Cooling a Macroscopic Mechanical Oscillator close to its Quantum Ground State

Rémi Metzdorff[a*], Leonhard Neuhaus[a], Salim Zerkani[a], Sheon Chua[a], Thibaut Jacqmin[a], Samuel Deléglise[a], Tristan Briant[a], Pierre-François Cohadon[a], Antoine Heidmann[a]

a. Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-Université PSL, Collège de France

∗ remi.metzdorff@lkb.upmc.fr

We present our recent results about the optomechanical cooling of a $33\ \mu\mathrm{g}$, $1\ \mathrm{mm}$ thick quartz micropillar with a compression-dilatation mode oscillating at $3.6\ \mathrm{MHz}$ with Q-factor above 10^6. A mirror coated on top of the pillar allows to construct a high-finesse Fabry-Perot cavity to optically detect and control the oscillator motion. In recent experiments, we have reached mechanical quality factors as high as 70×10^6 and an optical finesse near 10^5 at temperatures below $10\ \mathrm{K}$ in a dilution cryostat.

With a low-power laser beam locked to the cavity resonance in cryogenic operation, we have observed Brownian motion corresponding to mode temperatures down to $110\ \mathrm{mK}$. When driving the optomechanical cavity with a red-detuned laser beam of powers up to $25\ \mu\mathrm{W}$, we have been able to cool the mechanical oscillator to a mean thermal occupation number of 20 phonons. This limit is due to light absoption by the micropillar that casues an increased thermal bath temperature. The injection of even higher powers to enable further cooling is prevented by the self-oscillation of low-frequency suspension modes. New schemes to implement feedback cooling are presented to lower the mean thermal occupation number of phonons.

While our optomechanical device now fulfills the requirements for ground state cooling in a cryogenic environment, this experiment is prevented by about $10\ \mathrm{dB}$ excess cavity phase noise due to coupling mirror motion. We are currently designing mirror substrates structured with a phononic crystal in order to decrease this excess noise and enable cooling of our system to the mechanical quantum ground state. In this regime, we plan to inject squeezed light into our optomechanical cavity to test schemes for measuring mechanical displacement with sensitivities below the standard quantum limit.

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