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Fabrication of micro injection mold with modified LIGA micro-lens pattern and its application to LCD-BLU

Jong Sun Kim, Young Bae Ko, Chul Jin Hwang, Jong Deok Kim and Kyung Hwan Yoon[1]*
Precision Mold Team, Korea Institute of Industrial Technology (KITECH), Korea
[1]Mechanical Engineering, Dankook University, Korea

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Abstract

The light guide plate (LGP) of LCD-BLU (Liquid Crystal Display-Back Light Unit) is usually manufactured by forming numerous dots by etching process. However, the surface of those etched dots of LGP is very rough due to the characteristics of etching process, so that its light loss is relatively high due to the dispersion of light. Accordingly, there is a limit in raising the luminance of LCD-BLU. In order to overcome the limit of current etched-dot patterned LGP, micro-lens pattern was tested to investigate the possibility of replacing etched pattern in the present study. The micro-lens pattern fabricated by the modified LiGA with thermal reflow process was applied to the optical design of LGP. The attention was paid to the effects of different optical pattern type (i.e. etched dot, micro-lens). Finally, the micro-lens patterned LGP showed better optical qualities than the one made by the etched-dot patterned LGP in luminance.

Keywords : back light unit(BLU), thin-film-transistor liquid-crystal-display (TFT-LCD), light guide plate (LGP), LIGA, micro-lens, injection molding

1. Introduction

LCD-BLU is one of the kernel parts of LCD unit and it consists of several optical sheets (such as prism, diffuser and protector sheets), LGP (Light Guide Plate), light source (CCFL or LED) and mold frame as shown in Fig. 1 (Nagahara and Fukui, 2001; Chang *et al.*, 2004). There have been many researches to improve the quality of LCD-BLU. Especially for the LGP, it is well known that the number of optical sheets may be reduced by applying three-dimensional micro patterns with appropriate optical design. Currently the LGP of LCD-BLU is usually manufactured by forming numerous dots with 50~200 μm in diameter on it by means of printing or printless methods. For the printless method, the dots on LGP mold are usually fabricated by chemical etching process, namely, isotropic etching of micro-pyramids on LGP (Lin *et al.*, 2000; Seidel, 1990). The surface of etched dots in this type of LGP is very rough due to the characteristics of the etching process during the mold fabrication, so that its light loss is high along with the dispersion of light. Because there is no good way of improving the structure of surface, there is also a limit in raising the final luminance of LCD-BLU in the point of optical design. In order to overcome the limit of the current etched-dot patterned LGP, a micro-lens pattern with 50 μm was tested to investigate the possibility for replacing the current etched pattern in the present study. The fabrication method of various samples using LIGA with the thermal reflow process and the micro-injection molding has been developed previously (Lin *et al.*, 1996; Ruther *et al.*, 1997; Hwang *et al.*, 2005). The advantages of the LGP made by LIGA-reflow process were found to be the accurate control of patterns and a very low surface roughness value of a few nanometers. The LIGA process uses UV lithography, electroplating and injection molding (or hot embossing) process for fabricating micro parts (Malek and Saile, 2004; Becker *et al.*, 1986). The reflow process uses the heat treatment of PR (Photo Resist), and the cylindrical PR melts and flows to the pedestal edges to form the spherical micro-lenses by surface tension (Popovic *et al.*, 1998; Wu *et al.*, 2002).

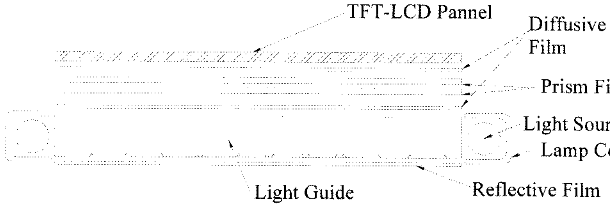
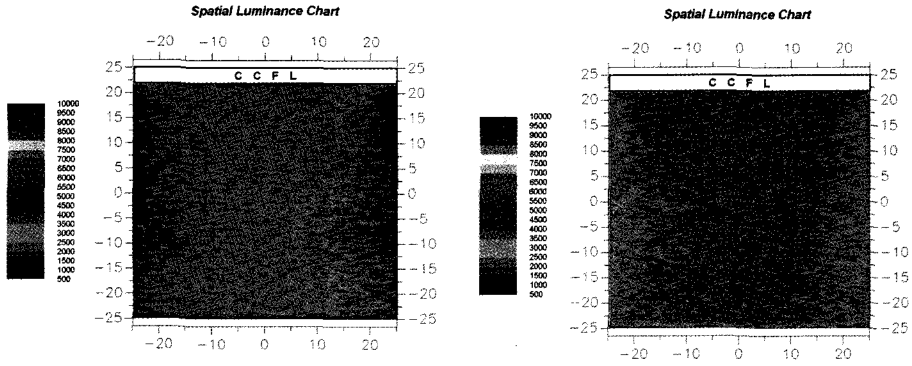


Fig. 1. A schematic diagram of LCD-BLU.

*Corresponding author: khyoon@dku.edu



(a) (b)

Fig. 2. Simulation results of spatial luminance of (a) etched-dot and (b) micro-lens patterned LGP.

2. Micro Optical Design for LCD-BLU

In order to understand the optical difference of the pattern, the LightTools program developed by Optical Research Associates was used for the optical analysis to compare the etched-dot patterned LGP with the micro-lens patterned LGP. The optical analysis model of the side flat type BLU was composed of a CCFL of flat-type, a lamp cover of specular reflection type, and a reflection sheet at the bottom as shown in Fig. 1. The material of LGP was Sumitomo MGSS Poly methylmethacrylate (PMMA) thermoplastic resin. The transmission rate of light for PMMA is about 98%, the refractive index is 1.492 at 550 nm and total reflection angle is 42.19.

Fig. 2(a) shows the simulation result of spatial luminance distribution for the BLU with the etched-dot patterned LGP. The average spatial luminance was 2,687 cd/m^2 and the peak value was 5,324 cd/m^2. The average spatial luminance out of simulation results for the BLU with micro-lens patterned LGP was 4,881 cd/m^2 and the peak value was 8,223 cd/m^2 as show in Fig. 2(b). The simulation was done to replace the position of etched dots with micro-lens shaped. From the above simulation the possibility of using micro-lens pattern to the LGP was proved. As shown in Fig. 3(a) and (b) higher light loss from etched-dot patterned LGP by diffusion can be explained than micro-lens patterned LGP which uses specular reflection as a main principle. An example of final design of optical pattern used in the present study with 200,000 dots is shown in Fig. 4.

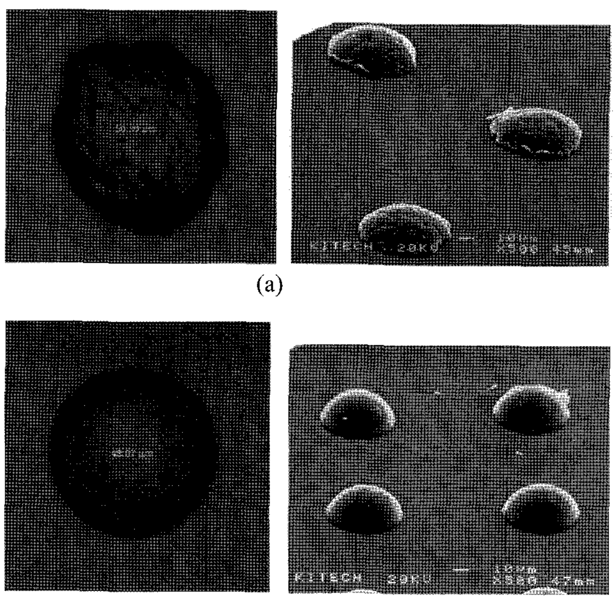


Fig. 3. Microscope and SEM image of (a) etched dots and (b) micro-lenses.

3. Micro Mold Fabrication with Modified LIGA Reflow Process

A schematic diagram of modified LIGA process with thermal reflow process is shown in Fig. 5. LIGA-reflow process is made up of three stages as follows; (i) the stage of lithography, (ii) the stage of thermal reflow process and

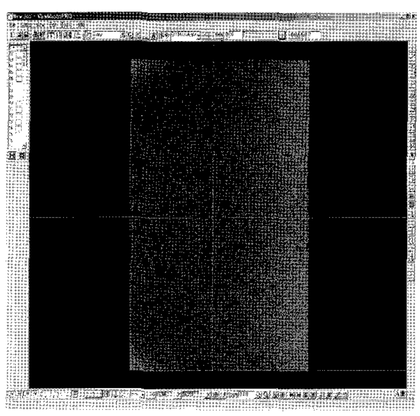


Fig. 4. An example of optical design pattern.

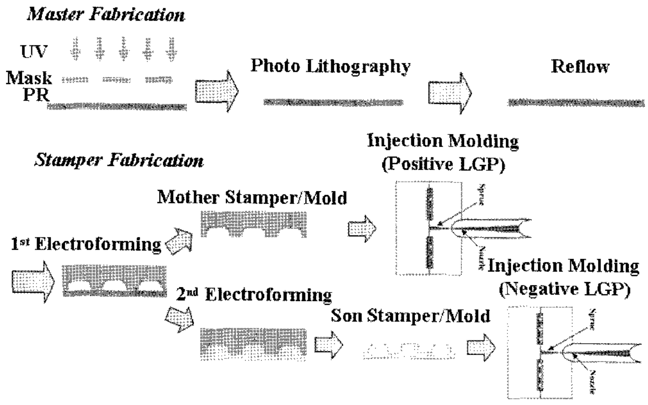
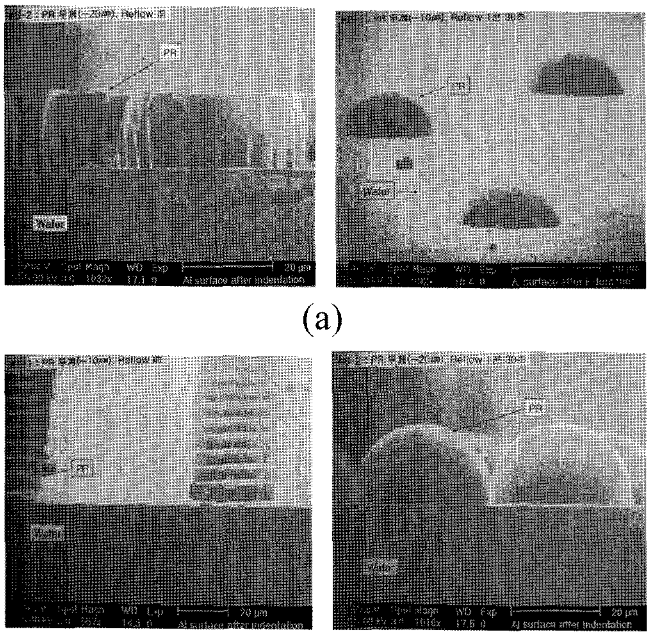


Fig. 5. A schematic diagram of LIGA-reflow process.



(a)

(b)

Fig. 6. Cylindrical PR structure after lithography and micro-lens structure after reflow process: ((a) PR thickness of 10 μm, (b) PR thickness of 20 μm).

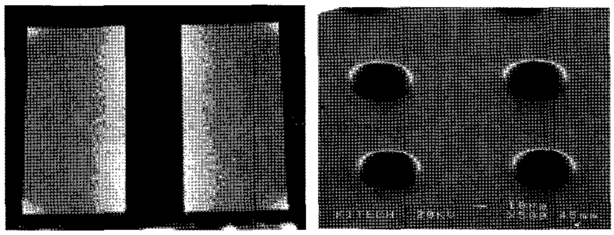
(iii) the stage of electroplating. In the stage of lithography a specific structure can be made by developing specific chemicals after exposing PR (photo resist) to the light source with a thickness up to hundreds of μm. To have a good exposure a mask that consists of the parts for both transmitting and absorbing UV or X-ray is used. Desired PR structure can be obtained through the process of development using the characteristics of photo-resist (PR), which can be dissolved into specific chemicals, namely, whose molecular structure is modified by the difference between the part irradiated by light and not being irradiated due to the mask. The PR structure obtained in the stage of lithography was cylindrical-shape. It change to micro-lens shape during reflow stage, while it is put in an oven with high

Table 1. The process conditions of LIGA-reflow.

process name	condition
Spin coating	1,300 rpm
	30 sec
Soft bake (oven)	95°C
	50 min
Relaxation	25°C
	30 min
Exposure	250 mJ/cm^2
Development	25°C
	8 min
Reflow (oven)	135°C
	5 min

temperature (about 135°C in this study) [Fig. 6]. The process conditions of LIGA-reflow are listed in Table 1. The film mask was converted from the CAD file containing the final optical design pattern. In the present study the Si wafer of 500 μm in thickness was coated with AZ9260 positive PR by spin coater. For soft baking, the Si wafer was placed in the convection oven at 95°C for 50 min. And it was cooled down gradually to room temperature. The exposure power used was 250 mJ/cm^2 and development time was 8 minutes. Finally, developed PR was placed in the convection oven at 135°C for 5 minutes for the reflow process.

This LIGA-reflow process is a simple method of producing micro-lens structure unlike other processes, but it has an excellent surface roughness of only a few nanometer. After the reflow process, the opposite shape of a PR structure was obtained through the electroplating process, and the electroplated part will be used as a stamper in injection mold. In the present study the Ni stamper was made by Digital Matrix's electroplated machine. The Electroplating was conducted at 55°C, pH of 4.2 with a low current density in order to minimize the internal stress and to obtain uniform thickness of 500 μm. Finally, an electroplated stamper was ready to be assembled in the mold



(a) (b)

Fig. 7. Positive patterned micro-mold with 50 μm micro-lenses ((a) a photograph of mold, (b) SEM image of mold).

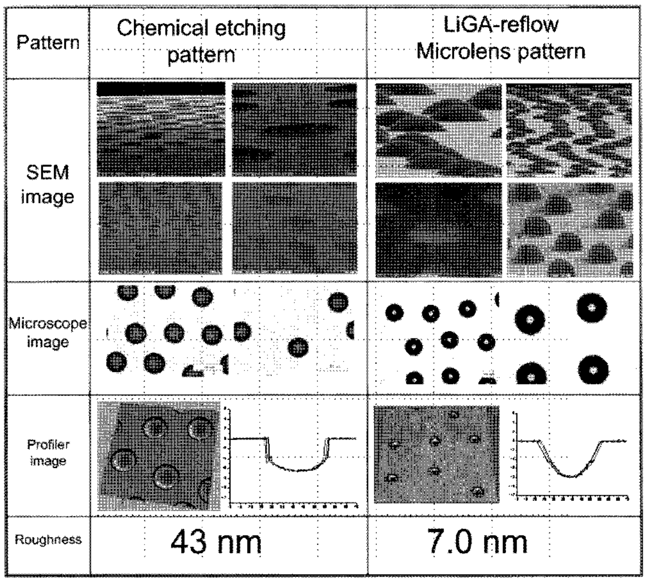


Fig. 8. Surface roughness of chemical etched mold and LIGA reflowed mold.

after back-polishing and cutting process. The final stamper for molding positive patterned LGP is shown in Fig. 7. As shown in Fig. 7 the diameter of micro-lens was about 50 ìm. And the average surface roughness of LIGA reflowed pattern on the mold was 7.0 nm, which can be compared with the value of 43 nm as shown in Fig. 8.

4. Micro Injection Molding of Micro-lens Pattern LGP

IS450GSW from Toshiba Co., Ltd. as shown in Fig. 9 was used as an injection molding machine in the present study. All the micro injection molding experiments were performed in the clean room (Class 10,000). The injection molding conditions were as follows: 0.85 second of the filling time was applied to 2.5 inch LGP molds with four cavities and multiple control of the injection speed. And the material in this experiment was optical grade PMMA (MGSS, Sumitomo Corporation, Japan). The mold temperature, one of the most influential factors upon micro pattern mold, was 70°C. In Fig. 10 injection molded LGP with sprue and runner system is shown. The SEM images shown in Fig. 11 were taken to evaluate the replication quality of micro-lens pattern for the injection-molded samples. Those micro-lens pattern on injection-molded LGP showed excellent three-dimensional structure as desired.

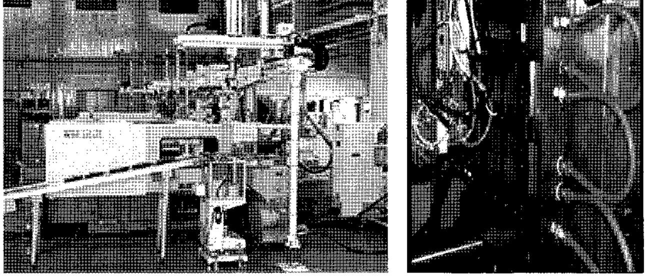


Fig. 9. The photographs of injection molding machine (Toshiba IS450GSW) and a mold used.

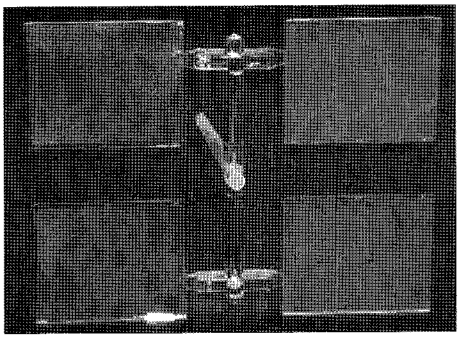
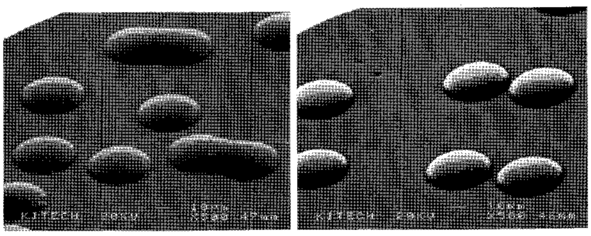


Fig. 10. Micro injection-molded LGP.

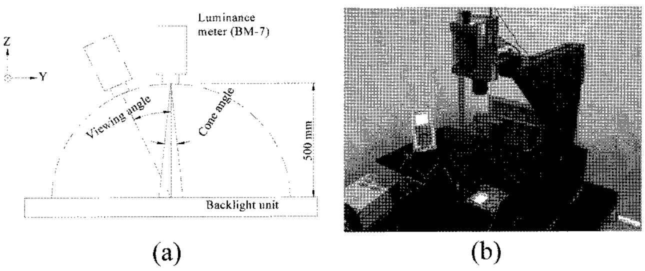


(a) (b)

Fig. 11. SEM images of injection-molded LGP.

5. Results of Optical Measurement using Injection-molded LGP's

In the present study BM-7 (Topcon, Japan) was used to measure the luminance of BLU. Fabricated etched-dot patterned and micro-lens patterned LGP's were placed on the side of a CCFL source for optical measurements. The experimental set-up is shown in Fig. 12, where the number of measuring points was 1,500, cone angle was 1°, and the nominal measuring distance was 500 mm away from the BLU surface. Fig. 13 shows the distribution of spatial



(a) (b)

Fig. 12. (a) A setup for luminance measurement (BM-7) of a backlight unit and (b) its photograph.

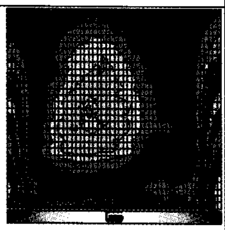
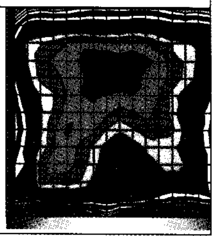
	Micro-lens LGP	Etched LGP
Average Brightness (cd/m^2)	4,018	1,987
Max. Brightness	6,349	3,927
Uniformity (%)	60	50
Distribution of luminance (1,500 point)		

Fig. 13. The results of luminance measurement of micro-lens and etched-dot patterned LGP's.

luminance for both LGP's. Average and maximum luminance of etched dot patterned LGP were 1,987 and 3,927 cd/m^2, respectively, and luminance uniformity was 50%. On the other hand, average and maximum luminance of micro-lens patterned LGP were 4,018 and 6,349 cd/m^2, respectively, and luminance uniformity was 60%. For both etched-dot patterned and micro-lens patterned LGP's average luminance values came out less than the simulation results, because replication ratio for real injection-molded samples cannot be 100%.

6. Conclusions

In the present study micro-lens patterned LGP made by LIGA reflow was tested to investigate the possibility to replace current etched patterned LGP in LCD backlight unit. The micro-lens pattern was proved to be very promising to improve the efficiency of current LGP design through both simulation and experimental work.

References

Becker, E.W., W. Ehrfeld, P. Hagman, A. Mauser and D. Münchmeyer, 1986, Fabrication of microstructures with high aspect ratios and structural heights by synchrotron radiation lithography, galvanoforming, and plastic moulding (LIGA process), *Microelectron. Eng.* **4(1)**, 35-56.

Chang, N., I. Choi and H. Shim, 2004, SDLS: Dynamic backlight luminance scaling of liquid crystal display, *IEEE TRANSACTIONS ON VERY LARGE SCALE INTEGRATION (VLSI) SYSTEMS* **12(8)**, 837-846.

Hwang, C.J., Y.B. Ko, S.Y. Ha, G.H. Lee and Y.M. Heo, 2005, Micro injection mold fabrication with modified LIGA microlens pattern and its application to LCD-BLU, *21st Annual Meeting of the Polymer Processing Society.*

Lin, L., T.K. Shia and C.J. Chiu, 2000, Silicon-processed plastic micropyramids for brightness enhancement applications, *J. Micromech and Microeng.* **10**, 395-400.

Lin, L., C.J. Chiu, W. Bacher and M. Heckele, 1996, Microfabrication using silicom mold inserts and hot embossing, *7th International symposium on Micro Machine and Human Science*, 67-71.

Malek, C.K. and V. Saile, 2004, Applications of LIGA technology to precision manufacturing of high-aspect-ration micro-components and -systems: a review, *Microelectronics Journal* **35**, 131-143.

Nagahara, T. and A. Fukui, 2001, Light-guide plate for liquid crystal display, *Matsushita Technical Journal* **47(3)**, 2-6.

Popovic, Z.D., R.A. Sprague and G.A.N. Connell, 1998, Technique for monolithic fabrication of microlens arrays, **27(7)**, *Applied Optics*, 1281-1284.

Ruther, P., B. Gerlachy, J. Götterty, M. Iliez, J. Mohry, A. Müllery and C. Oßmanny, 1997, Fabrication and characterization of microlenses realized by a modified LIGA process, *Pure Appl. Opt.* **6**, 643-653.

Seidel, H., 1990, The mechanism of anisotropic, electrochemical silicon etching in alkaline solutions, *Solid-State Sensor and Actuator Workshop, 4th Technical Digest., IEEE*, 86-91.

Wu, M.H. and G.M. Whitesides, 2002, Fabrication of two-dimensional arrays of microlenses and their applications in photolithography, *J. Micromech and Microeng* **12**, 747-758.