2152

Total internal reflection switching in electro-optically addressable domain-engineered $LiNbO_3$

Alexander J Boyland, Graeme W Ross, Sakellaris Mailis, Peter G R Smith, Robert W Eason

Abstract

We demonstrate a novel electro-optically addressable switch that uses electric-field controllable total internal reflection at an interface between two anti-parallel domains fabricated in single crystal $LiNbO_3$. With an applied field, the induced index change at the interface is sufficient to switch the beam from transmission to reflection with a contrast ratio exceeding 20dB in current samples.

Introduction

We have developed a novel electro-optically addressable total internal reflection (TIR) switch in a sample of z-cut domain-engineered congruent $LiNbO_3$. Electric field poling has been used to domain invert one half of the sample, producing a sharp boundary between the two anti-parallel domain regions. Such a switch has numerous advantages including ease of fabrication, high switching contrast ratios, (TIR is a 100% efficient process for reflection at an ideal interface), relatively low drive voltages, and a wavelength dependence that is less critical than other electro-optic devices such as Pockels cells. Although electro-optic modulation of periodically poled $LiNbO_3$ and $LiTaO_3$ structures has been implemented before for beam deflection, [1,2], to our knowledge such an electro-optic TIR switch has not yet been reported.

Device description

The $LiNbO_3$ was a 13.5mm x 15mm x 300μm z-cut sample supplied by Yamaju (Japan), and was photolithographically patterned and electric field poled to produce a structure consisting of two regions of opposite domain orientation. The boundary between these domain regions should ideally be very flat, straight and free from any residual poling-induced strain. In practice however, even after annealing the sample at 200°C for several hours, a small residual index difference of order 10^{-5} exists at this interface. Fresnel reflection from this interface at the grazing incidence angles used can still be significant, and this therefore affects the choice of incidence angle and hence the switching contrast ratio achievable. In practice, TIR switching fields, angle of incidence, quality of the interface and device length and thickness all affect the contrast ratio achievable. In this letter we show our first results from this device, and leave more detailed discussion for a future full-length paper.

An electric field, E_z, applied across the interface region (E parallel to crystal z axis), produces equal magnitude refractive index changes of opposite sign between the adjacent anti-parallel domain regions. If this value of index change is sufficiently large, TIR can occur for a beam incident on the interface at grazing incidence, (θ_{inc}~87°-89°), switching from transmission to reflection. A schematic for the TIR switch is shown in figure 1. The incident light was from a 0.5mW, *s* polarized green He-Ne laser (λ=0.543µm). This polarisation was chosen to access the largest electro-optic coefficient for $LiNbO_3$ ($r_{33} = 31 \times 10^{-12}$ mV^{-1}) [3]. The input beam was spatially filtered and focused into the 300µm thick sample using a lens of 160mm focal length, which produced a spot size in the middle of the device of order 40µm.

The index change Δn produced in either domain region from the applied field E_z is given by

$$\Delta n = -1/2\ r_{33}\ n_e^3\ E_z = \Delta n^*/2$$

(1)

where n_e is the extraordinary refractive index. The total index change, Δn^*, produced across the interface is twice this value, due to the local domain inversion. Switching effects have also been investigated for *p* polarised light, which accesses the r_{13} coefficient, which is roughly one third of r_{33}.

Results

Figure 2 shows results for transmitted and reflected powers versus voltage for *p* polarised light. Although the field required for TIR is higher with this polarisation, the results so far show improved beam quality over that for *s* polarization. The angle of incidence at the interface was ~89°. Figure 3 provides a direct comparison between the voltage switching characteristics for *s* and *p* polarization, at a similar angle of incidence, showing the expected reduced voltage requirement for *s* polarised light.

The transmission/reflection plots do not follow theoretical Fresnel reflectivity, as the incident beam is focused onto the interface, and therefore has some degree of angular divergence. These first results however show a contrast ratio for the transmitted beam of > 100:1 (20dB), and we expect this value to increase with improved interface quality and optimization of design parameters. Of importance here is the fact that apart from the values of electro-optic coefficient and refractive index there is no specific inclusion of a wavelength term in the switching field required. This is to be compared with conventional Pockels cells, for which the half-wave voltage is linearly proportional to wavelength.

Conclusions

To conclude, we have constructed a domain engineered electro-optic total internal reflection switch in a sample of $LiNbO_3$. This novel switching approach can be further improved and optimized, but already shows a good switching contrast ratio and the possibility for practical device implementation at longer infrared wavelengths.

Acknowledgements

The authors are grateful to the Engineering and Physical Sciences Research Council (EPSRC) for funding for AJB and grant no. GR/N00302

References

1. M.Yamada, M.Saitoh, H.Ooki, 'Electric-field-induced cylindrical lens; switching and deflection devices composed of the inverted domains in $LiNbO_3$ crystals'. Appl.Phys.Lett., **69**, 3659-3661, (1996)
2. K.T.Gahagan, V.Gopalan, J.M.Robinson, Q.X.Jia, T.E.Mitchell, M.J.Kawas, T.E.Schlesinger, D.D.Stancil, 'Integrated electro-optic lens/scanner in a $LiTaO_3$ single crystal', Applied Optics, **38**, 1186-1190, (1999)
3. R.S.Weis, T.K.Gaylord, 'Lithium niobate: summary of physical properties and crystal structure', Appl. Phys. **A 37,** 191-203 (1985)

Authors' affiliations

Alexander J Boyland, Graeme W Ross, Sakellaris Mailis, Peter GR Smith, Robert W Eason.

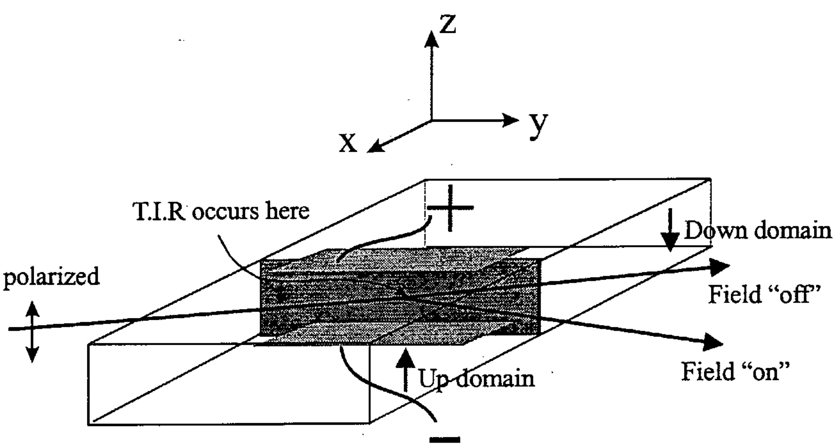
Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ

email: *ajb@orc.soton.ac.uk*

Figure Captions

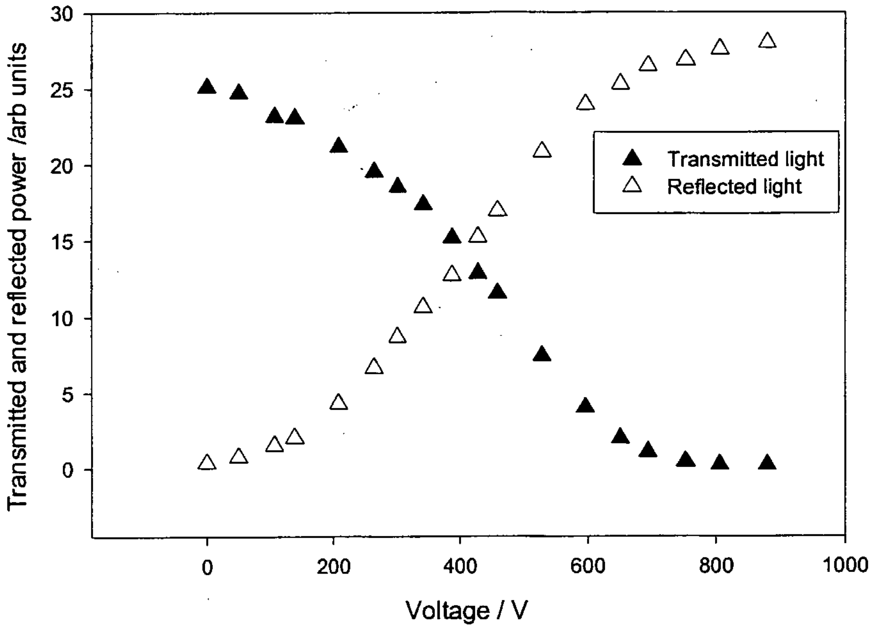
1. Schematic diagram for domain-engineered $LiNbO_3$ sample
2. Transmitted and reflected power as a function of voltage across interface
3. Comparison between transmitted *s* and *p* polarized input light

Figure 1



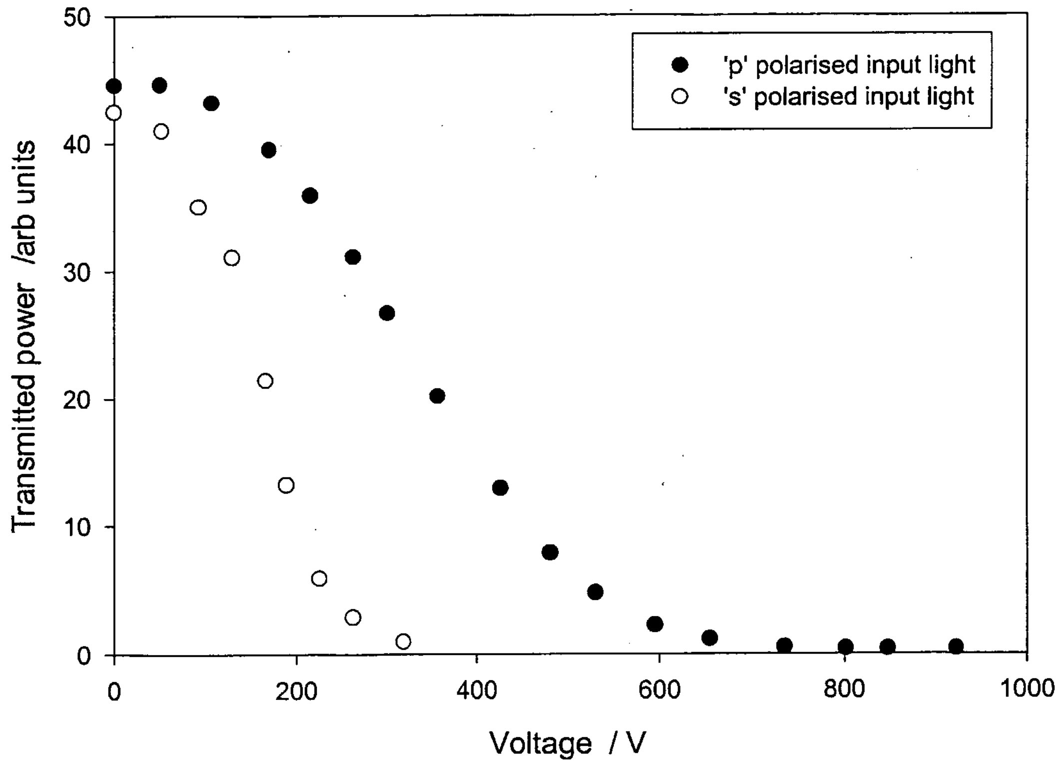
z
y
x
T.I.R occurs here
+
Down domain
' s ' polarized
Field "off"
Field "on"
Up domain
−

Figure 2



Transmitted and reflected power /arb units
30
25
20
15
10
5
0
0
200
400
600
800
1000
Voltage / V
Transmitted light
Reflected light

Figure 3



'p' polarised input light
's' polarised input light
Transmitted power /arb units
0
10
20
30
40
50
0
200
400
600
800
1000
Voltage / V