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Nanoscale cantilevers with integrated optomechanical readout: increasing speed and sensitivity

VLADIMIR AKSYUK, National Institute of Standards and Technology

Decreasing a mechanical probe size and mass into the nanoscale and sub-picogram range offers a way to increase the transduction bandwidth while maintaining the desired mechanical stiffness and, ideally, maintaining or lowering the mechanical damping and the associated fundamental thermal force noise. Such transducers require a new approach to low noise and fast motion readout that is also stable, practical, low power and capable of operating over a wide temperature range. We are using on-chip cavity optomechanical sensing for realizing fast, sensitive and practical integrated AFM probes. Integrated micrometer-scale silicon microdisk high Q optical cavities evanescently couple to sense motion of suspended silicon beams with nanoscale cross sections (e.g. 100 nm x 260 nm). The sensors achieve sub- $fm/Hz^{0.5}$ motion sensitivity, which is near the standard quantum limit for these beams, with dissipated optical power under 300 μW and the readout bandwidth of approximately 1 GHz. The mechanical properties of the beams are broadly adjustable by design, covering four decades of mechanical stiffness (0.01 N/m to 290 N/m) and frequencies from 250 kHz to 110 MHz, with similar motion readout sensitivity across the range. Combining the low mass mechanical transducer with the ultraprecise readout potentially opens up new regimes of operation while also posing design tradeoffs in gain, bandwidth and dynamic range. The mechanical probe can be excited and the dynamics can be tuned by optomechanical effects as well as application of optical and electrostatic forces via feedback. Effective stiffness modification, regenerative oscillation as well as optomechanical and feedback damping can be useful in different modalities of probe operation. Unresolved sideband operation gives the readout bandwidth larger than the mechanical frequency, which is particularly useful for broadband feedback actuation, e.g. to modify the transfer function, extend the useful measurement bandwidth and cool the sensor motion to reduce nonlinearity and mechanical backaction of the mechanical probe on the sample.