Hybrid Integration of High-Q Chalcogenide Microring Resonators on Silicon-on-insulator

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IEEE/OSA Conference on Lasers and Electro-Optics (CLEO 2020)

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Abstract: We demonstrate novel on-chip chalcogenide microresonators directly integrated on the silicon-on-insulator platform using an etchless fabrication method and thermal dewetting. A high Q greater than 4.6×10^5 is measured at telecommunication wavelengths.

1. Introduction

Silicon-on-insulator (SOI) has emerged as a versatile platform for low-cost and densely integrated photonics with applications in fields ranging from telecommunications to spectroscopy and quantum optics. Growing interest in SOI for non-linear optics and on-chip lasers is hindered by the strong multiphoton absorption and free-carrier effects in silicon. Integration of materials with complementary properties provides a path to high-efficiency, hybrid SOI components such as Brillouin lasers [1] and erbium-doped on-chip lasers [2]. Chalcogenide glasses are attractive candidates for hybrid integration as they combine excellent non-linear properties with low loss and rare-earth solubility [3]. In this work, we propose and demonstrate a novel approach to integrating As_2S_3 microring resonators with standard 220 nm SOI circuits. The microresonators are embedded in the SOI top cladding using thermal dewetting to create uniform structures. This method alleviates the requirement to etch the chalcogenide. The hybrid resonators exhibit a high loaded quality factor (Q) of 4.6×10^5 with the corresponding propagation loss below 0.9 dB/cm.

2. Microring Resonator Fabrication

The silicon chips were processed in a CMOS-photonics foundry (AMF, Singapore) on standard 220-nm SOI wafers. Trenches were etched in the top cladding SiO_2, acting as moulds for the chalcogenide glass waveguides. The hybrid device is depicted in Fig. 1 (a) with the bottom panel showing the waveguide cross-section coupled to a silicon bus waveguide. Light is tightly confined in the chalcogenide waveguide thanks to the high index contrast between As_2S_3 (n=2.45) and the cladding oxide (n=1.44). The microresonator radius is 100 μm and the chalcogenide waveguide width is 2.5 μm. The 500-nm wide silicon waveguide is tapered down to 314 nm in the bus region to enhance evanescent coupling in the microresonator. The gap g between the bus and the trench controls the coupling strength.

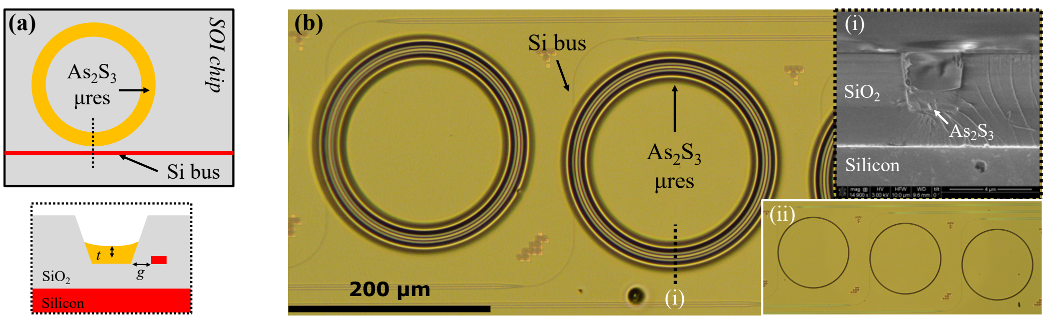

Fig. 1. (a) Schematic of the microresonator with the As_2S_3 waveguide (orange) coupled to a Si bus waveguide (red) with the coupling region cross-section shown in the lower panel. (b) Micrograph of the microresonators after thermal dewetting. Inset (*i*) is an SEM view of the cross-section of a similar waveguide and (*ii*) shows the same region before dewetting.

Following the standard CMOS-SOI fabrication process, 1.4-μm thick As_2S_3 thin-films were deposited in-house using a Nanochrome IntlVac electron beam evaporation chamber. After deposition, the chips were thermally annealed under an inert environment at 320°C for 30s. Annealing is done well over the glass transition temperature ($T_g \approx$200°C) of As_2S_3 to induce dewetting [4], resulting in a very smooth structure inside the trench. Fig. 1(b) shows the microresonators after dewetting alongside an SEM cross-section of a similar waveguide (inset i) and the same region before dewetting (inset ii). Dewetting also leads to a separation and retraction of the film around the cladding opening of more than 10 μm, preventing potential unwanted leakage to slab modes at a small radius.

3. Optical Measurement

The microresonator's optical transmission was measured using a LUNA optical vector analyzer (OVA). Light was coupled to and from the chip using tapered optical fibers with a spot size of 2.5 μm and on-chip inverse nanotapers. Fig. 2 (a) shows the normalized transmission across the C+L bands for TE-polarized light inside a 100 μm radius microresonator with a 200 nm designed gap. We note that the fabricated gap was larger (g>500 nm) due to the sidewall angle in the etched cladding oxide. The inset of Fig. 2 (a) shows a Lorentzian fit used to extract the linewidth $\delta\lambda$ of the resonance centered at $\lambda_0 = 1575.7191$ nm. The loaded Q-factor is then calculated as $Q = \lambda_0/\delta\lambda$, yielding a relatively high value of $Q > 460,000$ for this specific resonance. The large cross-section of the chalcogenide waveguide resulted in higher-order modes inside the resonator. This multimode behavior is highlighted in Fig. 2 (b), which shows the normalized transmission (top) and group delay (bottom) of two successive resonances for at least two mode families. According to the group delay measurement, resonances identified with the blue shading are overcoupled while resonances identified with the red shading are undercoupled. The two modes identified on Fig. 2(b) exhibit an order of magnitude difference in their Q-factors. This discrepancy is mainly attributed to their different overlap with the oxide rough sidewalls, leading to varied scattering strength.

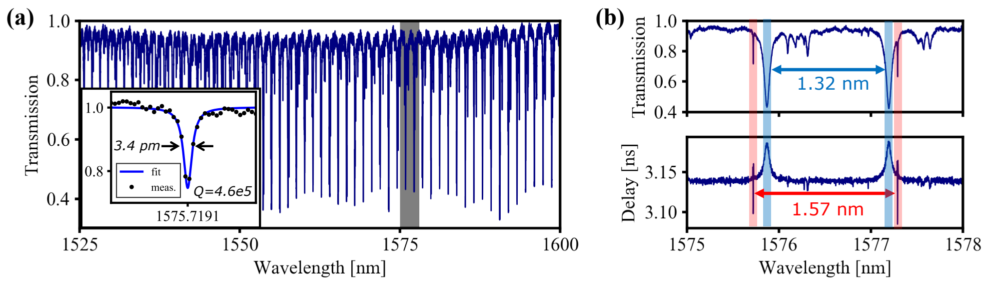

Fig. 2. (a) Normalized transmission of the microresonator with a Lorentzian fit on a high-Q resonance shown as inset. (b) Normalized transmission (top) and corresponding group delay (bottom) for a few resonances. The red and blue shading identifies two angular orders of the same mode family. The shaded region of (a) correspond to the zone shown in (b).

4. Conclusion

In summary, we have proposed and demonstrated a novel type of high-Q hybrid chalcogenide-silicon microresonator. These devices have potential for on-chip optical sources such as Kerr frequency combs and rare-earth doped lasers directly on SOI. Future works include process optimization to further increase the Q-factor and study of the non-linear properties of the resonators.

Acknowledgements: We acknowledge the support of the National Sciences and Engineering Research Council through strategic project grant (STPGP 494358-16).

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