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Preparation and Characteristics of PMMA Microlens Array for a BLU Application by An Inkjet Printing Method

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In this study, poly(methyl methacrylate)(PMMA) microlens array for a back light unit(BLU) application was fabricated by an inkjet printer, which loaded piezoelectric microchannel mounted 30 μm nozzles to deposit polymer droplets via drop-on-demand fashion. Before the inkjet printing, the surface of PMMA substrates was modified chemically by a phase separation technique. The surface topologies and aspect ratios of microlens were measured. A 5.2 × 7 cm² BLU plate with microlens arrays printed by the inkjet method was fabricated for the application of a mobile phone.

Keywords Hydrophobicity; inkjet printing; microlens; PMMA; surface modification

Introduction

Microlens arrays offer an enabling technology in critical domains such as sensors, communications, metrologies, and back light units, often providing solutions where other technologies prove unsuitable, unmanageable or cost-prohibitive [1–3]. Many methods were recently studied to produce microlens arrays [4–6]. Traditional fabrication technology among them has required clean rooms or complex processes including a photolithography [4]. Other common fabrication processes have employed resist processing, growth, reactive ion etching, hot pressing or mechanical fabrication, which were often costly or labor intensive works [5,6].

Inkjet printing is a familiar technique that creates and releases droplets of fluid on demand and precisely deposits those droplets on a substrate, as reported by Gans *et al.* and Tien *et al.* [7,8] It has received increased attention for its novelty and ability to produce patterned and template material structures. In the application

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of microlens fabrication, drop-on-demand (DOD) inkjet printers especially offered the advantages of contactless printing and eliminated the use of a die or photomask [8–10].

In this study, poly(methyl methacrylate) (PMMA) microlens arrays for a BLU application were fabricated by an inkjet printing method. Before the inkjet printing, the surface of PMMA substrates was modified chemically to vary microlens array shapes, and the surface morphology and aspect ratio of microlens array were analyzed. Finally, we fabricated a $5.2 \times 7\,cm^2$ BLU plate with microlens arrays produced by the inkjet method for a mobile phone.

Experimental and Sample Characterization

Inkjet DOD fabrication of microlens array consisted of a basic setup utilizing a heated fluid reservoir coupled to a piezoelectric ceramic, through which a machined nozzle dispensed uniform polymer droplets to the substrate mounted to xyz micro-controllers, as illustrated in Figure 1. The spherical drops with a diameter of 33 µm were generated with a Microfab device equipped with a nozzle of 30 µm diameter. The cleaned PMMA substrate was placed on a movable xyz table, onto which the spherical drops were deposited in a dust-free atmosphere. PMMA ink was an epoxy type, which could be cured in an air-atmosphere with about $500\ mW/cm^2$ of UV light radiation for less than 2 min and was transparent in wavelength range from 600 to 1700 nm. Due to the surface tension, the drops took a plano-convex shape rapidly and could be polymerized and hardened under UV light. Variation in not only inkjet printing condition but also surface state of PMMA substrate could be employed to modify lens shape, depth of field, and lens height.

To influence the profile of microlens elements and increase the aspect ratio of hemi-elliptical lenses, we proposed the chemical modification of PMMA substrates utilized in the earlier stage of the inkjet printing, which was similar with several published studies [11,12]. The modification was chosen to fabricate a hydrophobic surface at ambient room temperature via a simple "dipping and drying" route.

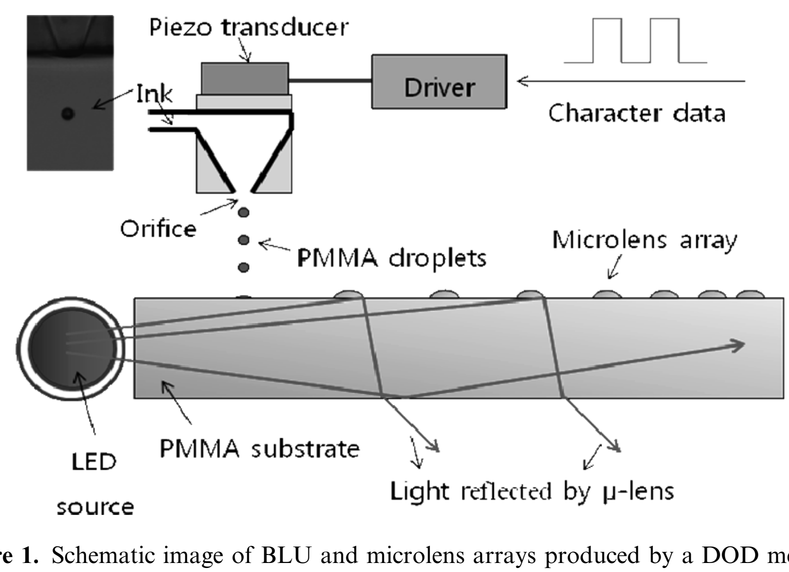


Figure 1. Schematic image of BLU and microlens arrays produced by a DOD method.

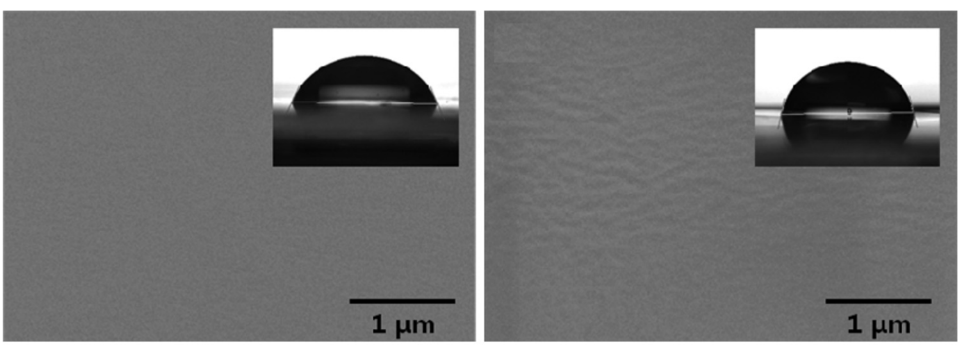
In the first place, a PMMA film (thickness: 500 nm) was spin-coated on the PMMA substrate by using dichloromethane (DCM, Aldrich Co., 99.9%) as a solvent, that could be easily evaporated (boiling point(b.p.): 39.4°C), and then the substrate was dipped into the polymer solution followed by slow evaporation of a 1,4-dichlorobenzene (p-DCB, Aldrich Co., 99.9%) solvent (b.p.: 138.4°C). The dipping and drying times were typically 30 sec and 10 min, respectively. The surface treatment generated various nano- and micro-structures of PMMA films and improved hydrophobicities. The surface topologies of the so formed PMMA surfaces were measured by a scanning electron microscope (SEM), an atomic force microscope (AFM), and an optical microscope (OM).

Results and Discussion

Surface Topologies and Aspect Ratios

Figures 2a, b show the SEM images of surface morphologies of a bare PMMA substrate and the PMMA film treated by a p-DCB solvent, respectively. The insets of Figures 2a, b are the results of water contact angle (CA) for both samples. The bare PMMA substrate, which presented a relatively dense and uniform structure, achieved the water CA of 67° and the surface free energy (E_S) of 44 mJ/m^2. However, when the PMMA film was coated and treated with a p-DCB solvent, a rough surface morphology was obtained, resulting in a improved hydrophobicity, with a water CA changing to 78°(E_S: 35 mJ/m^2). This phenomenon indicates that the treatment of p-DCB solvent by a "dipping and drying" method can play a vital role in the generation of hydrophobic coatings with a rough surface morphological structure.

Figures 3a, b give the AFM images in a $5 \times 5\,\mu m^2$ region for a bare PMMA substrate and a PMMA film after the surface treatment with p-DCB, respectively. When treated by p-DCB, the film surface became rougher than that of the bare substrate in nano- and micro-meter ranges. In the AFM image, the root-mean-square(RMS) roughnesses of the substrate and the film were approximately 0.5 and 2.5 nm, respectively. The OM images of microlens array prepared on a bare PMMA substrate and a PMMA film after the surface treatment with p-DCB are shown in Figures 4a, b, respectively. The microlenses were fabricated using a 30 μm Microfab nozzle with 5 drops per lens. In the case of p-DCB treatment, the average lens radii



(a) (b)

Figure 2. SEM images of the surface morphologies for (a) a bare PMMA substrate and (b) a PMMA film after the surface treatment with p-DCB. The insets are the contact angle results.

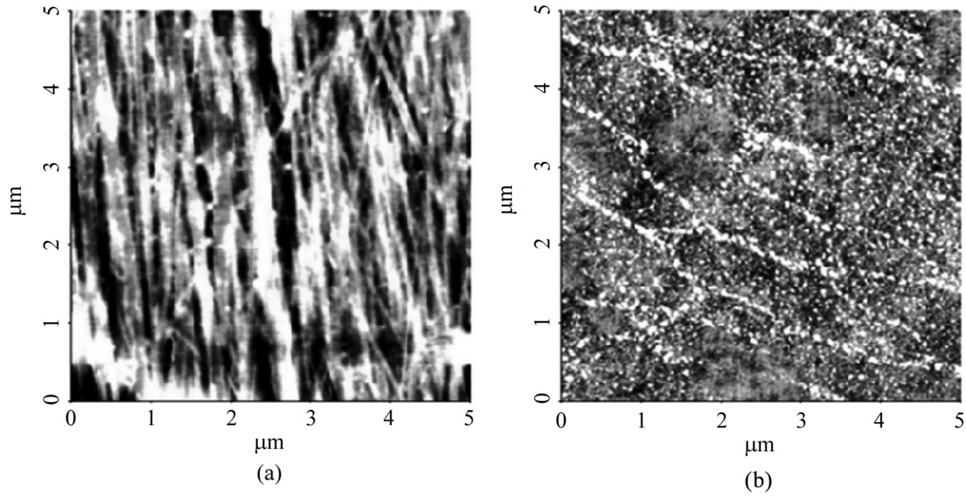


Figure 3. **AFM** height images in $5 \times 5\,\mu m^2$ region for (a) a bare PMMA substrate and (b) a PMMA film after the surface treatment with p-DCB.

decreased and the aspect ratio increased because of improved hydrophobicity. The average lens aspect ratios shown in Figures 4a, b were approximately 0.023 and 0.077, respectively.

The aspect ratio of microlens as a function of the dipping time in p-DCB solvent is shown in Figure 5. The aspect ratio peaked at a dipping time of 30 sec and decreased when the dipping time was more than 30 sec. Too high a dipping time might presumably lead to less formation of the hydrophobic surface in PMMA films, which might in turn induce a decrease in the microstructures formed by the phase separation. 30 sec was ultimately recommended for forming a hydrophobic surface. Figure 6 show a photograph image of $5.2 \times 7\,cm^2$ BLU produced by an inkjet method for a mobile phone. In the BLU, the interval between neighborhood microlenses was 400 μm and 10 drops per lens were used to make each lens. The average lens radius and aspect ratio were about 200 μm and 0.05, respectively.

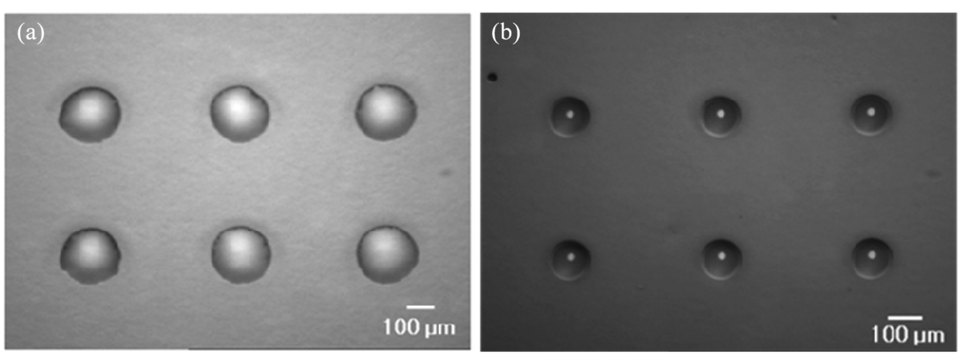


Figure 4. OM images of microlens array prepared on (a) a bare PMMA substrate and (b) a PMMA film after the surface treatment with p-DCB.

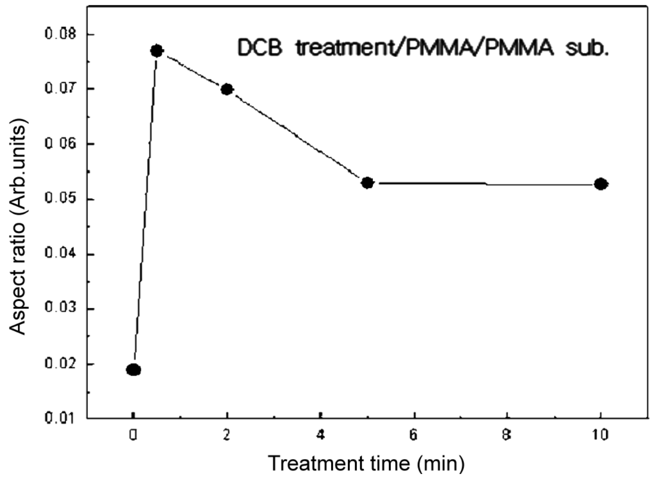


Figure 5. Aspect ratio of microlens as a function of the dipping time in p-DCB solvent.

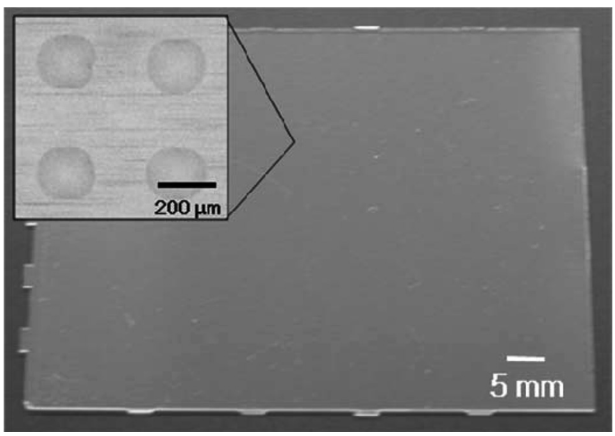


Figure 6. A photograph image of $5.2 \times 7\,cm^2$ BLU plate produced by an inkjet method for a mobile phone. The inset is the OM image of microlens array in the BLU plate.

Conclusion

This study has manufactured PMMA microlens arrays on PMMA substrates by using an inkjet printing technique and a chemical surface treatment. The surface topologies of optical microlens printed by using a piezoelectric 30 μm-sized Microfab nozzle via a DOD fashion were researched. The surface of PMMA substrate was modified chemically with a p-DCB solvent to get a good hydrophobic property and decrease wetability. The $5.2 \times 7\,cm^2$ BLU plate with microlens arrays printed by the inkjet method was fabricated for the application of a mobile phone. In the BLU, the average lens radius and aspect ratio were approximately 200 μm and 0.05, respectively.

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References

[1] Presby, H. M. & Giles, C. R. (1993). *IEEE Photonics Technol. Lett.*, *5*, 184.
[2] Duparré, J., Radtke, D., & Dannberg, P. (2004). *Appl. Opt.*, *43*, 4854.
[3] Fähnle, O. (2006). "Optical Fabrication Technology", Fifth annual graduate course, Delft University of Technology and FISBA Optik, Switzerland.
[4] Daly, D., Stevens, R. F., Hutley, M. C., & Dacies, N. (1990). *J. Phys., E1*, 759.
[5] Borrelli, N. F. (1999). *Microoptics Technology: Fabrication and Applications of Lens Arrays and Devices*, Marcel Dekker.
[6] Hutley, M. C. (1990). *J. Mod. Optics*, *37*, 253.
[7] Gans, B. J., Duineveld, P. C., & Schubert, U. S. (2004). *Adv. Mater.*, *16*, 203.
[8] Tien, C.-H., Hung, C.-H., & Yu, T.-H. (2009). *J. Display Technol.*, *5*, 147.
[9] Danzebrink, R. & Aegerter, M. A. (1999). *Thin Solid Films*, *351*, 115.
[10] Gans, B. J. & Schubert, U. S. (2003). *Macromol. Rapid Commun.*, *24*, 659.
[11] Zhang, X., Shi, F., Niu, J., Jiang, Y., & Wang, Z. (2008). *J. Mater. Chem.*, *18*, 621.
[12] Zhang, Y., Wang, H., Yan, B., Zhang, Y., Yin, P., Shen, G., & Yu, R. (2008). *J. Mater. Chem.*, *18*, 4442.