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Views & Comments

Meter-Level Optical Delay Line on a Low-Loss Lithium Niobate Nanophotonics Chip

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Photonic integrated circuit (PIC) technology provides an enabling platform for emerging applications ranging from big data science and artificial intelligence to high sensitivity sensing and quantum information processing. An outstanding challenge in achieving the large-scale photonic integration is to realize low-loss optical waveguides with small radii and high tuning efficiencies on a single photonic chip. Traditionally, silicon-on-insulator (SOI) has been studied as a major material platform for PIC technology because of its mature processing technology and being compatible with CMOS process.

In merely two decades, however, lithium-niobate-on-insulator (LNOI) has proven itself to be a powerful competitor as a new material platform for PIC technology.[1] Lithium niobate crystal, which has been described as "optical silicon", has favorable low-loss limit, nonlinear, acousto-optic, and electro-optic coefficients. These properties, combined with the high-index-contrast ridge waveguides on LNOI wafer, have enabled low-loss tunable optical waveguides of small curvature radii.[2] Such waveguides have been fabricated using lithographic techniques,[3−6] following by dry etching, such as inductive coupled plasma (ICP), reactive ion etching (RIE), etc. Still, fabrication of large-scale low-loss LNOI waveguides remains to be an outstanding challenge due to the accumulation of the stitching errors in the traditional electron beam lithography (EBL) or ultraviolet (UV) lithography.

Recently, Zhou *et al.* overcome these challenges using a femtosecond laser lithographic patterning of a chromium (Cr) thin film coated on the top surface of LNOI to generate the waveguides mask, then followed by chemo-mechanical polish for selective etch of the thin film of lithium niobate. The technique termed photo-lithography assisted chemo-mechanical etching (PLACE) is proved to be particularly suited for fabrication of low-loss waveguide that is stitching-free, and therefore, large-scale PIC devices.[7] Their work clearly demonstrates the ultra-smooth LN ridge waveguide surfaces produced by the PLACE technique can give rise to ultra-low propagation losses. They designed and fabricated reconfigurable optical true delay lines (OTDL) on the LNOI chip based on the electro-optic routing of the delay paths with several integrated Mach-Zehnder interferometer switches. The OTDL has a relative optical path length of 32.68 cm, corresponding to a relative time delay of 2.285 ns in theory. Experimentally, the output signal was measured to arrive at the photodetector with a time difference of ~ 2.2 ns using a femtosecond laser. The pulse propagation loss as low as ~ 0.03 dB/cm is confirmed. To examine the reliability of the fabrication approach for creating the LN ridge waveguides over large scales, the OTDLs with various lengths ranging from ~ 10 cm to ~ 100 cm are fabricated and the propagation losses in all the fabricated waveguides are measured on the level below 0.03 dB/cm.

The low-loss waveguides with highly miniaturized cross-sections are the basis of photonic integrated circuit technology. Besides OTDL, electro-optic switches and Mach-Zehnder interferometer, many other function components in PIC, such as optical micro-cavity, beam splitter, wavelength-division-multiplexing (WDM), frequency-division-multiplexing (FDM), and mode converter, all of these above consist of waveguides or waveguide circuits. Some active components, such as light sources (whether classical or quantum), optical modulators, optical memories, optical detectors, etc., are also highly dependent on high-performance optical waveguides or waveguide arrays. PLACE technique enables consistent low-loss waveguide fabrication over a large length at the meter level in a small on-chip footprint, and will have impor-

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tant impacts in the fields such as quantum photonic technology,[8] microwave signal processing,[9] optical gyroscopes,[10] to name a few.

References

[1] Sohler W, Hu H, Ricken R *et al.* 2008 *Opt. Photon. News* **19** 24
[2] Boes A, Corcoran B, Chang L, Bowers J and Mitchell A 2018 *Laser & Photon. Rev.* **12** 1700256
[3] He Y, Yang Q F, Ling J, Luo R, Liang H, Li M, Shen B, Wang H, Vahala K and Lin Q 2019 *Optica* **6** 1138
[4] Lu J, Surya J B, Liu X, Bruch A W, Gong Z, Xu Y and Tang H X 2019 *Optica* **6** 1455
[5] He M, Xu M, Ren Y *et al.* 2019 *Nat. Photon.* **13** 359
[6] Zhang M, Buscaino B, Wang C *et al.* 2019 *Nature* **568** 373
[7] Zhou J, Gao R, Lin J *et al.* 2020 *Chin. Phys. Lett.* **37** 084201
[8] Jin H, Liu F M, Xu P *et al.* 2014 *Phys. Rev. Lett.* **113** 103601
[9] Capmany J, Ortega B and Pastor D 2006 *J. Lightwave Technol.* **24** 201
[10] Ciminelli C, Dell'Olio F, Campanella C E and Armenise M N 2010 *Adv. Opt. Photon.* **2** 370