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Electro-optically addressable total internal reflection switch in domain-engineered $LiNbO_3$

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Abstract: We demonstrate a novel electro-optically addressable TIR switch in domain-engineered $LiNbO_3$. A sharp boundary between 2 anti-parallel domains totally internally reflects an incoming grazing incidence beam with a measured contrast ratio of greater than 20dB.

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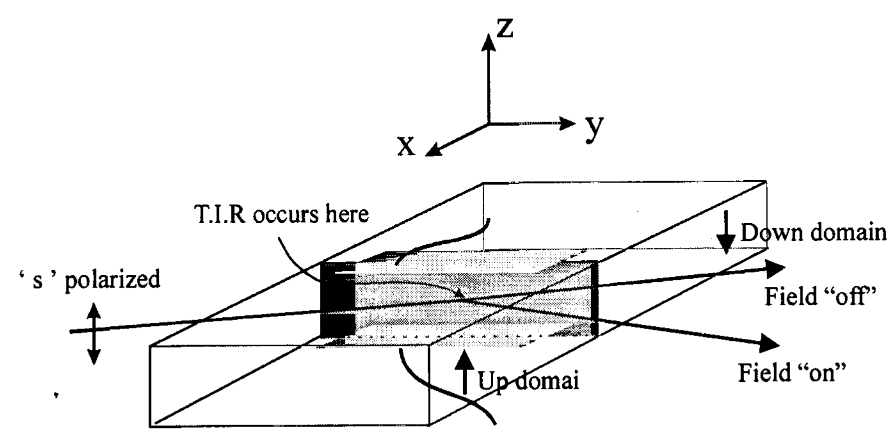
We have developed a novel electro-optically addressable total internal reflection (TIR) switch in a sample of $LiNbO_3$ that has been engineered to have a sharp boundary between two anti-parallel domain regions. Such a switch can provide numerous advantages including ease of fabrication, the possibility of high contrast ratios (TIR is a 100% efficient process), relatively low drive voltages, and a wavelength dependence that is superior to other electro-optic devices such as Pockels cells.

The $LiNbO_3$ sample is z-cut, and has been patterned and electric-field poled to produce equal areas of oppositely oriented domain regions. The boundary region should ideally be very smooth, and free from residual poling-induced strain. In our case we observe a static index difference at the boundary of between 1.5×10^{-5} and 2.8×10^{-5}, which affects the choice of angle for the grazing incidence beam and hence the contrast achievable experimentally. When an external electric field is applied to this boundary, equal magnitude refractive index changes of opposite sign will occur between the adjacent domain regions. If the value of index change is sufficiently large TIR can occur for the incident beam, thereby leading to switching of beam direction at the boundary from transmission to reflection. A schematic for the switch can be seen below in figure 1.

Figure 1. Schematic of switch.



Light incident on the boundary at an angle that is less than the angle for TIR will be transmitted through it. If however the light is incident on the boundary at angles greater than the TIR angle then it will be reflected with a theoretical efficiency of 100%. As the device consists of anti-parallel regions within a single electro-optic composite crystal the incident beam will only see a change in refractive index when a suitable field is applied. The change in index, applied electric field, TIR angle, and incident beam dimensions are all interdependent, but for suitably small angles, the whole beam can be arranged to undergo TIR at the boundary when a field is applied. Table 1 below lists example parameters for the switch. It should be noted that the effective index difference, Δn* produced via the normal electro-optic equation (1) should be doubled in this case, due to the equal and opposite sign change produced across the boundary,

$$\Delta n = -1/2\, r_{33}\, n_e^3\, E = \Delta n^*/2 \qquad (1)$$

where r_{33} is the electro-optic coefficient for this orientation, n_e is the extraordinary refractive index, and E is the applied electric field. The incident beam is extraordinarily polarized in our case, (*s* polarized input with respect to the plane of incidence) to experience the largest induced refractive index change.

Table 1. Example parameters for switching values for 300μm thick device.

Applied Voltage(V)	E(Vm^{-1})	Δn^*	θ_{TIR}(°)
10	3.33e4	1.25e-5	89.73
100	3.33e5	1.25e-4	89.15
1000	3.33e6	1.25e-3	87.33

We show below in figure 2 our initial results achieved for the transmitted and reflected powers versus voltage. Experiments have been performed for a range of incident angles, and applied electric fields, bearing in mind the residual index change measured at grazing incidence for the boundary region with no applied field. The results were obtained using *s* polarized light from a He-Ne laser at 543.5nm wavelength. It can be seen that the contrast ratio is at the 100:1 (20dB) level, and we expect improvements on this value once annealing has been performed on the material. We will further discuss the polarization selectivity, switching speed, and practical device implementation for longer infrared wavelengths.

Figure 2. Transmitted and reflected beam power versus applied voltage.