Ultra-high Q Thin Film Lithium Niobate Resonators

Xinrui Zhu, Yaowen Hu, Shengyuan Lu, Hana K. Warner, Xudong Li, Yunxiang Song, Leticia Magalhaes, Amirhassan Shams-Ansari, Neil Sinclair, and Marko Loncar

John A. Paulson School for Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138

loncar@seas.harvard.edu

Thin-film lithium niobate (TFLN) is a recently emerging versatile platform for integrated photonics, enabling many exciting applications [1]. To unlock the full potential of TFLN, the key is to further decrease the propagation loss, which is increasing the quality (Q) factor [2].

In this work, we present our design, fabrication, and characterization of TFLN resonators with a record-high intrinsic quality (Q) factor of twenty-nine million, corresponding to an ultra-low propagation loss of 1.3 dB/m [3]. For the design, we increase the width of resonators' waveguide to reduce the overlap between the optical mode and the sidewalls, minimizing the propagation scattering loss. We also increase the length of the racetrack to decrease the proportionality of bending region. In addition to the design selections, we have utilized our optimized fabrication process, including the E-beam lithography writing, plasmonic ionic beam dry etching, chemical cleaning, and annealing, as illustrated in Figure 1. We fabricate multiple devices all with high Q factors in different fabrication rounds, demonstrating the stability of our fabrication flow.

For the characterization, we use scanning electron microscopy (SEM) to examine the smooth waveguides sidewalls and well-defined coupling regions, as shown in Figure 2. We fit resonances and perform spectrum analysis on the high Q mode family, as shown in Figure 3. In addition, we have studied the relationship between the geometry and Q values statistically, verifying our hypothesis that wider waveguide and longer straight section will result in higher Q factors.

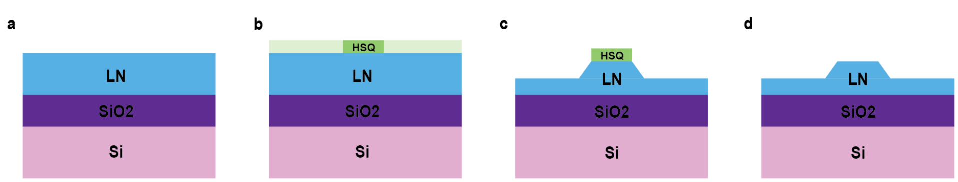

Figure 1: Fabrication Flow of TFLN Resonators: (a) The fabrication starting with LN and SiO2 on Si substrate wafer. (b) E-beam lithography using HSQ as the resist. (c) Dry etch of the LN layer. (d) Resists removal and chemical clean, followed by an annealing process.

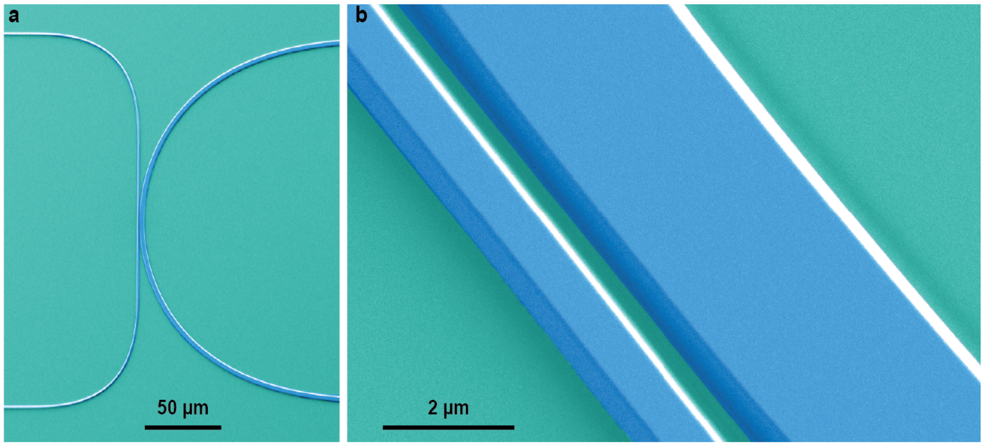

Figure 2: SEM Images of TFLN Resonators: (a) SEM image of a racetrack-shape resonator with 0.5 µm coupling gap and 3 µm width. (b) A detailed view of the coupling region for the same resonator.

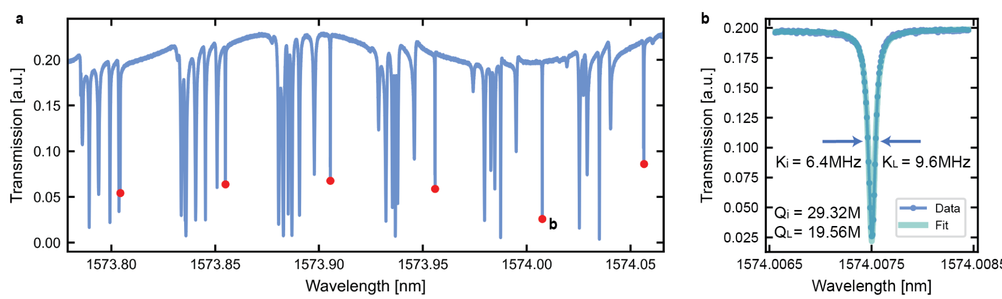

Figure 3: The Spectrum and Resonances of TFLN Resonators: (a) Selected resonator spectrum from a TFLN resonator. Red dots suggesting resonances belong to the same mode family with high Q factors. (b) The highest Q resonance features an intrinsic Q factor of 29 million at the wavelength of 1574 nm, corresponding to red dot labeled with "b" in (a).

References

1. Zhu, D., et al., *Integrated photonics on thin-film lithium niobate.* Advances in Optics and Photonics, 2021. **13**(2).
2. Zhang, M., et al., *Monolithic ultra-high-Q lithium niobate microring resonator.* Optica, 2017. **4**(12): p. 1536-1537.
3. Zhu, X., et al., *Twenty-nine million Intrinsic Q-factor Monolithic Microresonators on Thin Film Lithium Niobate.* arXiv:2402.16161, 2024.