PHOTONICS - EUROPHOTONICS MASTER COURSE

MASTER THESIS PROPOSAL

Course 2014 –2015

Laboratory/Institution: ICFO
City, Country: Castelldefels (Barcelona), Spain

Title of the master thesis: Coupling radio-frequency photons of a superconducting cavity to a mechanical resonator based on graphene.

Name of the tutor of the master thesis: Adrian Bachtold
E-mail address : adrian.bachtold@icfo.es
Phone number : 34 93 554 22 39
Website: http://bachtoldgroup.icfo.eu/

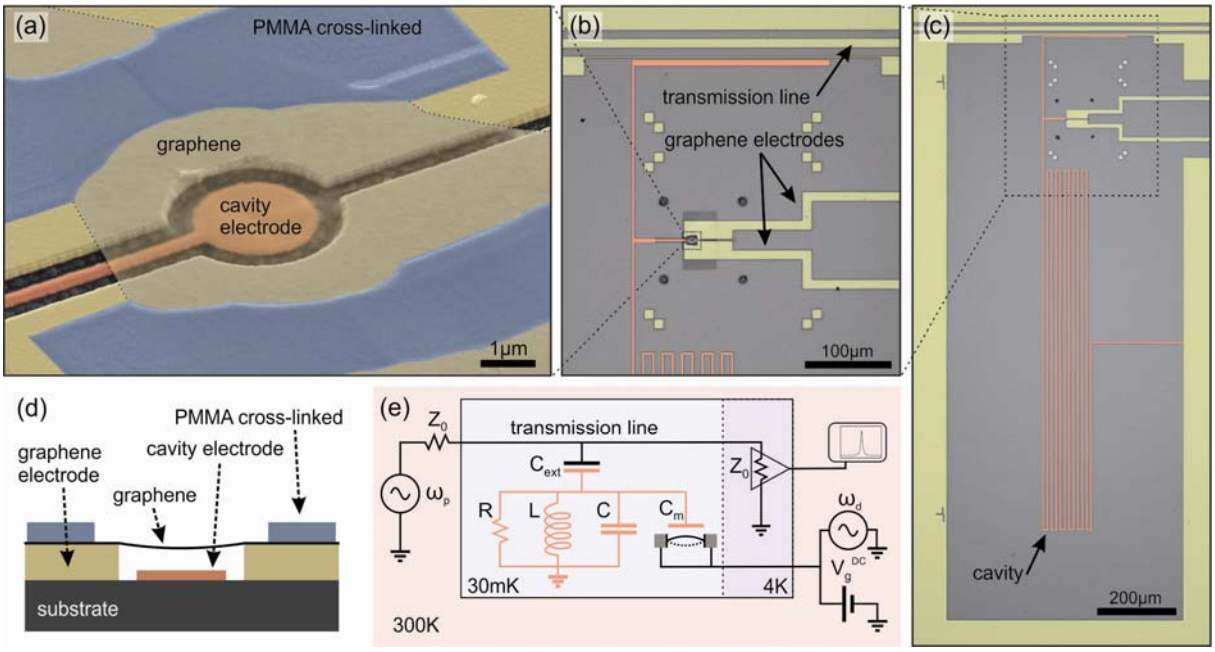
Summary of the subject (maximum 1 page):

Graphene, a single atomic layer of graphite, has generated a huge research interest in the past years. Its discovery was awarded with the 2010 Nobel Prize in physics. Being the thinnest material possible but mechanically very robust, graphene offers unique scientific and technological opportunities as nanomechanical resonators. For instance, they can be employed as ultra-sensitive sensors of mass and of force with unprecedented sensitivities [1,2]. Coupling the mechanical motion of graphene to the radio-frequency photons of a superconducting cavity is appealing: it holds promise for the detection of ultra-small displacements (that is, ultra-small amplitude of the vibrational motion of the resonator). Interestingly, in this limit, the physics is governed by the laws of quantum mechanics. Namely, the position and momentum of the resonator have a variance reaching the limit of the Heisenberg uncertainty principle.

There is a lot of interest in the scientific community to study the physics and the potential applications of mechanical motion in this so-called quantum regime [3]. Many research groups are employing resonators microfabricated in semiconducting and metallic materials, while graphene based resonators offer the advantage to have a relatively large vibrational amplitude in the quantum regime. In addition, mechanical nonlinearities of graphene resonators are particularly pronounced in comparison to other nanomechanical resonators [4,5] and might be sizeable in the quantum regime.

One aspect of the project will be to fabricate ultra-clean graphene resonators. Here the student will have the opportunity to learn how to use an electron beam lithography system, how to

produce graphene devices like the Nobel Prize winners, and how to transfer graphene with micrometer precision. The device will consist of a single graphene sheet that is suspended over a trench and that is coupled to a superconducting cavity (see figure). The other aspect of the project is to detect the motion of the graphene using the radio-frequency photons of the cavity [5]. In addition, the radio-frequency photons will be used to cool the graphene motion into the quantum regime. The principle of cooling is simple [3]; by scattering low energy photons with the resonator, vibrational energy is removed and dissipated by photons with higher energy.



(a) False color SEM image of a circular graphene resonator capacitively coupled to a cavity electrode. The graphene sheet is clamped in between cross-linked PMMA and graphene support electrodes. (b,c) Optical microscope images of the superconducting cavity, the two electrodes contacting the graphene flake, and the capacitively coupled transmission line. (d) Schematic cross-section of the mechanical resonator and the cavity counter electrode. (e) Schematic of the measurement circuit. See Ref. [5] for more details.

[1] Chaste, Eichler, Moser, Ceballos, Rurali, Bachtold, Nature Nanotech. **7**, 301 (2012)
[2] Moser, Güttinger, Eichler, Esplandiu, Liu, Dykman, Bachtold, Nature Nanotech. **8**, 493 (2013)
[3] Aspelmeyer, Meystre, Schwab, Physics Today **65**, 29 (2012)
[4] Eichler, Moser, Chaste, Zdrojek, Wilson-Rae, Bachtold, Nature Nanotech. **6**, 339 (2011)
[5] P. Weber, J. Güttinger, I. Tsioutsios, D. E. Chang, and A. Bachtold, Nano letters **14** (5), 2854-2860 (2014)

Keywords: Optomechanics, graphene, cryogenics (down to 0.015 K), low-noise radio-frequency measurements (up to 8 GHz), nanofabrication (with monoatomic membranes)

Additional information:

* Amount of the monthly allowance (if it is the case): up to 600 euros/month
* Miscellaneous: We have the funding to pay the master thesis as well as to continue the work with a PhD.