

Comment on “Evidence for Quantized Displacement in Macroscopic Nanomechanical Oscillators”

In a recent Letter, Gaidarzhy *et al.* [1] claim to have observed evidence for “quantized displacements” of a high-order mode of a nanomechanical oscillator. We contend that the methods employed by the authors are unsuitable in principle to observe such states for any harmonic mode.

(1) According to standard quantum mechanics, continuous measurement of the energy quanta in any resonator mode requires a probe whose interaction Hamiltonian commutes with the oscillator Hamiltonian, i.e., one requires a quantum nondemolition (QND) measurement scheme. However, with continuous linear measurement of position or velocity, the best energy sensitivity one can, in principle, achieve is $\Delta E \approx \hbar\omega\sqrt{\bar{N}}$, where \bar{N} is the average number of quanta, the so-called standard quantum limit [2]. The authors employ continuous magnetomotive detection [3]. This is a continuous linear measurement scheme and is not a QND measurement of the energy. In magnetomotive detection, the sample is immersed in a large magnetic field, and driven with an oscillating current through the mechanical element. The magnetic field transforms the applied oscillating currents into forces on the resonator, and transduces the resulting mechanical motion into measurable voltages. Such a detection scheme does not measure the absolute value of position, as the authors claim.

The authors drive the resonator many orders of magnitude above the ground and first excited state during the measurement shown in Fig. 4c. Given the reported parameters ($F \sim 45$ pN, $k_{\text{eff}} = 188$ N/m, and $Q = 150$), the average number of energy quanta in the resonator during the measurement is $\bar{N} = 120000 \gg 1$, which corresponds to an effective resonator temperature of 8800 K. Furthermore, the authors use a room temperature semiconducting amplifier with a noise temperature of $T_N = 440$ K to detect the magnetically transduced voltages [4]. Thus, in addition to the magnetic drive, the backaction current noise of such an amplifier will act as a thermal bath, driving the resonator far above the temperature of 100 mK quoted by the authors. One does not expect to observe any evidence of the lowest quantized energy states of the resonator using this method.

(2) For $Q \sim 100$ and $\omega = 10^{10}$ s $^{-1}$, the average lifetime of an energy quantum is ~ 10 nsec. Even if the authors could measure the oscillator energy with single quantum accuracy, the observed jumps due to decay would certainly not be as long as tens of minutes, which is the time scale indicated on Fig. 4c, a discrepancy of over 10 orders of magnitude from expectation.

(3) The magnetomotive response of the suspected 1.48 GHz mode is anomalous. Figure 3b shows the amplitude versus magnetic field where the authors claim that it demonstrates the expected quadratic dependence. The authors do not explain why the quadratic fit is not symmetric about the origin as is expected and widely observed; in-

stead it appears to fit a parabola offset by -2 T. This behavior has not been observed in other groups’ measurements of similar frequency resonators at low temperature.

Finally, no justification is offered for the assertion that the motion of the central beam is amplified from femtometers to picometers in comparison to the femtometer motion of the finger elements at 1.5 GHz. The high-order mode that the authors suggest they are observing is a “flapping” mode of the structure, in which the fingers move coherently and out of phase with the central support. Both the simulation shown by the authors and those performed by us indicate that the central beam moves with displacements which are similar in magnitude to that of the fingers. In principle, one expects no displacement amplification of the quantum motion by a passive structure: the result of making the structure larger to contain multiple subelements yields smaller quantum fluctuations since the quantum of energy, $\hbar\omega$, must be distributed over a larger mass structure.

In short, we argue that the magnetomotive impedance jumps, which Gaidarzhy *et al.* observed by driving their resonator to very high amplitude, are not a manifestation of quantum phenomena.

K. C. Schwab
Laboratory for Physical Sciences
National Security Agency
College Park, Maryland 20740, USA

M. P. Blencowe
Dartmouth College
Hanover, New Hampshire 03755, USA

M. L. Roukes
California Institute of Technology
Pasadena, California 91125, USA

A. N. Cleland
University of California
Santa Barbara, California 93106, USA

S. M. Girvin
Yale University
New Haven, Connecticut 06520-8120, USA

G. J. Milburn
Department of Physics School of Physical Sciences
The University of Queensland
Queensland 4072, Australia

K. L. Ekinci
Boston University
Boston, Massachusetts 02215, USA

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[1] Alexei Gaidarzhy *et al.*, Phys. Rev. Lett. **94**, 030402 (2005).

[2] See, for example, Braginsky and Khalili, *Quantum Measurement* (Cambridge University Press, Cambridge, England, 1992), Eq. 4.9, p. 52.

[3] D. S. Greywall *et al.*, Phys. Rev. Lett. **72**, 2992 (1994).

[4] Minicircuits model ZKL-2, (private communication).