Microlens Array Based on Electronic Pattering Method using Electrohydrodynamic Instability

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Abstract

We fabricated microlens arrays (MLA) using the electrohydrodynamic instability of the optically anisotropic liquid crystal polymer layer. The instability of the liquid crystal polymer layer with the electric filed could make the anisotropic flow on the patterned electrode, as a result, profile of the lens could be made on the transfer substrate. The optical property of the microlens array could be controlled by the surface property of the transfer substrate.

1. Introduction

The microlens array (MLA) is a key component for various optical systems, such as integral imaging for 3D displays, optical data storage, optical communication, and charge-coupled devices [1-2]. The two types of MLAs are studied: optically isotropic MLA (OIMLA) and optically anisotropic MLA (OAMLA). Most MLAs show optically isotropic characteristics because they are made of optically isotropic materials. OAMLA have been studied due to their axially dual-focus property, which is useful for the multi-focal camera modules in mobile phones and compensation devices for multi-layer optical storage [3]. Many kinds of methods have been studied such as reflow, UV molding with electroformed metal mold, hot embossing, photo-lithography sing a gray scale mask, laser interference lithography. However, they require the cumbersome processes.

A simple electrostatic technique to create lateral structures in polymer films was recently developed by using electrohydrodynamic instability (EHDI) [4]. The EHDI method makes possible various patterns, such as sphere and pillar, using optically isotropic organic materials on a submicrometer length scale.

In this paper, we report the fabrication of OIMLAs and OAMLAs with the same materials using EHDI and surface properties. Using patterned electrodes, we can generate EHDI and create MLAs, and the optical properties are controlled by the alignment layer, which contacts the lens materials [5].

2. Experiments

Figure 1 shows a schematic diagram of a fabrication process. First, we prepared a patterned electrode on an indium-tin oxide (ITO) coated glass as a master substrate to create EHDI. To produce a circular shape of MLA, the electrode is patterned as a circular shape with a diameter of 40 μm using a photolithographic technique. After the cleaning process, a solution of reactive mesogen (RM) (RMS03-001C, Merck) is spin-coated on the master substrate. RM is a liquid crystalline material that can be permanently fixed in the liquid crystal phase by polymerization. The ordinary and extraordinary refractive indices of used RM are 1.525 and 1.68, respectively. The initial thickness of the RM layer measured by the surface profiler is about 1.5 μm. To evaporate the solvent, it is heated at 60 °C for 3 minutes. Subsequently, the non-patterned substrate is spin-coated with an alignment material and placed under the substrate as a transfer substrate with a gap (d) of 5.5 μm as shown in Fig. 1(a). By controlling of alignment of the RM in the MLA structure, we can control the optical properties of the MLA. In order to make the OAMLA, we use planar alignment layers (AL22620 from JSR) that are rubbed unidirectionally by a velvet cloth. OIMLA can be achieved by using homeotropic alignment layer (AL1H659 from JSR).

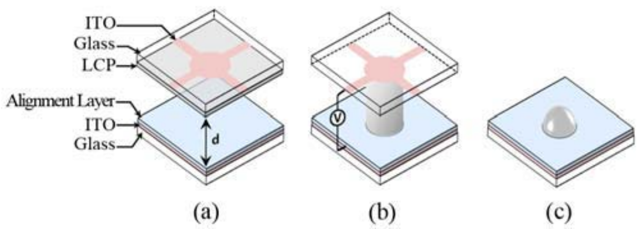

Fig. 1. Fabrication procedure of MLA fabricated by using EHDI.

When we apply an electric field larger than 4×10^6 V/m at 1 kHz for 10 seconds at room temperature, a pillar array on the electrode area is formed due to the EHDI, as shown in Fig. 1(b). When we remove the applied field, the pillar structure could be remained. If we remove the master (top) substrate, then the pillar structure is mechanically divided into the top and bottom substrates. The divided pillar structure becomes hemispherical in order to minimize the surface tension as shown in Fig. 1(c). The substrate with the hemisphere is exposed to UV (λ = 365 nm) for 5 minutes. RM monomers are polymerized by UV exposure, and the MLA is hardened and fixed on the substrate.

3. Result and Discussion

Figure 3 shows scanning electron microscope (SEM) images of pillar structures and the MLA after removal of the master substrate on planar alignment layer. For SEM observations, we exposed UV after formation of the pillar structures before removing the top substrate. Pillar structures are formed on the electrode area due to the anisotropic flow, as shown in Fig. 2(a). Figures 2(b) show a SEM image of MLAs which are exposed by UV after removal of the top substrate. The diameter and height of the microlens are about 50 μm and 3 μm, respectively. We note that we can produce MLAs with various diameters from sub-micrometers to several hundred micrometers by controlling various parameters, such as the diameters of the patterned electrode, thickness of the RM layer, distance between two substrates, and viscosity of the RM.

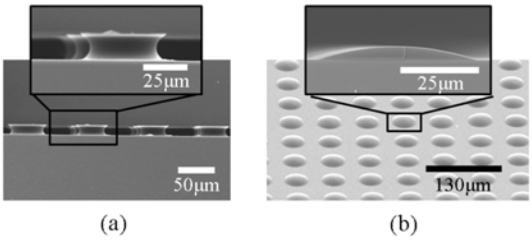

Fig. 2. SEM images of (a) cross-section and (b) top-view after forming a pillar array on the patterned electrode.

Figure 3 shows the alignment textures under crossed polarizers of the MLA on planar and vertical alignment layers. Figures 3(a) and 3(b) show dark and bright states when the rubbing direction is 0° or 45° with respect to the polarizer on the planar alignment layer, respectively. This means that RM molecules are aligned along the rubbing direction as shown in Fig. 3(d). Since RM monomers are liquid crystalline materials before polymerization, RM molecules are homogeneously aligned in the rubbing direction, and polymerized with UV exposure remaining the homogeneous alignment. Thus, the fabricated MLA has polarization dependent optical anisotropic property because the RM materials have the birefringent property. On the other hand, we can observe a pinwheel texture, which does not depend on the sample rotation on the homeotropic alignment layer (AL1H659), as shown in Fig. 3(c). This result demonstrates that RM monomers are aligned in the vertical direction with tilting by the surface shape, as shown in Fig. 3(e). Because the RM has symmetric alignment along the hemisphere surface, we expect OIMLA. These results demonstrate that we can easily fabricate OAMLA and OIMLA with the same material depending on the alignment capability of the surface.

The OAMLA has two kinds of focal length because the RM has two refractive indices. The extraordinary and ordinary refractive indices of RM are 1.68 and 1.525, respectively. So, when the optic axis of the RM was parallel and perpendicular to the polarization of incident light, the beam was focused at 115 μm and 130 μm from the MLA, respectively.

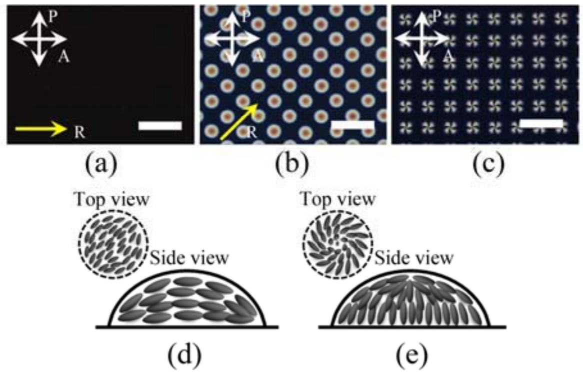

Fig. 3. The polarizing optical microscopic images for OAMLA and OIMLA: the rubbing direction is (a) 0° and (b) 45° with respect to the optic axis of polarizers. (c) Pinwheel texture on homeotropic alignment. (d) and (e) are schematic diagrams of the alignment states of RM molecules in OAMLA and OIMLA, respectively. P, A, and R denote the polarizer, analyzer, and rubbing direction, respectively. The scale bars in POM images are 130 μm.

4. Summary

We fabricated an OIMLA and OAMLA using EHDI with controlling the surface properties. The induced instability of the RM layer caused by a strong electric field leads to anisotropic flow towards the patterned electrode region. Depending on the surface property of alignment layer, we can easily fabricate OAMLA and OIMLA. We believe that this method is a straightforward, fast, and reliable process for MLA fabrication.

Acknowledgment

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