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Electrically controllable microlens array using a liquid crystalline polymer and a liquid crystal

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Electrically controllable liquid crystal (LC) microlens array have been fabricated using surface relief structure of UV curable polymer and liquid crystalline. The birefringent LCP provides the incident beam focusing ability of polymer lens structure as well as the LC aligning property. By engaging external voltage in LC layer, we can obtain much improved dynamic characteristics of LC microlens arrays. Moreover, by changing the polarization direction of incident light, we can control the focusing charecteristics of the device. Proposed structure is expected to play a critical role in the device for 3D display and optical communication systems.

1. Introduction

With the technological progress in optics, the need of microlens has been increased for various optical pplications such as optical interconnections, photonic devices, integrated optical, components and optical communication. In field of microlens the most active research part is a LC lens whose features variable focusing properties obtained by controlling the applied voltage. Thus liquid crystal lens has much researching interest and various kind of structure have been proposed.

Until now, several attempts have been made to achieve those properties. Such as designed electrode pattern, dielectric property modulation and polymer stabilized LC layer. In spite of such as these effort, LC lens has problems of limit switching characteristics, high operation voltage, dynamic focusing property, low stability. Among these problems, we focused about the dynamic characteristics of device in this work.

In this paper, we demonstrate a novel type of electrically controllable microlens array which is composed of a highly birefringent polymer microlens structure and a LC layer for polarization control of an incident light. The polarization state of incident polarized light is controlled by an applied electric field in the LC layer and then the light

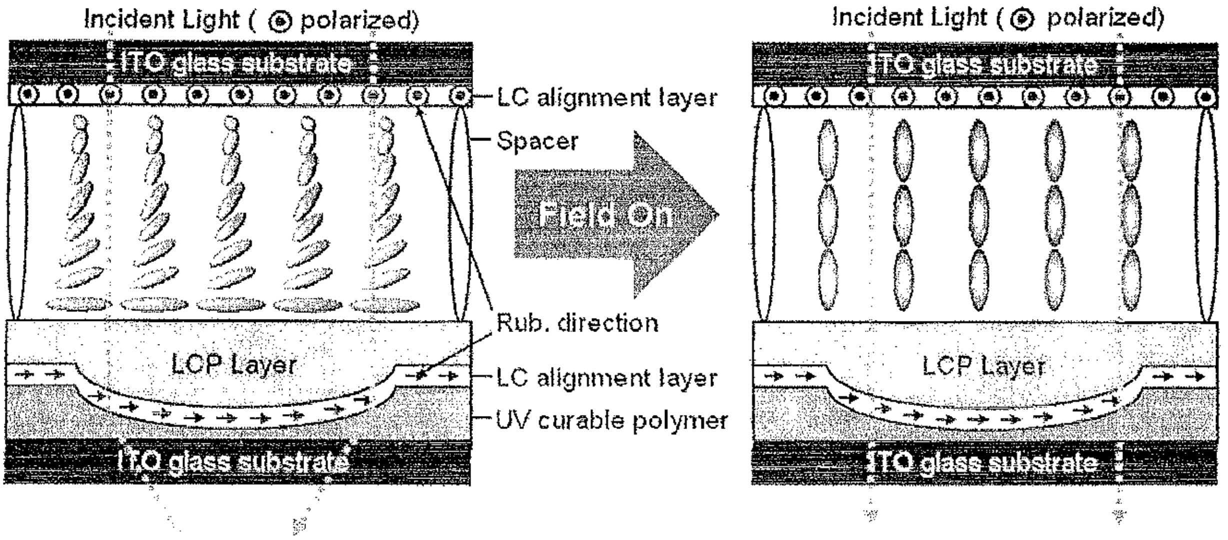

Fig. 1 Device configuration of birefringent bilayer LC

focused through the next refractive type polymer microlens array structure. Much enhanced dynamic focusing properties of LC microlens arrays can be achieved in this configuration since the static GRIN effect and the dynamic tuning effect are obtained from the polymer microlens structure and the twisted LC layer of flat boundary, separately. In addition suggested structure has advantages such as more simple fabrication, enhance light efficiency, reduced processing time, low production cost and stable operation dynamics.

2. Experimental

Device configuration of our LC microlens is illustrated in Fig. 1. First, a concave microlens array using a UV curable polymer (NOA60, Norland) was fabricated. The UV curable polymer was spin-coated on the ITO substrates at the rate of first step 1000rpm for 10s and second step 4000rpm for 30s. After making a thin polymer film on the ITO glass, the UV (λ=365nm) light was irradiated into the thin polymer film through a patterned photo mask. Such a irradiation process generated the diffusion of monomers in polymer compound from filled part to open part of the mask. After that we can obtain a surface relief concave structure by full curing process. And we prepare a homogeneous alignment layer of RN-1199 (Nissan Chemical) to generate LC alignment. It was spin coated with a unidirectional rubbing process. Then the liquid crystalline polymer was spin-coated on the concave structure at the rate of 3000rpm during 30s and cured by weak UV irradiation. When a LCP layer have been cured completely, a highly birefringent LCP film was produced due to the chain ordering of LCP film induced by the surface alignment layer [Fig. 2].

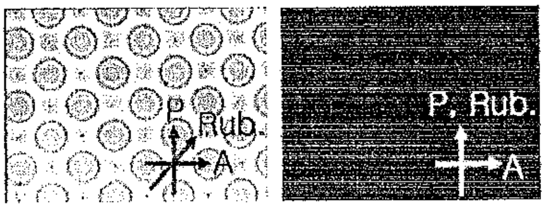

Fig. 2. Texture of cured LCP on the concave structure

To achieve a flat boundary of LCP layer, double spin-coating and cured process is required. As a result of measure ment by using an alpha-step, the depth of microlens array and double layer of LCP were 4.04 μm and 0.005 μm, respectively. And, the other substrate was spin-coated by a conventional homogeneous alignment layer. In our configuration, the additional alignment layer is not necessary because LCP acts as a homogeneous LC alignment layer due to polymer chain ordering effect. The cell thickness was maintained by using glass spacers of 4.0 μm thick and to achieve stable spacing through the whole sample LC was inserted by dropping method. Microscopic textures of the LC lens were acquired with a polarizing optical microscope (ECLIPSE E600 NIKON) under the crossed polarizers. All the focal images were captured by the CCD and computer-controlled image grabbing system at the focal plane of microlens array.

Materials	Extraordinary(n_e)	Ordinary(n_o)
MLC-6080	1.71	1.51
RMS03-001	1.684	1.529
NOA60	n_p=1.56	

Table 1
Summary of the ordinary and extraordinary refractive index of the materials at 590nm

3. Result and Discussion

At first we examined the microscopic texture of LC lens device as shown in Fig. 3 for assuring the achievement of TN mode LC configuration and surface relief structure. The stable twisted nematic (TN) structure was confirmed with microscopic texture as increasing the applied voltage. Complete dark image of the LC lens (Fig. 3 (b))was observed. The diameter of single LC microlens and the distance between lenses were 100 μm. Note that 10V application is enough to drive a LC lens.

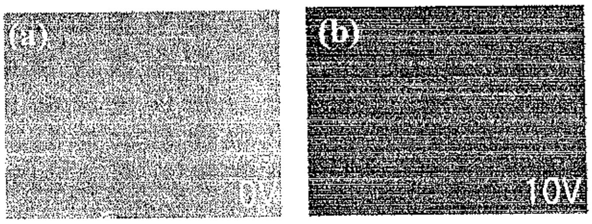

Fig. 3 Microscopic images of device textures under polarizing microscope for applied voltage of (a) 0V (b) 10V

The focusing property of the polymer microlens array is highly sensitive to an incident polarization of light due to the birefringent characteristic of LCP. In general driving scheme, we used the polymer lens structure as a convex lens because the light focusing and gathering has much more application in the field of optics.

For control the focusing properties, a twisted nematic (TN) LC layer was used on the flat boundary polymer microlens structure. Focused image was blurred as increasing applied voltage when the polarization direction of incident beam is parallel to the rubbing direction (see Fig. 4(a), 4(b)) while the completely opposite regime is applicable for different polarization (see Fig. 4(c), 4(d)) of the crossed polarizer.

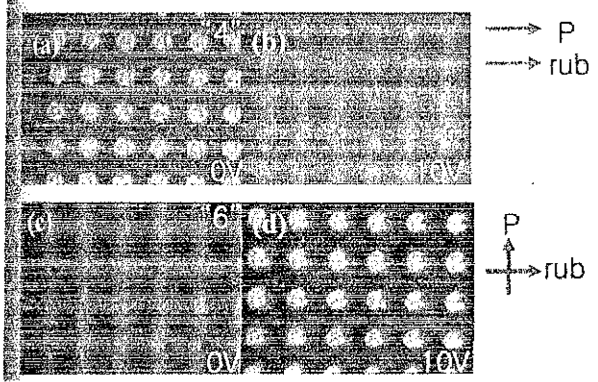

Fig. 4. Dynamic focus switching characteristics of our LC microlens array with voltage variation. (a) no external voltage applied (b) 10V was applied In case of (c) and (d), 0V and 10V was applied with opposite optical configuration.

The beam profile variations as changing an applied voltage are illustrated at the Fig. 5. Fig. 5(a) is the same condition with the Fig. 4(a), 4(b) and Fig. 5(b) is the same with the Fig. 4(c), 4(d). Also the focusing property is depend on the polarization direction of incident light as we expected. The FWHM(Full Width at Half Maximum) of each graph was measured as 18 μm and 20 μm, in case of Fig.5 (a) and (b), respectively.

Theoretically, the focal length doesn't change in the proposed structure in despite of changing an applied voltage into the LC layer. The measured static focal length was 11.4±0.2mm. The focal length of microlens, f, is given by $R / (n_{e\,LCP} - n_p)$, where $n_{e\,LCP}$ is the extraordinary refractive index of the LCP and R is the radius of curvature of the microlens, n_p was 1.56. In this case from the surface measure data, 1252 μm was calculated and the resultant theoretical value of the focal length was 10.1mm. This is almost consistent with the above measured value.

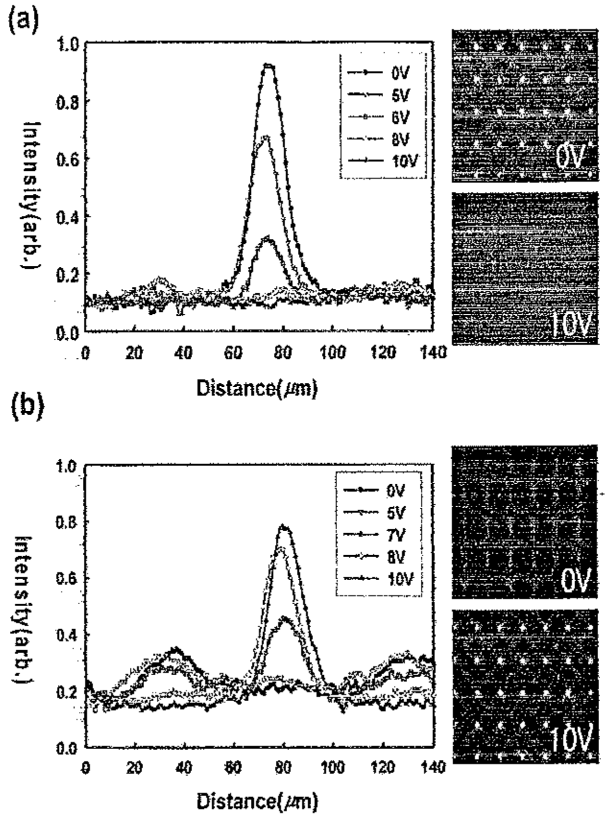

Fig. 5. The intensity profiles of focusing characteristics at the focal plan (a)when the incident polarization parallel to the rubbing direction of the LC layer and (b)when it is perpendicular to the rubbing direction.The intensity is comparable to each other.

4. Conclusion

In this paper, a new structure for the fabrication of electrically controllable LC lens was proposed and demonstrated. In this case, UV curable polymer lens structure was composed of UV curable polymer and LCP. The birefringent LCP provides the incident beam focusing ability of polymer layer as well as the LC aligning property. By engaging external voltage in the LC layer, we can obtain much enhanced dynamic characteristics of LC microlens arrays. The proposed LC lens show switching characteristic of static focal length and polarization dependent focusing characteristics.

Acknowledgement

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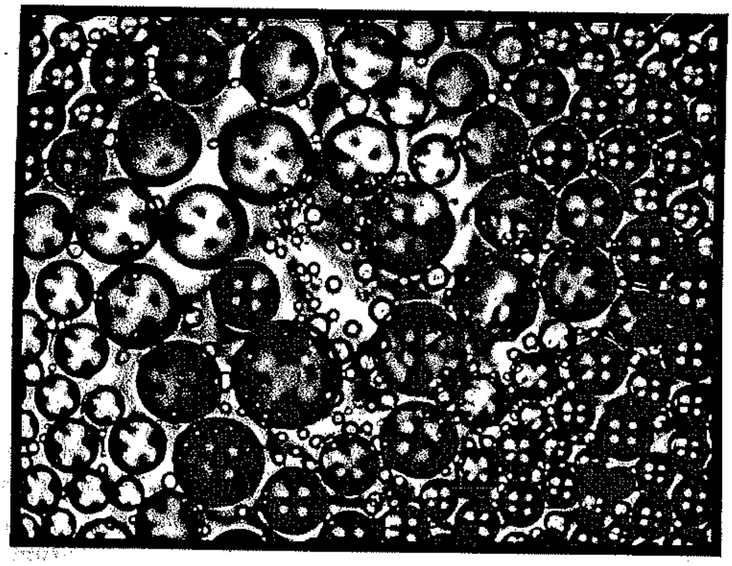

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