High-Q Lithium Niobate Microrings Enabled by a Hybrid Dry Etching and Wet Polishing Technique

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Abstract: We introduce a CMOS-compatible hybrid method combining dry etching and wet polishing, achieving ultra-low-loss lithium niobate waveguides (0.28 dB/cm) and high-Q microrings (Q = 1.4×10^6), enabling scalable integration of lithium niobate photonic networks.

1. Introduction

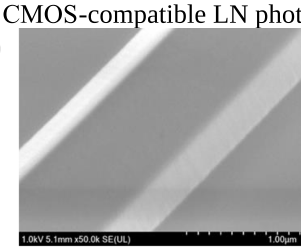
Lithium niobate (LN) is a key material in photonics due to its strong Pockels effect, enabling high-speed electro-optical modulation. The advent of wafer-scale thin-film lithium niobate (TFLN) has further expanded its potential for integrated photonics, offering tightly confined light propagation [1]. However, LN's challenging etch properties result in significant scattering losses, complicating the fabrication of low-loss waveguides. While etch-free methods such as proton exchange (PE) [2-4] and titanium diffusion [5,6] provide alternatives, they suffer from weak light confinement and poor CMOS compatibility. Dry etching via inductively coupled plasma-reactive ion etching (ICP-RIE) is widely used for LN waveguides due to its precision and CMOS compatibility [7-10]. Yet, achieving consistently low propagation loss remains difficult. Emerging techniques such as wet etching [11,12], focused ion beam (FIB) milling [13], and chemical mechanical polishing (CMP) [14,15] offer new possibilities but are limited by scalability and CMOS integration challenges. Fig. 1 (a) summarizes the key considerations of those strategies to fabricate LN waveguides. To address these issues, we propose a hybrid method combining dry etching with wet polishing, achieving ultra-low propagation loss of 0.28 dB/cm and high-Q microrings with a Q-factor of 1.4×10^6. This approach supports scalable, CMOS-compatible LN photonics.

(a)

Fab	Loss	Confinement	CMOS integration
PE	Low	Weak	Poor
Ti-diffusion	Low	Weak	Poor
ICP RIE	Moderate	Tight	High
Wet etch	Low	Moderate	High
FIB	Moderate	Tight	Poor
CMP	Very low	Moderate	Limited

(b)

(c)



(d)

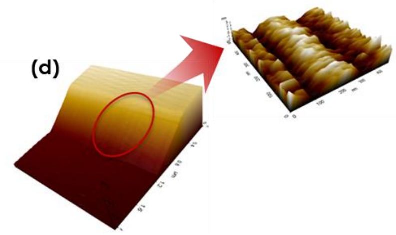


Fig. 1 (a) Comparison of key considerations for LN waveguide fabrication strategies. (b) Schematic of the proposed hybrid fabrication process for low-loss LN waveguides. (c) SEM image of an LN waveguide with smooth sidewalls. (d) AFM scan illustrating the minimized sidewall roughness of the LN waveguide.

2. Fabrication and Characterization

The fabrication process, shown in Fig. 1(b), begins with a Z-cut TFLN sample (600 nm LN on SiO_2). Hydrogen silsesquioxane (HSQ) is patterned via electron beam lithography (EBL) as a photoresist mask. Dry etching in argon plasma defines waveguides with a top width of 0.8 μm and height of 0.35 μm to support single-mode transmission. Wider widths of 1.6 μm and 2.4 μm are also fabricated to study dimensional effects. The waveguides are then wet-polished in an H_2O_2 and NH_4OH solution at 60 ℃ to smooth sidewalls, followed by HSQ mask removal with hydrofluoric acid and acid piranha cleaning. Fig. 1(c) shows smooth sidewalls achieved after the process observed by scanning electron microscope (SEM). Fig. 1(d) demonstrates an improvement in root-mean-square roughness (Rq) of 1.01 nm by the hybrid etching, indicating a significant improvement rather than 1.78 nm by dry etching only. Propagation losses were measured for the TE mode at 1550 nm, as shown in Fig. 2(a). The proposed method reduced propagation loss from 2.7 dB/cm by dry etch only to 0.28 dB/cm for waveguides with 0.8 µm width, and losses increased to 1.65 dB/cm, and 2.45 dB/cm as widths extends to 1.6 µm, and 2.4 µm, respectively. The increase in loss with wider width, attributed to higher-order modes (Fig. 2(b)), highlights the benefits of tighter confinement. This method achieved ultra-low loss while keeping CMOS compatibility and scalability (Fig. 2(c)).

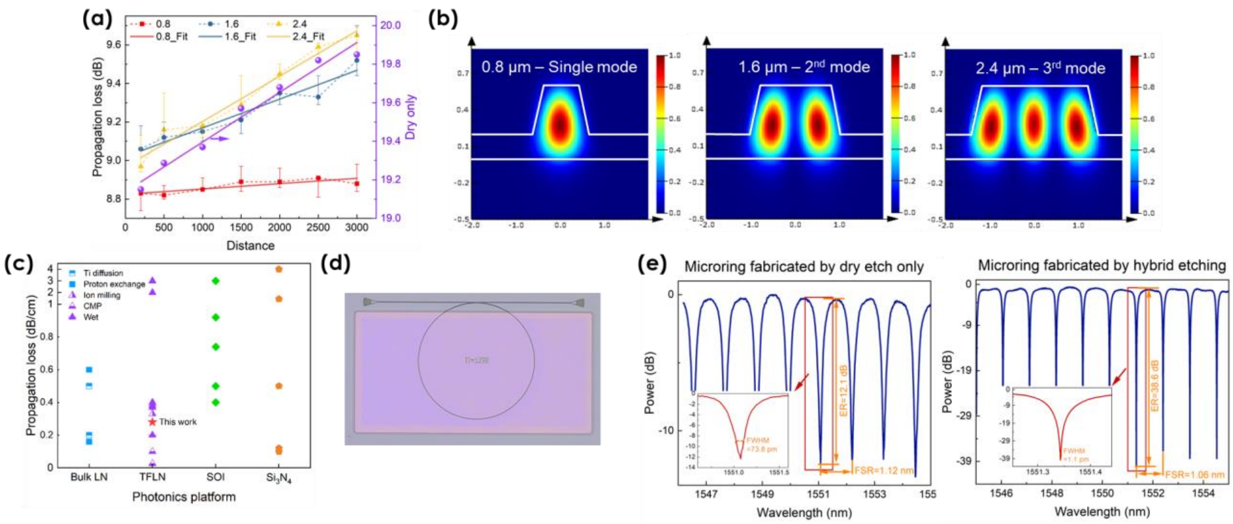


Fig. 2 (a) Propagation loss versus transmission length under different conditions. (b)Light mode transmission with different waveguide dimensions. (c) Propagation loss benchmark on primary optical platforms [2-26]. (d) A LN microring resonator. (e) Transmission spectrum of the resonator by dry and hybrid etch, respectively.

To evaluate the waveguide quality, a microring resonator of 150 µm radius was fabricated, as shown in Fig. 2(c). The transmission spectrum, presented in Fig. 2(d), reveals an extinction ratio (ER) of 38.6 dB, a free spectral range (FSR) of 1.06 nm, and a high Q-factor of 1.4×10^6. This marks a significant improvement compared to the Q-factor of 2.1×10^4 achieved with dry etching alone, demonstrating the substantial benefits of the proposed hybrid wet-joint polishing method.

3. Conclusion

This work introduces a novel etching approach that combines dry etching with wet polishing to achieve smooth sidewalls while ensuring high directivity and scalability. Characterization results confirm the effectiveness of wet polishing in improving sidewall quality by eliminating rough residuals, reducing propagation loss to below 0.3 dB/cm. This technique opens new avenues for the development of large-scale LN-based photonic networks.

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