membrane, the resonance frequency of the membrane is altered which can then be utilized to estimate the electro-mechanical coupling rate.

- **Observation of strong coupling regime**

We are still working on this aspect as we must overcome many difficulties, such as membrane electrodes distance and full control of rf noise.

- **Repeating experiments at low temperature**

This would be the final step. We are still working on the calibration of the new system as the new crystate system was delivered just few weeks ago.

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

- ITN cQOM workshop "Laser Stabilization and high-sensitivity displacement sensing", 2 - 4 April 2014, Paris, France.
- ITN cQOM workshop "Finite Element Modeling", 21 - 23 July 2014, Lausanne, Switzerland.
- Diavolezza 2015 annual ITN cQOM Workshop, 1 - 5 February 2015, Diavolezza, Switzerland.
- ITN cQOM workshop: "Taking a Research Idea to a Product", 30 Nov - 1 Dec 2015, Rüşchlikon, Switzerland.

4. Participation and role in dissemination and outreach activities

I participated in the following events and conferences to present my research work:

- Science Days in Camerino in 2014 and 2016 whereby all PhD students and postdocs present and share their recent research achievements in a poster session, and interact with visitors.
- Presentation at 71th Scottish Summer School in Physics, 21 July - 2 August 2015, Glasgow, Scotland
- Presentation at ITN cQOM workshop "Laser Stabilization and high-sensitivity displacement sensing", 2 - 4 April 2014, Paris, France. Oral presentation and poster.
- Invited talk at Isfahan - Fereiburg Summer School, 18 – 21 May 2016, Isfahan, Iran.

5. Publications (with links)

J. Li, I. Moaddel Haghghi, N. Malossi, S. Zippilli, D. Vital. *D Generation and detection of large and robust entanglement between two different mechanical resonators in cavity optomechanics*. New Journal of Physics, Volume 17, 103037-103053(17), 2015.

<http://www.ingentaconnect.com/content/iop/njp/2015/00000017/00000010/art103037>.

6. Career Plans after ITN

I plan to stay with my current host institution, University of Camerino, to complete my PhD by the foreseen date of 28.02.2017.