Cavity optomechanics with photonic crystal nanomembrane

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We present a new generation of optomechanical device designed to reach the quantum ground state. It combines the high reflectivity of a photonic crystal, with the high mechanical Q-factor and low mass of a nanomembrane. Optomechanical coupling between a moving mirror and quantum fluctuations of light first appeared in the context of interferometric gravitational-wave detection. Since then, several schemes involving a cavity with a movable mirror subject to radiation pressure have been proposed to detect the quantum position fluctuations of a mechanical resonator. The zero-point motion detection of an oscillator requires high resonance frequencies (MHz to GHz) and low temperature (in the hundreds μK range) only achievable by combining cryogenic and active cooling techniques such as laser cooling or cold damping, and also a sufficient sensitivity to the displacement measurement (high finesse cavity).

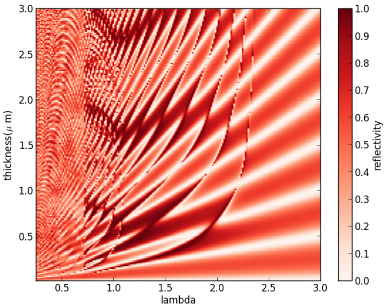

Figure 1: *Simulation of reflectivity for various geometrical parameters of the crystal.*

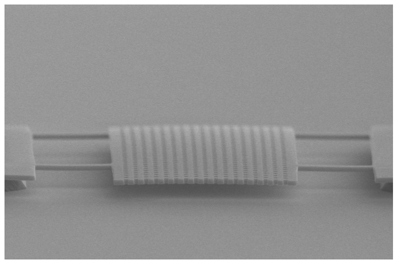

Figure 2: *MEB view of a photonic crystal nano membrane*

Most of optomechanical devices are coated with dielectric multilayer and suffer from the low mechanical Q-factor and large mass due to the coating. In this way photonic nanomembrane thanks to the high optical reflectivity, low mass and perfect mechanical characteristics, seems to be a promising candidate for such application. High reflectivity is insured by photonic crystal which is designed to have almost a total reflection at normal incidence Fig. 1) and the absence of a coating makes possible to have a mass around 100 pg [1]. To build a cavity with such a small system (30x30 μm^2)(Fig. 2) we need a very small optical beam waist (3 μm) therefore we have developed small radius of curvature coupling mirrors integrated in 200 μm length cavity. The sensitivity of this cavity is at $10^{-16} m/Hz^{1/2}$ level that is theoretically sufficient to observe the ground-state fluctuations. It has already allowed us to observe thermal noise.

We are currently developing a cold damping feedback loop in order to reduce the effective temperature of the membrane. Any active cooling relies on a viscous damping force that reduces the Q-factor of the resonator. It is then crucial to design a device with a very high initial Q-factor. Different geometries, materials, and stress in the membrane have been tested and we have achieved structures with Q-factor of 20000 at room temperature and 65000 at 20 K. We are also developing an integrated excitation scheme using capacitive coupling with the membrane. The small size of the nanomembrane give rise to a nonlinear behavior, which is due to the emergence of constrains generated by the large amplitude of displacements. We have observed both static nonlinear effect as bistability and dynamical effects such as phase conjugated generation or as the coupling between different modes of the membrane, which could be used in metrology to stabilize the oscillator frequency [2].

References

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