3-D Diffuser Lithography and Its Application to LCD/LED Backlight Unit and Flexible Front-light Unit

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ABSTRACT

3-D diffuser lithography which simply introduces an optical diffuser in the conventional contact lithography was newly developed to fabricate various 3-D micropatterns which are strongly required in recent advanced optical components. We successfully applied this technique to fabricate high-quality microlens array and inverse-trapezoidal micropatterns, which in turn played an important role in high-performance LCD/LED backlight unit and flexible front-light unit.

1. INTRODUCTION

As the optical systems become smaller, thinner, and lighter, needs for 3-D micropatterns such as microlenses, microprisms, and micro-conical lenses have been being increased, recently. Accordingly, techniques that can fabricate those micropatterns are actively researched so far.

In a conventional lithography, a collimated light is utilized that rectangular-like cross-section in a photoresist is the common and single shape we could obtain. Therefore, non-conventional techniques have been investigated, such as using photoresist reflow [1-2], adopting an inkjet droplet method [3], and employing a direct lithography method [4].

In this paper, we introduce a recently-developed technique which is simple and effective to be able to fabricate various 3-D micropatterns within a photoresist, such as a rounded cross-section and an inverse trapezoidal cross-section. Also described is how to deploy the proposed method to develop a couple of lighting components which include LCD backlight unit (BLU), LED BLU, flexible BLU, and flexible front-light unit (FLU) featuring special advantages of using less optical sheets or just a light guide plate (LGP) itself.

2. 3-D DIFFUSER LITHOGRAPHY

2.1 Front-side 3-D Diffuser Lithography

Instead of directly using the collimated light coming from the conventional contact mask aligner, we inserted an optical diffuser, which looks like a milky glass as shown in Fig. 1, in the UV pathway. Then, the light is randomized and forms a rounded front-end within a photoresist as shown in Fig. 2 [5]. After development, the rounded shape forms a recess when using positive photoresist and a protruding shape when using negative photoresist, respectively. Fig. 3 shows a couple of different cross-sectional shapes obtained by varying UV exposure dose [5].

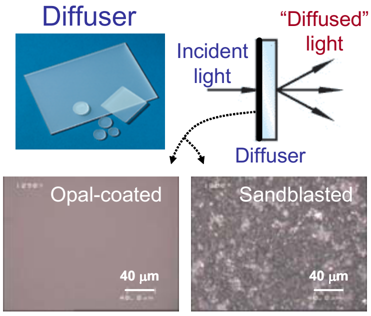

Fig. 1 Commercially-available optical diffusers

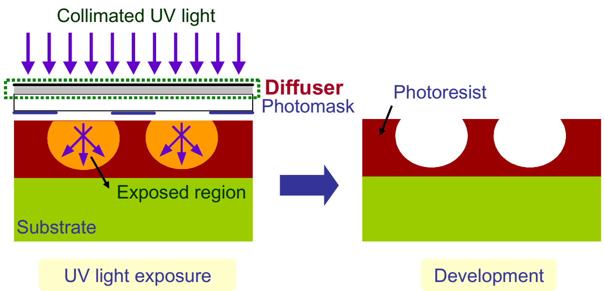

Fig. 2 Front-side 3-D diffuser lithography

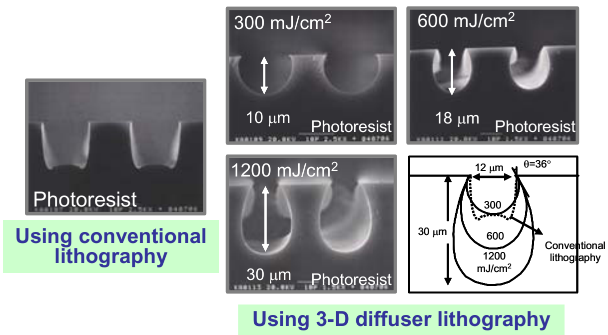

Fig. 3 Different cross-sectional shapes obtained by changing UV exposure dose

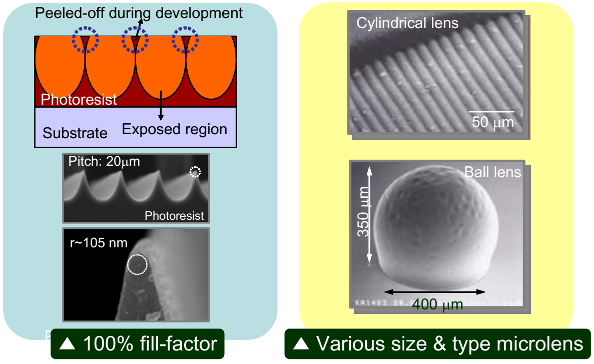

Fig. 4 Method to fabricate micropatterns with high fill-factor or a protruding shape

If the adjoining mask openings are sufficiently close with each other, we can obtain the microlens array shape with almost 100% fill factor (the radius of curvature of the seam is nearly 100nm) as shown in Fig. 4. Also, if the negative photoresist is used (with backside exposure) we can obtain a micro-ball lens. All of these various outcomes can show versatility of the 3-D diffuser lithography.

2.2 Backside 3-D Diffuser Lithography

Fig. 5 shows how to fabricate micropatterns having an inverse-trapezoidal cross-section using negative photoresist [6]. At this time, UV light is exposed from the backside of the glass substrate through the optical diffuser. A negative photoresist is coated on the front-side of the glass substrate where mask openings are made in between the photoresist and the glass substrate using thin Cr later. Intentionally, a large exposure dose is applied to make the sidewall as straight as possible. Very uniform micropatterns were obtained throughout the sample and used to fabricate a sheet-less BLU which is described later.

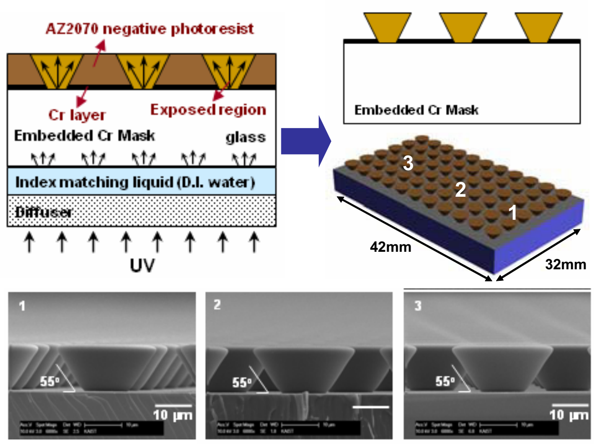

Fig. 5 Backside 3-D diffuser lithography used to fabricate micropatterns having an inverse-trapezoidal cross-section

3. APPLICATION TO LCD BACKLIGHT UNIT

Reducing the number of optical sheets in LCD BLU has been a key issue in order to make the whole LCD system more cost-effective, thinner, and lighter. From this perspective, we recently proposed a novel LCD BLU using an LGP with high fill-factor microlens array and a conical microlens array sheet excluding additional diffuser and prism sheets, as shown in Fig. 6 [7]. In order to fabricate microlens array, we used the 3-D diffuser lithography and polydimethylsiloxane (PDMS) replication process as shown in Fig. 7. As can be seen in Fig. 8, the proposed less-sheet BLU showed comparable luminance and even better viewing angle compared with the conventional BLU.

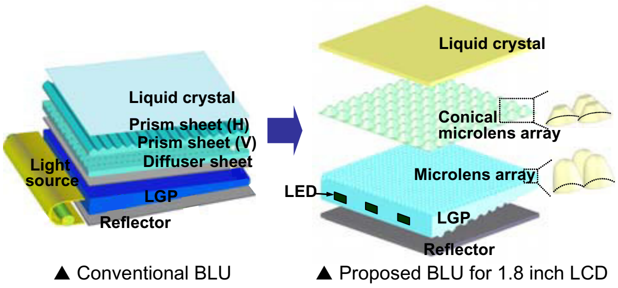

Fig. 6 Comparison between the conventional BLU and the proposed less-sheet BLU

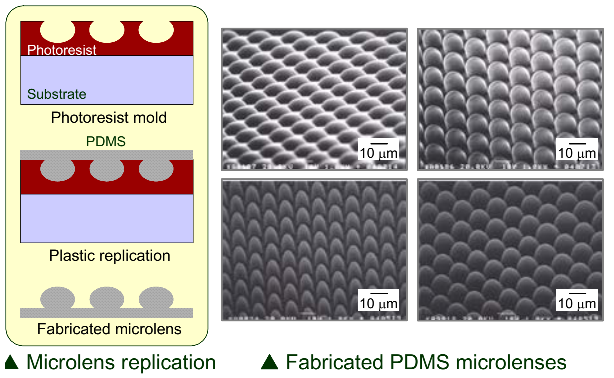

Fig. 7 Microlens array fabrication method using 3-D diffuser lithography and PDMS replication

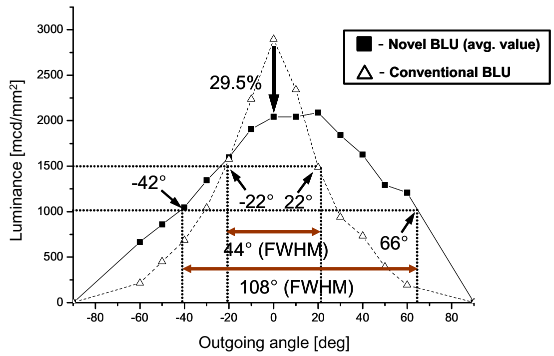

Fig. 8 Luminance distribution comparison between the proposed and conventional BLU's

4. APPLICATION TO LED BACKLIGHT UNIT

Recently, LED has been spotlighted to be used as a light source in the flat panel displays for achieving better color reproducibility and solving environmental issues. In the LED backlight system, a diffuser is strongly required to spread out light from the LED so as to reduce the color mixing depth and the number of LED's. Among various methods to realize the diffuser, employing microlens array has been one of the most promising solutions since it can easily customize the diffuser characteristics [8-9]. In this sense, we actively used the 3-D diffuser lithography to fabricate high-quality microlens array having high-fill factor, small seam between the microlenses, and small radius of curvature at the lens head [10].

The fabricated microlens showed perfectly parabolic shape and high aspect ratio even larger than 2 as shown in Fig. 9. The fabricated diffuser showed very uniform far-field patterns and high radiation angle of 150° as shown in Fig. 10.

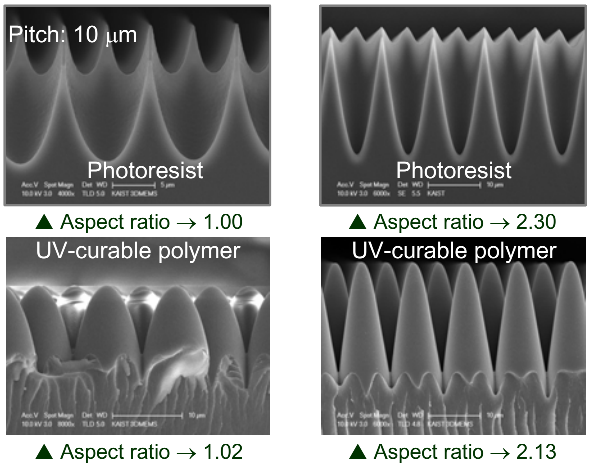

Fig. 9 Fabricated microlens array diffuser using 3-D diffuser lithography

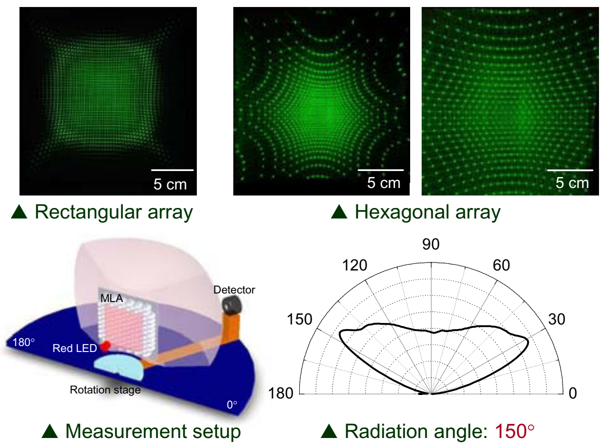

Fig. 10 Far-field patterns obtained with a laser source (up) and radiation distribution obtained with an LED source (down)

5. APPLICATION TO FLEXIBLE FRONT-LIGHT UNIT

As the display system has been passing through the flat-panel era to eventually go to the flexible era, flexible light sources are gathering highlights today. Recently, we have reported a flexible BLU comprising only a single-sheet LGP made of PDMS as shown in Fig. 11 [6], [11]. This has been fabricated by using the aforementioned photoresist mold with inverse-trapezoidal micropatterns together with two consecutive replications of the micropatterns into the final PDMS LGP. Since the PDMS by itself has high degree of flexibility, the fabricated BLU also shows high flexibility as can be seen in Fig. 11.

When we flip over the fabricated BLU on a paper, the light coming from the BLU hits the paper, is reflected by the paper, penetrates the BLU again, and finally comes out of the BLU to be seen by our eyes. In this way, we are able to highlight only the area on the paper over which the flexible front-light unit (FLU) is placed.

Fig. 12 shows how the selective area on the paper turns to be bright by means of the flipped-over BLU, which now becomes the FLU [12]. This simple and flexible FLU is expected to have many applications where front light is strongly required, such as Qualcomm iMoD, e-papers, and all other reflective-type display devices. We may be able to read an e-book in a completely dark bedroom by help of the FLU developed here, in the near future.

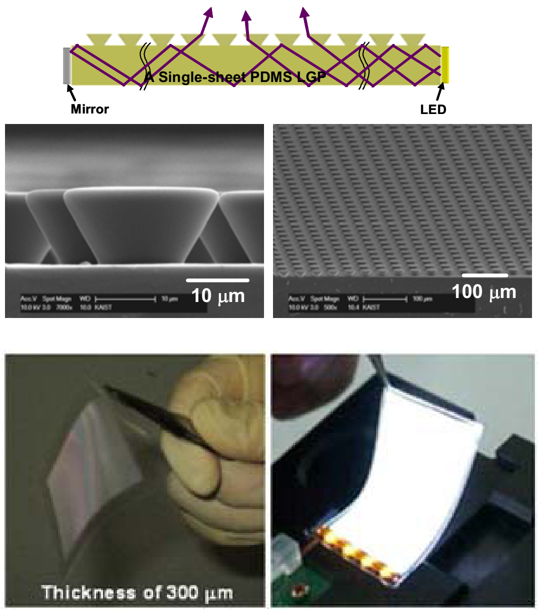

Fig. 11 A flexible BLU comprising only a single-sheet LGP made of PDMS [6], [11]

Fig. 12 A flexible FLU which is just a flipped-over BLU having the inverse-trapezoidal micropatterns

6. CONCLUSION

In this work, we developed a novel method to easily fabricate various micropatterns, so-called 3-D diffuser lithography. By inserting an optical diffuser in a UV pathway in the conventional contact lithography, we can randomize the light and have versatility to form various useful shapes in the photoresist. Consequently, we could obtain a couple of high-performance optical components using those useful shapes in micropatterns, including a high-quality diffuser, less-sheet BLU's, and sheet-less flexible BLU/FLU.

The developed method will enlarge possibility to obtain various display components with high optical performance and many futuristic features.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] J. Chen, W. Wang, J. Fang, and K. Varahramyan, “Variable-focusing microlens with microfluidic chip,” Journal of Micromechanics and Microengineering, vol. 14, pp. 675-680, 2004.

[2] M.-G. Han, Y.-J. Park, S.-H. Kim, B.-S. Yoo, and H.-H. Park, “Thermal and chemical stability of reflowed-photoresist microlenses,” Journal of Micromechanics and Microengineering, vol. 14, pp. 398-402, 2004.

[3] A. W. Lohmann and S. Singzinger, “Array of doublet lenslets,” Optik **93**, 84-86 (1993).

[4] R. Yang and W. Wang, “Out-of-plane polymer refractive microlens fabricated based on direct lithography of SU-8,” Sensor. Actuat. A-Phys. **113**, 71-77 (2004).

[5] S. -I. Chang and J. -B. Yoon, "Shape-controlled, high fill-factor microlens arrays fabricated by a 3D diffuser lithography and plastic replication method," Opt. Express **12**, 6366-6371 (2004).

[6] J. -H. Lee, H. -S. Lee, B. -K. Lee, W. -S. Choi, H. -Y. Choi, and J. -B. Yoon, "Simple liquid crystal display backlight unit comprising only a single-sheet micropatterned polydimethylsiloxane (PDMS) light-guide plate," Opt. Lett. **32**, 2665-2667 (2007).

[7] J.-H. Lee, J.-Y. Choi, S.-M. Bae, and J.-B. Yoon, "A Novel LCD Backlight Unit using a Light-guide Plate with High Fill-factor Microlens Array and a Conical Microlens Array Sheet," SID Simposium Digest **38**, 465-468 (2007).

[8] R. Tasso, M. Sales, S. Chakmakjian, D. J. Schertler, and G. M. Morris, in Proc. SPIE **5530**, 133 (2004).

[9] H. Urey and K. D. Powell, Appl. Opt. **44**, 4930 (2005).

[10] S. -I. Chang, J. -B. Yoon, H. Kim, J. -J. Kim, B. -K. Lee, and D. H. Shin, "Microlens array diffuser for a light-emitting diode backlight system," Opt. Lett. **31**, 3016-3018 (2006).

[11] H.-S. Lee, J.-H. Lee, B.-K. Lee, W.-S. Choi, H. Song, H.-Y. Choi, and J.-B. Yoon, “Monolithically Fabricated Micropatterned Light Guide Plates for Sheet-Less Backlight Unit,” IDW'07, to be presented (FMCp-40).

[12] J. -H. Lee, H. -S. Lee, B. -K. Lee, W. -S. Choi, H. -Y. Choi, and J. -B. Yoon, "Single-sheet Micropatterned Polydimethylsiloxane (PDMS) Light-guide Plate for Sheet-less LCD Back Light Units and Front Light Units in Flexible Displays," Submitted to Journal of SID (2007).