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Fabrication of Ridge Waveguides in Lithium Niobate by Differential Etching Following Spatially Selective Domain Inversion

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Abstract

Ridge structures have been fabricated in z-cut $LiNbO_3$ using the technique of differential etching following spatially selective domain inversion. Waveguides within these ridges have been achieved using the techniques of ion beam implantation, proton exchange, and titanium indiffusion. Using this last method, guides with losses <0.8dBcm^{-1} have been realised for light at a wavelength of 1.3µm. We briefly discuss applications for these structures.

Lithium Niobate, $LiNbO_3$, is a material of considerable interest to the optical, laser and communications industry due its large values of nonlinear optical, electro-optic, piezoelectric and acousto-optical coefficients and figures of merit [1]. When periodically poled it has achieved record efficiencies in quasi-phase matched non-linear interactions [2] as well as being used for parametric generation and amplification [3]. In the microwave communications field it is used extensively in surface acoustic wave (SAW) delay lines and filters [4]. In telecommunications, commercially available integrated optical modulators have achieved switching rates of 10 GHz, and modulators capable of 40 GHz have been demonstrated experimentally. Lastly, $LiNbO_3$ continues to generate interest for optical data storage, holographic and phase conjugate applications.

The ferroelectric domain structure has been studied for many years [5] using the technique of differential etching, to reveal the domain orientations (±z directions) within a sample. It has also been demonstrated that one of these etches, consisting of hydrofluoric acid (HF) and nitric acid (HNO_3), can be used to produce three dimensional structures, such as ridges, tips and channels in samples that have been selectively spatially domain inverted[6]. Characteristically the walls produced were near vertical and extremely smooth (<5nm roughness).

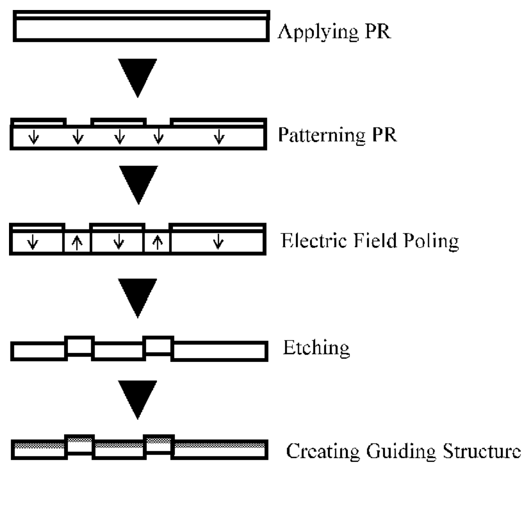

Fig. 1: Schematic diagram of fabrication steps

These features suggest several possible applications. Side access to the interaction region of a Mach- Zehnder modulator enables more efficient positioning of the electrodes, reducing the half-wave voltage and/or the interaction length required. The high refractive index difference between $LiNbO_3$ and the air cladding suggest both a reduction in bend losses and a reduction in size of integrated optical components.

The ridges produced have been fabricated into guiding structures by the three different methods of proton exchange (PE), ion beam implantation (IBI) and titanium indiffusion (TI) and the losses measured by a cut-back method.

Samples were supplied by Yamaju Ceramics, Japan, in the form of 300µm thick 3" diameter z-cut wafers with an optical polish. These were diced in-house to produce samples 15mm square. Photoresist (PR) was applied to the -z face and patterned to produce channel features parallel with the crystal y axis, with widths varying from 2µm to 20µm. Subsequent quasi-DC electric field poling using liquid electrode contact transferred the pattern from the PR to the ferroelectric domain structure in the sample. After cleaning, the samples were etched to create ridges ~5µm high. The etchant used consisted of $HF:HNO_3$ in a 1:2 ratio and was heated to 49ºC. At this temperature the -z face etches at ~2.4µm/hour, whilst the +z face is completely untouched.

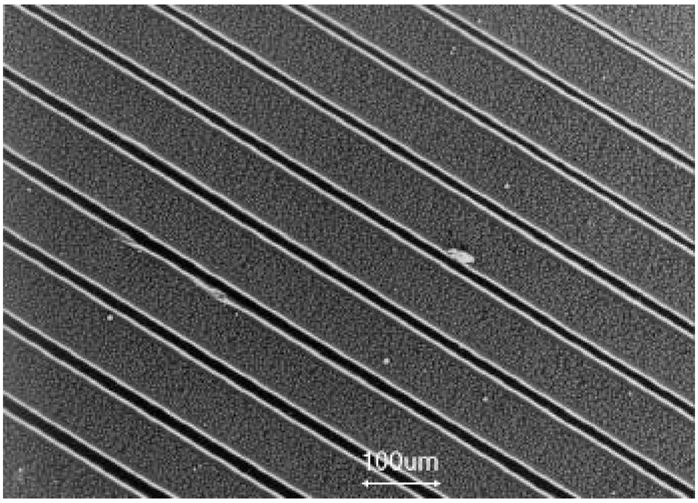

Fig. 2a: SEM micrograph of plan view of ridge structures showing different widths of guides

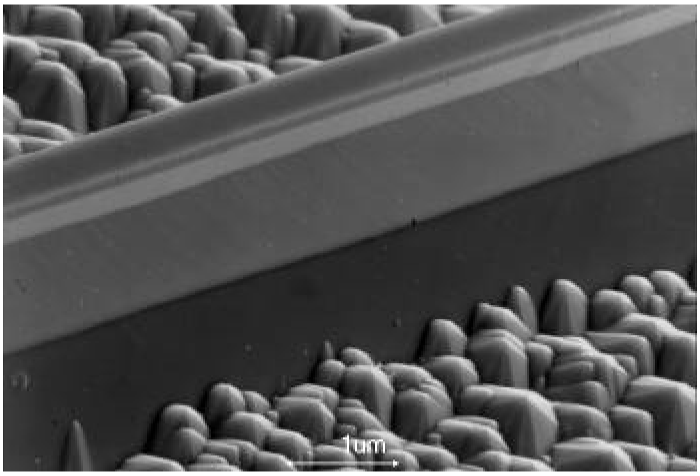

Fig. 2b: SEM micrograph of ridge structure, showing smooth sides and top.

IBI was performed at 77K, with 2.26 MeV $^4He^+$ ions at a dose of 1.6×10^{16} cm^{-2}. This produced a damage layer approximately 5µm below the surface whose refractive index was ~3% lower than bulk values [7].

PE consisted of immersing the sample for 6hrs 20min in molten benzoic acid diluted with 0.5%mol lithium benzoate at 240ºC. This produced an increase of the extraordinary refractive index by $\Delta n=0.12$ but a reduction of the ordinary refractive index, thus permitting TM polarisation guiding only. The proton exchanged region was formed by a combination of diffusion along the z and the x axes of the crystal, from the top and sides of the ridges respectively. The calculated depths of diffusion were 3.6µm and 5µm respectively.

TI involved the deposition of 200nm of titanium on the ridges, followed by heating of the sample to 1050ºC for 10hrs in a dry O_2 atmosphere. This produces a maximum refractive index increase in the diffused area of ~0.01 for the refractive indices [8]. The guiding region was calculated to be approximately 5µm deep.

The loss measurements were performed at 1.3µm using a pigtailed laser diode. The light was butt-coupled into the end polished guides fro
m a single mode fibre with a 9µm core diameter and the polarisation was set using a fiber polarisation controller. The output from the guides was imaged onto a calibrated powermeter.

Cutback measurements were made to separate guide losses from combined launch and other passive losses. Additional measurements were made at the He-Ne wavelength 632.8nm. Photorefractive damage was observed however, so the guides were annealed to remove any damage, and these measurements discontinued.

The pictures in figure 2 show the characteristic smoothness and near vertical nature of the structures produced. Whereas the etch is still proceeding in the rough area, the +z face which forms the top of the ridge, is left virtually untouched. Minor etching only occurs on this face at sites of surface defects.

Method	TE	TM
Ion Beam Implantation	4.11 $dBcm^{-1}$	2.07 $dBcm^{-1}$
Proton Exchange	Does Not Guide	50 $dBcm^{-1}$
Titanium Indiffusion	0.80 $dBcm^{-1}$	1.54 $dBcm^{-1}$

Table 1: Table of loss measurements for IBI, PE and TI in TE and TM polarisations

Table 1 summarises the results obtained. IBI can be an inherently lossy method of obtaining guiding, and the comparatively high losses measured in these guides are thus not surprising [7]. As expected the PE guides did not guide for the TE polarisation. The losses for the TM polarisation are high, ~50$dBcm^{-1}$ when compared with typical values of around 1$dBcm^{-1}$ achievable in planar guides [9,10]. The TI treated guides show the most promising results, with losses as low as 0.8$dBcm^{-1}$ achieved on these initial runs.We anticipate achieving losses lower than this value after optimisation.

We foresee a range of applications for these ridge guiding structures. As stated earlier, the large difference between guide and cladding indices permits tight bends, and hence compact device architecture. Access to side walls permits direct electrode access, and hence increased versatility compared to indiffused channels for example. Additionally, these micron sized ridges, when bonded to planar substrates allow the fabrication of ~μm^2 cross section channels for use in applications involving microfluidic flow devices [11], and we are currently pursuing these several directions.

It has been demonstrated that ridge guides suitable for integrated optics applications can be manufactured by electric field poling, differential etching and post-etch processing to complete a guiding structure. Of the three methods employed Ti indiffusion produced the most promising losses of <0.8$dBcm^{-1}$. Optimisation of process parameters should allow easy improvement of initial loss values. Potential applications are numerous and are currently under further investigation.

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References

[1] A M Prokhorov and Yu S Kuz'minov, 'Physics and Chemistry of Crystalline Lithium Niobate' Adam Hilger, Bristol, (1990)

[2] D Taverner, P Britton, P G R Smith, D J Richardson, G W Ross and D C Hanna Opt. Lett., **23**, 162, (1998)

[3] P E Britton, N G R Broderick, D J Richardson, P G R Smith, G W Ross, D C Hanna, **23**, 1588 , (1998)

[4] A A Oliver (ed), 'Acoustic Surface Waves' , Topics in Applied Physics vol 24, Springer-Verlag, (1978)

[5] N Niizeki, T Yamada, H Toyoda, Jap. Jnl. Appl. Phys., **6**, 318, (1967)

[6] I E Barry, G W Ross, P G R Smith, R W Eason, Mat. Letts., **37**, 246, (1998)

[7] P D Townsend, P J Chandler, L Zhang, 'Optical effects of Ion Implantation', Cambridge University Press, (1994)

[8] W K Burns, P H Klein, E J West, L E Plew, J. Appl. Phys., **50**, 6175, (1979)

[9] K K Wong, GEC J. Res., **3**, 243, (1985)

[10] A L Dawar, J C Joshi, V K Sharma, A Rustagi, A Kapoor, K N Tripathi, Opt. Eng., **32**, 101, (1993)

[11] P Gravesen, J Branebjerg, O S Jensen, J. Micromech. Microeng. **3,** 168, (1993)