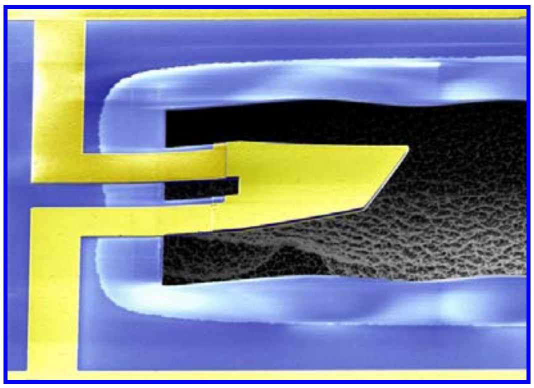
Measuring the quantum harmonic oscillator

Andrew N Cleland
Department of Physics
University of California, Santa Barbara

We have recently published (A.D. O'Connell et al., *Nature* **464**, 697-703 (2010)) an account of an experiment providing the first demonstration of a large mechanical system operating in its quantum ground state. Coupled with the ground state demonstration, we were also able to inject a single quantum of mechanical energy, a phonon, into the mechanical system, and detect its presence and measure its lifetime. We were furthermore able to create a quantum superposition, where the mechanical system was in a superposition of its ground and first excited states.



Colorized electron micrograph of mechanical resonator used in this experiment. The diameter of the central potrtion of the resonator is about 35 micrometers.

This result was the outcome of more than ten years' development of nanomechanical and quantum circuit technology, with the parallel development of our understanding of the primary concepts needed to measure quantum behavior in mechanical as well as electromagnetic systems. Key requirements included a mechanical design that supported a microwave-frequency mechanical resonance at 6 GHz; using a piezoelectric material in order to achieve very strong electromechanical coupling; and employing a Josephson junction, implemented as a phase quantum bit (qubit), to measure and interact with the mechanical resonator. Operating at 25 mK on the mixing chamber of a dilution refrigerator, this integrated electromechanical system will cool to its quantum ground state without additional intervention; using the extraordinary nonlinearity provided by the Josephson qubit allows us to control and measure the quantum state of the resonator using standard microwave electronics, without destroying the very delicate harmonic oscillator states.

In my talk, I will try to briefly summarize the key concepts that made this result possible, as well as describe the limitations of our approach.