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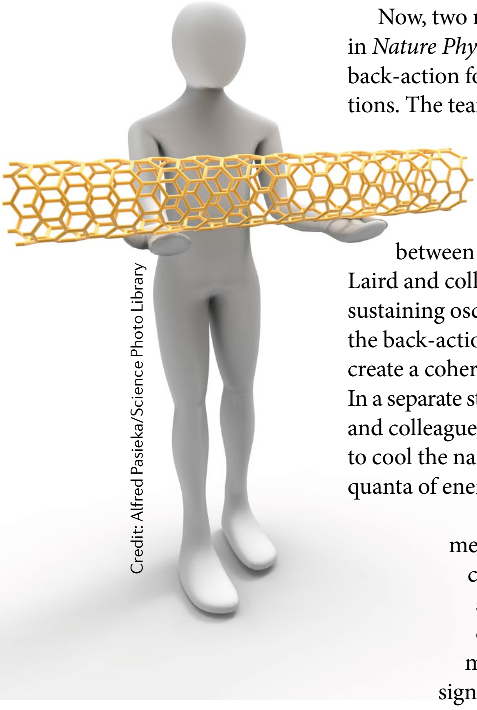
NANOELECTROMECHANICS

Pumping up and cooling down

Sensitive sensors made by combining mechanical resonators with electronic transistors can be used for detecting small gas molecules, DNA strands or even helium superfluidity. The components are coupled so that the motion of the resonator affects the current through the transistor, and thus the mechanical displacement can be measured as an electrical signal. At small scales, fluctuations in the transistor can in turn mechanically perturb the resonator, in an effect known as electron back-action.



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Now, two research groups writing in *Nature Physics* harness electron back-action for different applications. The teams use similar setups: carbon nanotubes, which act as both transistor and resonator, suspended between two electrodes. Edward Laird and colleagues find that self-sustaining oscillations caused by the back-action can be used to create a coherent phonon source. In a separate study, Adrian Bachtold and colleagues use back-action to cool the nanotube to just a few quanta of energy.

In such nanoelectromechanical systems, it is challenging to detect small forces and to convert these forces into measureable electrical signals. "When one electron hops onto the resonator, the added electrostatic force is less than one piconewton," explains Laird. "To respond to this force, we had to use the smallest mechanical oscillator we could make, which is the reason to use a suspended carbon nanotube. Even so, the motion we needed to detect was tiny."

The motion of the nanoresonator is measured using radio-frequency techniques and with the aid of a superconducting amplifier. An electrostatic gate controls the number of electrons in the nanotube. At a certain gate voltage, a specific number of electrons are within the nanotube and a feedback loop emerges between the resonator motion and electron tunnelling in the transistor. Laird and his colleagues use this feedback loop to create a self-sustaining coherent oscillation, similar to a phonon-laser source.

In the second study, Bachtold and his team harness the back-action to dampen the mechanical oscillations of the nanotube. The mechanism behind the back-action in this system is slightly different. A more conductive carbon nanotube is used and, as a result, the fluctuation of current is caused by Joule heating. Using this technique, the researchers cool the nanotube down to less than five quanta of energy.

Harnessing electron–phonon interactions at this scale opens up a new platform to observe polaron physics. If the system can be cooled down to the ground state, while keeping the potential of the mechanical vibrations nonlinear, Bachtold hopes that a mechanical qubit may be realized. "In comparison with existing qubits, mechanical qubits may be easier to couple to different quantum systems, such as spins, photons and cold atoms," says Bachtold. "Also, they are expected to be endowed with particularly long dephasing times. However, the realization of mechanical qubits has been out of reach in all the mechanical systems fabricated thus far."

Laird intends to study how quantum mechanics affects the nanoresonator. "In our experiment, the two-level system is a single-electron transistor and behaves in a way that is ultimately completely classical," explains Laird. "With a quantum two-level system, such as a double quantum dot, a spin or a superconducting qubit, the back-action would be different." Laird concludes, "Can we use it to prepare an entire nanotube in a superposition of motion? I would find that fascinating."

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ORIGINAL ARTICLES Urgell, C. et al. Cooling and self-oscillation in a nanotube electromechanical resonator. *Nat. Phys.* https://doi.org/10.1038/s41567-019-0682-6 (2019) | Wen, Y. et al. A coherent nanomechanical oscillator driven by single-electron tunnelling. *Nat. Phys.* https://doi.org/10.1038/s41567-019-0683-5 (2019)