Compact Photonic Crystal Nanobeam Cavity on Si_3N_4 Loaded LNOI Platform

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***Abstract*—In this paper, we design and experimentally demonstrate a photonic crystal nanobeam cavity device based on the Si_3N_4 loaded LNOI platform with a mode volume of 3.06 μm^3, which is potential in achieving low power devices. The device shows an insertion loss of 0.89 dB, and a 3-dB bandwidth of 0.284 nm.**

Keywords*—*LNOI, photonic crystal, nanobeam

I. INTRODUCTION

Lithium niobate on insulator (LNOI) has emerged as a promising platform due to its attractive properties, such as the strong Pockels effect (r_{33} = 33 pm/V), large nonlinear coefficient (d_{33} = 27 pm/V), and wide transparency (0.35 ~ 5 μm) [1]. High speed modulators [2] and mode (de)multiplexers [3] have been experimentally demonstrated on LNOI to satisfy the demands of various applications. Compared with the silicon on insulator (SOI) platform, the refractive index contrast of the LNOI platform is lower, which results in less light confinement and larger device footprints for LNOI devices. Schemes for patterning waveguides directly on the LNOI platform include the mechanical method [4] and dry etching. Among them, argon milling is mostly used [5]. However, due to the material property of lithium niobate (LN), the waveguides can have a significant sidewall angle. To avoid the direct etching of the LN thin film, the hybrid platform with a readily etched loading material on top of the LNOI chip is another solution. Several optical loading materials have been investigated on the LNOI platform, such as silicon nitride (Si_3N_4) [6], polymers [7], and titanium dioxide (TiO_2) [8]. Among them, Si_3N_4 is attractive as it has a similar refractive index and transparency window with LN. In addition, the fabrication of the Si_3N_4 waveguide is compatible with the mature Complementary Metal-Oxide-Semiconductor (CMOS) process, and it combines the strong Pockels effect and large nonlinear coefficient of LN based on the mature fabrication process of Si_3N_4. High speed racetrack resonator modulators (RRM) [9], and Mach-Zehnder interferometer-based modulators (MZM) [10] have been demonstrated on Si_3N_4 loaded LNOI platform. However, due to the large footprints and mode volume of the RRMs and MZMs, it is challenging to reduce the power consumption of the modulators.

Photonic crystal nanobeam (PCN) cavity is promising to achieve low-power, compact electro-optical modulators and switches [11, 12], with the merits of compact footprint, extremely small model volume, relative ease of design and fabrication. Low power thermal optical switches and modulators based on PCN have been demonstrated on SOI platform. However, due to the electro-optical properties of silicon materials, it is challenging to achieve high speed modulation rate while maintaining a compact footprint. Hence, it is highly desired to investigate the implementation of high-speed and compact modulators based on the Si_3N_4 loaded LNOI platform.

In this paper, we design and experimentally demonstrate a PCN cavity device on Si_3N_4 loaded LNOI platform, which resonates at 1559.614 nm with an insertion loss of 0.89 dB. A 3-dB bandwidth of 0.284 nm (Q ~5500) is achieved with a compact footprint of 1.6 μm × 84 μm. And the mode volume of the device is calculated as 3.06 μm^3 using finite-difference time-domain (FDTD) simulation.

II. DEVICE DESIGN

We design the device on Si_3N_4-LNOI platform, Fig. 1 shows the 3D schematic of the proposed device. The thickness of the X-cut thin film $LiNbO_3$ and Si_3N_4 are chosen to be h_{LN} = 300 nm and h_{SiN} = 300 nm, respectively. The width of the Si_3N_4 waveguide is 1.6 μm, where the optical confinement in the thin film $LiNbO_3$ is about 62% for fundamental TE_0 mode,

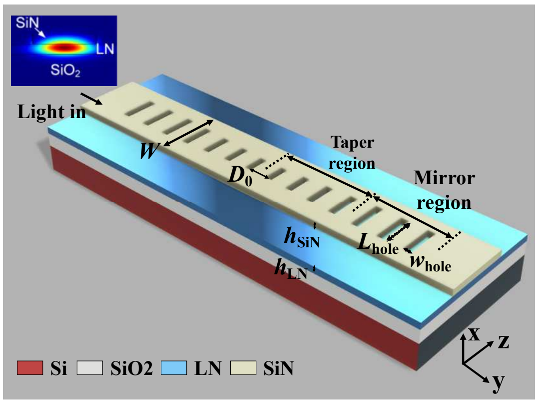

Fig. 1 The schematic diagram of the proposed PCN cavity.

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which can allow us to make full use of the Pockels effect of the $LiNbO_3$ efficiently. The PCN cavity is oriented along the y-axis to utilize the highest Pockels coefficient r_{33} of the thin film LN. The PCN cavity consists of 200 etched air holes to form a FP cavity which is symmetric with respect to its center. The period of the holes in mirror region is chosen to be a=420 nm in order to get a resonance around 1550 nm. We taper the period from a to 0.9×a linearly through 10 holes to avoid the mismatch between the waveguide mode and the Bloch mode. The widths of the holes are $w_{\text{hole}}(\text{i}) = 0.26\times a\times$ [0.9+ 0.01×(i-1)], (i = 1, …, 10), $w_{\text{hole}}(\text{i}) = 0.26\times a$, (i = 11, …, 100), and the length of the holes L_{hole} are 6 times the width of each hole to enable a sufficient perturbation. In our design, 100 holes are arranged in each side to get a low Q resonance, which can support a sufficient bandwidth for high data transmission. There is a tradeoff between insertion loss and Q factor. One could increase the number of air holes in the FP cavity to get a high Q resonance while introducing excess losses.

III. DEVICE FABRICATION AND EXPERIMENTAL RESULTS

A. *Device Fabrication*

The fabrication of the device is based an X-cut lithium-niobite-on-insulator (LNOI) wafer with a 300-nm-thick LN layer and a 2-μm-thick buried silica layer (purchased from NanoLN). A 300-nm-thick silicon nitride layer is deposited on the LNOI substrate using plasma-enhanced chemical vapor deposition (PECVD). The PCN structures and grating couplers are patterned on the resist (AR-P 6200.09) and transferred to the silicon nitride layer by electron-beam lithography (EBL, Vistec EBPG 5200+) and inductively coupled plasma (ICP) dry etching (NMC), respectively. Fig. 2(a) shows the optical microscope graph of the fabricated PCN cavity device, and Fig. 2(b) shows the scanning electron microscope (SEM) photo of the PCN device. The footprint of the device is 1.6 μm × 84 μm.

B. *Experimental Results*

The PCN device is characterized by using a tunable laser (Keysight 81960A), and an optical power meter. On-chip grating couplers are used to couple light into/out of the silicon-nitride-loaded LN waveguides. The normalized transmission spectrum is shown in Fig. 3. Measured results show a resonance peak at 1559.614 nm with an insertion loss of 0.89 dB, and an extinction ratio (ER) of 23 dB. The 3-dB bandwidth is measured as 0.284 nm (Q ~5500). One could adjust the period a_0 and the cavity length D_0 of the PCN to get a resonance at 1550 nm.

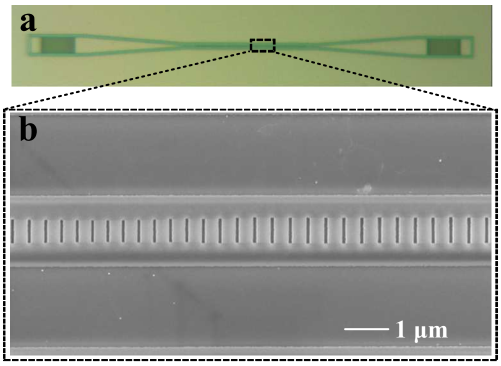

Fig. 2 Images of the fabricated device. (a) optical microscope graph and (b) SEM photo of the fabricated PCN cavity device.

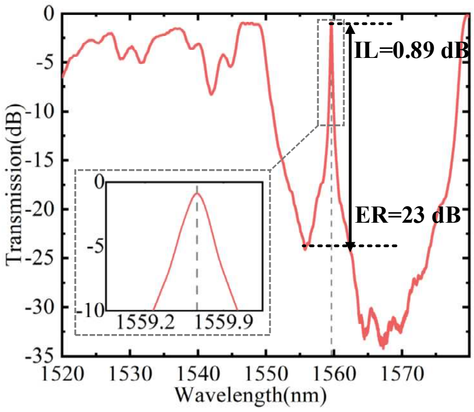

Fig. 3 Normalized transmission spectrum of the tested PCN cavity device.

IV. CONCLUSION

In summary, we design and experimentally demonstrate a PCN cavity device on Si_3N_4 loaded LNOI platform, which resonates at 1559.614 nm with an insertion loss of 0.89 dB. A 3-dB bandwidth of 0.284 nm (Q ~5500) is demonstrated with a compact footprint of 1.6 μm × 84 μm. Our device is potentially useful in achieving high speed and low power modulators and switches.

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