



Garching, 13.04.2008

Press Release

## Laser light cools microchip

### MPQ scientists apply atomic laser cooling to mesoscopic systems

**Macroscopic objects follow the laws of classical physics, microscopic objects obey the laws of quantum mechanics. This is for sure. But at what point does a system stop to behave classically and start to show quantum properties? Mesoscopic systems with diameters of several micrometers like the ones a team of scientists around Dr. Tobias Kippenberg at the Max Planck Institute of Quantum Optics is dealing with may serve as a testing ground. As the scientists have shown in a recent publication<sup>1</sup> they have already succeeded in the damping of mechanical oscillations of a micro-resonator by applying the method of laser cooling which has been developed for single quantum particles. Now they have shown that even “resolved-sideband cooling” – a special kind of laser cooling – is applicable to this object consisting of about  $10^{14}$  molecules. This experiment is an important step towards attaining the ultimate quantum ground state of a mesoscopic object. The effective cooling process demonstrated here successfully may be of practical interest as well, since it may be used to improve techniques such as scanning probe microscopy.**

The experiments of the independent Max Planck Junior Research Group “Laboratory of Photonics” headed by Dr. Tobias Kippenberg at MPQ, go back to an idea which has been formulated by the Russian theoretician Vladimir Braginski in the 1970ies. When light is confined in a cavity the phenomenon of dynamical back-action occurs: the pressure of the photons exerts a force that may be used to heat up as well as cool down the mechanical oscillator. However reaching the regime where dynamical back-action leads to efficient cooling requires optomechanical systems with high mechanical frequency and high optical finesse. Only recent advances in materials and technology have enabled the creation of devices with which the idea of Braginski could be successfully demonstrated. Nowadays researchers around the world are seeking and racing to use lasers to cool mechanical oscillators to ever lower temperatures. At the moment a number of labs across the planet are working in this field, including the MPQ, the Laboratoire Kastler-Brossel in Paris and the Institute for Quantum Optics and Quantum Information in Vienna, in the USA the Yale University, the California Institute of Technology (Caltech), the National Institute of Standards and Technology (NIST), the Massachusetts Institute of Technology (MIT) and the University of California Santa Barbara (USCB).

Drawing on strong analogies with atomic laser cooling, theoretical work (in collaboration with Wilhelm Zwerger at TUM, and by a second group from Yale and LMU) has however identified a major obstacle in cooling to the quantum regime: The back-action forces are mediated by quantum objects, namely photons, and therefore exhibit quantum noise, driving the mechanical oscillator to

Press & Public Relations,  
Dr. Olivia Meyer-Streng

Phone:  
+49(0)8932 905-213  
E-mail: [olivia.meyer-streng@mpq.mpg.de](mailto:olivia.meyer-streng@mpq.mpg.de)

Hans-Kopfermann-Str. 1  
D-85748 Garching

Phone: +49(0)8932 905-0  
Fax: +49(0)8932 905-200

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<sup>1</sup> Schliesser, A., Del'Haye, P., Nooshi, N., Vahala, K. J. & Kippenberg, T. J.

**Radiation pressure cooling of a micromechanical oscillator using dynamical backaction**  
*Physical Review Letters* **97**, 243905 (2006).

random motion again. For all experimental systems demonstrated to date this would prevent reaching the quantum ground state, in which the motional energy of the oscillator would be limited to its quantum mechanically allowed minimal value. But theorists also found a solution to this problem: Ground-state cooling should in principle be possible in the “resolved-sideband regime”, as demonstrated with trapped atom and ions.

When a trapped ion oscillates with a certain frequency, its absorption spectrum consists of a series of sidebands that are displaced from the original resonance frequency by multiples of the oscillation frequency. Now cooling can be achieved by exciting the ion with laser light that is tuned to one of the energetically lower-lying sidebands. This way the photons that are absorbed by the ion are, on average, of lower energy than the photons that are emitted. This is how cooling proceeds.

In analogy to trapped ions, resolved sidebands also occur in the absorption spectra of mesoscopic optomechanical systems. Reaching this regime requires however that the mechanical oscillator frequency exceeds the optical dissipation rate of the optical resonator, that is, photons must be stored in the resonator for many mechanical oscillation periods. “Only in this case, the cooling effect can outbalance the heating induced by the fluctuations of the light force”, explains Albert Schließer, PhD student working on the project.

Together with his co-authors Rivière, Anetsberger and Dr. Arcizet he has now been able to demonstrate just this very regime experimentally – taking a key step towards ground state cooling. To this end, the researchers lithographically fabricated silica microtoroids (60 micrometer diameter, 70 Megahertz resonance frequency) in the cleanroom facilities of Prof. Jörg Kotthaus (Ludwig-Maximilians-Universität München). These devices reside deeply in the resolved-sideband regime, and highly efficient cooling at unprecedented cooling rates is demonstrated. The effect of the laser cooling could be accurately quantified, as an independent laser system was used to monitor mechanical displacements with a sensitivity that reaches  $10^{-18}$  m (about 100,000,000-times smaller than the diameter of a hydrogen atom) in one second averaging time. If the ground state can be achieved remains to be proven; after all researchers worldwide have been working on this already for more than a decade. But with the new method at hand – which has removed a fundamental roadblock – the way towards the ground state is now boldly signposted and will allow some exciting science over the coming years. [AS/OM]

#### **Original publication:**

##### **Resolved Sideband Cooling of a Micromechanical Oscillator**

A. Schliesser, R. Riviere, G. Anetsberger, O. Arcizet and T.J. Kippenberg  
*Nature Physics*, DOI 10.1038/nphys939 (2008)

#### **Contact:**

##### **Dr. Tobias Kippenberg**

Max Planck Institute of Quantum Optics  
Hans-Kopfermann-Straße 1  
85748 Garching  
Phone: +49 - 89 / 32905 727  
Fax: +49 - 89 / 32905 200  
e-mail: tobias.kippenberg@mpq.mpg.de  
<http://www.mpq.mpg.de/k-lab/>

##### **Dr. Olivia Meyer-Streng**

Press & Public Relations  
Phone: +49 - 89 / 32905 213  
Fax: +49 - 89 / 32905 200  
e-mail: olivia.meyer-streng@mpq.mpg.de