Optomechanical transducer for investigation of frequency fluctuations

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Microelectromechanical systems (MEMS) have applications ranging from consumer products to fundamental science. In many cases, achieving a state of stable oscillation is essential to their operation. However, frequency fluctuations are often observed [1]. Identifying their origin, which requires us to make high-precision measurement of nanoscale mechanical motion, is difficult. To address this problem, we have developed an on-chip cavity-optomechanical transducer platform with high bandwidth and sensitivity near the standard quantum limit. Our device is compact, robust, and has the potential for low-cost batch fabrication inherent in MEMS [2]. This transducer allows us to investigate the origins of frequency fluctuations in MEMS.

Our fully-integrated, fiber-pigtailed transducers combine high sensitivity (0.5 $\mathrm{fm \cdot Hz^{-1/2}}$ to 100 $\mathrm{fm \cdot Hz^{-1/2}}$), high bandwidth optomechanical readout and built-in electrostatic actuation. We use a wafer-scale microfabrication process combining one e-beam patterning, six stepper, and three contact mask aligner lithography steps, as shown in Figure 1. These define the high mechanical Q-factor (up to 5×10^5) silicon nitride (SiN) membrane, the single-crystal silicon-on-insulator (SOI) microdisk optical cavity with high optical Q (up to 2×10^6), SOI optical waveguides, and the patterned gold layer for electrostatic fringe-field actuation. The front-side v-grooves for single-mode optical fiber attachment are defined using an anisotropic potassium hydroxide (KOH) silicon etch. Two sacrificial silicon dioxide layers are removed by an isotropic hydrofluoric acid (HF) etch to free the mechanically movable structures.

The SiN membrane is excited by an electrical signal supplied to an integrated electrostatic fringe-field actuator. As the membrane oscillates, the gap separating the optical micro disk cavity and the membrane is modulated, directly modifying the resonant optical properties of the high-Q whispering gallery mode confined in the micro disk. Consequently, this transducer couples the optical resonance wavelength and the motion of the membrane, enabling fast, sensitive measurements of displacements. Our current design comprises a set of four differently sized membranes having stiffnessnesses of 5 N/m to 150 N/m and a resonance frequency of 100 kHz to 1 MHz in the first harmonic. However, the design can easily be tailored for specific sensing applications.

REFERENCES:

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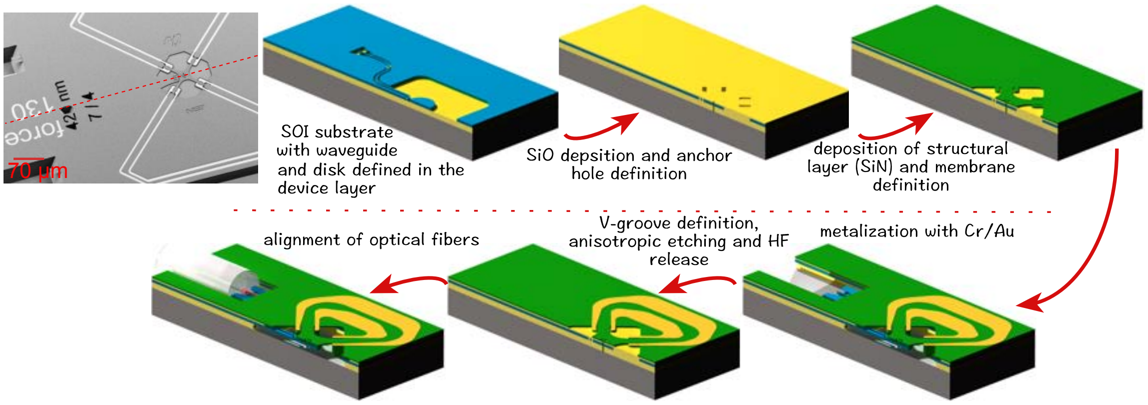

Figure 1 Transducer fabrication process. The image in the upper left shows a scanning electron micrograph of the final device. The dashed red line indicates the course of the cross section. The following images show cross sections of selected process steps.

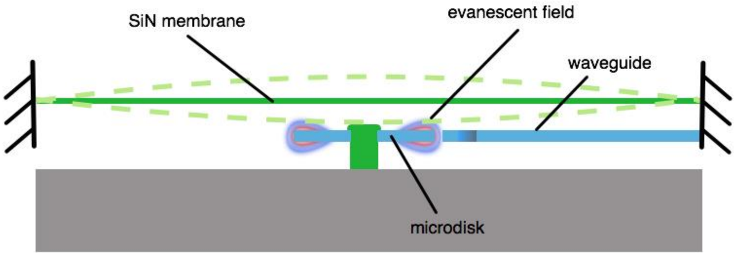

Figure 2 Device concept. A moving silicon nitride membrane modulates the gap between membrane and an underlying optical silicon micro disk cavity, altering its optical resonance frequency.

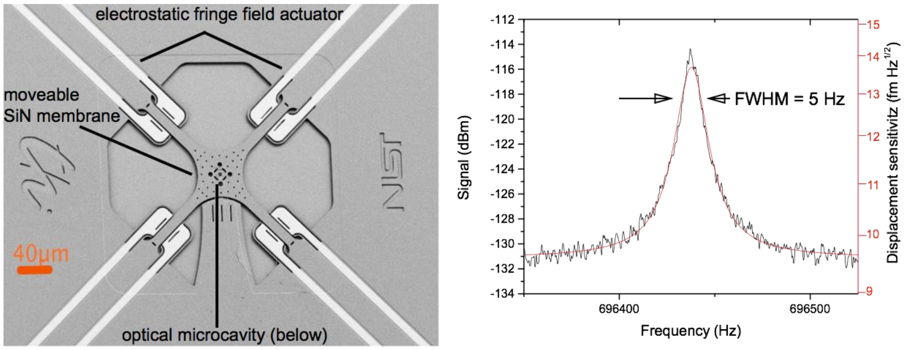

Figure 3 Scanning electron micrograph of the device (left). Measured mechanical frequency noise spectrum of the membrane with Lorentzian fit. The displacement, calibrated using the equipartition method [3], shows a noise imprecision of ≈ 10 fm·Hz$^{-1/2}$.