Cantilever array with optomechanical read-out and integrated actuation for simultaneous high sensitivity force detection

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***Abstract*—We present an on-chip cavity optomechanical cantilever array with integrated actuation, that combines high measurement bandwidth and very low displacement noise floor with compactness, robustness, small size, and potential for low cost batch fabrication inherent in micro- electro- mechanical-systems (MEMS)**

***Keywords*—optomechanics; cantilever array; integrated actuation**

I. Introduction

Research and development of transducers based on cavity optomechanics is a topic of high interest particularly because these transducers enable measurement of mechanical motion down to the fundamental limit of precision imposed by quantum mechanics. We have developed an on-chip cavity optomechanical cantilever array that combines high bandwidth and high sensitivity with compactness, robustness, small size, and potential for low cost batch fabrication inherent in MEMS. The parallelization of multiple probes within one transducer array allows the simultaneous measurement of serial forces or mass detection [1].

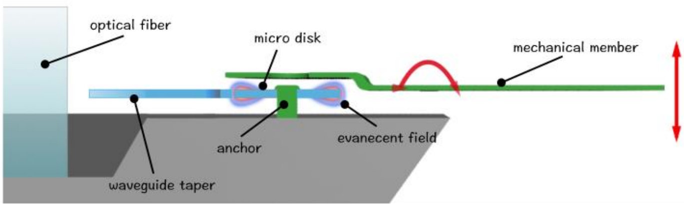

Fig. 1: Exemplary schematic of the transducer (not to scale) showing overhung cantilever on a torsional pivot as the mechanical device.

II. Fabrication

Our fully-integrated, fiber-pigtailed cantilever array combines high sensitivity ($\approx$ 0.5 fm·Hz$^{-1/2}$ to $\approx$ 10 fm·Hz$^{-1/2}$), high bandwidth optomechanical readout and built-in thermal actuation. We use a wafer-scale microfabrication process combining one e-beam patterning, six stepper, and three contact mask aligner lithography steps. These define the silicon nitride (SiN) cantilever, the single-crystal silicon-on-insulator (SOI) microdisk optical cavity with high optical Q (up to $\approx 2\text{x}10^6$), SOI optical waveguides, and the patterned gold layer for bimorph actuation [2]. Back and front side anisotropic potassium hydroxide (KOH) silicon etch allows the cantilever to hang over the edge of the silicon chip and to define v-grooves for single- mode optical fiber attachment. Two sacrificial silicon dioxide layers are removed by an isotropic hydrofluoric acid (HF) etch to free the mechanically movable structures. The fabrication process is shown in Fig. 3 on the example of a single cantilever device.

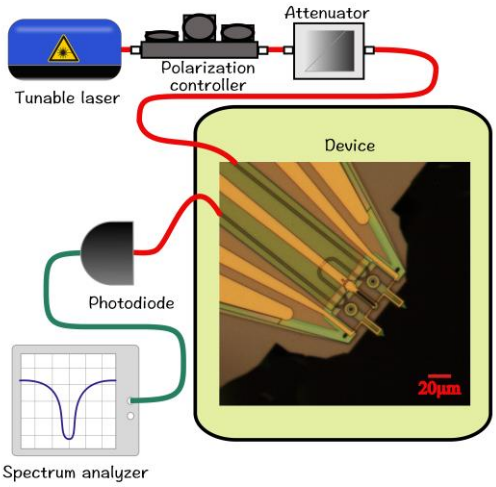

Fig. 2: Schematic of the detection setup with an embedded optical micrograph of the cantilever array.

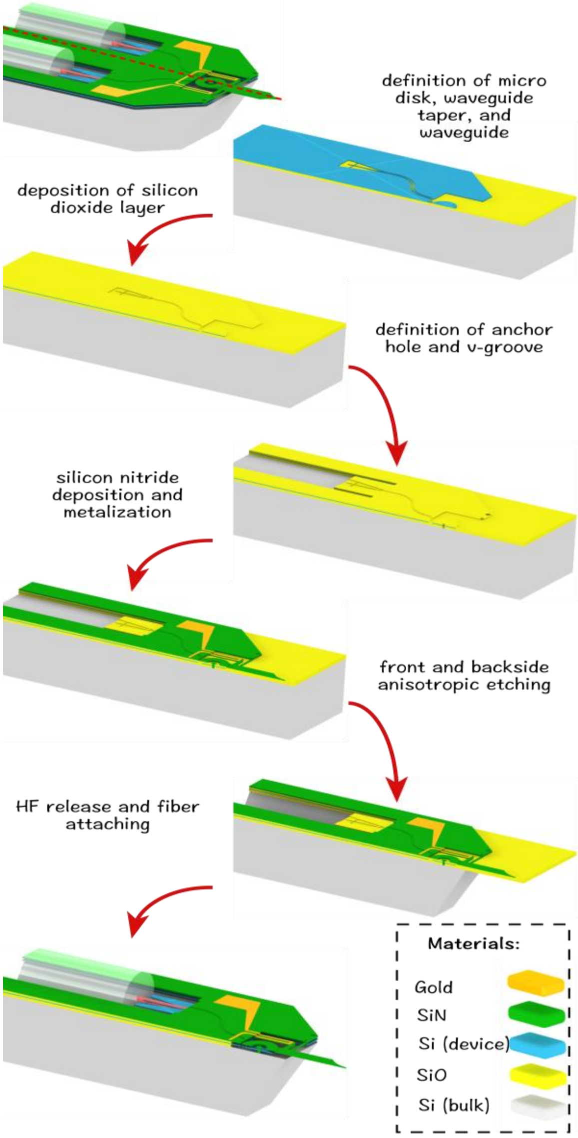

Fig. 3: Representation of the process flow for the transducer with integrated thermal actuation and overhanging tip. The image in the top left shows the whole device. The dashed red in indicates the path for the cross sectional views (a).

The SiN cantilever can be excited by an electrical signal supplied to an integrated thermal actuator. The cantilever is evanescently coupled to a high-Q optical whispering gallery mode of the optical microdisk cavity and the motion is detected by measuring the resonance frequency shift of the optical cavity mode. A schematic of the cantilever is shown in Fig. 1. The actuator can be used to individually address the cantilevers and dynamically move them as well as to tune the distance between the cantilever and the optical cavity, to change the sensitivity and range of measurement of the cantilever. One side of the cantilever overhangs the edge of the chip, where it can be easily coupled to a variety of off-chip samples and physical systems of interest. A ≈ 10 um long probe is currently designed to have a stiffness of ≈ 0.1 N/m to ≈ 5 N/m and a resonance frequency of ≈ 50 kHz to ≈ 4 MHz. The design can be easily and broadly tailored for specific sensing applications.

The detection setup used to characterize the device is shown in Figure 2. Motion of the cantilever results in a frequency modulation of the optical cavity modes, which can be translated into an intensity modulation by probing these modes on the side of their resonance minima. The output signal is intensity-modulated in proportion to the mechanical motion, and is transduced by a photodetector before being sent to an electronic spectrum analyzer to reveal the spectrum of mechanical modes (Fig.4).

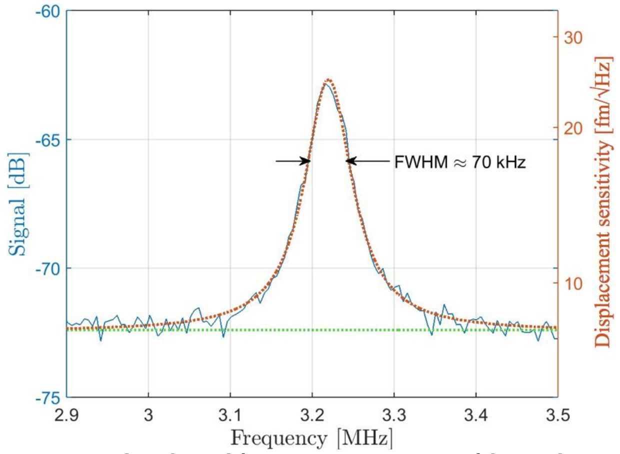

Fig. 4: Measured mechanical frequency noise spectrum of the cantilever transducer in vacuum with Lorentzian fit. The dotted green line indicates the background noise level. Signal power is reported relative to 1 mW.

III. CONCLUSION

We have demonstrated the micro- and nanofabrication process and characterization of a novel type of fully- integrated cavity optomechanical cantilever array for high sensitivity force detection.

REFERENCES

[1] H. Miao, K. Srinivasan, and V. Aksyuk, "A microelectromechanically controlled cavity optomechanical sensing system," *New J. Phys.*, vol. 14, no. 7, p. 075015, Jul. 2012.

[2] T. Michels and I. W. Rangelow, "Review on Scanning Probe Micromachining and its Applications within Nanoscience," *Vac. Sci. and Technol.*, pp. 1–21, Mar. 2014.