Surface acoustic microwave photonic filters on etchless lithium niobate integrated platform

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Abstract: We experimentally demonstrated high-performance surface acoustic microwave photonic filters on an etchless lithium niobate integrated platform, achieving acoustic time delays of 21–106 ns and passbands with bandwidth as narrow as 0.89 MHz. © 2023 The Author(s)

1. Introduction
Microwave filtering is one of the most important functionalities in integrated microwave photonics (MWP) for signal processing in the 5G/6G wireless communication [1], which separates signals of interest from the noise background and mitigates unwanted interference [2]. For applications that require narrow linewidths and/or free spectral ranges (FSRs), long delays become necessary, leading to large footprints and high losses. Surface acoustic waves (SAWs) with significantly lower velocities than optical waves can be adopted for overcoming this difficulty and for obtaining the required long delays within a small footprint. Moreover, SAWs have very high energy confinement and can attain a large overlap with the optical mode of a planar waveguide on an integrated platform, and thus can be an excellent candidate for obtaining the long delays in integrated MWP filters.

Lithium niobate on insulator (LNOI) has emerged as a promising platform for integrated photonics due to its excellent material properties. Recently, a fundamentally new photonic architecture based on the principle of “bound states in the continuum (BICs)” was demonstrated by patterning a fabrication-friendly optically transparent material on single-crystal thin-film substrate without the need for etching of the substrate [3]. Here, by monolithically integrating an interdigital transducer (IDT) with a multitap photonic microcavity, we demonstrated high-resolution MWP filters on an etchless LNOI integrated platform for signal processing.

2. Results

Figure 1(a) illustrates the surface acoustic MWP filter fabricated on a z-cut LNOI platform. (b) Cross-sectional view of the acousto-optic modulation region near the IDT. The dark blue part denotes the polymer waveguide, the yellow part denotes the IDT made of gold, the light blue part denotes the lithium niobate layer, and the gray part denotes the bottom silicon oxide (the insulator). w, d, p, and t represent the width of the polymer waveguide, the distance between adjacent taps, the period of the IDT, and the width of the IDT fingers, respectively. (c) (Upper) Calculated propagation loss of a straight waveguide as a function of the waveguide width w. (Lower) Calculated propagation loss of a bent waveguide as a function of the bend radius R with fixed w = 1.74 μm. In both cases, the simulation was performed at the wavelength of 1510 nm.

Figure 1(a) illustrates the surface acoustic MWP filter fabricated on a z-cut LNOI substrate with an etchless process. Figure 1(b) shows the cross section of the acousto-optic interaction region, where the thicknesses of the IDT gold electrodes, the lithium niobate layer, the polymer atop, and the silicon oxide underneath are 80 nm, 300 nm, 400 nm, and 2 μm, respectively. An input microwave signal with frequency f was applied to the IDT to generate SAWs of the same frequency. When pf matches the velocity v of an SAW, the SAW can be excited and propagate away from the IDT, which induces a phase modulation to light as it crosses a tap due to the acousto-optic effect.

Note that the optical loss can have considerable effects on the system’s performance, because it transforms into the microwave loss quadratically due to the square law in optical-to-electrical conversion by photodetectors [4]. To
obtain a high-quality photonic microcavity with multiple taps as shown in Fig. 1(a), one should minimize the waveguide propagation loss in all the straight and bent sections of the microcavity. The upper panel of Fig. 1(c) shows that the propagation loss of the fundamental TM mode in a straight waveguide depends on the waveguide width $w$. A zero propagation loss can be achieved at $w = 1.74 \, \mu m$ at the wavelength of 1510 nm. The lower panel of Fig. 1(c) plots the simulated propagation loss of the TM mode in a bent waveguide as a function of the bend radius $R$ with $w = 1.74 \, \mu m$. When $R$ is larger than 60 $\mu m$, a zero propagation loss can be obtained at periodic $R$ values ($R = 78, 92, 106 \, \mu m$ ...). The insets show the modal profiles of the fundamental TM mode in a straight waveguide (upper) and in a bent waveguide (lower) at the respective BIC point as marked in Fig. 1(c).

Based on the simulated results, we designed the multitap photonic microcavity by satisfying the BIC conditions for both straight and bent waveguides ($w = 1.74 \, \mu m, R = 134 \, \mu m$). We also designed the nearby SAW IDT with $p = 2w = 3.48 \, \mu m$ to achieve maximal acousto-optic modulation efficiency. Figure 2(a) shows a top-view optical microscope image of a fabricated 4-tap device. The measured optical transmission spectrum in Fig. 2(b) indicates loaded optical quality factors $Q_L$ of $\sim 1.2 \times 10^5$ and an FSR of 0.355 nm near the wavelength of 1510.0 nm. To characterize the microwave filtering performance of our fabricated devices, we measured normalized $|S_{21}|$ spectra of 4- and 6-tap surface acoustic microwave photonic filters at frequencies near 0.78 GHz (c) and 1.60 GHz (d). The right figures show the zoomed-in spectra of the central peak, where a full width at half maximum of 0.89 MHz and 2.9 MHz was obtained from the 6-tap filter. Here both the 4- and 6-tap filters have $d = 2R = 268 \, \mu m$. (e),(f) Normalized impulse response, derived from the measured complex-valued frequency response in (c) and (d). The orange solid lines plot the corresponding exponential fits.

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References
[1] D. Marpaung, J. Yao, & J. Capmany, “Integrated microwave photonics”, Nat. Photonics, 13, 80–90 (2019).
[2] V. J. Urick, K. J. Williams, J. D. McKinney, Fundamentals of Microwave Photonics (Wiley, Hoboken, New Jersey 2015).
[3] Y. Yu, Z. Yu, L. Wang, and X. Sun, “Ultralow-loss etchless lithium niobate integrated photonics at near-visible wavelengths,” Adv. Opt. Mater. 9, 2100060 (2021).
[4] Y. Liu, A. Choudhary, D. Marpaung, & B. J. Eggleton, “Integrated microwave photonic filters”, Adv. Opt. Photonics, 12, 485–555 (2020).