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Press Release

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On the road to quantum world with spoke wheels

MPQ-scientists develop optomechanical system with extremely small dissipation which might enable the observation of quantum behaviour in tangible, mesoscopic objects.

How heavy or how big can an object be before losing its quantum properties and obeying to the laws of classical physics? This question drives many research groups all around the globe. Answers still remain to be given as currently there are no systems which allow observing the expected tiny signatures of quantum effects in macroscopic objects. The novel system developed in the MPG Junior Research Group "Laboratory of Photonics" led by Dr. Tobias Kippenberg could resolve this problem (Nature Photonics, DOI 10.1038/nphoton.2008.199, Advance online publication, 28 September 2008). The scientists succeeded in developing a micron-scale on-chip resonator which allows for optimized mechanical and optical quality even though these quantities in general have opposing requirements. The system combines the world`s best optical and mechanical coherence properties and its sensitivity could be used for basic research such as exploring the quantum behaviour of tangible micron-scale objects as well as for applications such as further improving frequency and time standards.

At the beginning of the previous century seminal work of Werner Heisenberg gave birth to the theory of quantum mechanics. It dictates that mechanical motion is quantized — from the microscopic motion of electrons around nuclei to the macroscopic behaviour of everyday objects. It was only in 1986 — more than 60 years after Heisenberg's initial work — that quantum jumps of individual electrons leading to the characteristic emission spectra of atoms could be directly observed. Ten years later, the advances in laser techniques and quantum optics allowed also observing non-classical motional states of individually trapped ions — which can be 100'000 times heavier than electrons. However a fundamental question has remained: Why don't also larger objects which we deal with in our daily lives follow the rules of quantum mechanics but behave classically instead?

It is generally assumed that decoherence prevents us from observing quantum effects in macroscopic objects. Decoherence subsumes the fact that interaction with the environment disturbs and eventually destroys the quantum behaviour of individual systems which — well isolated — would be expected to behave according to the laws of quantum mechanics. Today, quantum mechanical effects have never been observed in tangible, mesoscopic oscillators, i.e. objects consisting of trillions of atoms. This goal requires a combination of well isolated mechanical systems and a coherent readout technique whose sensitivity is sufficient to observe quantum effects.

Quartz oscillators which are used e.g. in wristwatches exhibit high mechanical coherence and would thus satisfy the former criterion. The electrical circuits which are used to read out their mechanical motion, however, at the moment offer insufficient sensitivity which makes this route towards observing possible quantum effects virtually impassable. Many research groups therefore pursue combining highly coherent mechanical systems with quantum optical methods which offer incomparably higher sensitivity. But this approach faces the chal-

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lenge that the requirements for optical and mechanical coherence often oppose each other.

The group of Dr. Tobias Kippenberg at MPQ was able for the first time to combine the world's best optical and mechanical coherence properties in a single on-chip resonator. In their experiment the scientists used toroidal glass resonators with a diameter of about 75µm mounted on a silicon chip which were produced in the cleanrooms of the Ludwig-Maximilians-University Munich (LMU) at the chairs of Prof. Jörg Kotthaus and Prof. Jochen Feldmann. Via glass nano-fibers laser light is coupled into the toroids.

The strong coupling of optical and mechanical degrees of freedom renders these structures very special. The system can store light, i.e. photons, orbiting around the torus if its wavelength „fits" into the toroid, that is when the torus' circumference is an integer multiple of the wavelength. The mechanical oscillations modulate the toroid's circumference and thus imprint themselves on the optical resonance frequency. On the other hand the circulating photons exert a force on the toroid pointing radially outwards.

The mechanical eigenmodes of the resonators experience friction forces of different origins which determine the coupling to the environment leading to decoherence. The mechanical clamping of the structure to its support plays a very important role in this process. The experiments showed that the different mechanical modes of the toroids can couple to each other and the support in a complicated fashion. Elucidating this coupling was the key to understanding the losses caused by friction. These could be considerably reduced by mounting the toroid on the silicon chip via glass "nano-spokes" (cf. Fig.). By optimizing the geometry, i.e. the length and width of the spokes Rémi Rivière and Georg Anetsberger, lead author of the study, could „tailor" the eigenmodes of the resonator leading to a 1000-fold reduction of clamping losses.

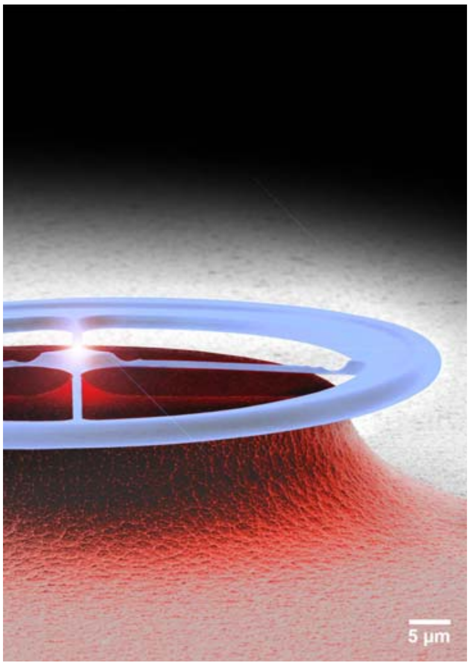

Fig.: The glass microresonator (blue) combines the world's best properties of optics and mechanics. On the one hand it stores photons which can circulate around its outer rim for hundreds of thousand times before leaving it again. The eventually emerging photons allow extremely accurate measurements of the mechanical oscillations of the resonator. The optimized support of the glass structure via four nano-spokes strongly decouples its mechanical oscillations from the environment. Excited mechanical modes can thus oscillate up to 80'000 times before decaying.

The thus optimized microtoroids can store photons for hundreds of thousands of orbits. At the same time they perform up to 80'000 mechanical oscillations before these decay due to the interaction with the environment. In a sense this system can be compared to quartz oscillators which can be driven by light (instead of electrical current) and read out by a resonant optical circuit.

"This is the first system which allows controlling optical and mechanical degrees of freedom within a chip-scale device. For the first time we were able to combine mechanical quality factors rivalling those achieved in nano- and microelectronics with the highest values of optical quality“, says Georg Anetsberger. This represents a major step towards the long term goal of observing quantum mechanical effects in a macroscopic oscillator. But beyond the fundamental importance, the research may also impact technology. Mechanical quartz oscillators are ubiquitous in science and technology and understanding dissipation is at the heart of any improvement in terms of the oscillators’ stability for timekeeping — whether in a wristwatch or as flywheel in an atomic clock. [G.A.]

Original publication:

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