Periodical domain inversion in singlemode Ti:MgO:LiNbO$_3$ channel waveguides

Y.L. Lee, H. Suche, G. Schreiber, R. Ricken, V. Quiring and W. Sohler

Periodic electric field assisted poling of low-loss (~0.1 dB/cm) singlemode Ti-diffused channel waveguides in MgO(5 mol%):LiNbO$_3$ has been achieved for the first time using a periodically patterned metal electrode under vacuum conditions and a homogeneous liquid ground electrode at atmospheric pressure. Using selective chemical etching, the periodic ($\Lambda \sim 17\ \mu$m) domain inverted structure is confirmed.

Introduction: Periodically poled LiNbO$_3$ waveguides are used for efficient all-optical wavelength conversion in fibre optic communications and spectroscopy, for all-optical signal processing and as the key component of tunable optical parametric oscillators [1, 2]. However, at the high intensities needed for efficient quasi-phasematched nonlinear interactions, photorefractive effects ('optical damage') can deteriorate the continuous wave (CW) performance of the wavelength converters. The shorter the wavelength, the stronger the optically-induced phase mismatch becomes, reducing the conversion efficiency significantly. There are two approaches to reduce photorefraction. One is to use high operating temperatures to increase the dark conductivity of LiNbO$_3$ [3]. The other is doping of LiNbO$_3$ with bivalent metal ions such as Mg^{2+} and Zn^{2+} to increase the photoconductivity [4]. An increased conductivity helps to shortcircuit the internal optically-generated space charge field which induces changes of the index of refraction via the electro-optic effect.

Among the different dopants, Mg^{2+} proved to be the most effective to reduce photorefractive effects [4]. Kuroda and Kurimura were the first to investigate a homogeneous domain reversal of MgO:LiNbO$_3$ at room temperature [5]. Harada and Nihei successfully applied the Corona discharge method for periodic poling of short MgO:LiNbO$_3$ bulk samples [6]. In such substrates waveguide fabrication by annealed proton exchange was investigated [7]. In this present contribution to our knowledge, the first demonstration of periodic domain inversion in Ti:MgO:LiNbO$_3$ channel waveguides is reported.

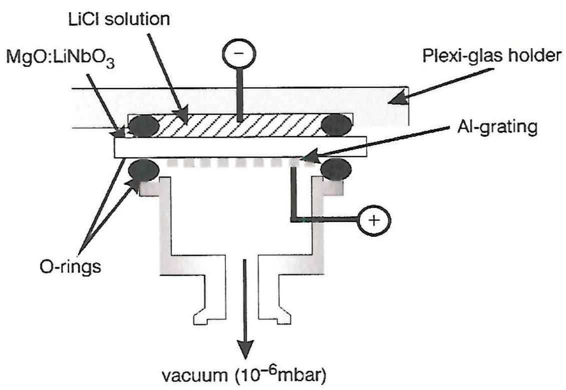

Fig. 1 *Schematic diagram of electric field poling setup*

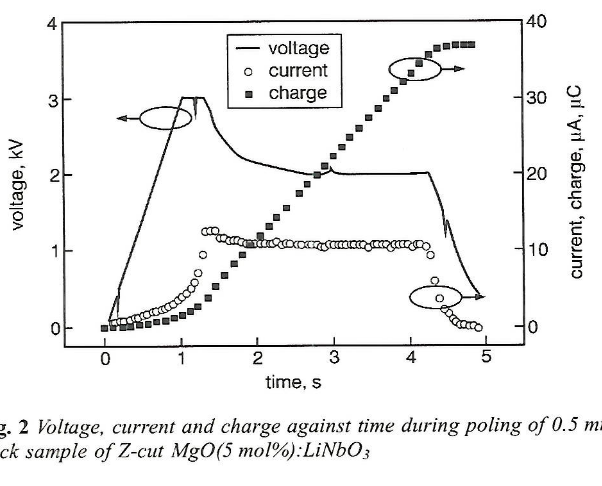

Fig. 2 *Voltage, current and charge against time during poling of 0.5 mm-thick sample of Z-cut MgO(5 mol%):LiNbO$_3$*

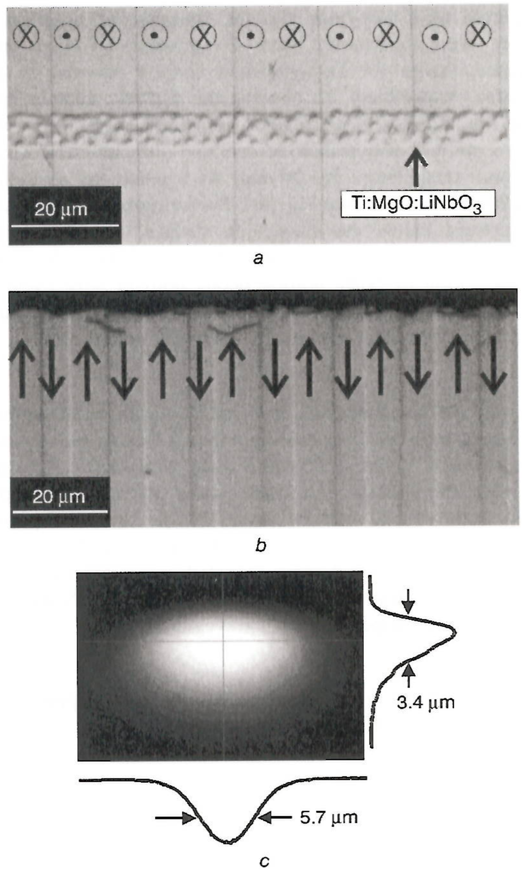

Fig. 3 *Periodic domain structure in MgO:LiNbO$_3$ after selective chemical etching and mode intensity distribution of Ti diffused waveguide at 1550 nm wavelength*

a On $+Z$ surface
b On $+Y$ surface
c Mode intensity distribution

Experiments: Singlemode channel waveguides were fabricated on the ($-Z$)-face along the crystallographic X-axis of 12 mm-wide (along Y), 0.5 mm-thick Z-cut MgO(5 mol%):LiNbO$_3$ substrate by indiffusion of 115 nm-thick and 7 µm-wide Ti stripes (15 h at 1130°C in an argon atmosphere with a 1 h postdiffusion at 1130°C in oxygene to reoxidise the material completely). These diffusion parameters significantly differ from the ones used for undoped (congruent) LiNbO$_3$ due to the much lower diffusivity of Ti in MgO:LiNbO$_3$ [8]. The waveguides were first characterised in terms of mode intensity distribution and loss at about 1550 nm wavelength. Intensity FWHM figures for the TM-mode size are 5.7 µm (along Y) $\times$ 3.4 µm (along Z), respectively (see Fig. 3*c*). The average propagation loss of the TM-mode of a number of waveguides was determined by the Fabry-Perot method [9] to be 0.1 dB/cm (with 0.06 dB/cm for the best channel). After waveguide fabrication and characterisation, complete domain inversion was done by the liquid electrode poling method [10] to have the waveguides in the $+Z$ surface. This allows a better uniformity of the subsequently fabricated microdomain grating as domain nucleation always starts on the $+Z$-face of the crystal. A periodic microelectrode (~17 µm period) was photolithographically defined in a sputtered 100 nm-thick Al-layer on the $+Z$-face. Afterwards, electric field poling was performed by applying the poling voltage to the patterned metal electrode in vacuum (1×10^{-6} mbar), whereas a homogeneous liquid (LiCl-solution) electrode on the backside of the sample was grounded (under atmospheric pressure) (see Fig. 1). The vacuum environment of the periodic metal electrode improves the insulation against the grounding electrode, but conversely reduces the surface conductivity of the substrate between adjacent fingers of the periodic. This helps to avoid merging of neighbouring microdomains. Fig. 2 shows voltage, current and integrated charge against time during the poling process. First, a higher voltage is applied to initiate the domain inversion everywhere along the waveguide independent of inhomogeneities of the coercive field strength of MgO:LiNbO$_3$. The average coercive field strength of 4.1 kV/mm and the spontaneous polarisation of 81 μC/cm^2 were determined from the measured voltage and the accumulated charge for homogeneous domain reversal of a well defined area, respectively. To observe the periodic domain inverted structure, the poled Ti:MgO:$LiNbO_3$ waveguide surface was slightly etched in a mixture of hydrofluoric acid and nitric acid (HF:HNO_3 = 1:2) at room temperature for 20 min. As a result the microdomain structure became visible (see Fig. 3*a*). Furthermore, to investigate the domain pattern below the waveguide surface, samples were cut, polished and selectively etched along the *Y*-faces. Fig. 3*b* shows the result in a region of fairly homogeneous domain duty cycle (58% average) and complete reversal normal to the waveguide surface. There are, however, other regions of fractional poling only.

Conclusion: We have fabricated low-loss Ti indiffused waveguides in *Z*-cut 0.5 mm-thick MgO (5 mol%) doped $LiNbO_3$ and obtained a periodical domain inverted structure using the electric field poling method with the periodic electrode under vacuum for improved insulation and reduced surface conductivity. Further experiments such as second-harmonic generation (SHG) are needed to investigate the homogeneity of the domain inverted microstructure and the reduction of photorefractive sensitivity of Ti:MgO:PPLN waveguides in comparison to undoped Ti:PPLN waveguides.

Acknowledgment: We gratefully acknowledge the support of this work by the European IST-project ATLAS.

22 April 2002
Electronics Letters Online No: 20020545
DOI: 10.1049/el:20020545

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