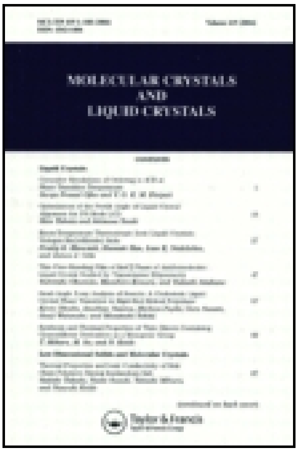

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LINEAR PRISM LIQUID-CRYSTAL POLARIZER

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Abstract A linear prism polarizers, based on oriented nematic liquid crystal layers, are considered. The operational parameters are given.

INTRODUCTION

In this paper we report the main characteristics of new family of linear polarizers - prism liquid-crystal polarizers (PLCPs).[1-3] Such polarizers use oriented layers of nematic liquid crystals as the anisotropic crystalline plate. The principal advantages of PLCPs against usual calcite porizers are the simplicity of production, low cost and possibility of obtaining large linear aperture. PLCPs may be useful for polarization of various sources in the spectral region from 300-400 to 2600-2900nm.

CONSTRUCTION OF POLARIZER

Such a device is well known deflector[4] without electrodes. A uniaxial oriented layer of nematic, which can be characterized by the refractive indices N_o for the ordinary ray and N_e for the extraordinary (principal value), is used in the PLCP. The action of the polarizer reduce to dividing the unpolarized light beam (when it is incident obliquely on the interface between the glass and oriented NLC layer) into two polarized components because of the total internal reflection of that component whose polarization correspond to the polarization of the ordinary ray (Figure 1).

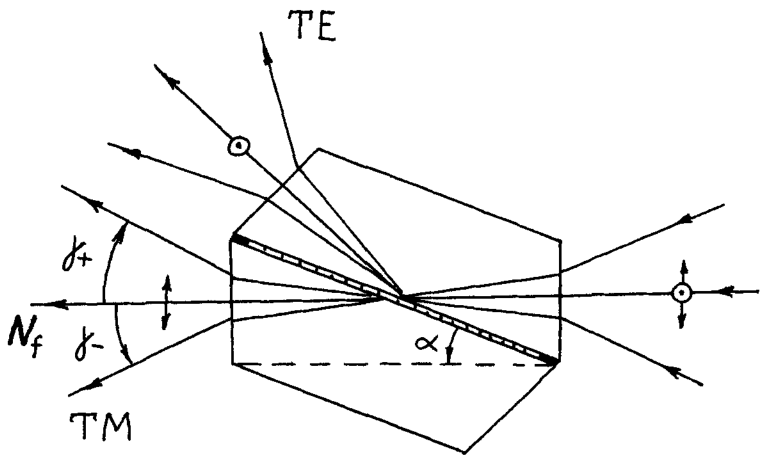

FIGURE 1 Schematic representation of linear prism liquid crystal polarizer. The heavy glass prisms are separated by teflon spacers. NLC layer has a homeotropic orientation.

Here N_f is the normal to PLCP face. The angles γ_+ and γ_- characterize the polarization field in air. The acute angle α of the polarizing prism satisfy the relationship

$$\cos \alpha > \frac{N_o}{N_{GL}}$$

where N_{GL} is the refractive index of the glass. It follows from this relation that a NLC with the smallest possible N_o and a glass with the largest possible value of N_{GL} must be used to obtain a compact polarizing prism.On the other hand such a polarizer posses the lowered transmission in UV and visible region; reduction of N_o is accompanied by the reduction of birefringence ΔN. This factors lead to decrease of PLCPs transmission and narrowing of the polarization field 2γ (γ_+ and γ_- with respect to normal to the entrance face, $\gamma_+ = \gamma_-$). Consequently, the choice of glass and NLC must be made on the basis of required parameters of PLCP.

OPTICAL GLASSES

Table I lists some of the parameters of the new and well known glasses, developed in S.I. Vavilov Optical Institute. The refractive indices N_{GL} are given for the wavelengths λ=435,8nm and 589,3nm.

TABLE I Optical glasses.

Glass	λ_{GL}^{UV}(0.9) (nm)	N_{GL} (435.8nm)	N_{GL} (589.3nm)	λ_{GL}^{IR} (nm)
Phosphate N 80	290	1.590	1.578	2750
Fluorophosphate N 53	320	1.608	1.594	2750
BF117-1320	355	1.640	1.621	2800
TF1	390	1.673	1.648	2650
TBF117-1246	360	1.720	1.693	2800
TBF11	390	1.957	1.833	2800
STF117-02	390	2.010	1.949	2850

The N_{GL} values for the other wavelengths in the region of transparency can be obtained by a graphical extrapolation using Cauchy formula with the first two terms taken into account. The short-wavelength transmission cutoff is denoted by $\lambda_{GL}^{UV}(0.9)$ and is determined for the 0.9 internal transmission level (for 1 cm). For PLCP with a light diameter ~20mm resulting transmission of device without antireflection coating amounts to ~ 0.5 (for all glass-NLC pairs) for so defined boundary wavelength. Table I also give the approximate values of the long wavelength transmission cutoff λ_{GL}^{IR}.

NEMATIC LIQUID CRYSTALS

Among the known NLC systems there are mixtures that have comparatively low values of N_o and high light transmission in the UV region. The optical and operational parameters of some NLC (N_o, ΔN, the approximate transmission cutoff λ_{NLC}^{UV} and the mesomorphism interval) are listed in Table II.

TABLE II

NLC	λ_{NLC}^{UV} (nm)	N_o λ= 435.8 nm / λ= 589.3 nm	ΔN λ=435.8 nm / λ=589.3 nm	Nematic interval (°C)	Developer of mixture
ZK-805	220	1.465 1.454	0.057 0.054	-27...+95	NIOPIK
ZK-1280	290	1.485 1.472	0.090 0.084	-29...+72	NIOPIK
N 247	290	1.512 1.493	0.127 0.122	-20...+76	Vilnius University
ZK-1282	370	1.530 1.508	0.206 0.170	-20...+62	NIOPIK
SZK-1	370	1.547 1.522	0.257 0.222	-7....+56	Vilnius University

The refractive indices N_o and N_e can be extrapolated in the same way as for the glass in the region of transparency.

It must also be pointed out that the possibilities for the synthesis of new NLC materials with recordly low N_o and appreciable ΔN are far from exhausted in our opinion[5].

CALCULATED CHARACTERISTICS OF PLCPs

Table III summarizes the calculated characteristics of PLCPs based on all the glasses and homeotropically oriented layers considered for ZK-805, ZK-1280, ZK-1282 and SZK-1 mixtures for λ=589.3nm.

The short wavelength transmission cutoff of the PLCPs in this situation is determined by the properties of the glasses (it coincides with $\lambda_{GL}^{UV}(0.9)$). The long -wavelength cutoff also coincides with λ_{GL}^{IR}, since the first molecular absorption band of NLC is located in the 3300-3600nm region.

The size of the polarization field in air is assumed to be constant for the entire series of prisms with a given NLC mixtures and is determined from the condition that it is symmetrical for the glass prism with the highest refractive index. For example, a polarizer based on STF117-02 glass and ZK-1280 has a symmetrical polarization field $2\gamma = 8.0^o$ ($\gamma_- = 4.0^o$, $\gamma_+ = 4.0^o$) For other glasses used with the same mixtures the polarization fields are no longer symmetrical, but they completely enclose the above-stated field (γ_-=4.0 and $\gamma_+ = 8.5^o$ for TF1/ZK-1280 pair etc.) In some cases two values of the polarization field are given for the same glasses and mixtures in order to illustrate the quantitative variations of other characteristics of the PLCPs. Values of the acute angle α, the transmittance $T_{\parallel}^2$ of the operating (i.e., passing through the NLC layer) component of radiation by the two glass-homeotropic NLC layer interface, its transmittance τ^2 by the entrance and exit faces, and the resulting transmittance $T = T^2 \cdot \tau^2$, are also

TABLE III Calculated characteristics of PLCPs.

Glass	τ^2	ZK-805 ($2\gamma = 7.0^0$)			ZK-1280 ($2\gamma = 8.0^0$)			ZK-1282				SZK-1 ($2\gamma = 18.5^0$)		
		α	$T_{\parallel}^2$	T	α	$T_{\parallel}^2$	T	2γ	α	$T_{\parallel}^2$	T	α	$T_{\parallel}^2$	T
N 80	0.90	20.2	0.88	0.87	-	-	-	-	-	-	-	-	-	-
N 53	0.90	21.8	0.86	0.77	-	-	-	-	-	-	-	-	-	-
BF117 -1320	0.89	23.9	0.78	0.69	22.5	0.94	0.84	-	-	-	-	-	-	-
TF1	0.88	25.6	0.74	0.65	24.4	0.92	0.81	18.5	18.0	0.99	0.88	-	-	-
								8.0	21.1	0.99	0.88	-	-	-
TBF117 -1246	0.87	-	-	-	27.5	0.87	0.76	18.5	21.7	0.99	0.86	-	-	-
								8.0	24.7	0.99	0.87	-	-	-
TBF11	0.83	-	-	-	34.4	0.78	0.65	18.5	29.5	0.88	0.74	28.9	0.97	0.81
STF117 -02	0.80	-	-	-	39.3	0.71	0.57	18.5	34.8	0.85	0.68	34.3	0.93	0.74

Angles α, 2γ are expressed in degrees given in Table III.

The blank spaces in the table mean that the use of this glass-NLC pair is unadvisable because of the smallness of the acute angle of the polarization prism or the narrowness of the polarization field.

The parameters of a polarizer based on known STK3 glass and ZK-1282-type mixture were calculated for the λ=1064nm (N_{GL}=1.646, N_O =1.491, ΔN =0.149). For $\alpha=20.0^0$ we obtained τ^2 = 0.884, $T_{\parallel}^2$ = 0.995 and T= 0.880. This case is of special interest because of high laser induced damage threshold of STK3 glass[6].

EXPERIMENTAL DATA

The transmission of polarized radiation, contrast ratio for normal incidence and laser induced damage threshold were determined experimentally for λ=1064nm. First test sample of PLCP with 20mm linear aperture and $\alpha=20^\circ$ was fabricated from above mentioned STK3 glass and ZK-1282-type mixture. The thickness of homeotropical NLC layer, specified by the pieces of teflon, was 30μm. Antireflection coating of entrance and exit faces was absent. For pulsed Nd:YAG laser (duration of impulse 10ns) we recorded the transmission T= 0.87 for polarized beam. The experimental result is in quite good agreement with calculated one. This means that losses of the beam intensity for given optical materials are determined practically almost by reflection at both PLCP faces. In these conditions contrast ratio was $5\cdot10^{-4}$ for normal incidence. Laser induced damage (exit face destruction) was observed at $(4-8)\cdot 10^8$ W/cm^2 power density. For the cw Nd:YAG laser our sample revealed no any damage after 5-minutes action of 160W beam (beam diameter was 1cm).

CONCLUSION

The data presented in this paper make it possible to conclude that linear prism liquid-crystal polarizers are suitable for use in a broad spectral region, possess of acceptable transmission, contrast ratio and high laser induced damage threshold. We believe it possible to replace the classic calcite polarizers by the low cost PLCPs in some specific situations, especially when significant linear aperture (up to 100mm or more), the broad spectral interval (up to 2900nm), the high transmission (up to 0.48-0.49 with AR-coating) and a high laser induced damadge threshold are the necessary features of required devices.

Future efforts will involve measurements of angular dependence of contrast ratio for different NLC orientations and improvement of length to aperture ratio.

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