CryOptics – A dilution cryostat for nano-optics and nano-optomechanics

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EQUIPMENTS

LABORATORIES: NEEL

PRINCIPAL INVESTIGATORS : Olivier Arcizet and Laetitia Marty (equipment supervisors), Francesco Fogliano, Benjamin Besga, Julien Jarreau, Eric Eyraud, Wolfgang Wernsdorfer, Corinne Felix, Benjamin Pigeau.

The CRYOPTICS project aimed at developing a novel instrument capable of realizing ultrasensitive optical and optomechanical experiments with nanoscale samples at dilution temperatures. It is based on a 20 mK "sionludi" platform - an inverted dilution cryostat, with dimensions and operation modes compatible with ultrasensitive optical experiments, entirely developed at NEEL. Cryo-compatible optical elements were also developed internally, such as large numerical apertures (0.75) fibered objectives producing diffraction limited optical spot (400 nm) with interferometric imaging capability. They can be piezo-scanned for imaging.

A first nano-optomechanical experiment allowed us to validate the experimental developments (test of optics, thermalisation of the samples, vibration level). It consists in reading out optically the vibrations of a singly clamped, suspended silicon-carbide nanowire. Those nanoresonators with subwavelength-sized diameters and extreme aspect ratios (2000) represent ultrasensitive scanning vectorial force sensors, with 10 attonewton/$Hz^{1/2}$ sensitivities at 300K, only limited by the thermal noise. The latter can be much reduced at cryogenic temperatures, while benefiting from increased values of the mechanical quality factor. This requires an efficient thermalization of the nanowire, and avoiding optical heating. The thermal conductance becomes extremely weak (~10^{-14} WK^{-1} at 100mK), which lead us to develop optomechanical readout techniques operating in the photon counting regime using avalanche photodiodes. We could observe nanowires thermalized down to 40 mK while injecting only a picowatt of laser light, with a ~10 mK/pW heating rate. Force sensitivities of 40 zeptonewton/$Hz^{1/2}$ were reported, which represents a 10-fold improvement over existing experiments, and corresponds (in 1 s) to the Coulomb interaction between 2 electrons separated by ~100 µm.

Future developments are oriented towards the realisation of fluorescence imaging and improved optics, cavity nano-optomechanics and the incorporation of electrical transport.

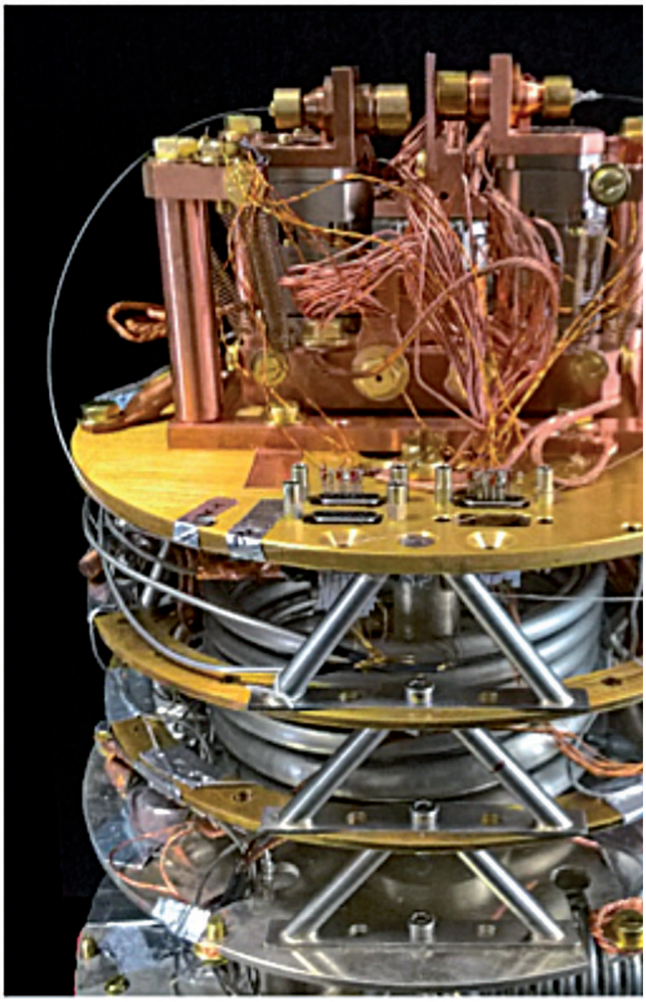

Fig. 1. The cryoptics experiment, built on top of a "sionludi" cryostat. Well visible are the optical fibers used to inject and collect light from the sample. The sample and the fibered interferometric objectives can be finely positioned with piezo-actuators. The experiment is suspended by 8 springs to isolate it from acoustic vibrations.

OUTCOMES

Publications:

[1] Eigenmode orthogonality breaking and anomalous dynamics in multimode nano-optomechanical systems under non-reciprocal coupling, Nature Commun. 9, 1401 (2018).
[2] Ultrasensitive nano-optomechanical force sensor at dilution temperatures (in preparation,2018).

Oral presentations :

GDR MecaQ, Paris 2017;
ENS Lyon 2017,
LOMA Bordeaux 2018;

Leverage:

ERC proof of concept, CARTOF, 2017.
ANR NC2 2016,
ANR QCFOrce 2016