Fabrication Method of Fresnel Lenses Based on Electrohydrodynamic Instability

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Abstract

We have proposed the fabrication technique of Fresnel lenses in a binary type by using electrohydrodynamic instability (EHDI) of the optically anisotropic layer. It was found that the Fresnel lens has a high-efficiency performance with fast, simple and reliable fabrication for producing Fresnel lens.

1. Introduction

Fresnel lenses have been widely applied to various optical systems, including long-distance optical communication and optical information processing [1]. The Fresnel zone plate is a circular diffraction grating with an outwardly increasing line density. It creates point foci of different order via constructive interference. Zone plates are highly chromatic and therefore have to be used with radiation of a narrow spectral bandwidth to show diffraction limited focusing. Their focal length (f) is defined by their diameter (D), the wavelength (λ) of the light they are used at and their outermost zone width (Δr), which also determines their spatial resolution. Conventional Fresnel lenses, fabricated by thin film deposition or electron beam writing, have several limitations, including a static focusing efficiency, narrow fabrication tolerance and high coast of process [2, 3]. Recently, Fresnel lenses based on liquid crystal (LC) have been developed for real-time reconfigurable optical applications of fast optical switching, beam steering, and wave front shaping [4-7]. Two approaches have been employed to fabricate LC Fresnel lenses zone plate such as photo-lithographic [6] and photo-alignment technique [7]. But these methods also have problems UV diffraction thorough photo mask and imprecision of pattern in etching process.

Here, interest in lateral structure in polymer films, fabricated by electrohydrodynamic instability (EHDI), was renewed by the potential development as a new method [8-10]. This EHDI method creates stripe or pillar shapes using optically isotropic organic materials according to the electrode structure.

In this paper, we propose the fabrication of Fresnel lenses in a binary type by using EHDI of the optically anisotropic layer. This method is simple, fast, and reliable fabrication for producing Fresnel lens.

2. Experiment

Figure 1 shows a schematic diagram for fabricating a binary-phase Fresnel lens using the EHD patterning. To induce π phase shift between neighboring binary-phase Fresnel zones, a liquid crystalline polymer (LCP) was used. The key element is the patterned indium-tin-oxide (ITO) with Fresnel zone patterns. The innermost zone has radius r_1=25mm and n[th] zone has radius r_n which satisfies $r_n^2 = nr_1^2$; n is the zone number.

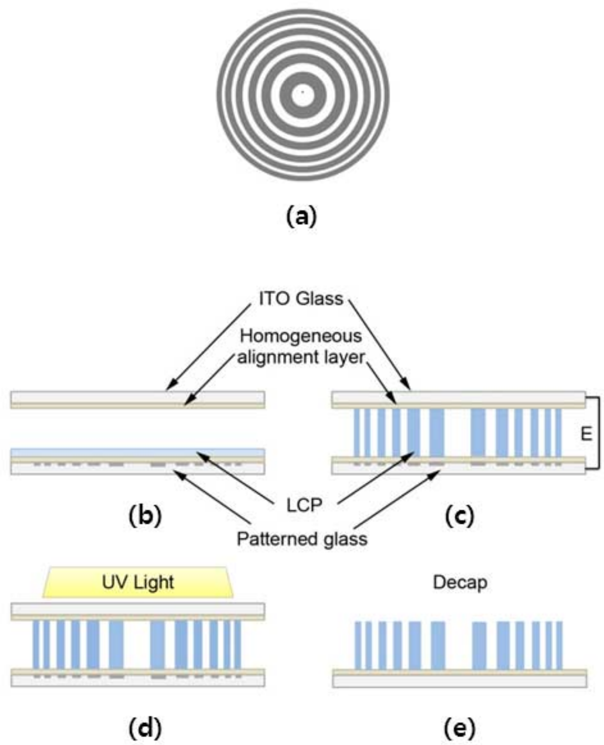

Figure 1. The schematic diagram for fabricating a binary-phase Fresnel lens using the electrohydrodynamic instability (EHDI) of liquid crystalline polymer (LCP)

As shown in Fig. 1 (a), the odd-zone non-electrodes of the pattern mask are transparent and even-zone electrodes of the pattern mask are opaque. Thus, the EHD process will be take place in the even-zone electrodes resulting in π phase retardation corresponding to the patterned electrodes.

The polyimide alignment layer (RN1199, Nissan Chemical) was spin-coated onto the substrate of patterned ITO glass and the other polyimide alignment layer (AL22620, JSR Inc.) was spin-coated onto the substrate

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of target ITO glass. They were soft-baked to vaporize solvent under 100 °C for 10 min and were hard-baked to polymerize the alignment layer under 210 °C for 2h. Next, the liquid crystalline polymer (LCP, RMS03-013c, Merck Ltd.) was spin-coated onto the patterned glass, coated polyimide (RN1199, Nissan Chemical) and baked at 60 °C for 1 minute. The cell thickness of the assembled substrates was maintained with 2.0 μm ball spacers and the cell obtained air gap between the patterned glass and the target glass [Fig. 1(b)]. The cell thickness was satisfied with a half-wave plate in the LCP rings. After the external voltage of 100 V was applied and removed from the cell [Fig 1(c)], UV light was illuminated under the assembled cell [Fig 1(d)]. Finally, detaching the cell, the Fresnel lens with LCP was remained, as shown in Fig. 1(e).

3. Results and Discussion

Figure 2 shows field emission scanning electron microscope (FESEM) images of Fresnel lens using the EHD patterning after removal of the master substrate. The width of the first ring which was consists of the fabricated Fresnel lens was about 47 μm, as shown in Fig. 2(a). The widths of the rest Fresnel lens are decreased gradually as following $r_n^2 = nr_1^2$. Actually, the width of the first ring designed by the photo-mask was about 48 μm. Fig. 2(b) shows the SEM image of cross section of the Fresnel lens using the EHD patterning. The height of the lens was about 2.0 μm (cell gap). This cell gap shifted $\lambda/2$ of phase with control the Δnd. Considering the refractive indices of the LCP (n_e = 1.680 and n_o = 1.543), the height of the lenses approximately matches to the half-wave condition., the Fresnel lens has approximately half the zone width. Consequently, these result confirn that this method is highly reliable technique for the production of Fresnel lens.

Figure 3 shows the polarizing microscopic images of the binary-phase Fresnel lenses by using the EHD instability of the LCP layer. The domain sizes of the platelet texture range from 10 to 50 μm. In Fig. 3(a), the odd zones are opaque and even zones are transparent when the optic axis of the rubbing direction was rotated by 45° to one of crossed polarizers. On the other hand, the odd zones are transparent and even zones are opaque when the optic axis of the rubbing direction was rotated by 45° to parallel polarizers, as shown in Fig. 3(b). Therefore, these results confirmed that the liquid crystal polymer (LCP) Fresnel lenses have successive orthogonal homogenous alignment with retardation configuration, and no residual LCP was existed in the even-zone non-electrodes. So, odd-zone electrodes of the pattern were white state and even-zone non-electrodes of pattern were black state when the rubbing direction was rotated by 45° with respect to one of crossed polarizers.

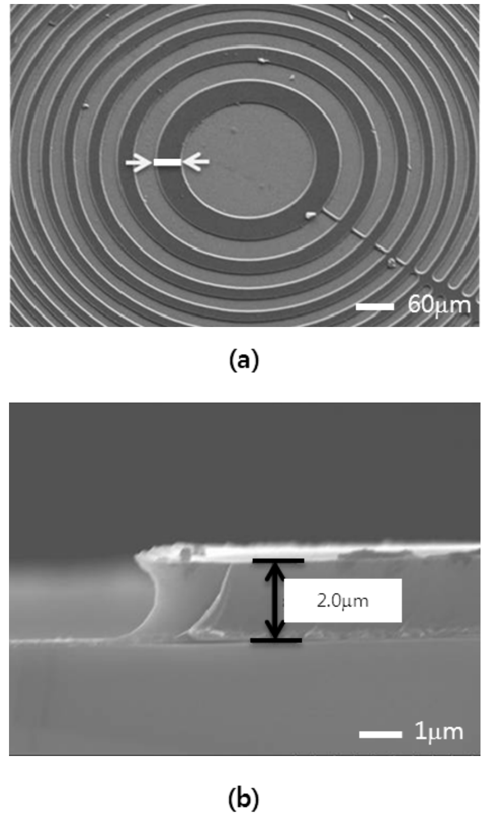

Figure 2. FESEM image of (a) top-view and (b) cross section of Fresnel lens

Plots the measured beam profiles of LCP Fresnel lenses was shown in Fig. 4. When the optic axis of the LCP Fresnel lens is parallel to the polarization of incident light, the light has an ordinary refractive index n_0 of LCP, and the best beam is focused at 26mm, as shown in Figure 4; the measured profiles fit a Gaussian distribution. These results corroborated that the focal length of LCP Fresnel lens (f = 26 mm) approximately matches the expected focal length of the pattern mask (f = 25 mm). Therefore, this EHDI method is straightforward, fast, and reliable process for Fresnel lenses.

4. Conclusion

In summary, we suggested a fabrication method for an optically anisotropic Fresnel lens by using the electrohydrodynamic (EHD) instability. The liquid crystalline polymer (LCP) Fresnel lenses have successive focusing characteristic. Therefore, the device is simple, fast, and reliable fabrication. Furthermore, this method is applicable to polarization-independent liquid crystal (LC) Fresnel lenses of dynamic focusing using the LCP Fresnel zone plate.

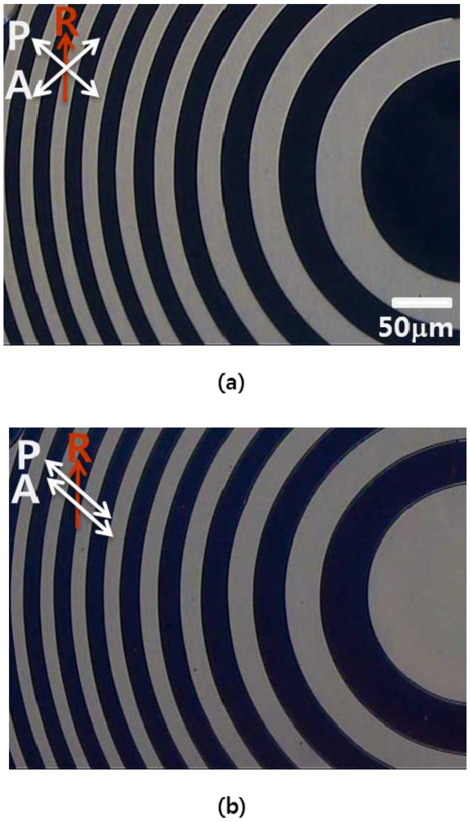

Figure 3. The polarizing microscopic images of the LCP Fresnel lens: the rubbing direction is 45 ° with respect to (a) one of optic axis of crossed polarizer and (b) parallel polarizer

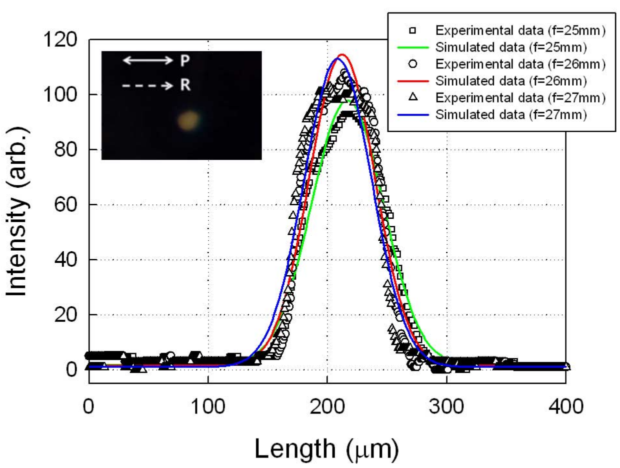

Figure 4. Focusing properties of the LCP Fresnel lenses: (a) the beam intensity profile of the lenses and (b) focused CCD images at focal point at 25mm

5. Acknowledgement

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