P-73: A Novel LCD Backlight Unit using a Light-guide Plate with High Fill-factor Microlens Array and a Conical Microlens Array Sheet

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Abstract
In this paper, we have proposed a novel LCD backlight unit (BLU) composed of a light-guide plate (LGP) mounting high fill-factor microlens array and an optical sheet of conical microlens array with a slanted angle of 54.5°. The proposed BLU shows 13.6% improvement in the total luminance compared with the conventional BLU and the viewing angle of 108° (-42° ~ 66°). We also have fabricated Ni-stamper with the microlens array pattern for injection molding, one of the cost-efficient methods for mass production.

1. Introduction
In the market of portable information devices, liquid crystal displays (LCDs) are the dominant one which requires low power consumption, high brightness, small thickness, and light weight. To satisfy these market requirements, it is necessary to continuously improve the backlight unit (BLU) because it consumes more than 60% of the total energy consumption in LCD modules. Therefore, many studies have been conducted for the design of BLU for LCDs using backlighting technologies such as LGP based on micro-patterned structures and LGP with highly scattering optical transmission (HOST) polymer [1]–[3].

In this paper, we have developed a new BLU as shown in Figure 1, which consists of LGP with the traditional acrylic material, i.e. poly-carbonate (PC) or poly-methyl-metha-crylate (PMMA), mounting a microlens array fabricated by 3D diffuser lithography [4], and only one optical sheet of a conical microlens array made by proximity lithography.

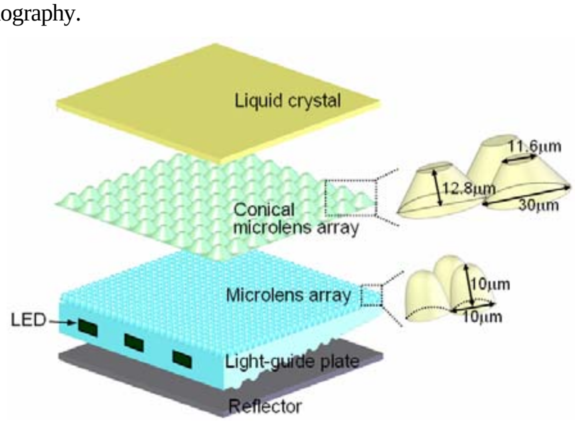


Figure 1. A schematic view of the proposed BLU.

Using the proposed BLU, we have achieved excellent performances of the total luminance and viewing angle. The designed backlighting technology can be very cost-efficient since injection molding is possible by making Ni-stamper for the microlens array sheet

2. Design
Figure 2 shows the ray trajectory displaying how the lights go inside the proposed BLU. The microlens array on the top of LGP plays a role to concentrate the out-going angle of light on about ±30° after passing through the designed LGP due to the curvature of the microlens. To make the light come out in the direction perpendicular to the surface of LGP, we have proposed to use only one additional optical sheet: the conical microlens array with the optimized slanted angle of 54.5°. By the inclined side-wall of the conical microlens, the light focused on about ±30° turns towards the vertical direction with angle of 0°.

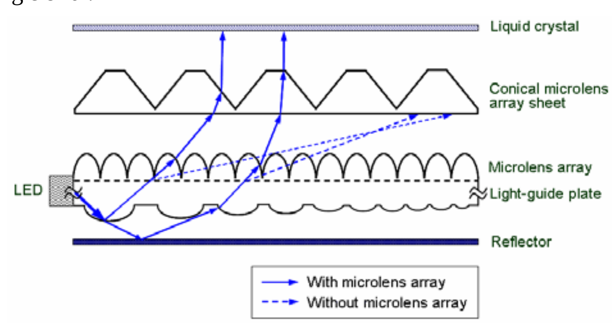
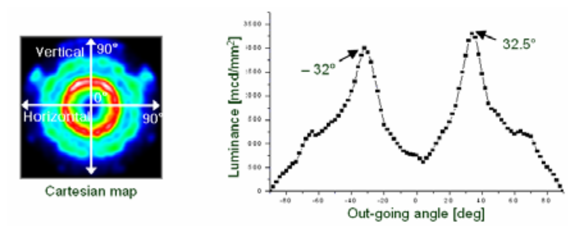
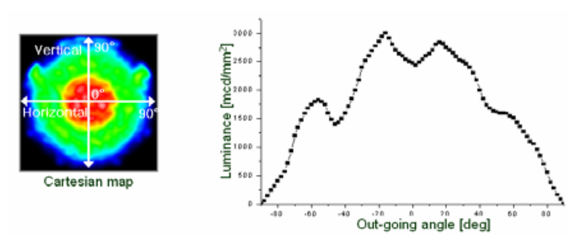


Figure 2. The conceptual ray trajectory in the proposed BLU.



(a)



(b)

Figure 3. The luminance profiles of the proposed BLU simulated by SPEOS (Optis Co.): (a) the intensity distribution on the designed LGP; (b) the intensity distribution on the designed LGP plus the conical microlens array sheet.

We used SPEOS simulation to demonstrate the idea of the proposed BLU. As can be seen in Figure 3, the light was converged on about $\pm 30^{o}$ after passing through the designed LGP (Figure 3(a)) and ejected to the right direction after the conical microlens array sheet (Figure 3(b)).

3. Fabrication

3.1 The microlens array

There have been many researches on the methods to fabricate microlens array, such as photoresist thermal reflow method [5], mass transport method [6], direct lithography method [7]. These methods have their own advantages but they are not suitable for the proposed microlens array because it should have high fill-factor and high aspect ratio. So we used another microlens array fabrication method: 3D diffuser lithography which utilizes randomized light by diffusers to form various cross-sections (circular or elliptical) in the photoresist [4].

Figure 4 shows the fabrication process of the microlens array mold with 10µm in width and height by 3D diffuser lithography. After the thick AZ9260 photoresist (Clariant Co. Ltd) spin-coating (1500rpm, 2sec for 68µm thickness) on the substrate and soft-baking (85°C, 80min) (Figure 4(a)), the thick photoresist was exposed to the randomized UV light by diffusers, as shown in Figure 4(b). Then the circular or elliptical cross-section in the photoresist was formed after development (Figure 4(c)). To show optical characteristics of the fabricated microlens array, the focal spot of the polydimethylsiloxane (PDMS) replica (Figure 5(a)), which was cast on the photoresist patterns and peeled off after curing, was measured (Figure 5(b)). The focal spot diameter was 1.15µm which was very close to the theoretical value of 1.13µm.

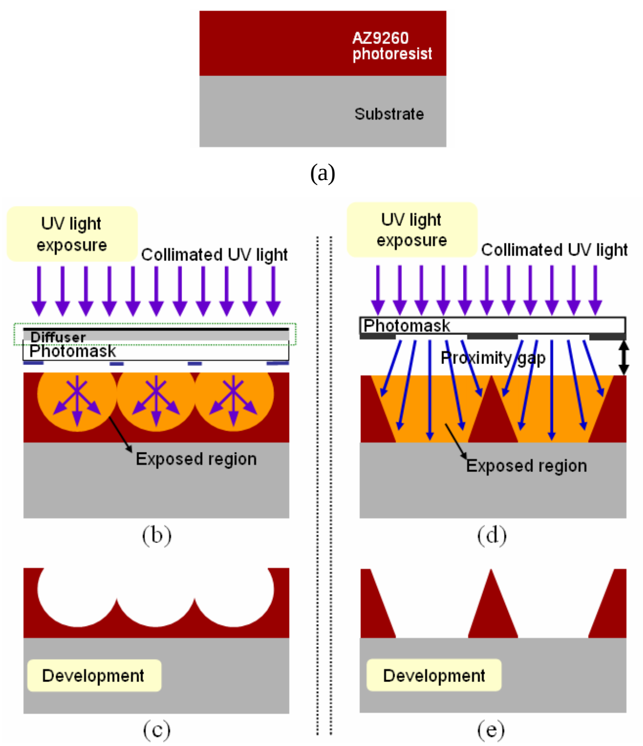


Figure 4. The fabrication process of the microlens array mold and the conical microelens array mold: (a), (b), and (c) for the former; (a), (d), and (e) for the latter.

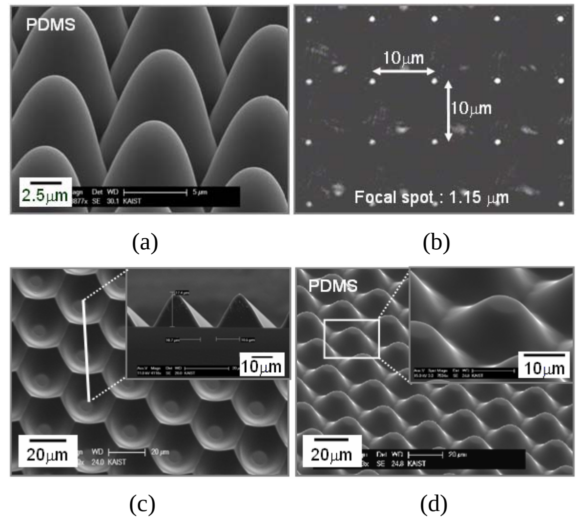


Figure 5. SEM photographs of the microlens array and the conical microlens array : (a) the PDMS replica of the microlens array and (b) the focal spot of it; (c) the photoresist mold of the conical microlens array and (d) the PDMS replica of it.

3.2 The conical microlens array

To fabricate the conical microlens array, the proximity lithography [8], which is simple and cost-efficient, was used. Figure 4 also describes the fabrication process of the conical microlens array. After the thick AZ9260 photoresist (Clariant Co. Ltd) spin-coating (2000rpm, 5sec for 20µm thickness) on the substrate and soft-baking (85°C, 20min) as shown in Figure 4(a), the thick photoresist was exposed to the diffracted UV light by the proximity gap between photomask and photoresist (Figure 4(d)) and the inclined cross-section in the photoresist was made after development (Figure 4(e)).

The SEM photographs of the fabricated conical microlens array with inclined angle of 54.5^{o} at proximity gap of 930µm and the PDMS replica were shown in Figure 5(c) and 5(d), respectively.

3.3 Stamper technology

The new Ni-stamper technology appropriate for injection molding, one of the cost-efficient and reproducible methods, is proposed. In order to make the same concave forms of Ni-stamper as the microlens photoresist mold, Cu was chosen to use as the in-between mold.

Figure 6 shows the fabrication process of Ni-stamper. After forming the photoresist mold (Figure 6(a)), the Cu seed layer was deposited on the top of it and then Cu was electroplated, as shown in Figure 6(b). The electroplated Cu mold was separated from the photoresist mold by dipping in acetone (Figure 6(c)) and chemically treated to be easily detached from the later Ni-stamper (Figure 6(d)). Then sulfamate Ni was electroplated and detached from the Cu mold, as shown in Figure 6(e) and 6(f), respectively. The final Ni-stamper with thickness of 560um and dimensions of 3.2cm×2.9cm was fabricated.

SEM photographs and RMS values of surface roughness measured by AFM for each step are provided in Figure 7. As we proposed, the concave photoresist mold was clearly transferred to the Ni-stamper by using the intermediate Cu mold. It also shows that there is a negligible change in surface roughness during the transferring steps.

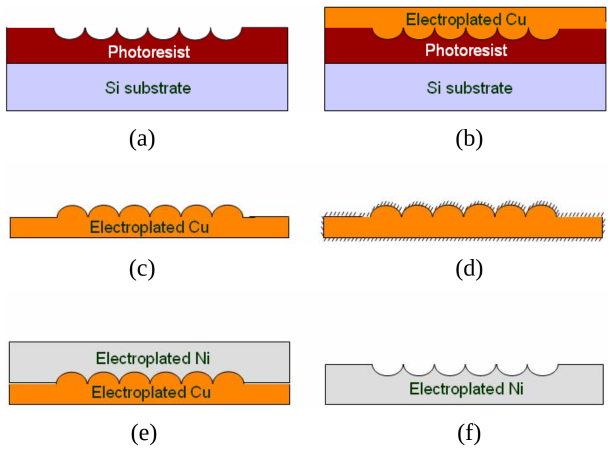


Figure 6. The fabrication process flow chart of Ni-stamper.

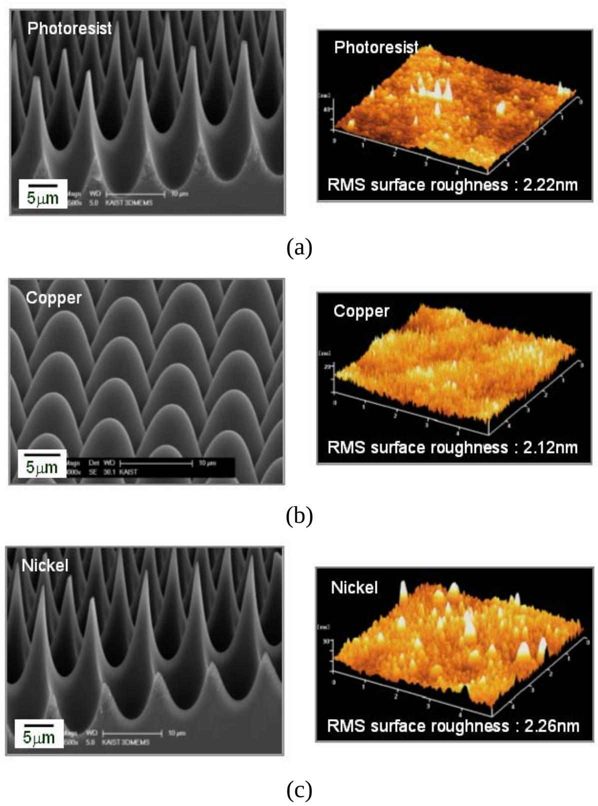


Figure 7. SEM photographs of the each step to fabricate Ni-stamper and their surface roughness measured by AFM.

4. Results and Discussion

The luminance profile was measured by a commercially available luminance colorimeter (TOPCON Co., BM-7) at 9 points which were distributed widely throughout the proposed BLU. It was composed of 3 LED light sources (1200mcd/mm^2 for each LED), a reflector, the LGP (NAM-4) with the microlens array, and the conical microlens array sheet. Figure 8 explains how to mount the microlens array on the LGP. First, UV curable polymer which has the same refractive index of LGP was coated on the fabricated Ni-stamper (Figure 8(a)). Then, the conventional LGP made of poly-carbonate (n=1.56) was attached on it (Figure 8(b)). After the UV curing and separating step, the designed LGP was completed. In the similar way, the conical microlens array sheet was also made.

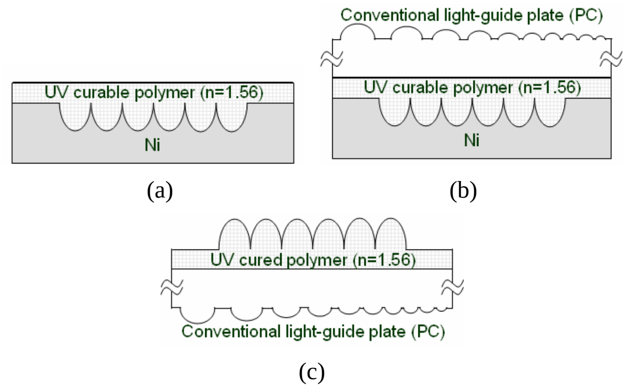


Figure 8. The fabrication process of the designed LGP : the conventional LGP mounting the microlens array.

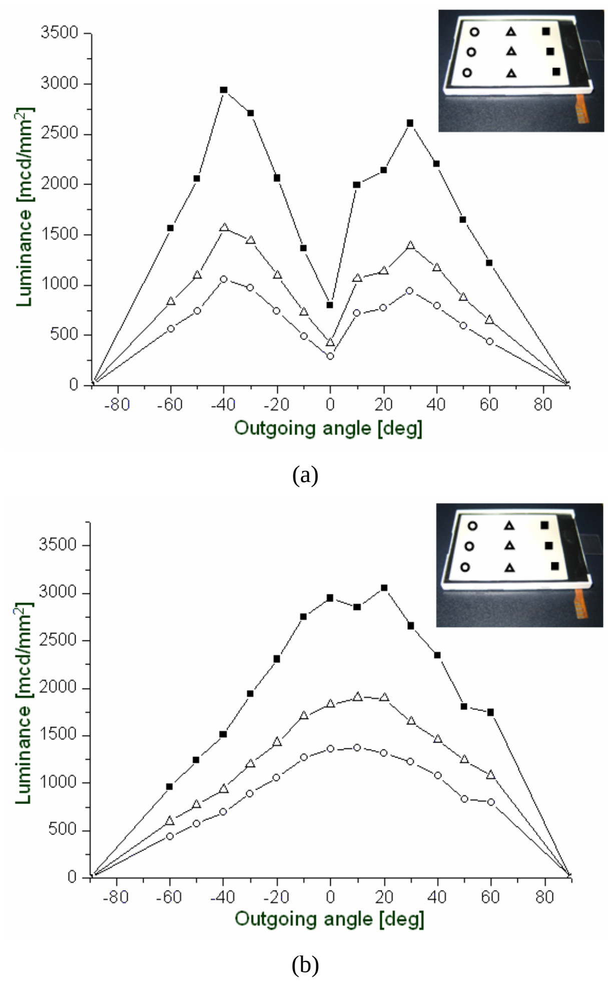


Figure 9. The measured luminance profiles of the proposed BLU : (a) the intensity distribution on the designed LGP only; (b) the intensity distribution on the proposed BLU including the conical microlens array sheet.

Figure 9 indicates the luminance distribution of the designed LGP and the proposed BLU including the conical microlens array sheet. As simulated, the lights passing by the designed LGP are centered on about ±30°~40° (Figure 9(a)) and headed to the vertical direction after passing through the conical microlens array sheet (Figure 9(b)).

The average luminance profile of the proposed BLU compared with that of the conventional BLU is shown in Figure 10. As a result, the total luminance and the luminance angle are improved by 13.6% and 245%, respectively.

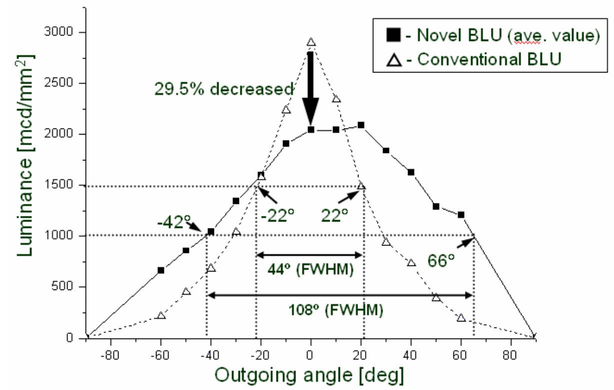


Figure10. The average luminance distribution of the proposed BLU compared to that of the conventional BLU.

However, some problems are still left such as the non-uniform luminance profile in the overall BLU and the decrease of the peak luminance by 29.5%. In near future, those challenges will be overcome by the optimization of dot-patterns of LGP and the density distribution of microlens array.

5. Conclusions

We have developed the novel BLU for thin LCD applications which is composed of the LGP mounting a microlens array with high fill-factor and only one additional conical microlens array sheet with the slanted angle of 54.5°. The proposed BLU has achieved 13.6% improvement in the total luminance compared with the conventional BLU. The viewing angle has also been enlarged from 44° in the conventional BLU to 108° in the fabricated BLU. Furthermore, we confirm that the process we suggested could be more cost-efficient using the stamper technology with the micro-patterns for injection molding. We believe that our design method can be improved and expanded to other LGPs with different sizes.

6. References

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