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V. V. Presnyakov [a b] & T. V. Galstian [a c]

[a] Centre d'Optique, Photonique et Lasers, Université Laval, Département de Physique, Québec, G1K 7P4, Canada

[b] Design and Technological Bureau "Nauka", Krasnoyarsk, 660049, Russia E-mail:

[c] Photintech inc., 1245 Ch. Ste-Foy, Québec, G1S 4P2, Canada E-mail:

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LIGHT POLARIZER BASED ON ANISOTROPIC NEMATIC GEL WITH ELECTRICALLY CONTROLLED ANISOTROPY OF SCATTERING

V. V. Presnyakov and T. V. Galstian†*
Centre d'Optique, Photonique et Lasers, Département de Physique, Université Laval, Québec, G1K 7P4, Canada

A new kind of polarizer with electrically controlled efficiency of polarization is demonstrated, which is based on anisotropically scattering domain structures in polymer stabilized nematic liquid crystals. Structural, electro-optical and light polarization characteristics of such elements are investigated.

Keywords: nematic; polarize; polymer-stabilized liquid crystals

INTRODUCTION

Electrically controlled light scattering in two-phase liquid crystal/polymer systems was successfully used for electro-optical device applications [1]. The most studied system of this kind is the polymer dispersed liquid crystal (PDLC) presenting a polymer film with liquid crystal droplets dispersed in it. Mismatching or matching of the refractive indexes of the LC droplets and polymer matrix is provided by electric field induced reorientation of LC and causes controllable scattering. PDLC films with ensemble of uniaxially oriented nematic liquid crystal (NLC) droplets were investigated in Ref. 2–9. Strong anisotropy of scattering is the characteristic of such films [2,4,6–8], allowing their use as light polarizers [2,4] and as optoelectronic elements with electrically controlled polarization characteristics [7,8]. The uniform orientation of ellipsoidal nematic droplets is usually achieved by uniaxial stretching [2,4,7,9] or shearing [3,5,8] of PDLC film.

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*On leave from Specialized Design and Technological Bureau "Nauka", Krasnoyarsk, 660049, Russia, vpresnia@phy.ulaval.ca

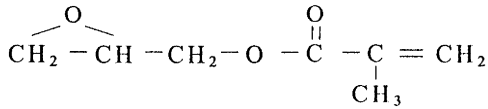
†Also with Photintech inc., 1245 Ch. Ste-Foy, Québec, G1S 4P2, Canada, galstian@phy.ulaval.ca

The light scattering from anisotropic nematic gels was investigated also [1,10]. In such gels a cross-linked anisotropic polymer network is formed in the homogeneous oriented NLC layer. In the absence of an electric field, the gel is transparent, irrespective of the light polarization. Upon the field application, anisotropically scattering domains are formed in the gel due to the reorientation of free NLC molecules and being at rest of those, which are in close proximity to polymer network. Strong anchoring of these NLC molecules also prevents to achieve the field induced homogeneous nematic texture, and thus the gel remains scattering at high voltage. After switching the voltage back to zero, the system reverses completely to the initial orientational state and the gel becomes transparent again.

In this paper, we present an anisotropic nematic gel, which exhibits an inversed behavior. It reveals anisotropic scattering in the field-off state, while upon applied voltage the gel becomes practically transparent for all polarizations of the incident light.

EXPERIMENTAL

We used a monofuctional monomer SR-379 from Sartomer Company:



The refractive index of this monomer at 25°C is 1.447. Carbon tetrabromide and ethyl 4-dimethylaminobenzoate, both from Aldrich, were added in monomer to support the reaction of polymerization. The commercially available nematic mixture E7 (Merk) was used as a non-reactive liquid crystal. The concentration of the monomer in the total mixture was 3.3 wt.%. The cells of thickness of 9 μm provided with transparent indium-tin-oxide electrodes were filled with this mixture. To obtain uniform planar orientation of NLC in the cell we used rubbed polymethyl-methacrylate (PMMA) layers. Polymerization of monomer was initiated by UV radiation 1.2 mW/cm^2 emitted by a high-pressure mercury lamp at room temperature during 10 minutes. No electric field was applied during the irradiation. After polymerization, the sample was placed into thermo-stabilized oven for electro-optical measurements. He-Ne laser beam ($\lambda = 543$ nm) was used as a probe at normal incidence on the sample (see Fig. 1). The polarization state and intensity of the probe beam were varied with $\lambda/2$ plate and Glan prism. Light transmission through the sample was measured using a photodiode with a total collection angle of 0.5° and computer controlled LabView data acquisition system. The

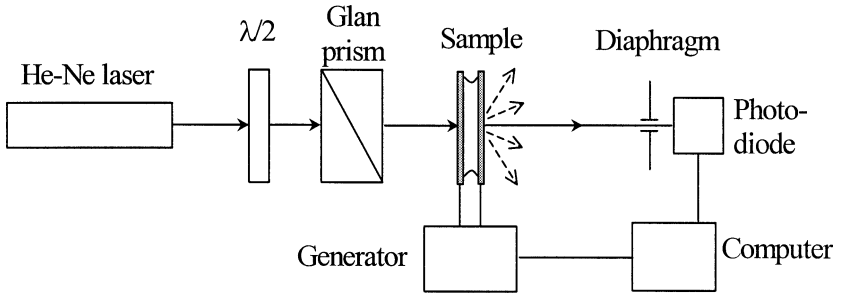


FIGURE 1 Experimental set-up for electro-optical measurements.

frequency of driving electric field was 1 kHz. The structure of the sample was analyzed using a polarizing microscope.

RESULTS

Before polymerization, the sample demonstrated homogeneous texture corresponding to the planar orientation of the nematic. The axis of orientation everywhere coincides with the direction of rubbing of the PMMA layers. No defects were observed. Application of electric field results in the reversible planar-homeotropic reorientation of the sample.

After the polymerization, the initial texture is conserved in general and the cell remains homogeneous. However, the electric field induced texture doesn't relax into the initial state after the field is removed. In Figure 2a, the optical micrograph of the polymerized area in the sample placed between crossed polarizers is presented after such a cycle of reorientation. The large and relatively bright central area is an artifact caused by the non-uniform illumination of the sample. The right part of the photo (a quarter approximately) corresponds to the non-polymerized region. Here the NLC director has kept its initial state, and the sample looks dark when the direction of molecular orientation is set parallel to one of the crossed polarizers. Bright domains are clearly observed in the polymerized area of the sample (Fig. 2a – left part). The observations without analyzer (Fig. 2b,c) show these formations as optical non-homogeneities in the form of chains aligned preferable in one direction. From comparison of Figure 2b and Figure 2c one can see, that the domain structure is visible more clearly for the light polarized parallel to the direction of initial molecular orientation in the sample (Fig. 2b), than for perpendicular polarized component (Fig. 2c). This should be related to the stronger scattering of light for the parallel-polarized probe than for the perpendicular polarized one.

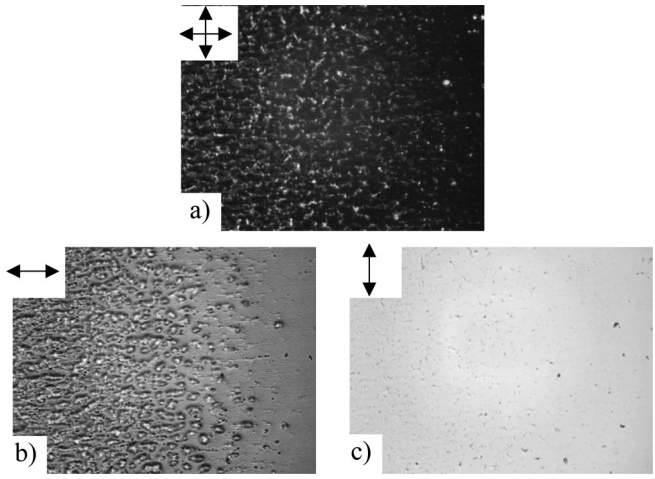


FIGURE 2 Optical micrographs of the polymerized sample in field-off state. Arrows indicate the orientation of the polarizers. The direction of initial molecular orientation is in the plane of pictures, parallel to their horizontal margins.

Indeed, the light transmission through the polymerized sample depends strongly on the direction of light polarization. In Figure 3, transmissions of the light polarized parallel ($T_{\|}$) and perpendicularly ($T_{\perp}$) to the direction

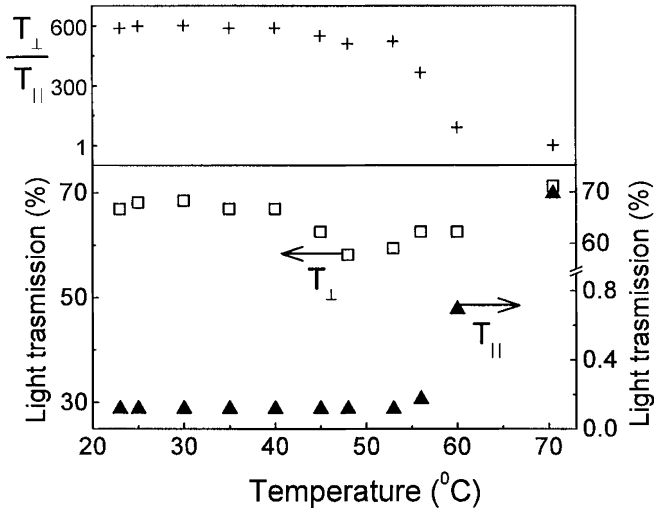


FIGURE 3 Polarized components of light transmission $T_{\perp}$, $T_{\|}$ and polarizing efficiency $T_{\perp}/T_{\|}$ of the polymerised sample as a function of the temperature.

of the initial molecular orientation are presented as a function of the temperature of the sample in the field-off state. One can see, that the $T_\perp$ is considerably higher than $T_\parallel$ in the whole temperature range when the liquid crystal is in the nematic phase. So, at the temperature 23°C we have $T_\perp = 67\%$ and $T_\parallel = 0.12\%$. At the temperature exceeding the temperature of nematic-isotropic phase transition, the light transmission for both components reaches the maximal value and becomes practically identical, about 70% at 70°C. The polarizing efficiency characterized by the ratio $T_\perp/T_\parallel$ achieves the value 600 (Fig. 3) and has no significant variations in the temperature range from 23°C to 40°C. It decreases with the temperature increase and reaches the unit in the isotropic phase of NLC.

In Figure 4a, the light transmission dependences on applied voltage are presented at temperature 35°C. The increasing of the voltage up to 10 V

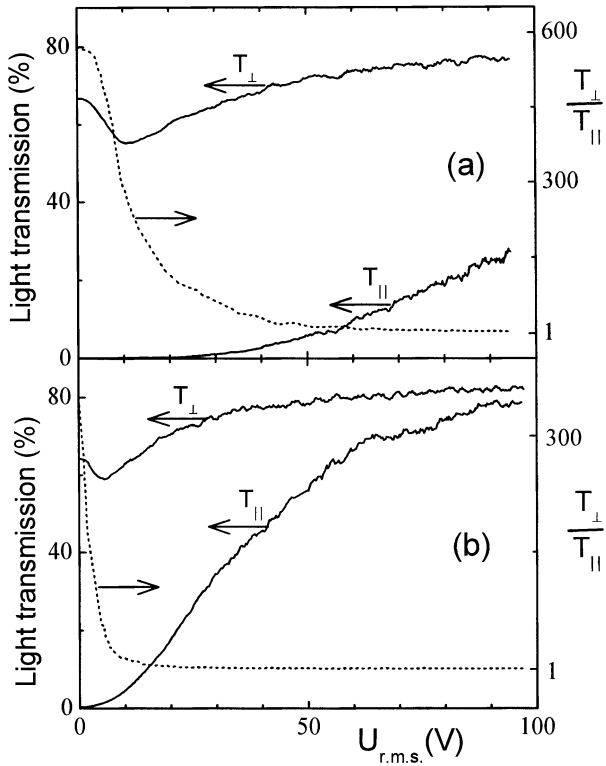


FIGURE 4 Polarized components of light transmission $T_\perp$, $T_\parallel$ and polarizing efficiency $T_\perp/T_\parallel$ of the polymerized sample at temperature 35°C (a) and 56°C (b) as a function of applied voltage.

results first in the decreasing of the $T_{\perp}$. Then $T_{\perp}$ grows again and reaches saturation. The character of changes of $T_{\parallel}$ in the range of voltages from 0 up to 25 V is difficult to explore because of the small level of the signal ($T_{\parallel}$ is about 0.1%). At $U > 25$ V the light transmission of parallel polarized component continuously grows without achieving saturation up to 95 V. The ratio $T_{\perp}/T_{\parallel}$ decreases with increasing the voltage from maximal at $U = 0$ V to 1 practically at $U > 60$ V. Figure 4b shows the same characteristics but at the temperature 56°C. It may be seen, that in this case, the light transmission for both components increases more rapidly, than at temperature 35°C. The maximal value of ratio $T_{\perp}/T_{\parallel}$ here is less and comes close to unit already at $U = 15$ V.

DISCUSSION

We believe that obtained results can be interpreted as follows. During the process of polymerization a polymer network is formed as chains aligned preferably parallel to the direction of the nematic orientation. Here, the polymer network doesn't break down the initial planar structure of NLC. The electric field application leads to the reorientation of nematic director to the homeotropic state. Probably there are NLC molecules, which are strongly bound to the network and do not reorient completely. It is the reason of the residual light scattering observed in the "on-state" (Fig. 4, $U \approx 100$ V). After switching the voltage back to zero, the nematic director doesn't reverse into initial planar state in the whole volume as in Ref.10. In our case, the character of polymer formation prohibits the nematic relaxation. It is probably due to the quasi-permanent reorientation of a part of polymer network into the electric field direction. As a result, only free NLC molecules become relaxed completely, while those, which are in close proximity to the network, remain tilted with respect to the planar orientation. Thus a non-uniform domain structure is formed in the sample (Fig. 2). Anisotropic scattering by the gel in the absence of electric field (Fig. 3 and Fig. 4 for $U = 0$) can be explained by this structure. The component of light, polarized in the direction perpendicular to the initial molecular orientation, will not be scattered since there is almost no refractive index variation along its path. In contrary, the parallel-polarized component of light will be strongly scattered due to large variation of refractive index along its path.

CONCLUSION

We have demonstrated an anisotropic nematic gel, which exhibits a strongly anisotropic scattering in the absence of an electric field: it scatters

the component of light polarized parallelly to the direction of gel orientation and is practically transparent for perpendicular polarized one. The ratio of the intensity of polarized component in the passed through the gel radiation achieves the 600 and can be varied by electric filed. Thus, a light polarizer with electrically controlled efficiency of polarization can be realized on the base of these gels. Such polarizers are capable of working in a wide spectral range (visible and near infrared) practically without absorption of light. It should be noted, that to achieve the effect of anisotropic scattering any additional procedure of mechanical orientation of the material is not required.

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