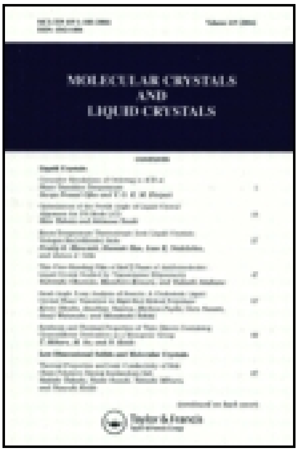

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HIGH-SPEED PRISM MODULATOR BASED ON LAGERWALL -CLARK EFFECT.

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Abstract A modulator for 400–2900nm spectral band and modulation frequencies up to 10 kHz is reported.

INTRODUCTION

Optical switches using ferroelectric liquid crystal (FLC) in a total internal reflection (TIR) configuration were introduced by Meadows, Handschy and Clark.[1] Bawa et.al. showed how to calculate rubbing direction and improved the aperture to length ratio.[2,3] In this paper we report the significant step forward in the optical response times. The method supposed for calculation of such a modulator makes it possible to obtain maximum air aperture angle, optimum value of modulator prism acute angle for given glass-FLC pair and the angle of rubbing direction.

CONSTRUCTION OF MODULATOR

The modulator geometry is similar to formerly described ones (Figure 1). Here β is acute angle of modulator prism, ψ_0 is the angle of rubbing direction. The angles ψ_+ and ψ_-

characterize the motion of director along the conical surface around the normal to smectic layers; γ_+ and γ_- characterize the modulator air aperture angle.

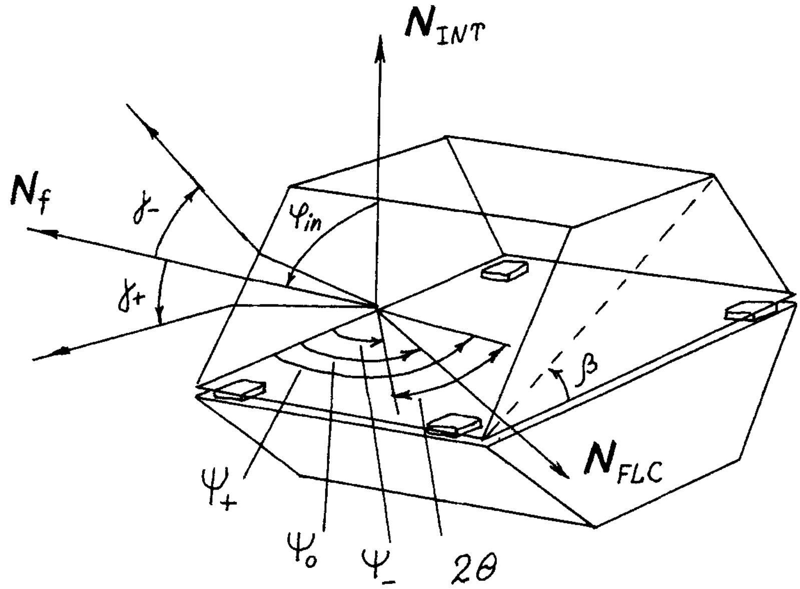

FIGURE 1 Geometry of prism FLC-based modulator. Here $\mathbf{N}_f$, $\mathbf{N}_{INT}$ and $\mathbf{N}_{FLC}$ are the normals to face, interface of modulator and FLC layers respectively, ϑ is the tilt angle of FLC.

THEORETICAL CONSIDERATION

A method, based on the solution of two combined equations[4-6], which we adapted for the case of director and incident ray displacement in different planes, was used for the calculation of modulator parameters. First equation connects the refractive indices of FLC layer and the second one is the refraction law for TIR situation:

$$n_e(\alpha) = N_o N_e \left(N_o \mathrm{Sin}^2\alpha + N_e \mathrm{Cos}^2\alpha \right)^{-1/2}$$

$$n_e(\alpha) = N_{GL}\ \mathrm{Sin}\ \varphi_{in}$$

Here α is the angle between the extraordinary ray direction and optical axis of FLC layer; $n_e(\alpha)$ and N_o are the indeces of refraction for extraordinary and ordinary rays; $N_e = n_e(90^\circ)$ is the principal value of the extraordinary refraction index. The angle φ_{in} is the angle of extraordinary ray incidence in glass.

We can connect the modulator parameters with these combined equations if we shall take into account the following. For every specified magnitude of extraordinary ray incidence angle φ_{in} (naturally, for $\mathrm{Sin}\ \varphi_{in} > N_o/N_{GL}$) there is the defined position of director in FLC layer plane, characterized by angle ψ, that is the boundary position between ON and OFF states of modulator. Formally for this magnitudes of φ_{in} and ψ we can put $\alpha = \psi$ (TIR situation). After this step the analytical connection between the parameters of optical materials and modulator parameters may be easily obtained. From expression for ψ (or α) one may receive the air aperture angle and rubbing direction, if ϑ value is known. Apart from ϑ value it is necessary to establish the ranges of variation of all refractive indices (i.e. the spectral region) and range of angle β variations. The simple computer program was prepared for specific calculation of modulator parameters.

OPTICAL MATERIALS

The STK8 glass was selected due to its high refractive index. The ferroelectric liquid crystal SZK-236 was chosen because of its high spontaneous polarization and considerable tilt angle value. Parameters of optical materials are listed in Table I.

TABLE I Parameters of optical materials.

Refrac. indices		Wavelength (nm)			Tilt angle (deg.)	Transition temperatures (°C)		Spontan. polariz. (nC/cm^2)
		435.8	578.0	632.8		$Cr \rightarrow S_C^*$	$S_C^* \rightarrow S_A$	
STK8		1.721	1.704	1.700				
SZK-236	N_o	1.511	1.495	1.493	27	0	56	100-110
	N_e	1.693	1.654	1.645				

RESULTS OF CALCULATION

The data from Table 1 were used for calculation of modulator parameters. The spectral region was chosen from 400 to 1500nm. The boundary refraction indices were obtained by graphical extrapolation using Cauchy formula with the first two terms taken into account. Figure 2 shows the existence of optimum value of acute angle β for obtaining some given aperture angle (for example, $2\gamma=10^\circ$). For this β (approximately 23°) it is necessary relatively small ($2\vartheta \simeq 34.5^\circ$) variation of the optical axis position in FLC layer plane to provide the given 2γ value. If the variations of β from optimum value achieve certain $\beta=\beta_1$ and $\beta=\beta_2$, the restriction of aperture angle $2\gamma=10^\circ$ takes place. The restriction of 2γ is determined by the extraordinary ray reflection for $\beta < \beta_1$ and ordinary ray transmittance for $\beta > \beta_2$.

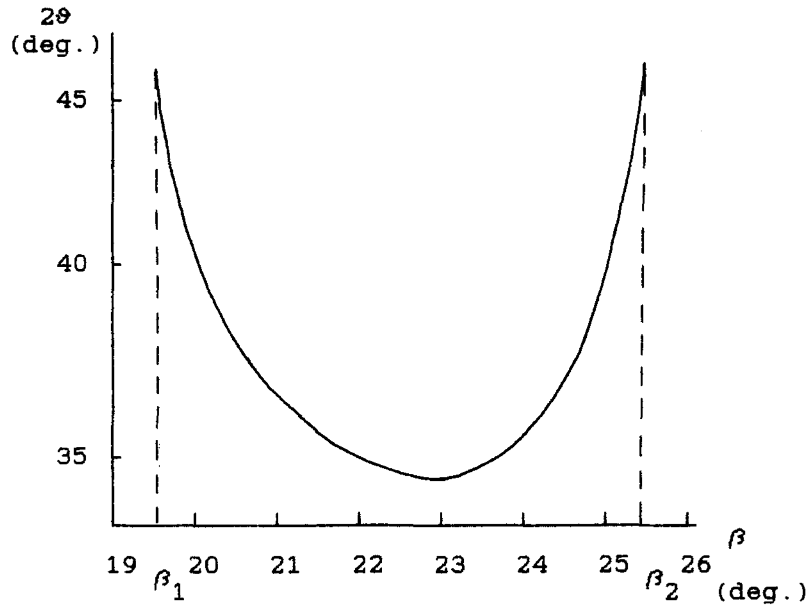

FIGURE 2 The angle 2ϑ versus acute angle β for simmetrical air aperture angle $2\gamma=10^{\circ}$.

Figure 3 represents the symmetrical air aperture angle as a function of 2ϑ angle. For $2\vartheta=54^{0}$, the calculation yielded $2\gamma \simeq 17^{0}$, i.e. the parameters of optical materials permit us to obtain considerable aperture angle of modulator.

EXPERIMENT

The test sample of such a modulator with $\beta=23.0^{\circ}$ and 5mm linear aperture was fabricated from the listed optical materials. The thickness of FLC layer, specified by teflon pieces, was $7\mu m$. For FLC orientation we have used the method, developed in the Institute of Crystallography of Russian Acad. of Science[7]. For testing this device the colli-

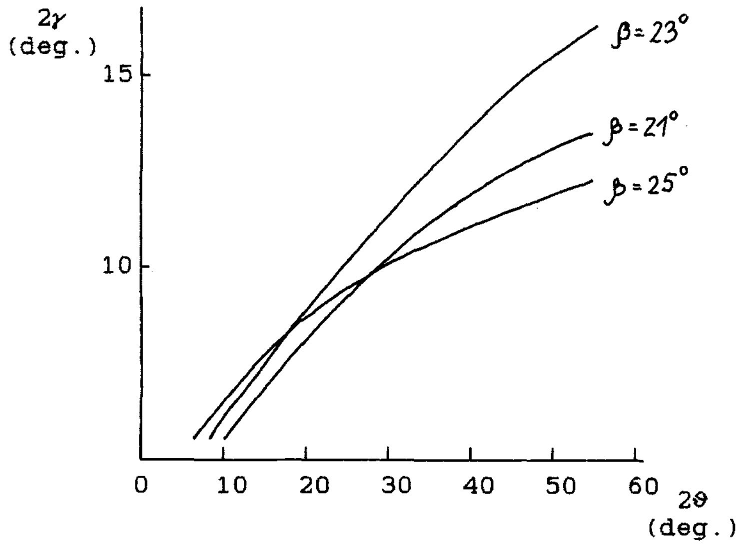

FIGURE 3. Symmetrical air aperture angle 2γ for three values of β as a function of 2θ (2θ angle is limited by $2\theta=54^{\circ}$ magnitude).

mated beam from incandescent lamp and fast silicon photodiode were used. The aperture angle measurements were carried out on a goniometer with a He-Ne laser as the light source. The main results are the following:

transmission of unpolarized beam (AR-coating is absent)	0.3
contrast ratio	$>10^4$
switching times	$\tau_1 = 18\mu s$
	$\tau_2 = 28\mu s$
driving voltage	± 24 V
aperture angle in air (λ=632.8nm)	17°
rubbing direction	49°

CONCLUSION

The considered device may be useful as a sound frequency rate modulator or liquid-crystal fiber-optic switch. Further investigations, including use of other materials and optimization of cross-talk performance, are in progress.

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