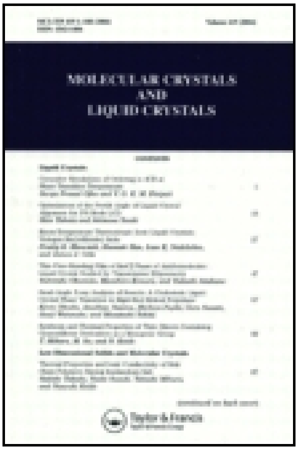


Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Fast Cholesteric Liquid Crystal Light Switch Based on Field-Controlled Total Internal Reflection

Per Rudquist [a] & Lachezar Komitov [a]
[a] Department of Physics, Chalmers University of Technology, S-41296, Göteborg, Sweden
Version of record first published: 24 Sep 2006.

To cite this article: Per Rudquist & Lachezar Komitov (1996): Fast Cholesteric Liquid Crystal Light Switch Based on Field-Controlled Total Internal Reflection, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 282:1, 387-393

To link to this article: http://dx.doi.org/10.1080/10587259608037592

Mol. Cryst. Liq. Cryst., 1996, Vol. 282, pp. 387–393
Reprints available directly from the publisher
Photocopying permitted by license only

FAST CHOLESTERIC LIQUID CRYSTAL LIGHT SWITCH BASED ON FIELD-CONTROLLED TOTAL INTERNAL REFLECTION

PER RUDQUIST AND LACHEZAR KOMITOV

Department of Physics, Chalmers University of Technology,
S-41296 Göteborg, Sweden

Abstract A new fast cholesteric liquid crystal light switch with response times in the microseconds region is presented. Light is partially transmitted or totally reflected depending upon the field-controlled position of the optic axis in a uniformly aligned short-pitch cholesteric subjected on an electric field perpendicular to the helix. Its performance is temperature independent in a broad temperature range and a contrast ratio of 20:1 is achieved.

INTRODUCTION

In short-pitch cholesteric liquid crystals aligned in ULH (uniform lying helix) texture, the helix axis takes on the properties of a macroscopic optic axis. Recently, flexoelectricity has been found to give rise to a linear electro-optic effect in cholesterics when an electric field is applied normal to the helix axis[1,2]. The effect seems to be very promising for applications due to the large values of the field-induced deviation of the optic axis of the cholesteric layer and in some materials, an induced tilt approaching 30 degrees has been achieved[3]. To a great extent the induced tilt is a linear function of the applied field and can be also temperature independent, which is a big advantage. Moreover, the response time of the effect is very short, usually in the microsecond region.

The electric-field-controlled total reflection by nematics has been used in different optical devices almost 20 years ago starting with the pioneering work of R.A.Kashnow and C.R.Stein[4]. Since then, a couple of new devices operating on this principle have been developed using nematics or smectics[5-8].

In this work we present a new fast cholesteric liquid crystal optical switch based on the linear electrooptic effect in a uniformly aligned cholesteric layer and the field-controlled total internal reflection at the boundary of a high index glass prism and the cholesteric layer.

EXPERIMENT

Device operational principle

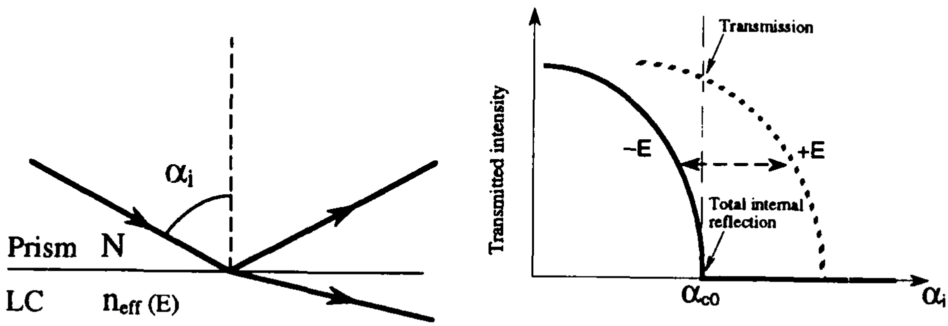
The critical angle of incidence for total internal reflection α_c at the prism-liquid crystal interface, according to Figure 1, is given by

$$N \sin\alpha_c = n_{eff}(E) \tag{1}$$

where n_{eff} is a function of the field-controlled direction of the optic axis. At α_c we get for TE light

$$n_{eff} = \frac{n_\parallel n_\perp}{\left(n_\parallel^2 \sin^2\phi(E) + n_\perp^2 \cos^2\phi(E)\right)^{1/2}} \tag{2}$$

where $\phi(E)$ is the angle between the optic axis and the electric field vector of the light. $n_\parallel$ and $n_\perp$ are the refractive indices parallel and perpendicular, respectively, to the optic



a) b)

FIGURE 1 a) Transmitted and reflected light beam at the boundary between the high index glass prism and the liquid crystal. b) Schematic transmitted light intensity as a function of angle of incidence for -*E* (solid curve) and +*E* (dashed curve). For fixed $\alpha_i = \alpha_{c0}$ the device is switching between partial transmission (+*E*) and total reflection (-*E*).

axis of the cholesteric layer aligned in ULH texture. Thus, we can calculate α_c for all $\phi(E)$ provided that $N > n_{eff}$ as $\alpha_c = \arcsin(n_{eff}/N)$ and α_c appears to be a field dependent quantity (Figure 2).

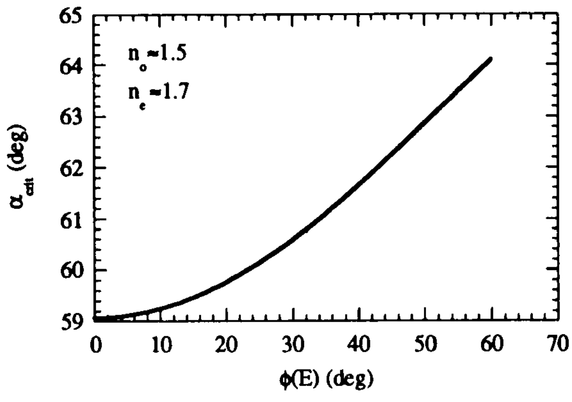


FIGURE 2 α_c as a function of the field controlled position of the optic axis ϕ(E) with a convenient choice of n_e and n_o.

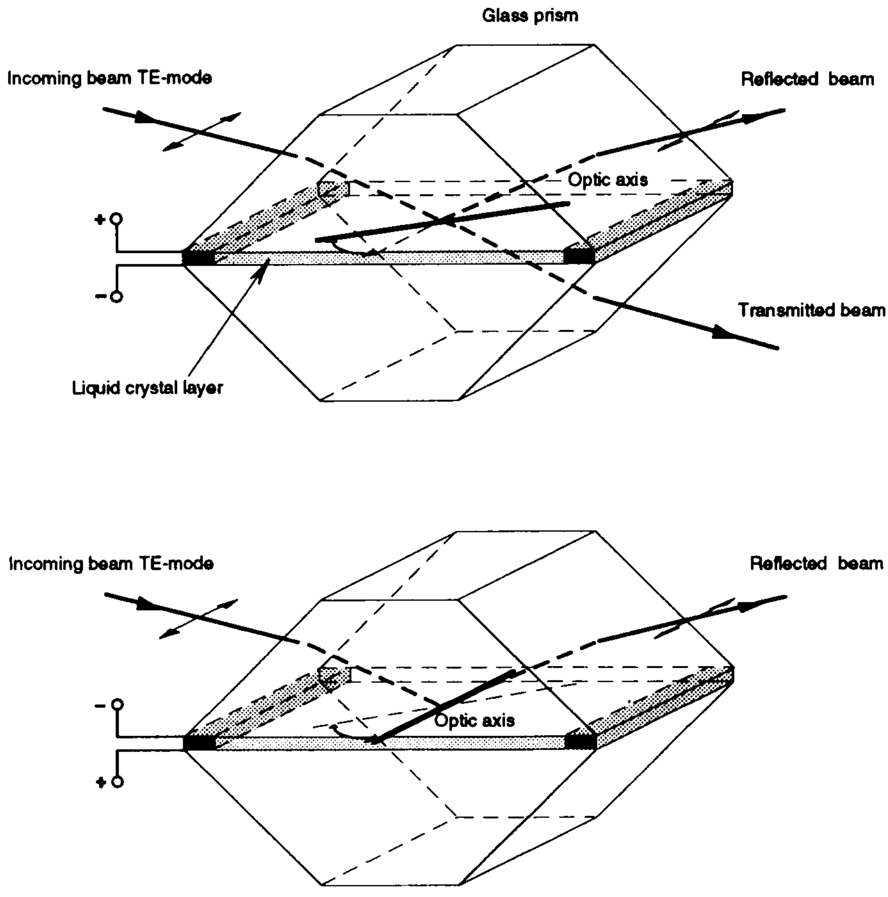


FIGURE 3 Schematic illustration of the switching of the light beam with TE polarization by the cholesteric switch device.

Let us define α_{c0} as the critical angle of total internal reflection for $\phi(E) = 0$ giving $n_{eff} = n_{\parallel}$. The conditions for transmission and total reflection is then $\alpha_c > \alpha_{c0}$ and $\alpha_c < \alpha_{c0}$, respectively. The operation of the light switch is illustrated in Figure 3. As we shall see later it turns out that the device, depending on the choice of the initial angle of light incidence, can operate in two different modes, as:

- an electro-optic switch
- a continuous electro-optic light modulator

Electro-optic characteristics of the cholesteric material

First, we studied the electro-optic characteristics of the short-pitch cholesteric material (TI827 Merck) in a sandwich cell with thickness of about 2 μm. In order to attain ULH texture, the cell was sheared under an electric field[2,3]. The electro-optic characteristics of the material were measured in the set-up described elsewhere[9]. As can be seen, the

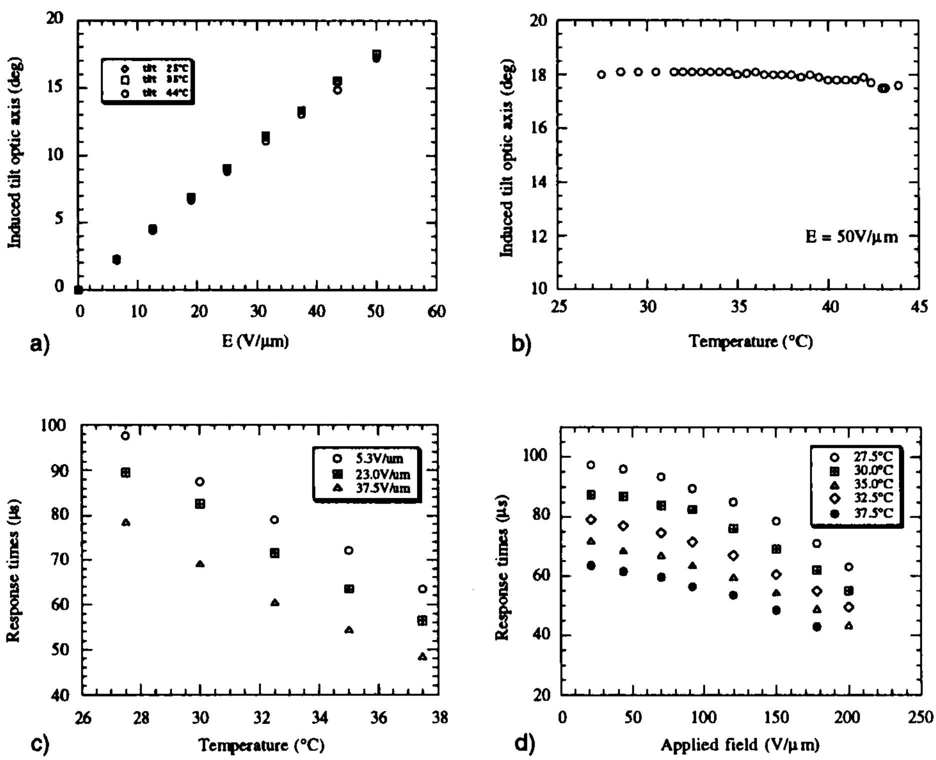


FIGURE 4 Electrooptic characteristics of the cholesteric mixture TI827 measured in a sandwich cell with gap of 2 μm.

induced tilt of the optic axis is a linear function of the applied field and large values of the tilt have been achieved at moderate electric fields (Figure 4a). Remarkably, the field-induced tilt of the optic axis is almost a temperature independent quantity (Figure 4b). The measured response times are in the microsecond region and do not change substantially neither with the applied voltage nor with temperature (Figures 4c and d).

Cholesteric light switch device

The light switch consists of two 45° high refractive index prisms (N=1.748) whose hypotenuses form a cavity of 4 μm thickness filled with the short-pitch cholesteric material TI827 aligned in ULH texture. The ULH-alignment was achieved by unidirectionally rubbed polyimide coatings deposited on the prism hypotenuses. On cooling from the isotropic phase under a high ac electric field with frequency of about 2kHz the helix oriented along the rubbing direction. The rubbing direction was chosen to give an angle between the zero-field optic axis and the electric field vector of the TE wave of 15°. The quality of the alignment was checked by polarizing microscopy and even if the achieved ULH-texture was not homogeneous over the entire cell area, monodomains large enough for studying the switching characteristics of the device were available.

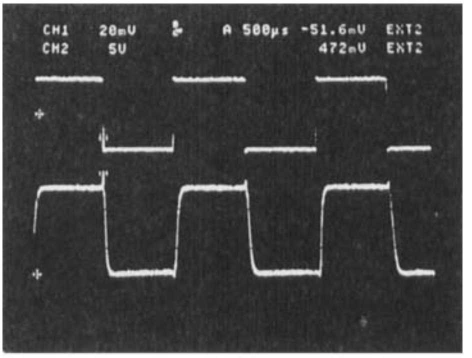
Experimental technique

The light switch was placed on a rotating table with the plane of light incidence parallel to the table. A HeNe-laser was used as light source and a $\lambda/4$ wave plate and a polarizer assured pure TE-polarized light hitting the device. The transmitted light intensity as a function of the applied electric field was monitored at room temperature by means of a photo diode and an oscilloscope, respectively.

Device performance

The hypotenuse of one of the prism was illuminated by the laser beam at an angle of incidence α_i equal to the critical angle α_{c0} of total internal reflection for TE. As mentioned above, the zero-field optic axis corresponds to $\phi(E=0)$ = 15° and a field-induced tilt of the optic axis of ± 15° then makes the device operate as a light switch, switching the beam between two states - transmission (bright state) and total reflection (dark state), cf. Figure 5a. The response times of the device correspond to those measured in the sandwich cell and a contrast ratio of about 20:1 was obtained. If α_i is set to be lower than α_{c0}, the device can work as a linear modulator, see Figure 5b.

a)



b)

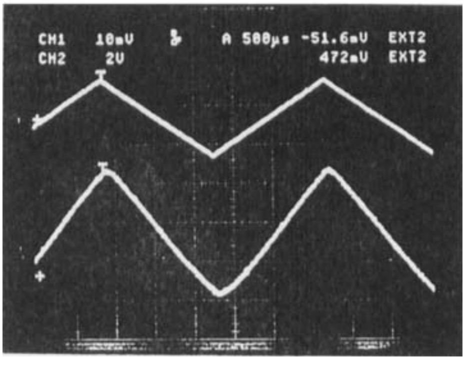


FIGURE 5 Applied voltage (upper curve) and transmitted light intensity (lower curve) for a) switching mode and b) modulation mode. Photographs are taken from the oscilloscope screen.

DISCUSSION AND CONCLUSIONS

The electro-optic response due to flexo-electric effect in cholesterics has demonstrated very promising features suitable for applications in the field of electro-optics such as light switches and modulators. The high switching speed and the large induced tilt angles of the optic axis are the most remarkable characteristics of such devices.

In this work, we present for the first time a fast cholesteric liquid crystal light switch based on field-controlled total internal reflection. The two device operational modes, as light switch and modulator, respectively, are demonstrated. Still, the achieved contrast is not very high but it should be significantly increased if the cholesteric layer would be aligned in a perfect homogeneous UHL texture, without defects and inhomogeneities. However, the achievement of such uniform alignment over the whole device area is still a problem and require a lot of efforts to be solved positively.

ACKNOWLEDGEMENTS

We would like to thank Dr Keith G. Archer for supplying us with cholesteric mixtures. This work was supported by the Swedish Research Council for Engineering Sciences under contract TFR 95-807.

REFERENCES

1. J.S.Patel, R.B.Meyer, Phys. Rev. Lett., 58, 1538 (1987)
2. P.Rudquist, L.Komitov, S.T.Lagerwall, Phys. Rev.E, 50, 5020 (1994)
3. P.Rudquist, M. Buivydas, L.Komitov, S.T.Lagerwall, J.Appl.Phys., 76, 7778 (1994)
4. R.A.Kashnow, C.R.Stein, Appl.Optics, 12, 2309 (1973)
5. G.Labrunie, S.Valette, Appl.Optics, 13, 1802 (1974)
6. S.Synov, V.Synov, L.Komitov, Quantum Electronics (Russ), 5, 1396 (1978)
7. R.A.Soref, D.H.McMahon, Optics Lett., 5, 147 (1980)
8. S.S.Bawa, A.M.Biradar, K.Saxena, S.Chandra, Appl.Phys.Lett., 57, 1479 (1990)
9. L.Komitov, S.T.Lagerwall, B.Stebler, A.Strigazzi, J.Appl. Phys., 76, 6 (1994)