Laser cooling a nanomechanical oscillator close to its ground state

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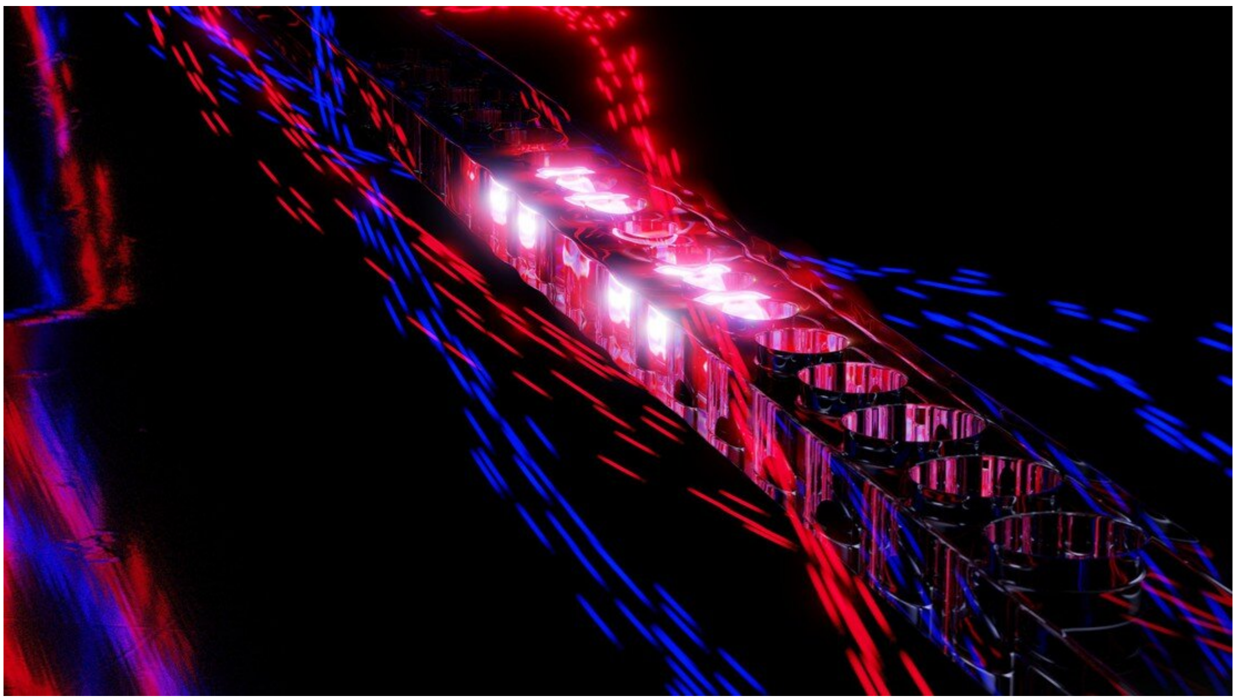

Artist's rendition of the optomechanical silicon nanobeam being laser cooled. Credit: Simon Hönl, IBM Research Europe.

Researchers at the Swiss Federal Institute of Technology Lausanne (EPFL) and IBM Research Europe recently demonstrated the laser cooling of a nanomechanical oscillator down to its zero-point energy (i.e., the point at which it contains a minimum amount of energy). Their successful demonstration, featured in *Physical Review Letters*, could have important implications for the development quantum technologies.

For a very long time, researchers specialized in different areas of science and technology have been developing tools that leverage the acoustic properties of objects, such as acoustic resonances or mechanical vibrations. For instance, mechanical resonances have long been used to process signals or for the collection of highly precise measurements.

At a more fundamental level, these resonances follow the laws of quantum mechanics. Future technologies that leverage acoustic properties of materials could thus also take advantage of their quantum mechanical characteristics, such as the entanglement between two mechanical vibrations or the superposition of two vibrational states.

"This entry into the quantum regime parallels other quantum technologies, such as quantum computers," Dr. Itay Shomroni, one of the researchers who carried out the study, told Phys.org. "The quantum nature of these relatively large objects is masked by external influences from the environment, the most pervasive of which is thermal noise—random fluctuations due to a finite temperature."

To reach a regime in which it is possible to observe quantum mechanical effects, researchers first have to remove the noise derived from environmental influences. This can be achieved by cooling a mechanical oscillator to its lowest possible energy state, known as ground state.

Due to the laws of quantum mechanics, an oscillator does not freeze when in its ground state, but rather, it contains a minimum amount of energy, the so-called 'zero-point energy." Over the past decade, different research groups have come increasingly closer to bringing mechanical motion to the ground state and thus to the zero-point energy, using a variety of nano- and micro-mechanical oscillators.

"One approach is simply to cool the whole apparatus to extremely low temperatures, in the milli-Kelvin range," Shomroni said, "but this increases the complexity of experiments and introduces other constraints. We have also been aiming to reach ground-state cooling in our system that operates at several Kelvin."

In their study, Liu Qiu, Shomroni, and their colleagues tried to cool a nanomechanical oscillator down to its zero-point energy using laser cooling techniques. Remarkably, they were able to attain an extremely low occupancy (i.e., 92% ground state occupation), pushing the system much deeper into the quantum regime.

"We use laser light to cool the motion of our mechanical oscillator, which may seem surprising at first," Shomroni explained. "This is a well-known technique that was used in other experiments, as well. Light exerts a force on matter called radiation pressure. This force can be used to damp and cool mechanical motion, provided that it is applied correctly, opposing the velocity of the object."

In the experiment, the mechanical vibration occurs in a section of a silicon nanobeam that is several microns long and 220 nm x 530 nm in cross-section. This section also forms part of an optical cavity into which the researchers injected laser beams. The vibration and light pressure in this system are interdependent, thus, they relate in a way that ultimately cools the system.

"As we know, light can also heat up objects because it is absorbed," Shomroni said. "In order to minimize the effect of absorption, we surrounded our oscillator with a small amount of helium gas, so that excess heat could dissipate quickly."

Using their laser cooling-based method, Qiu, Shomroni and their colleagues were able to cool a nanomechanical oscillator very close to its zero-point energy. The results they achieved demonstrate the effectiveness of approaches that leverage the interaction of laser technology with mechanical vibrations for cooling mechanical objects.

The researchers also measured the residual thermal energy in their system in situ using a calibration-free metric offered by the oscillator itself—namely, the ratio of its absorption and emission rates. This particular metric is also known to be a signature of an oscillator's quantum nature.

The ability to cool a quantum system down to its ground state could open up new possibilities, both for the development of new quantum technologies and for further research in quantum mechanics. For instance, this ability could enable the creation of a relatively large mechanical object in a quantum superposition state known as Schrödinger cat state.

Moreover, the development of a method that can bring mechanical systems closer to their zero-point energy could have important implications for quantum computing. Researchers at IBM are currently trying to develop devices that can efficiently transduce quantum information, converting it from superconducting qubits to optical photons.

"Such devices would serve as a means of connecting quantum computers based on superconducting qubits with fiber-optic cables to create a quantum network and further scale the computing power," Paul Seidler, another researcher who carried out the study, told Phys.org "To date, the most successful approaches to microwave-optical transduction utilize a mechanical system as an intermediary. For this application, the ability to initialize the mechanical system in its ground state can be essential."

In future work, the EPFL-IBM team plans to use its technique for cooling mechanical systems down to their zero-point energy to control their motion in new interesting ways. For instance, the researchers would like to explore their method's potential for producing a variety of exotic quantum states.

More information: Liu Qiu et al. Laser Cooling of a Nanomechanical Oscillator to Its Zero-Point Energy, *Physical Review Letters* (2020). DOI: 10.1103/PhysRevLett.124.173601