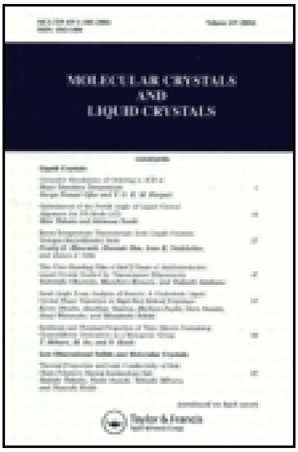

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Modulation of the Energy Coefficient of Reflection From Glass - Ferroelectric Smectic C* Interface in an Electric Field

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MODULATION OF THE ENERGY COEFFICIENT OF REFLECTION FROM GLASS - FERROELECTRIC SMECTIC C^* INTERFACE IN ELECTRIC FIELD

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Abstract Peculiarities have been studied of modulation of nonpolarized light in reflection from glass-plane parallel ferroelectric smectic C^* boundary in the vicinity of total-internal-reflection angle under the action of electric field. LC materials with optical inclination angle of the local director of the smectic layer with respect to normal to the layer 45^o are discussed.
Optical characteristics are studied of modulated light beam for the cases of one- and two-fold reflection from the boundary. The results of investigations makes it possible to contruct an LC-valve characterized byhigh transmission ($\approx$ 90%) of nonpolarized light in a wide spectrum range in the open state.

INTRODUCTION

Most light-switching devices based on nematic liquid crystals (NLC) operate in polarized light and, therefore contain polarization elements which considerably limit transmission in the open state. Thus, with modulation of nonpolarized light losses exceed 50% even in the best case. Another limitation that has been impeding the use of liquid crystals in light valves is their relatively low response speed. Progress made in the electrooptics of ferroelectric smectics has again made the use of LC valves a topical problem. However, in contrast to the class of nematics, where twisted and supertwisted structures hold a firm place, new materials possess a specific geometry that makes their fast and wide practical use highly problematic. This is connected with the fact that as the cell switches over to the open state is transmission is de-determined by the phase incursion between ordinary and extraordinary waves. Therefore, when laser light sources are used a rigid fixing of the layer thickness is required. In operation with natural light based on the phase- effect, sufficiently thick layer should be used (20 mm and higher) so that the transmission would not practically depend on thickness[1]. However, in this case, transmission of a cell (equipped with polaroids) in the open state would decrease by another factor of two and be equal to a quarter of the incident flux at maximum. Situation becomes better if thin layers (1.7 to 2.0 mm) are employed, and in this case the transmission can reach the level characteristic of traditional twisted nematic structures widely used in LC displays[2].

RESULTS OF INVESTIGATIONS

In order to increase transmission of a LC-valve in the open state, polaroids should be discarded. One of the versions of such geometry is proposed in our patent[3] We used twice the effect of total internal reflection from the glass-liquid crystal interface. The same geometry turned out to be most suitable to solve the problem of increasing the valve transmission in the open state in the case of using ferroelectric smectic C^* as an LC-material. The most convenient for the above purpose is the material whose structural inclination angle of the local director of mono-molecular layer with respect to smectic layer normal is equal to 45^o. An optical circuit of such a valve is illustrated in Fig.1 (a,b), where (a) corresponds to the open state and (b) to the closed state.

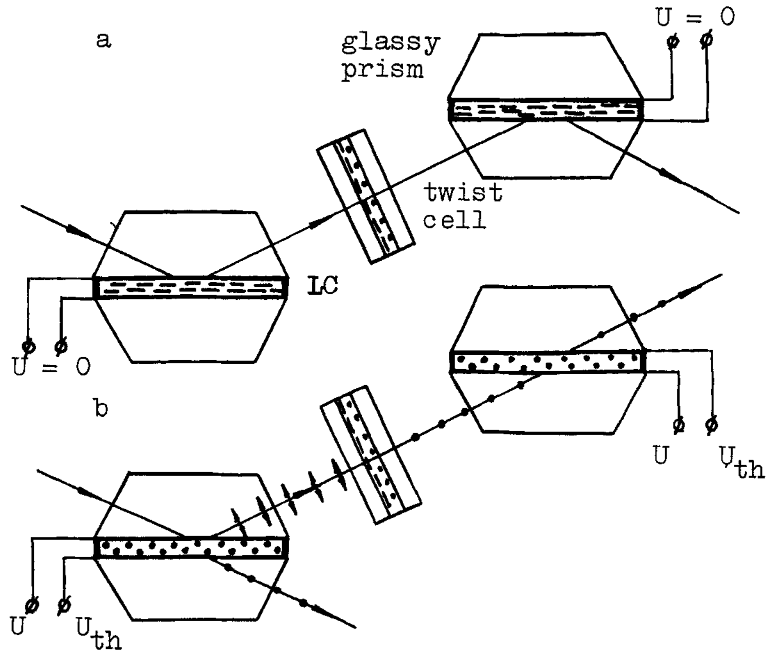

FIGURE 1.

If it considered that while reorienting itself in electric field the layer director moves along generator of a cone (which is typical of all ferroelectric smectic C^*) with an apex angle $\phi = 90^o$ in our case, then, changes in the energy reflection coefficients for the waves whose vector E oscillates in the incidence plane (R_p) and the plane (R_s) perpendicular to it as the director reorients itself from one state to the other will be described by known Frenel equations modified for a uniaxial crystal (we ignore weak biaxiality of smectics):

$$R_p = \frac{\left[n_e^2(\alpha)\cos\alpha - n_\perp\sqrt{n_e^2(\alpha) - n_\perp^2\sin^2\alpha}\right]^2}{\left[n_e^2(\alpha)\cos\alpha + n_\perp\sqrt{n_e^2(\alpha) - n_\perp^2\sin^2\alpha}\right]^2} \qquad (1)$$

$$R_s = \frac{\left[n_\perp\cos\alpha - \sqrt{n_o^2 - n_\perp^2\sin^2\alpha}\right]^2}{\left[n_\perp\cos\alpha + \sqrt{n_o^2 - n_\perp^2\sin^2\alpha}\right]^2} \qquad (2)$$

In this case, the refractive index for e-wave is related to the incidence angle by the following relationship:

$$n_e(\alpha) = \sqrt{n_{II}^2 - ((n_{II}^2 / n_\perp^2) - 1)n_\perp^2 \sin^2\alpha} \; ; \; (n_\perp = n_o) \qquad (3)$$

For ferroelectric LC materials used by us, the refractive indexes for o- and e-waves at room temperature are equal to $n_o = 1.50$ and $n_e = 1.66$, respectively. As a glass, we made use of a heavy crown glass (HC 21) with the refractive index n_e ($n_\perp = 1.66$).

Fig. 2 shows the dependences of the energy coefficients of reflection of the light beam from LC layer on the incidence angle α for p- and s-polarizations that are obtained by using Eqns. (1) and (2). Here, the total reflection angle for both polarizations (in geometry shown in Fig.1a) is equal to $\alpha_o = 64.6^o$.

Now, let us fix the angle α_i at a value $\alpha_1 > \alpha_o$ (for

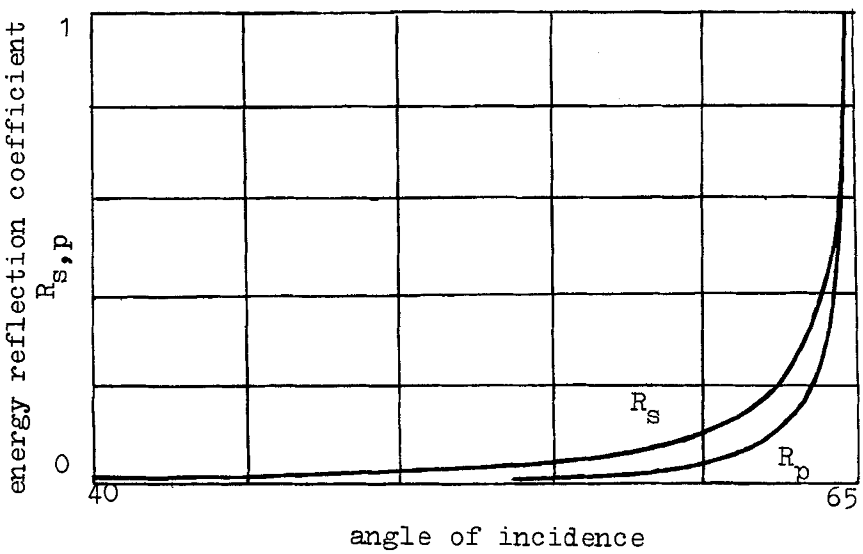

FIGURE 2.

example, $\alpha_1 = 75^o$) and apply to the LC layer an electric field sufficient for the the layer director to reorient itself to the position (b) (Fig. 1). Moving along the cone generator, it will rotate by an angle $\phi = 90^o$ in the substrate plane, while in the direction perpendicular to the substrates it will be deflected by an angle $\beta = 45^o$ from the substrate plane and, then, will turn back to its initial direction. In this case, rotation of the director in the plane parallel to the substrate planes will have no effect on the p-component of the reflected light beam, the s-component will diminish in proportion to ($\cos^2\phi$) and fall down to zero at $\phi = 90^o$. Changing of the director inclination relative to the substrate planes will cause a change in the refractive index of the extraordinary wave. The interrelationship of the total internal reflection (TIR) angles α_i and the director rotation angles β_i will be described by the following simple relation:

$$\alpha_i = \arcsin\left[\frac{n_\perp n_{II}}{n_\perp\sqrt{n_1^2\sin^2\beta_i + n_{II}^2\cos^2\beta_i}}\right] \quad (4)$$

which is illustrated in Fig. 3. As follows from the curve given, the value of $\beta_i = 45^o$ is obtained with the TIR angle $\alpha_i = 71.5^o$, which is greater than $\alpha_o = 64.6^o$. But since the

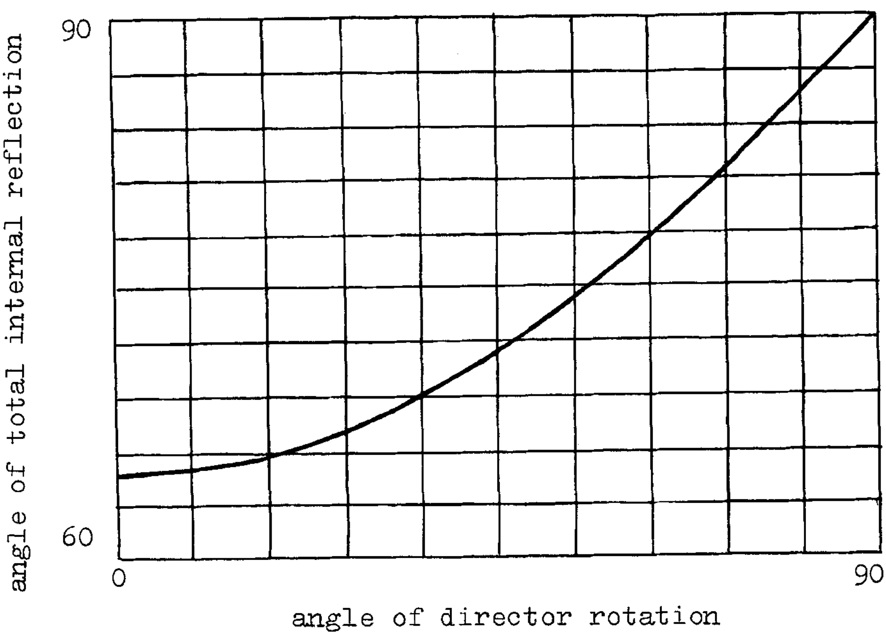

FIGURE 3.

initial incidence angle value was chosen to be equal to $\alpha_1 = 75^o$, this fact will not cause any disturbance of the TIR p-component and will not generate a jump of the reflection coefficient on the dependence $R = R_p + R_s\cos^2\phi$. As is seen in the optical circuit in Fig.1, between the first and second prism blocks there is a twist-cell which rotates the polarization plane of the light coming out of the first prism by 90^{o}, i.e. interchanges the R_s- and R_p-components. Hence, p-component that leaves the first prism undergoing no changes will turn into the s-component and will diminish in proportion to $\cos^2\phi$, while the s-component diminishing as it passes through the first prism will not be affected by the second prism block after it has passed the twist-cell. Consequently, in the geometry under consideration, switching of the whole light valve will result in changing of the reflection coefficient of the passing natural light by the following law: $R = R_o\cos^2\phi$, where ϕ changes from 0^{o} to 90^{o}. (Other cases, corresponding to α_1 values in the range from α_o to α_{imax}, can be easily analyzed by using the data given.

By changing smoothly the voltage across the prisms, we can control the reflection coefficient in a wide range. Further, by leaving a certain residual voltage across the prisms, it is possible to control the amount of maximum valve opening in the dynamic operation modes, thus, combi-combining valve and attenuator functions in one device.

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