Quantum ground state and single-phonon control of a mechanical resonator

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The burgeoning field of optomechanics has as one of its important initial goals, laser cooling of a mechanical oscillator into the quantum ground state. Even though the quantum of energy for a 1 MHz mechanical oscillator corresponds to a temperature scale of only about 50 micro-Kelvin, great experimental progress towards this goal has been achieved in the last few years [1]. O'Connell et al. have taken a different tack. They have constructed a very high frequency (6 GHz) mechanical oscillator and simply cooled it to the quantum ground state using a dilution refrigerator. The more difficult part of the exercise is to actually prove that the oscillator is in its quantum ground state. This cannot be done by simple linear coupling of a drive/measurement system to the oscillator. Some sort of non-linearity is required. To accomplish this, O'Connell et al. constructed the oscillator out of a piezoelectric material and used the microwave electric field caused by the oscillator's motion to couple the mechanical system to a superconducting qubit. Once this coupling is established, the ability to measure the quantum state of the qubit translates into an ability to measure the quantum state of the mechanical oscillator and prove that it is in the quantum ground state (the $n = 0$ phonon Fock state). Similarly, the ability to control the quantum state of the qubit can be used to produce coherent superpositions of zero and one phonon in the mechanical oscillator, in close analogy to what has been achieved with superconducting qubits and microwave electrical resonators [2,3].

This work represents a significant step towards complete control of the quantum state of a mechanical system. This opens a new regime to test questions about macroscopic quantum phenomena and the possibility of quantifying the decoherence of a massive object by observing the time dependence of the Wigner function, as this same UCSB group has already done with an electromagnetic resonator. With further advances and assuming the mechanical Q of the oscillator can be further increased, one can imagine using these compact mechanical resonators as quantum memories and quantum information buses for arrays of superconducting qubits.

References

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