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High Refractive Index Contrast Ridge Waveguides in $LiNbO_3$ Thin Films

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Optical waveguides of high refractive index contrast enable small cross section dimensions and small bending radii of curved waveguides, a prerequisite for high density integrated optics [1]. For nonlinear optics in materials like lithium niobate ($LiNbO_3$, LN) the resulting small mode size yields a high guided mode intensity increasing the efficiency of nonlinear interactions.

Recently, strongly guiding LN ridge guides have been reported [2]. They have been fabricated by processing a thin smart-cut LN layer either bonded to a SiO_2-layer on LN [3] or bonded to benzocyclobutene on a LN substrate [4]. We favour crystal bonding to a SiO_2 cladding layer due to its lower refractive index and better thermal stability, which allows thermal annealing at much higher temperatures to recover electro- and nonlinear optical properties after ion implantation. A significant progress is reported to fabricate large area (~ 30 x 15 mm^2), high quality crystal bonded LN thin films on a SiO_2-layer, deposited on a LN substrate. Using such films, ridge guides and photonic "nanowires" of excellent optical properties were developed.

The fabrication method for crystal bonded LN thin films is similar to the smart cut process widely used for silicon-on-insulator (SoI) wafer fabrication [5]. At first, a Z-cut LN sample was implanted by 250 keV He ions with a dose of 4×10^{16} ions/cm^2 forming an amorphous layer at about 900 nm underneath the surface. Another Z-cut LN handle sample was coated by a SiO_2 layer of 1.8 µm thickness by plasma enhanced chemical vapour deposition (PECD), and then annealed at 450 ^oC for 8 hours to drive off the gases trapped in the oxide layer. With chemical mechanical polishing (CMP) the surface roughness was reduced from 6 nm to 0.35 nm to enable crystal bonding. After cleaning and before bonding, the surfaces of the implanted and the handle sample were covered by a NH_4OH solution [6]. The bonded pair of samples was annealed (165 ^oC, 16 hrs; 190 ^oC, 6 hrs) to improve the bonding strength. By a further annealing procedure at 228 ^oC for 2 hours the handle sample did split along the He-implanted layer leaving a single crystal LN film of 900 nm thickness on top of the SiO_2/LN substrate. Fig. 1(left) shows such a "LNoI" film of 30 × 15 mm^2 size. The sample was annealed at 450 ^oC for 8 hours to increase the bonding strength. After a CMP process, the surface roughness and the film thickness became 0.5 nm and 730 nm, respectively

Such a "LNoI" substrate was used for the fabrication of high quality ridge guides of (sub)micrometer dimensions by Ar-ion beam milling. Photoresist stripes of 1.7 µm thickness and of 1 to 5 µm width served as etch masks. A LN-etching rate of about 7.6 nm/min was adjusted resulting in an etching depth of 460 nm after one hour of processing. As result, ridge guides of trapezoidal cross sections were obtained with etched trenches along both sides. Finally, the end faces of the sample were carefully polished to enable efficient end-fire coupling. Fig. 1(middle) shows as example a SEM micrograph of a ridge guide of 1 µm top width.

Laser radiation of 1.55 µm wavelength was coupled into the ridge guide by a 60×, 0.6 N.A. objective. It was collected at the output side by a 100×, 0.9 N.A. objective with a diffraction limit of about 1 µm. Fig. 1 (right) shows a TE mode distribution in a ridge guide of 1 µm top width. The propagation losses in a guide of 2 µm top width are below 3 dB/cm estimated by the Fabry-Perot method at 1.57 µm wavelength.

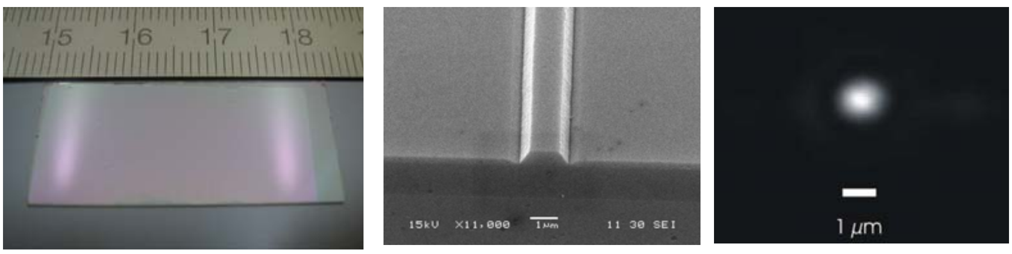

Fig. 1 Left: "Smart-cut" LN thin film crystal bonded to a SiO_2/LN substrate before CMP polishing. Middle: SEM micrograph of a ridge guide of 1 µm top width. Right: Measured TE mode distribution of the ridgeguide shown in the middle.

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