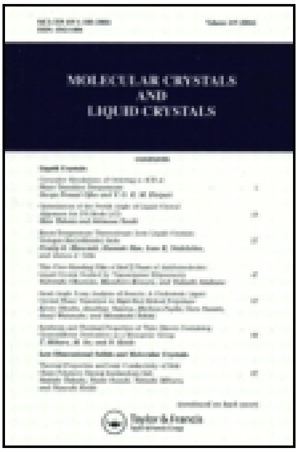

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ELECTROCLINIC LIGHT SWITCH

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Abstract : A light switch based on the electroclinic effect in the chiral orthogonal smectic phases (A*, B* and E*), aligned in a bookshelf geometry, is described. The switch consists of a linear polarizer, a double electroclinic cell and a $\lambda/4$ optical plate. The switch can be used as an optical element for performing logic operations based on different polarization states of the light. Corresponding to zero electric field and to opposite sign of the applied electric field the light after passage of the switch, can be in one of three different polarization states. If the incoming light is linearly polarized these states can, by mutual adjustment of polarizer and $\lambda/4$ plate, be chosen for instance as two orthogonal linear vibrations and one circular, or two orthogonal circular vibrations and one linear.,Moreover, the electroclinic switch is characterized by a fast response time (of the order of a few μs), which is the same independent of switching direction.

Introduction

The electroclinic effect is a field induced molecular tilt in the orthogonal smectic phases built up of chiral molecules, such as the phases A*, B* and E* / 1 - 4 /. The induced tilt is linear in the applied electric field. Moreover, typical response times may go below 1μs at room temperature. These features make the effect very attractive for applications in such fields as optical logic and computing elements, optical processors or modulators and switches in general. Recently, different combinations of liquid crystal cells, utilizing the electroclinic effect with retarders and polarizers were described and their characteristics were discussed / 5 /. It was shown that a double electroclinic cell, a package consisting of two electroclinic cells designed as half-wave plates, would rotate the direction of the light polarization by 90 degrees when an optimum molecular tilt of 11.25 degrees is induced by the applied field. At present, a few mixtures are available yelding this tilt at room temperatures and at moderate field strengths/ 6 /.
In this paper we describe an electroclinic light switch consisting of a linear polarizer, a

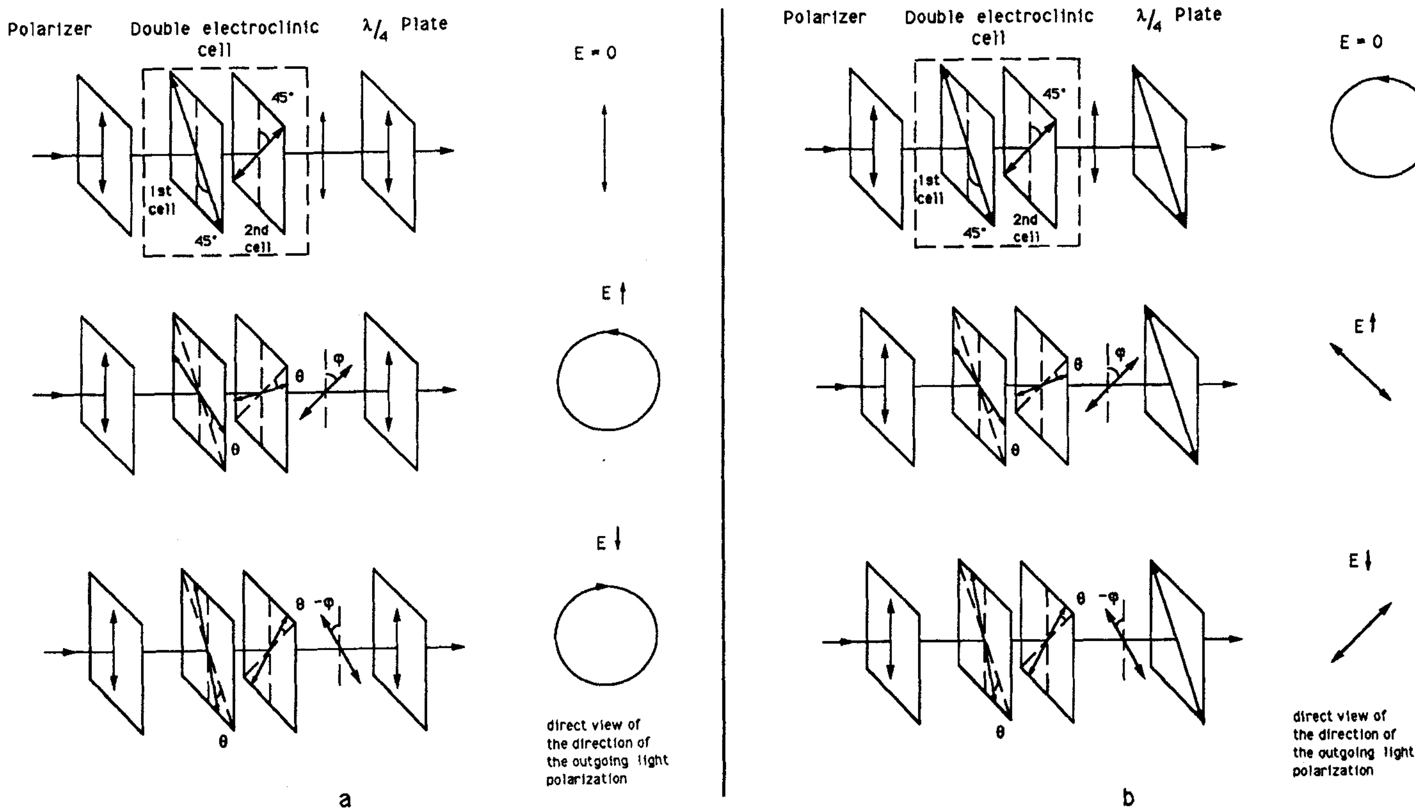


Fig.1 The arrangement of the electroclinic light switch elements in the two described configurations. At E=0 the optic axes of the two electroclinic cells are crossed and the transmission direction of the polarizer is at 45°with respect to them. The fast optic axis of the λ/4 plate can be oriented either parallel (a) or at 45° (b) to the polarizer. φ is the angle of rotation of the polarization of the incoming light by the electroclinic double cell.

With this mixture, the cells satisfied approximately the λ/2 plate condition for a thickness of about 2 μm. Two electroclinic cells were piled together to form a thin package (the double electroclinic cell) in such a way that their optic axes are mutually perpendicular. In order to form the light switch, the double cell was placed between a polarizer, with transmission direction being at 45 degrees with respect to the optic axes of the single cells, and a λ/4 plate (see Fig. 1). The optic axis of the λ/4 plate was directed either parallel to the transmission direction of the polarizer (Fig.1 a) or at 45 degrees (Fig.1 b) with respect to it. If a dc voltage is applied to both electroclinic cells but with opposite polarities then the optic axis of the first cell turns clockwise, and that of the second one counter - clockwise. When the value of the induced molecular tilt becomes 11.25 degrees then the double cell turns the polarization plane of incoming light by φ = 45 degrees clockwise or counter - clockwise, depending of the polarities of the applied voltage. Without any voltage applied, the linearly polarized light passes through the double cell unchanged. Then, combining the cell properly with a λ/4 optical plate one can switch between three different end states of which the polarisation and direction of polarization are dependent on the mutual adjustment of the components, as is shown in Fig.1 a and b. The polarization state of outgoing light before and after the λ/4 plate was determined in the standard way using an additional λ/4 plate combined with a linear polarizer. The additional λ/4 plate and the polarizer were turned independently, until a minimum of the light intensity was found. The optical signal was detected by a photodetector, the set-up being shown in Fig.3.

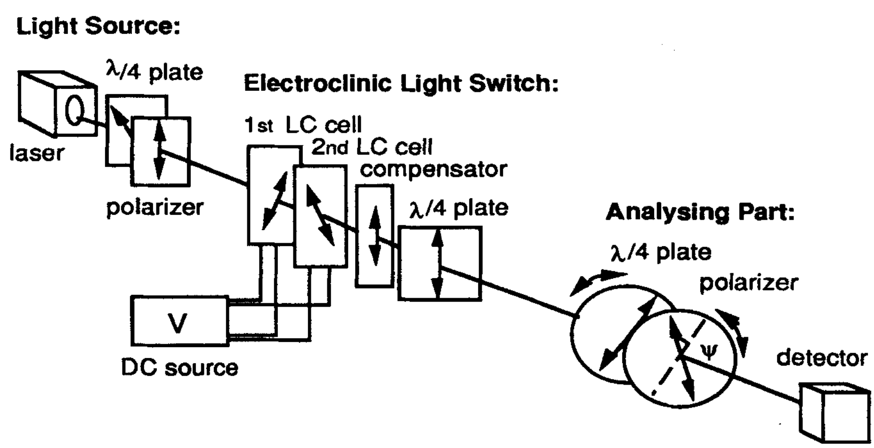


Fig.3 Set-up for the measurements of electro-optical characteristics of electroclinic light switch.

Then, the slow axis of the additional λ/4 plate corresponded to the polarization direction or, when the light was elliptically polarized, to the long axis of the ellipse. The angle between this direction and the one of the incident light is labelled as φ. The double electroclinic cell and a λ/4 optical plate (Fig.1), and demonstrate its electro-optical characteristics. With this device one can switch the outcoming light between three states of polarization with some freedom of selecting the convinient states.

Experimental

The cells used for the double electroclinic cell were of usual sandwich type with inner surfaces covered subsequently by ITO and SiO (evaporated at normal incidence). The liquid crystal mixture introduced into the cells was 870E from BDH with optical anisotropy $\Delta n = 0.17$. It possesses a smectic A* phase at room temperature which can be aligned in the desired bookshelf geometry (with smectic layers normal to the substrates) by the shearing technique. The field induced tilt angle θ and the response time τ as a function of applied voltage across a 2 μm thick electroclinic cell are given in Fig. 2 . For the lower temperatures the induced tilt starts to deviate from the linear relationship $\theta = e_c E$ and shows sign of saturation.

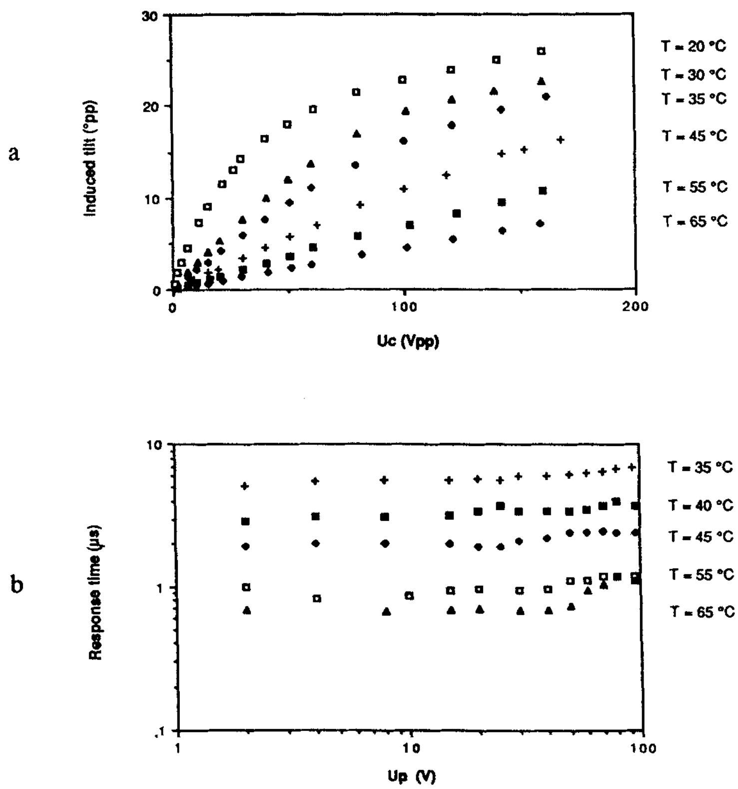
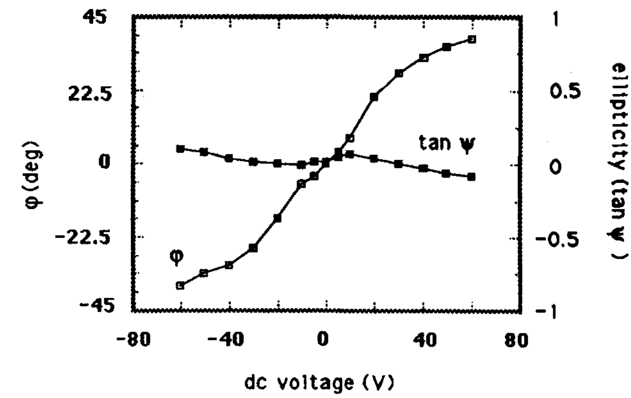
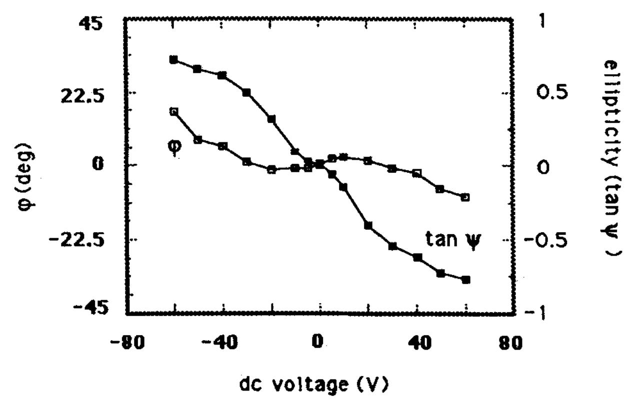


Fig.2 Induced tilt angle (a) and response time (b) as a function of applied voltage over a 2 μm sample of the mixture 870E.

ellipticity of the light is expressed by tan ψ, where ψ is the angle between the fast axis of the additional λ/4 plate and the transmission direction of the linear polarizer behind it. The angle 2ψ is then the latitude on the sphere in the Poincaré representation, where the positive values of ψ correspond to right handed polarization and the negative values to left handed polarization. Since our experimental cells deviated somewhat from the required λ/2 condition it was necessary to compensate the difference by inserting an adjustable compensator behind the double electroclinic cell. The compensation was exact at one voltage only, but it improves the device performance over the whole voltage range. In Fig. 4 is shown the performance of the double electroclinic cell compensated in such a way, with and without a λ/4 plate behind it.

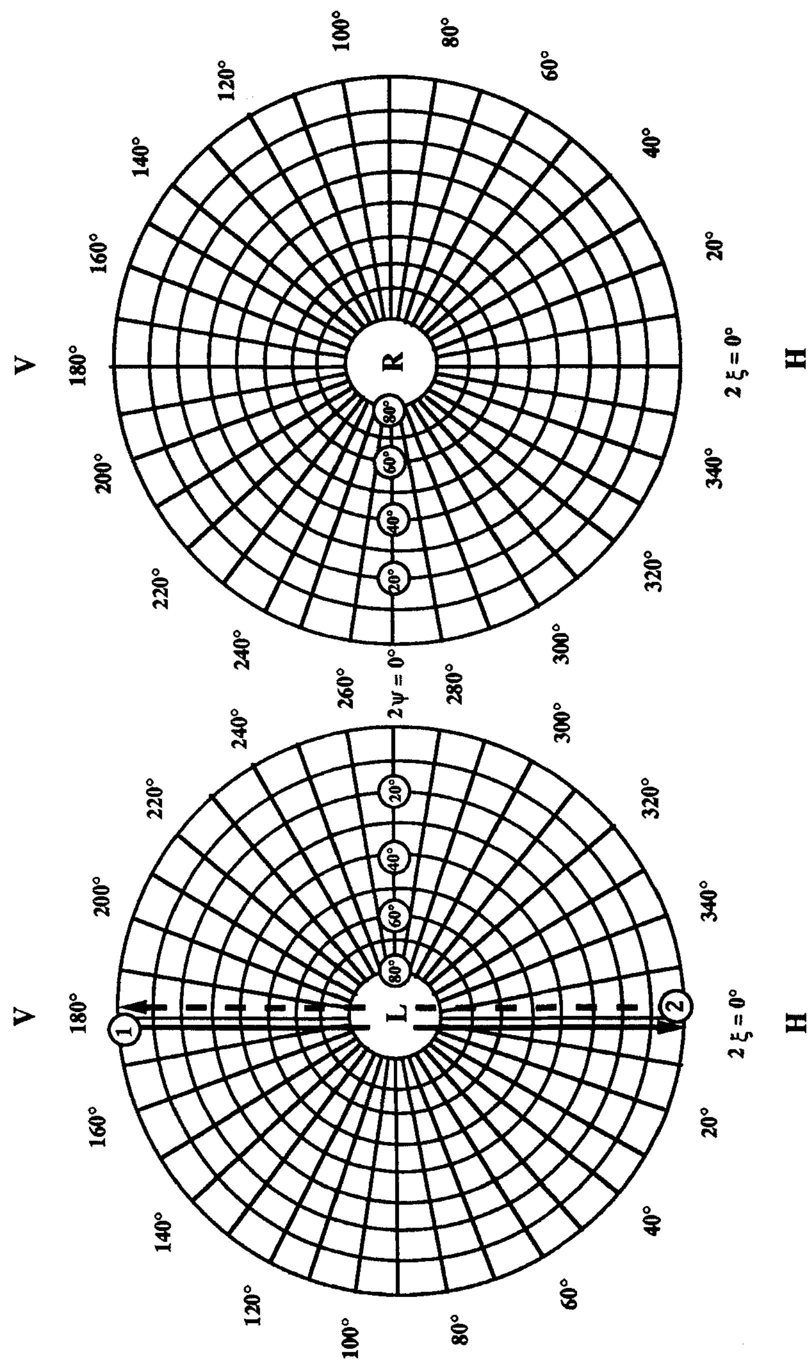


a

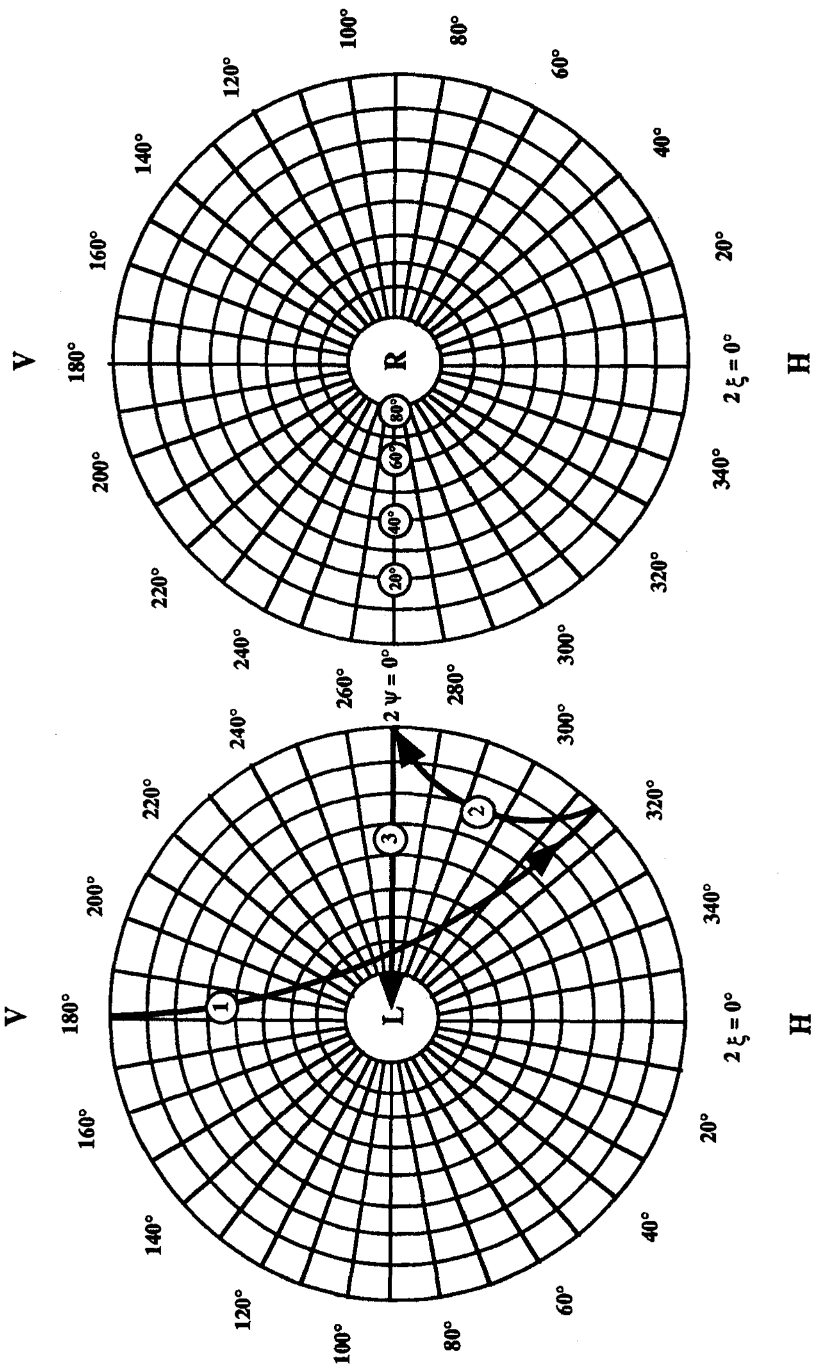


b

Fig.4 Electro-optical characteristics of electroclinic light switch in the arrangement shown on Fig.1 a, (a) without and (b) with λ/4 optical plate.



a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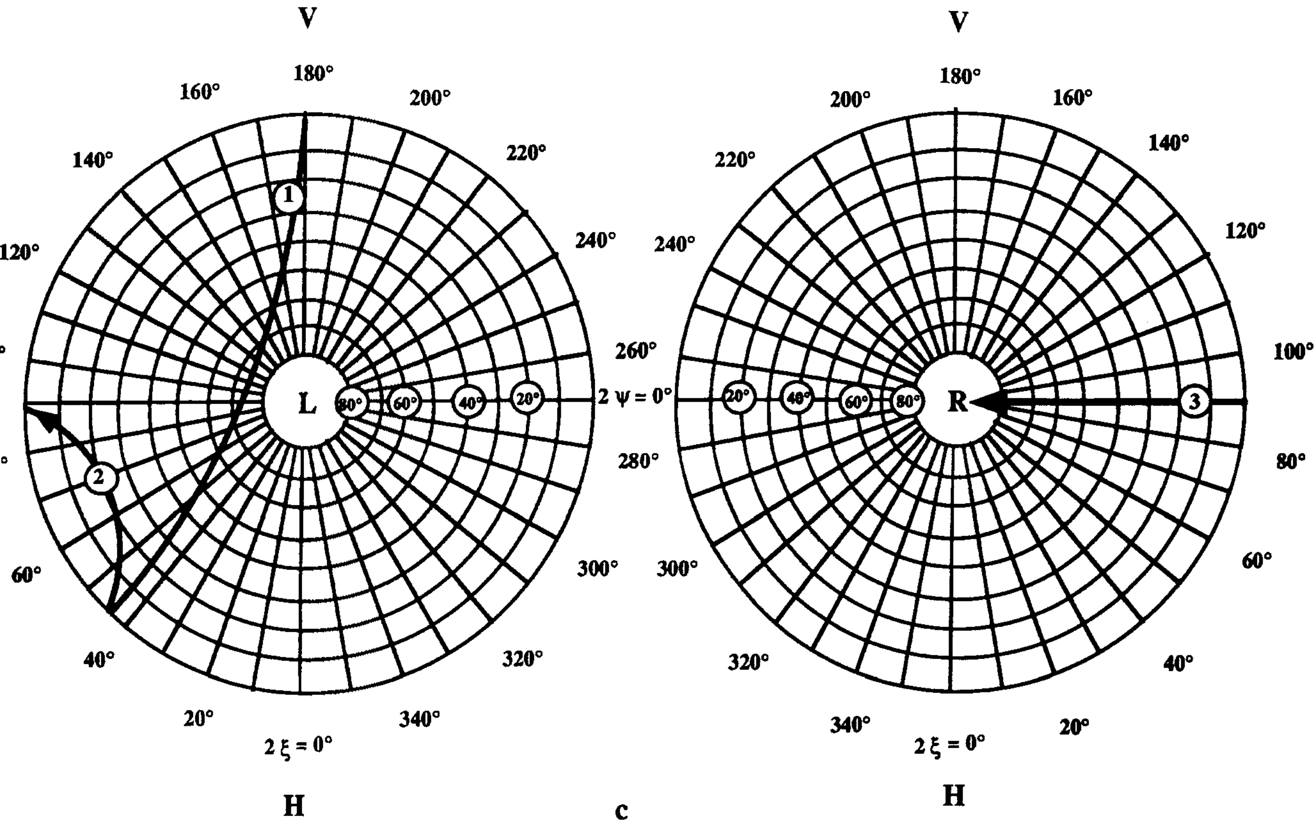
b



c

sphere representation of the electro-optical characteristics of electroclinic light switch. Any particular state of the light polarization is characterized by the 2ψ and longitude 2ξ of a point on the surface of the Poincaré sphere, where $\xi = \varphi + 90°$. The polarization state of outgoing ligh is shown when : a) no volt b) the applied voltage induces 11.25° tilt in the cells , c) the field applied to the cells are reversed. The arrows 1, 2 and 3 denote the light polarization afte of the first electroclinic cell, the second one and the λ/4 plate, respectively.

The polarization state of the light after passing the double electroclinic cell should be linear. However, in reality, for the A* mixture used and as a consequence of the not satisfied $\lambda/2$ condition for the whole range of applied voltages, the polarization state became slightly elliptically polarized, when φ was approaching 45 degrees (Fig.4 a). This deviation from the truly linear polarized state, caused an effective rotation of the incident light polarization direction by the $\lambda/4$ plate, as it is shown in Fig.4 b. The actual sample thickness of our empty single cells were found to vary slightly between 2.1 µm and 2.2 µm. With the HeNe wave length of 632,8 nm, the birefringence Δn of the A* mixture would have to be about 0.14 in order to satisfy the $\lambda/2$ condition at $d = 2.2$ µm. In reality Δn lies around 0.17. Mixtures with a birefringence in the range 0.14 to 0.16 would thus be highly desirable for full potential of this kind of device. With the materials development under way presently, such optimized mixtures ought to be readely available in the next future.

The switching behaviour of the device in the arrengement of Fig. 1 a, using a Poincaré sphere representation, is illustrated in Fig. 5. In the first chart, the vertical linear polarization of the incomming light is transformed to a horizontal position and back to its original state passing through the cells when no voltage is applied, and is consequently unchanged by the $\lambda/4$ plate (Fig.5 a). In the second chart, a voltage inducing an 11.5 degrees tilt in both cells (clockwise and counter-clockwise, respectively) is applied and the outgoing light appears with a circular polarization (Fig.5b). In the third chart, the voltage across the cells is reversed and, as a consequence, the handedness of the light polarization is reversed (Fig.5 c).

Conclusion

An electroclinic light switch is described and its electro-optical characteristics are presented. The device is capable of switching the light between three different states with response time of the order of a few µs. Using the polarization state logic, multiple uses can be foreseen in optical communication systems, in optical processing and optical computing.

Acknowledgements

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