Optomechanical sensing of wine-glass modes of a BAW resonator

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***Abstract*— A critical element for inertial navigation is precise knowledge of the angular kinematics which are measured using gyroscopes. Optomechanics has been shown to be the most sensitive scheme for measuring mechanical motion [1, 2]. In this paper, we demonstrate electrostatic actuation and optical sensing of orthogonal wineglass modes on a silicon-on-insulator (SOI) platform as a fundamental building block for a Coriolis force measuring z-axis bulk acoustic wave (BAW) gyroscope [3]. To measure the wineglass modes, we monitor the laser light modulation from changes in the waveguide to ring resonator coupling due to the mechanical motion.**

Keywords—optomechanics; BAW; wineglass; Coriolis

I. INTRODUCTION

Various angular kinematics measurement schemes have been proposed and implemented ranging from electrostatic Coriolis force measuring schemes to phase shift measurement in optical fibers. The electrostatic schemes are chip-scale but are limited in displacement sensitivity by amplifier noise and sampling clock rate. Fiber optic gyroscopes (FOG) are extremely sensitive and robust, but are not yet chip scale. We propose a scheme for measuring the Coriolis force using on-chip optomechanics to achieve both the small form factor possible from micro fabrication techniques and high sensitivity from photonics.

II. EXPERIMENT

The silicon optomechanical resonator was fabricated on a SOI wafer (the fabrication process is detailed in [4]). Fig.1 is an SEM of the device showing the resonator's two mechanically coupled rings. Electrostatic actuation benefits from doping and metallization as it leads to lower insertion losses. This, however, introduces free-carrier losses for the optics. The design presented here allows us to decouple the electrostatic actuation from the optical sensing. The mechanical mode of one ring (actuator side of Fig.1) is electrostatically actuated and the coupling structure is designed to couple the motion to the optical cavity ring (BAW resonator side of Fig.1). A conventional λ/2 coupling beam around 22 MHz would need to be about 175um long, making it unfeasible from a fabrication point of view. Instead, we design a structure with a mechanical resonance at the wineglass mode frequency and a node at the central ground anchor point to reduce anchor losses. The motion of the optical cavity ring changes the optical cavity to waveguide coupling rate, which then modulates the light in the waveguide. The ring suspensions have been designed taking into account the orientation of the silicon crystal axes to achieve a mode-split of 80 KHz between the wineglass modes at 22 MHz.

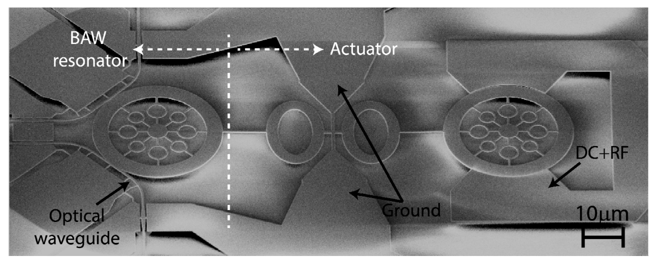

Figure 1: SEM showing the two mechanically coupled rings. Ring outer radius is 15µm, ring width is 3.7µm, driven mode spoke radius is 2.12µm, sense spoke radius is 1.75µm, waveguide to resonator gap is 90nm, and electrode to resonator gap is 100nm

Fig.2 shows a schematic of the setup used for the measurement. One ring is electrostatically actuated by the two electrodes placed so as to preferentially drive the wineglass mode. The electrodes are driven by a DC-biased RF signal from port 1 of the network analyzer. Continuous wave (CW) laser light is coupled to the on-chip waveguide through optical grating couplers. The on-chip waveguide couples light into the optical cavity ring and the transmitted light through the waveguide is incident on a photodetector to measure the

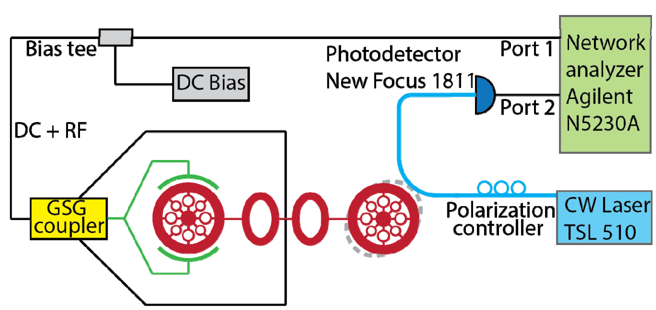

Figure 2: Schematic of the measurement setup. The left ring is electrostatically actuated with a DC+RF drive from the network analyzer. The resulting mechanical motion in the second ring modulates the CW laser in the waveguide which is measured by the photodetector.

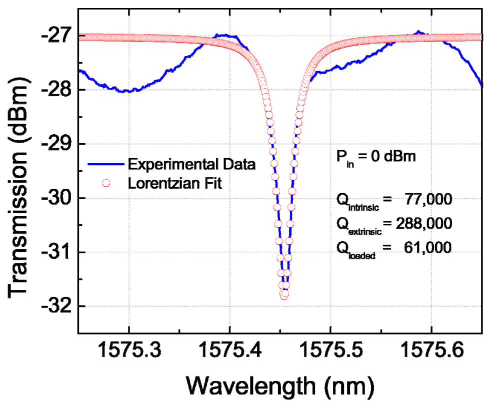

Figure 3: Transmission spectrum of the optical mode used in the experiment

resulting RF modulation on port 2 of the network analyzer. This gives a S_{21} measurement of the wineglass mode signal.

III. Results

Fig.3 shows the optical transmission spectrum (at 1atm) of the optical mode used in this experiment with a loaded optical Q of 61,000 measured at 0 dBm input optical power from a 1550nm laser. The 27 dBm insertion loss is primarily from the optical grating couplers. For the transmission spectrum measurements (at $1.6*10^{-5}$ mbar) we biased the laser blue detuned from the same optical mode. Fig.4 shows the S_{21} amplitude of the two wineglass modes at 22 MHz (drive) and 22.12 MHz (sense) with mechanical Q's of 11,500 and 7,670, respectively, and measured with an electrostatic drive of V_{DC}=4V and P_{AC}=-8dBm. The frequency mismatch of 120 kHz is close to the designed mode spacing of 80 kHz (see fig. 4 inset for modes shapes), which was designed with the eventual goal of a mode mismatched operating gyroscope.

The optomechanical transduction scheme is designed such that the waveguides are placed at the nodes of the 22 MHz (drive) mode and at the anti-nodes of the 22.12 MHz (sense) mode. Even though the waveguide is at the node of the drive mode, optomechanical path length changes from the shape of the drive mode (left resonant peak in fig. 4) result in modulated light at 22 MHz.

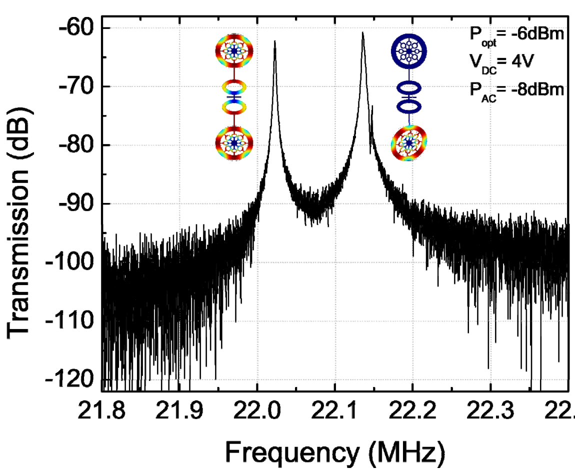

Figure 4: S_{21} measurement of the mechanical wineglass modes. Insets are the Comsol simulated mode shapes of the respective drive (22 MHz) and sense (22.12 MHz) modes

The $\lambda/2$ coupling beam was designed to decouple the two rings for the sense mode (22.12 MHz), such that the optical ring is isolated, and should not be excited by the drive electrodes. Due to error sources such as electrode misalignment and cross-axis coupling terms, the electrostatically actuated ring is weakly coupled to the optical cavity ring, resulting in excitation of the sense mode at 22.12 MHz. This is why the S_{21} response shows both wineglass modes.

The resonant signal measured at the drive frequency (left peak in fig. 4) can be cancelled through differential optical pickoff. This differential scheme, which will be implemented in the future, uses two optical waveguides positioned at the out of phase spatial locations of the sense wineglass mode (as shown in fig. 1). The driven wineglass mode is a "common mode" and will be in phase on the two waveguides, resulting in a suppressed signal amplitude in this differential measurement [5]. The feedthrough signal measured at the sense frequency can be reduced through improved suspension isolation and error correction electrodes. While these error sources need to be compensated and corrected, the measurement of the two resonance peaks is a significant first step towards demonstrating this architecture as a viable optomechanical gyroscope (OMG).

IV. Conclusion

We have shown an on-chip silicon optomechanical system with an electrostatically driven wineglass mode at 22 MHz and optically sensed orthogonal wineglass mode at 22.12 MHz. A transmission spectrum measurement was performed in vacuum with a measured loaded optical Q of 61,000, mechanical Q's of 11,500 and 7,670 for the drive and sense wineglass modes respectively, and a measured frequency split of 120 KHz which is very close to the designed split of 80 KHz. The goal of this optically interrogated BAW resonator system is for it to be used as a Coriolis force sensing z-axis gyroscope.

References

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