A Platform for On-Chip Silica Optomechanical Oscillators with Integrated Waveguides

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Abstract: We present a new phosphosilicate glass photonic integrated circuit platform for optomechanical systems. Wafer-scale reflow enables high-*Q* (1.5×10^6) resonators and closely-spaced (250nm) waveguides. Optomechanical resonance (71.9MHz) is demonstrated.

OCIS codes: (220.4880) Optomechanics; (130.3120) Integrated optics devices

1. Introduction

Radiation-pressure-induced optomechanical systems have attracted considerable interest due to their ability to amplify or cool mechanical motion [1–4]. Such interaction is greatly enhanced when high-*Q* optical cavities are combined with high-*Q* mechanical resonators. Previously, silica resonators with high optical *Q* have been demonstrated by CO_2-laser reflow process [2,3]. However, shrinkage of the resonators during the melting process prohibits the integration of optical waveguides. Integrated optomechanical systems have been demonstrated in silicon, but optical *Q*s are lower ($\leq10^5$), increasing threshold power for optomechanical oscillation [4,5].

In this paper, we demonstrate a new photonic integrated circuit (PIC) platform in phosphosilicate glass (PSG) for optomechanical systems. The PSG PIC utilizes a wafer-scale annealing process to reduce etched sidewall roughness while maintaining lithographically-defined dimensions. We integrate high-*Q* resonators and "half-ridge" waveguides with coupling distances ranging as small as 250 nm. The integrated waveguides and the access through grating couplers allow for rapid probing of the individual resonators at wafer level. The optical *Q* ($\sim1.5\times10^6$) is over ten times higher than previous integrated optomechanical devices [5]. We demonstrate regenerative optomechanical oscillations at frequencies of 71.9, 40.3, and 18.6 MHz in spoke-supported ring resonators with 15, 25, and 52.5 µm radii. Optomechanical frequency combs with harmonic frequencies as high as 470 MHz are also observed.

2. Device layout and fabrication

The schematic of the PIC is shown in Fig. 1. A tunable laser ($\lambda \sim 1550$nm) is coupled to the on-chip waveguide through a 15 µm x 15 µm grating coupler followed by a taper down to the integrated waveguide (Fig. 2).

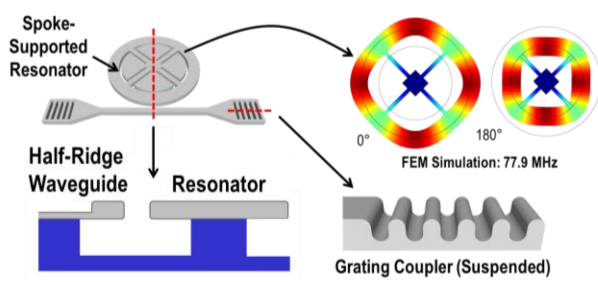

Fig. 1. Schematic of fully-integrated optomechanical oscillator with grating coupler and waveguide. The inset shows the simulated mode shape of a spoke-supported optomechanical ring resonator at 77.9MHz.

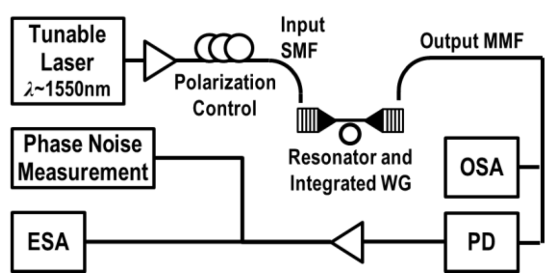

Fig. 2. Optical characterization set-up. Input and output cleaved fibers are separately aligned to input and output vertical grating couplers.

Our fabrication process enables both integration and high optical *Q* (Fig. 3). Optical components are made from an 800 nm-thick layer of PSG, which we reflow to minimize surface roughness (Fig. 3(e)). The grating couplers and integrated waveguides are formed by partially etching the PSG device layer to about 300 nm. Upon release (Fig. 3(f)), the PSG waveguides, gratings, and resonators are completely suspended to avoid light leakage to Si substrate.

The optomechanical resonators demonstrated here are spoke-supported ring resonators, shown in Fig. 4. This type of geometry has a lower threshold power than a plain disk would have because of the lower effective mass. We can design the spokes to optimize mechanical *Q* [6] while choosing the ring width to minimize optical scattering off the spokes. In addition, "half-ridge" integrated waveguides are used to allow precise control of the coupling distance between the waveguides and the resonators. The mode profile of a 900 nm-wide half-ridge waveguide is shown in Fig. 5. Using deep UV lithography, waveguide-resonator spacing as small as 250 nm has been achieved.

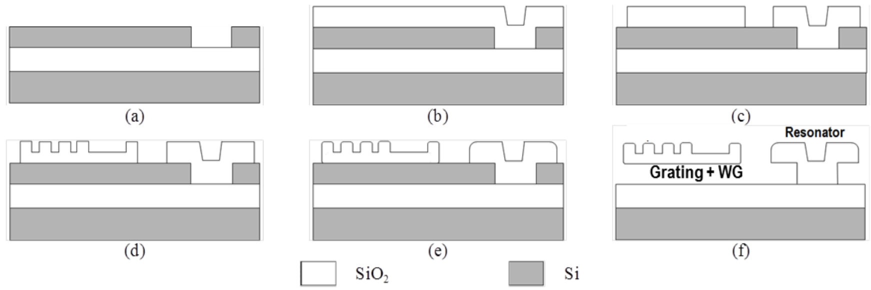

Fig. 3. Fabrication process. (a) Etch anchor vias in SOI device layer. (b) Deposit phosphosilicate glass. (c) Define and RIE devices. (d) Define and partial RIE gratings and waveguides. (e) Reflow PSG in furnace at 1050°C. (f) Release in XeF_2.

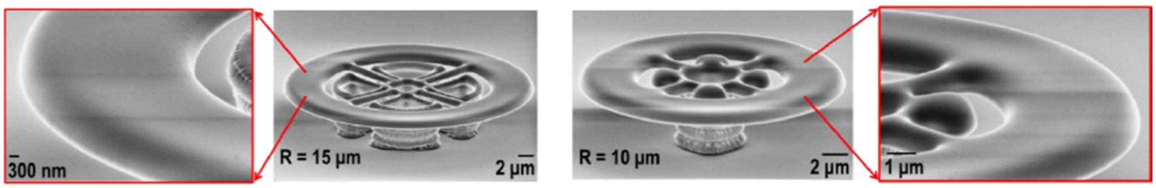

Fig. 4. SEMs of optomechanical resonators following PSG reflow process. Sidewalls are smoothed, achieving $Q_{opt} > 10^6$

3. Results

The fabricated device is shown in Fig. 5. Fabricated devices have an optical $Q \sim 10^6$, with the best being 1.5 million. For optical characterization (Fig. 2), we align cleaved optical fibers to the input and output gratings of a device. The output goes into a photodetector, and we measure optomechanical oscillations on an electrical spectrum analyzer. We observe oscillations in three different device radii, with mechanical frequencies of 18.6, 40.3, and 71.9 MHz. These correspond to the first contour modes, according to FEM simulations of the structures' eigenmodes. In addition, at higher input powers, we observe optomechanical frequency combs, as shown in Fig. 6.

Fig. 5. SEMs of fabricated devices. (left) Cross-section of unreleased grating. (center) Wide-angle view of integrated waveguide and four-spoke optomechanical ring resonator. (right) FEM simulation of waveguide optical mode overlaid on SEM of half-ridge waveguide cross-section.

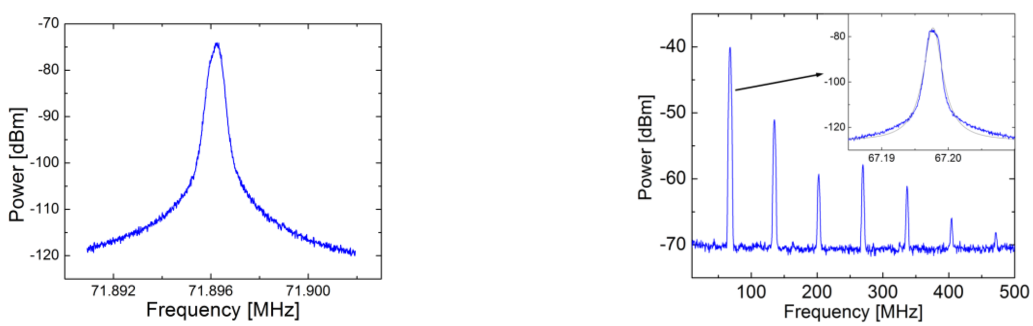

Fig. 6. (left) RF spectrum of optomechanical oscillation at 71.9MHz in 15µm radius, 4-spoke resonator. (right) Optomechanical frequency comb in 15µm, 2-spoke resonator under high optical input power. Fundamental oscillation is at 67MHz. Harmonics up to 470MHz are observed.

4. References

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