Wafer-Scale Lithium Niobate on Insulator (LNOI): A New Platform for Integrated Optics

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***Abstract*—The development of wafer-scale single crystalline thin lithium niobate films on a SiO_2/LN substrate (LNOI) is reviewed. They can serve as a new platform for ultra-compact active integrated photonic devices and circuits.**

Keywords-integrated optics; lithium niobate; photonic wires; periodical poling; second harmonic generation.

I. INTRODUCTION

Optical waveguides of high refractive index contrast – such as the well-developed Silicon-On-Insulator (SOI) "photonic wires" - can have a very small cross section (< 1 μm^2) and bending radius (~ 10 μm), enabling the development of ultra-compact photonic integrated devices and circuits. A corresponding technology for Lithium Niobate-On-Insulator (LNOI) is still in its infancy, though LNOI offers – in contrast to SOI - excellent electro-optic, acousto-optic, and nonlinear optical properties. Moreover, it can be easily doped with rare-earth ions to get a laser active material.

In this contribution, the fabrication of wafer-scale LNOI as a new platform for high-density integrated optics with active devices of high efficiency is reported. Moreover, fabrication and properties of (periodically poled (PP)) LNOI photonic wires are reviewed with the demonstration of Second Harmonic Generation (SHG) as a specific example.

II. FULL WAFER FABRICATION OF LNOI

In analogy to the fabrication of SOI [1], a "smart cut" process was used for the fabrication of single crystalline LN films on SiO_2 on a LN substrate. The full wafer fabrication process is schematically sketched in Fig. 1.

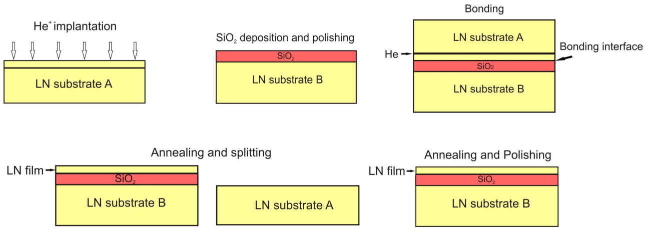

Figure 1. Fabrication scheme of LNOI: a "smart cut" single crystalline LN-film of sub-micrometer thickness is directly bonded to a SiO_2/LN substrate.

At first, a Z-cut LN wafer (A) of 3`` diameter is implanted by 250 keV He-ions with a dose of 4×10^{16} ions/cm^2, forming a thin amorphous layer at ~ 760 nm depth. Another Z-cut LN handle sample (B) is coated by a SiO_2-layer of 1.3 μm thickness by plasma enhanced chemical vapor deposition (PECVD) and then annealed at 450 °C for 8 hours. With a chemical mechanical polishing (CMP) process, the surface roughness is reduced from about 6 nm to 0.35 nm enabling direct wafer bonding. The bonded pair of samples is then annealed to improve the bonding strength; by a further increase of the temperature to 228 °C for 2 hrs the sample splits along the He implanted layer. Afterwards, it is annealed at 450 °C for 8 hours. Fig. 2 presents a LNOI wafer of 3 inch diameter fabricated by the process sketched above. The good homogeneity of the interference colors shows the homogeneity of the fabrication process.

Different sandwich structures with a thin metal electrode either underneath the SiO_2 layer or underneath the $LiNbO_3$ film have also been fabricated. Such structures should enable electric field induced poling and electro-optic control of light propagation. Even LNOI with a MgO:$LiNbO_3$ film has been demonstrated [2].

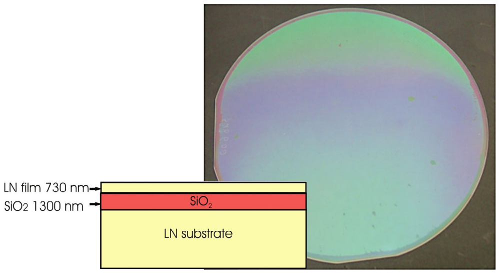

Figure 2. Schematic cross-section (left) and photograph (right) of a LNOI-wafer of 3`` diameter.

III. LNOI PHOTONIC WIRES

A. *Fabrication*

LNOI photonic wires have been fabricated by Ar-milling Fig. 3, left). Photoresist stripes of 1-7 μm width and 1.7 μm thickness were used as etching mask (The etching ratio of LN and photoresist is about 1). Using an Oxford Plasmalab System 100 etching system, photonic wires were defined by

Ar-milling for 60 min with 100 W inductively coupled plasma power and 70 W RF power coupled to the sample table; the result was an etching depth of 460 nm. Fig. 3 (middle) shows a scanning electron micrograph (SEM) of a photonic wire of 1 µm top width. The SiO_2 layer can be seen underneath the LN layer. On both sides of the ridge, etched trenches can be observed resulting from etching by ions reflected by the angled walls of the ridge [3].

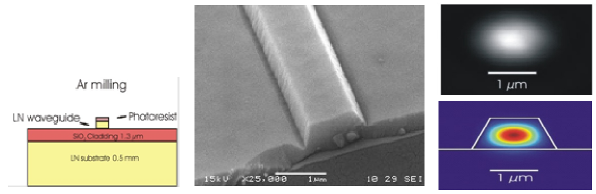

Figure 3. Fabrication scheme of a LNOI photonic wire (left). SEM micrograph of a fabricated structure of 1 µm top width (middle). Measured and simulated qTM-polarized mode distributions (λ = 1550 nm) (right).

B. *Mode Distributions, Dispersion Properties and Losses*

A tunable laser diode was used to investigate the photonic wires around 1550 nm wavelength. Fig. 3 (upper and lower right) shows the measured and calculated mode distribution for quasi TM-polarization of a photonic wire of 1 µm top width, respectively. The waveguide mode dispersion is determined by the material dispersion of core and cladding materials and also by the waveguide dimensions. Some results are displayed in Fig. 4 together with the dispersion of bulk LN and SiO_2. Also the group index has been calculated; it agrees well with the measured one [3]. The measured propagation losses are 9.9 dB/cm for qTM-polarization [3].

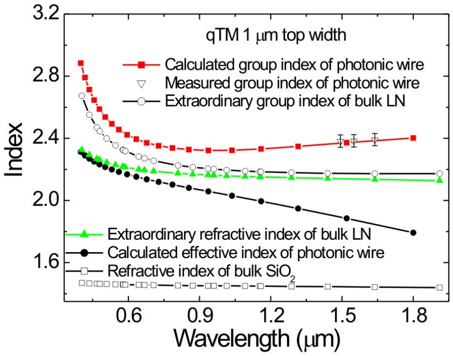

Figure 4. Calculated effective and group indices for the fundamental qTM mode in a photonic wire of 1 µm top width and 730 nm thickness versus wavelength. Measured group indices, calculated group indices of bulk LN, and refractive indices of bulk LN and SiO_2 are shown as well for comparison.

IV. PERIODICALLY POLED LNOI (PPLNOI)

A. *Fabrication*

Periodically poled (PP) bulk LN samples (A) (see Fig. 1) of 3.2 and 9 µm periodicity were processed in the same way as described above to fabricate PPLNOI. To get periodically poled photonic wires, Ar-milling was used again. Fig. 5 shows an optical micrograph of a photonic wire with 3.2 µm periodicity.

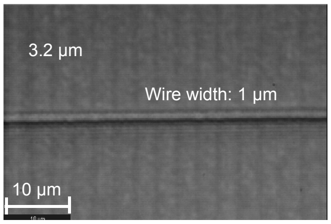

Figure 5. Optical micrograph of a PPLNOI photonic wire and substrate of 3.2 µm periodicity.

B. *SHG in in PPLNOI Photonic Wires*

A 1064-nm narrow-band laser diode of up to 40 mW output power was used to demonstrate quasi phase matched (QPM) second harmonic generation (SHG) in a PPLNOI photonic wire of 9 µm periodicity. The calculations showed that third order QPM type I SHG should be possible in a wire of 1 µm top width and 730 nm thickness. Fig. 6 shows calculated and measured results [4].

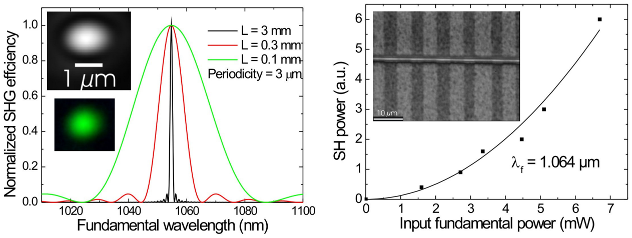

Figure 6. Left: Calculated QPM SHG efficiency for different interaction lengths L. Insets: measured fundamental (1064 nm) and SH (532 nm) mode distributions (qTM). Right: measured (dots) and simulated (solid line) SH power versus fundamental input power. Inset: optical micrograph of a PPLNOI photonic wire of 1 µm top width and 9 µm domain periodicity.

V. CONCLUSIONS

The recent development of LNOI has been described. It might become a new platform for ultra-compact integrated photonic devices and circuits [5]. The great potential of LNOI based devices will lead to novel concepts and architectures for high-density integrated optics with highly efficient electro-optical, nonlinear-optical, and laser/amplifier devices.

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