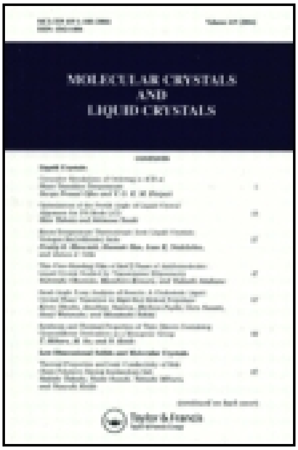

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Polarization Independent Static Microlens Array in the Homeotropic Liquid Crystal Configuration

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We propose a novel microlens array structure in a homeotropic liquid crystal (LC) configuration. The symmetry of molecular ordering in the homeotropic alignment on a circular surface relief structure provides the polarization independent focusing characteristics of the LC microlens. The surface relief structure of polydimethylsiloxane (PDMS) supports an initial convex lens driving scheme of the LC microlens as well as easy modification with great aging property.

Keywords: homeotropic configuration; liquid crystal; microlens array; polarization independence; PDMS

INTRODUCTION

One of major applications of the liquid crystal (LC) technology is the development of various optical devices for photonic systems such as an optical switch and a light modulator. *In particular, a microlens array is currently one of the most promising devices for its versatile usage like optical switch, amplifier, isolator, attenuator in optical communication systems, a waveguide to fiber coupling, an arbitrary wavefront detector*

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in integrated optics, and an essential device for future three-dimensional displays [1–4]. So far, many attempts to fabricate the microlens using the LCs have been reported due to the large anisotropic optical properties and the electro-optical nature of the LCs [5–10]. Although several approaches exhibit some of useful characteristics such as tunability of the focal length and the fast switching property [9–10], for practical photonic applications, it is highly important to achieve the polarization independence feature of the microlens array device.

In this work, we report a novel microlens structure in a homeotropic LC configuration on the polymer concave surface relief. The surface relief structure of poly-dimethyl siloxane (PDMS) provides the homeotropic alignment of the LC and convex lens characteristics of the microlens device simultaneously. The focusing properties of LC microlens are found to be insensitive to the polarization of an incident beam from the surface-driven symmetry of the LC. The PDMS surface relief structure can be obtained by casting and curing on the pre-arranged UV-controlled surface mold of an UV curable polymer [11–12]. Thus, it has simple modification property as well as good aging feature [13].

LC MICROLENS IN A HOMEOTROPIC CONFIGURATION

In order to achieve the polarization insensitivity, we selected the homeotropically aligned structure of the LC configuration and the circular concave lens-shape polymer relief to impose the symmetry in the molecular ordering on the microlens device. The schematic diagram of a homeotropically aligned LC microlens structure is shown in Figure 1. The LC is inserted into a sandwiched cell whose lower substrate consists of a periodic array of concave polymer microlens. Only the upper substrate was coated by a homeotropical alignment agent. The homeotropical alignment of the LC was obtained on the bottom substrate with no surface aligning treatment because of the interaction between the PDMS surface and the LC molecules. A more detailed study on the physical and chemical characteristics of the PDMS surface remains to be carried out.

Since the refractive index of the PDMS is smaller than that of the LC used in this study, an input beam becomes focused when passing the interface of the LC and the surface relief [14]. The focal length of the LC microlens can be determined statically in the absence of an applied voltage from the cell parameters such as the radius of curvature and the refractive indices of both the LC and the surface material. In the presence of an applied voltage, the LC with negative dielectric anisotropy is reoriented to become the planar alignment which produces the de-focusing state of the microlens device. During

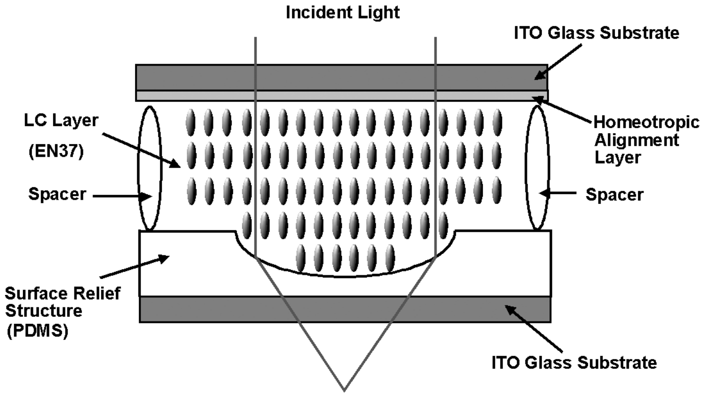

FIGURE 1 The schematic diagram of a homeotropically aligned NLC microlens. The refractive index of the LC layer should be larger than that of the surface relief material to have the focusing capability.

this reorientation process, the symmetry in molecular ordering symmetry is preserved due to the morphological effect of the surface relief structure [15], and thus the polarization dependence of the LC microlens is eliminated. Since any arbitrary polarized incident light experiences the same optical refractive index change at the LC interface in our microlens structure, the focusing property with the polarization-independence is obtained in such microlens configuration.

EXPERIMENTS

The LC cell of microlens array was made on two-sandwiched indium-tin-oxide (ITO) glass substrates. One of the substrates had a concave surface relief structure of the PDMS material and the other had a homeotropic alignment layer. In order to construct a surface relief structure of the PDMS, we used a lens-shaped mold of the UV curable polymer. The UV polymer mold structure was obtained by the selective UV irradiation through a photomask [9,11–12]. The PDMS surface relief layer was then made by molding the PDMS material on a pre-designed pattern through spin-casting and heat-curing processes. The PDMS surface film of about 60 μm thick was obtained at the spinning rate of 1000 rpm for 100 seconds and cured at 100°C for 1 hour.

A commercial homeotropic alignment layer of JALS 684 (Japan Synthetic Rubber) and a nematic LC of LIXON EN-37 (Chisso) with negative dielectric anisotropy were used in this study. The dielectric anisotropy, the ordinary and extraordinary refractive indices of

EN-37, the cured refractive index of the PDMS are $\Delta\varepsilon = -3.0$, $n_o = 1.488$, $n_e = 1.582$, and $n_{PDMS} = 1.41$, respectively. The cell thickness was maintained using glass spacers of 25 μm thick.

Microscopic textures of the LC microlens were acquired with a polarizing optical microscope (Nikon, Optiphotpol II) under the crossed polarizers. All the focal images were captured by the CCD and a computer-controlled image grabbing system at the focal plane of microlens.

RESULTS AND DISCUSSION

Microscopic textures of the LC microlens initially in the homeotropic configuration are shown in Figure 2 under several applied voltages of (a) 0 V, (b) 16 V, (c) 18 V, and (d) 20 V. A completely dark texture

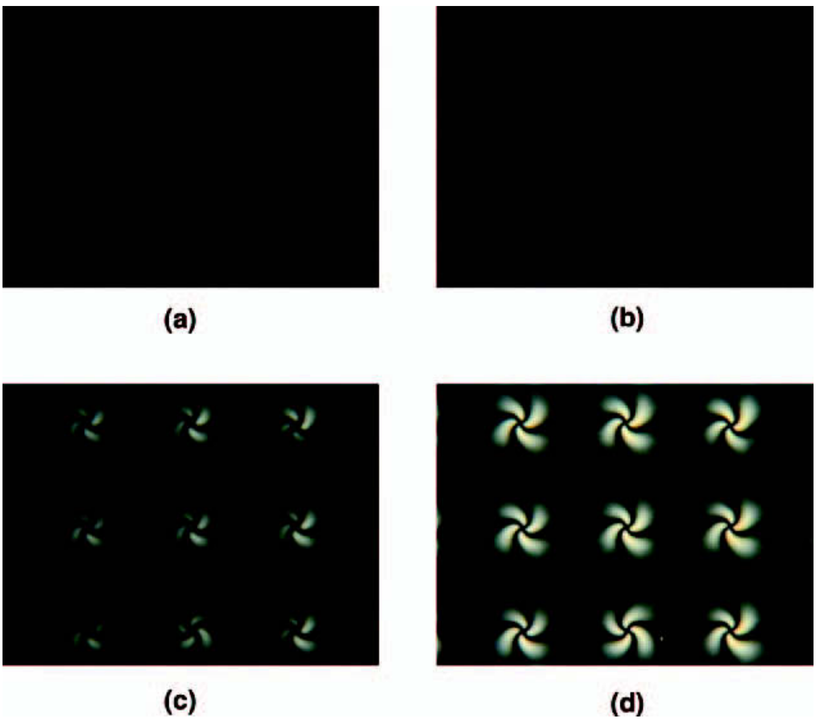

FIGURE 2 Microscopic textures of the homeotropically aligned NLC microlens array under crossed polarizers. The applied voltages were (a) 0 V, (b) 16 V, (c) 18 V, and (d) 20 V.

was observed under crossed polarizers in the absence of applied voltage. This corresponds to the homeotropic alignment of the LC molecules. The dark state is maintained below the threshold at 16 V as shown in Figure 2(b). Under the applied voltages above the threshold, axially symmetric textures were developed in the surface relief structure [16] as shown in Figures 2(c) and 2(d). In this regime, the focusing capability of the LC microlens disappeared.

Figure 3 shows the focusing properties of our LC microlens under the applied voltage of (a) 0 V and (b) 20 V. The focused image at 0 V was blurred and almost disappeared at 20 V. The measured static focal length was 9.2 ± 1.0 mm. In a simple model [14], the focal length of microlens, f, is simply given by $R/(n_o - n_{PDMS})$, where n_o is the ordinary refractive index of the LC and R is the radius of curvature of the surface relief structure. From the spherical radius of the surface relief used in our microlens structure, $R = 630\,\mu m$, the theoretical value of the focal length is calculated to be 8.1 mm. This is consistent with the measured value of 9.2 ± 1.0 mm.

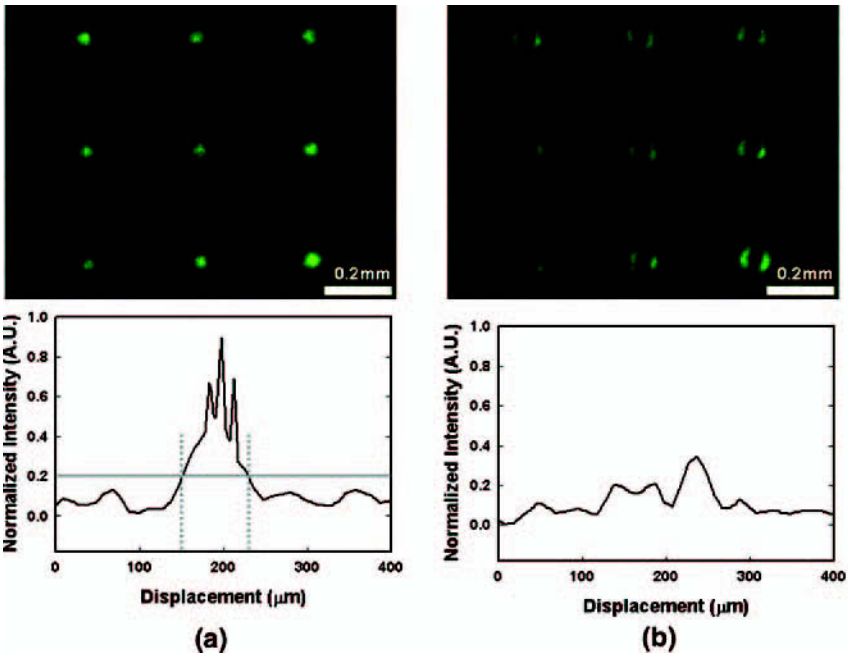

FIGURE 3 Focusing characteristics of the NLC microlens array. The applied voltages were (a) 0 V and (b) 20 V. The intensity profiles across the NLC microlens are shown in the bottom graphs. The focusing size of the NLC microlens is about 100 μm, guided by two dotted lines in (a).

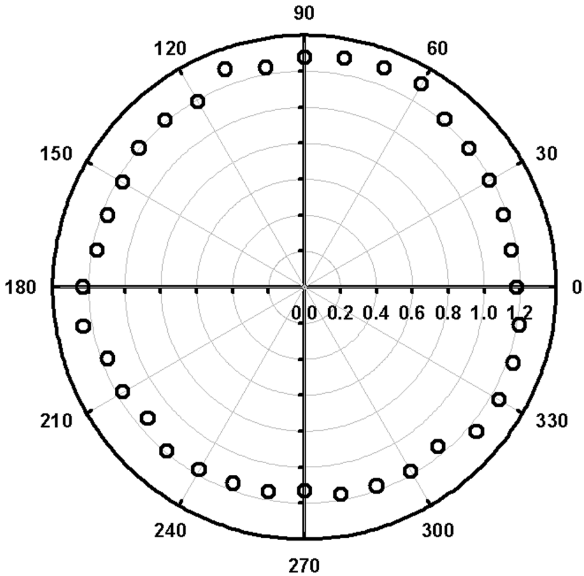

FIGURE 4 The polar plot of the focusing intensity in the microlens focal plane as a function of the polarization direction of the incident light. The intensity is presented in an arbitrary unit.

We now examine the polarization dependence of the focusing characteristics of our LC microlens device. The intensity measured at given point in the focal plane is shown in Figure 4 as a function of the polarization state of the input beam. It is clear that the measured intensity is nearly constant in any direction of the input polarization. It is concluded that the focusing properties of the LC microlens in a homeotropic configuration is polarization independent.

CONCLUSION

We demonstrate the novel microlens structure in a homeotropically aligned LC configuration which produces the polarization independent focusing property. The surface relief structure of the PDMS material assures both the circular symmetry in molecular ordering of the LC and the homeotropic alignment of the LC. The measured static focal length of the LC microlens was found to agree well with the theoretical value predicted in a simple model. *This refractive type LC microlens array structure would be highly applicable for practical photonic systems needed the polarization independent focusing properties such as* *optical switch, attenuator, coupling device without any additional polarization control components. The optimization and detailed study of focusing characteristics of LC microlens array remain to be explored.*

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