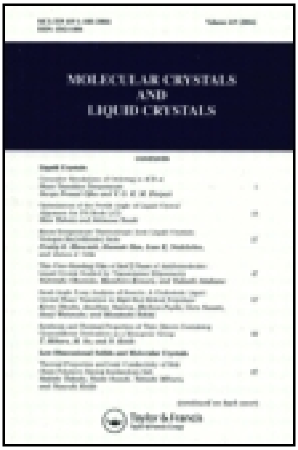

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VARIABLE FOCAL LENGTH LENS BASED ON POLYMER-STABILIZED NEMATIC LIQUID CRYSTALS

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VARIABLE FOCAL LENGTH LENS BASED ON POLYMER-STABILIZED NEMATIC LIQUID CRYSTALS

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Spatially non-homogeneous polymer stabilized nematic liquid crystal has been produced by photopolymerization technique with Gaussian laser beam. The distribution of refractive index in this structure under action of uniform electric field has a lens-like character. Field operated focusing properties of such lens are investigated.

Keywords: lens; nematic; polymer-stabilized liquid crystals

INTRODUCTION

In order to create lens-like distribution of the refractive index in the flat layer of nematic liquid crystal (NLC) a spatially distributed electric field is usually used to induce suitable configuration of the nematic director [1–6]. Surface relief microlenses may be also immersed in the standard NLC-cell [7]. A small amount (up to 3%) of reactive monomer was mixed with a NLC and *in situ* polymerised by homogeneous UV radiation to stabilize the lens, produced with a circular-hole-patterned electrode structure on the one [8] or both [9] cell substrates. A pattern irradiation (with a mask in the form of concentric dark and transparent rings) was used in similar compounds to produce regions with different threshold voltage, and so, a switchable Fresnel lens with a fixed focal length [10]. The idea of using a Gaussian-shaped laser beam to induce a spatially distributed polymer network in the NLC has been proposed for the variable focal length lens design [11]. In this case a uniform electric field application to the

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non-pixelated cell leads to a non-homogeneous reorientation of NLC. As a result a tunable lens-like distribution of the refractive index forms in the cell.

In this paper we study the electro-optical and focusing properties of this polymer-stabilized NLC lens, produced by *in situ* photopolymerization technique with a Gaussian laser beam.

EXPERIMENTAL

We used a monofuctional monomer glycidyl methacrylate (SR-379, Sartomer Company) in combination with photoinitiation complex (dye, initiator and coinitiator), described in Ref. [12]. The solution was added to the conventional NLC E7 (Merk). The concentration of the monomer in the total mixture was 3 wt.%. Industrial electro-optical cells (providing parallel nematic alignment) with gap of 5 μm were filled with this mixture and irradiated by Verdi laser beam ($\lambda = 532$ nm) having Gaussian intensity distribution with diameter of 2.3 mm. No electric field was applied during the irradiation. The power of polymerizing beam and exposure time were varied to obtain optimal conditions for the process of photopolymerization. Electro-optical measurements were carried out with an experimental set-up, which allows examining different points of the cell [11]. He-Ne laser beam ($\lambda = 543$ nm) of diameter 0.7 mm was used as a probe at normal incidence on the cell, which was placed between crossed polarizers, mounted at 45° with respect to the optical axis of the cell. The nematic reorientation was provided by source of sinusoidal signal with 1 kHz frequency.

RESULTS AND DISCUSSION

In Figure 1 the light transmission through the cell before and after polymerization is presented as a function of the probe beam position in the sample under different values of applied voltage. In the operating range of the cell (X from 3 to 12 mm) the birefringence take a place, and T is different from zero. Field induced NLC reorientation is homogeneous in the non-polymerized sample (see dashed line) and no features are observed, excepting the edge effects. After the polymerization (see solid line) the initial optical homogeneity of the cell is preserved for $U = 0$. However the applied voltage induces either decreasing or increasing of the light transmission in the form of clearly expressed peak in the center part of the cell ($X_c = 7.2$ mm). The voltage variation causes a change of the amplitude of the peak. Analysis of the peak shape is presented in Figure 2. One can see, that the center of the peak coincides with the maximum of intensity distribution in the polymerizing beam. The form and width of the peak reproduce approximately those of the polymerizing beam.

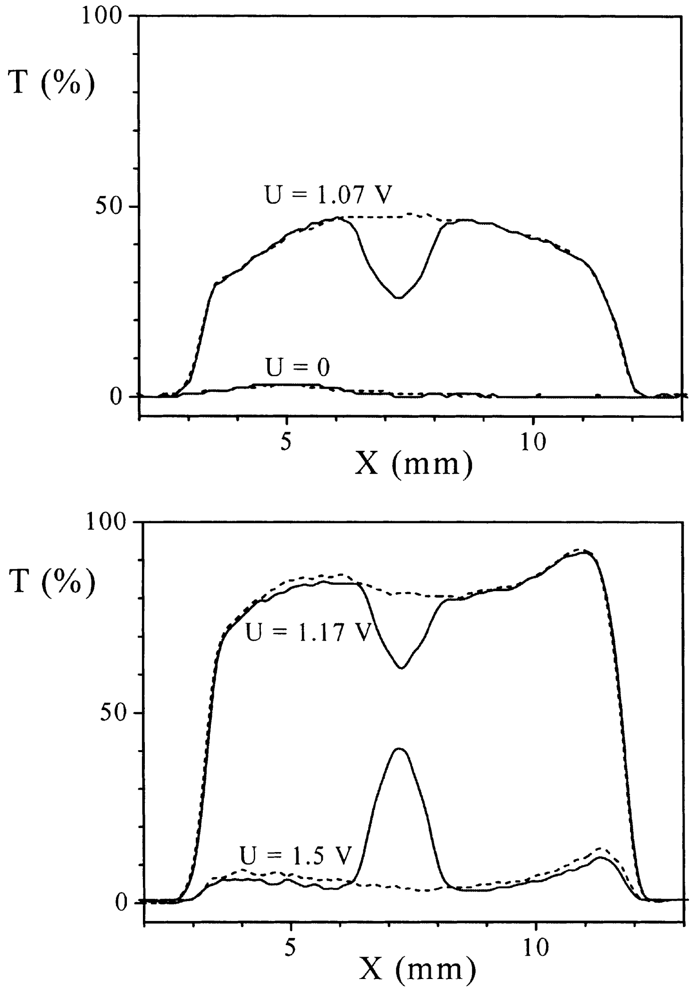

FIGURE 1 Light transmission T as a function of the probe beam position X in the non-polymerized (dashed lines) and polymerized (solid lines) cell under different values of applied voltage.

In Figure 3 transmissions of the light passed through two different points of the polymerized cell are presented as a function of applied voltage. The comparison of these dependences can explain why the peak on the light transmission profile curves exhibits either minimum or maximum (see Fig. 1, solid curves). From Figure 3 it can also be seen that given transmission-voltage dependences are equivalent qualitatively, but are shifted with respect each other along the voltage axis. It means that

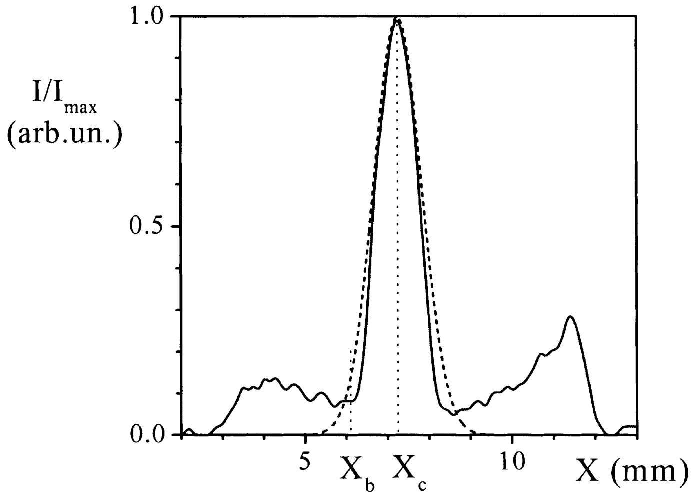

FIGURE 2 Normalized intensity of the light passed through the polymerized cell under U = 1.5 V (solid line) and Gaussian intensity distribution in the polymerizing beam (dashed line).

the character of the field-induced nematic reorientation at the points X_c and X_b is similar. However the reorientation at the polymerized point X_c requires higher voltage, than the same reorientation at the non-polymer-

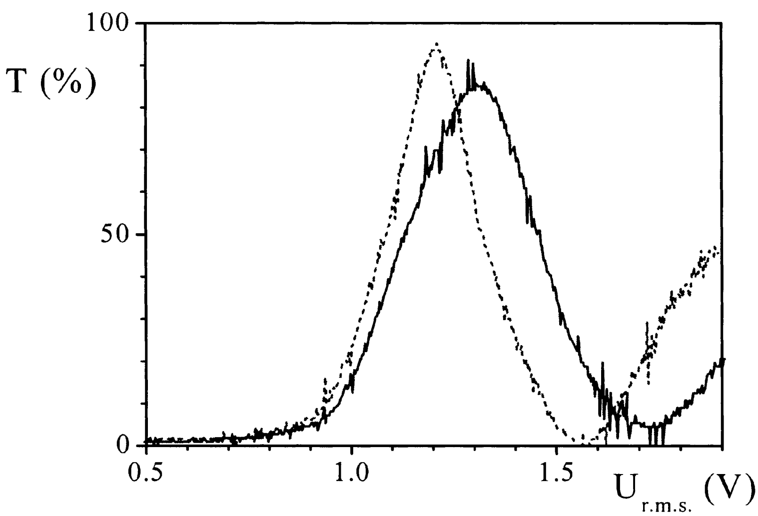

FIGURE 3 Light transmission as a function of applied voltage for the central point X_c (solid line) and border point X_d (dashed line) of the polymerized spot in the cell.

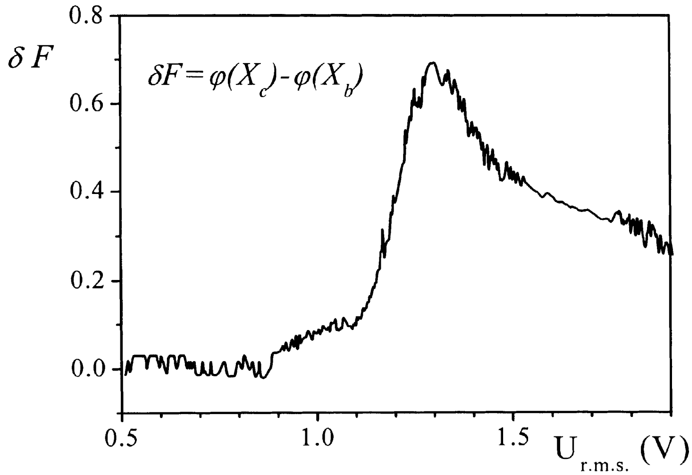

FIGURE 4 Maximal induced phase shift δF at the polymerized cell versus applied voltage.

ized one X_b. Based on these measurements the phase difference φ between extraordinary and ordinary waves for different points of the cell can be obtained from the equation:

$$T = Sin^2 2\beta Sin^2(\varphi/2), \tag{1}$$

where $\beta = 45^\circ$ – angle between direction of polarization of incident light and optical axis of the cell; $\varphi = \frac{2\pi d}{\lambda}(n_e - n_o)$; d – cells thickness; n_e, n_o– extraordinary and ordinary refractive indexes, respectively.

The focal length of the obtained lens is defined by the phase shift δF of light passing through the center of polymerized spot, relative to light traveling through the border area. In Figure 4 the phase shift $\delta F = \varphi(X_c)$–$\varphi(X_b)$ is presented as a function of applied voltage, where $\varphi(X_c)$ and $\varphi(X_b)$ have been calculated from relation (1). One can see that δF can be changed from zero to maximum value by small variation of applied voltage.

In Figure 5 the effective focal length of the lens is presented as a function of applied voltage. The curve has been obtained using Fresnel's approximation [13]:

$$f = \frac{\pi a^2}{\lambda \delta F}, \tag{2}$$

where $a = X_c - X_b = 1.15\,\text{mm}$ is the radius of the lens. Obviously, the operation of the obtained lens is dependent on the polarization of light. However, this dependence may be easily overcome for the normally incident light using two crossed cells.

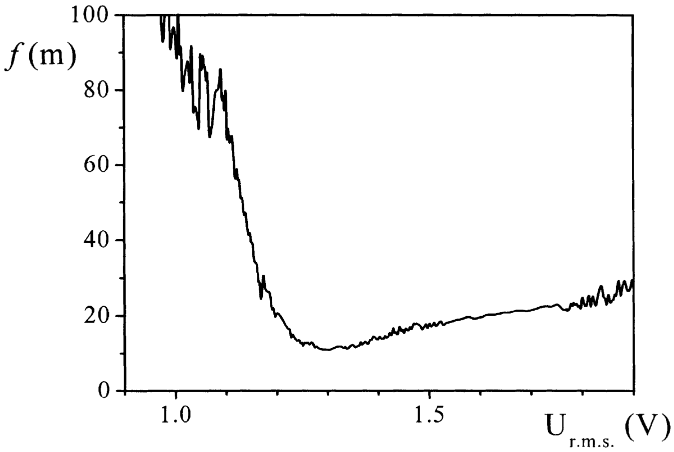

FIGURE 5 Effective focal length of the obtained lens as a function of applied voltage.

CONCLUSION

A new approach to fabricate variable focal length lenses based on liquid crystal is developed. The approach is based on curing of a polymer/liquid crystals mixture with a single Gaussian shaped laser beam to induce a spatially inhomogeneous polymer network formation. Applying a uniform voltage to the pixel-free cell leads to a circular-symmetric (lens-like) distribution of refractive index in the cell. Based on this technique the long focal length lens with Gaussian profile of refractive index has been obtained. The focal length of this lens can be varied by applied voltage. To obtain a lens with shorter focal length it is necessary to optimize the composition of the mixture, thickness of the samples as well as the parameters of exposition (intensity of the beam and time of exposition).

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