Korea-Australia Rheology Journal
Vol. 19, No. 3, November 2007 pp. 171-176

A study on the fabrication method of middle size LGP using continuous micro-lenses made by LIGA reflow

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

(Received July 10, 2007; final revision received October 14, 2007)

Abstract

LCD-BLU (Liquid Crystal Display-Back Light Unit) of medium size is usually manufactured by forming numerous dots with 50~300 μm in diameter by etching process and V-grove shape with 50 μm in height by mechanical cutting process. However, the surface of the etched dots is very rough due to the characteristics of the etching process and V-cutting needs rather high cost. Instead of existing optical pattern made by etching and mechanical cutting, 3-dimensional continuous micro-lens of 200 μm in diameter was applied in the present study. The continuous micro-lens pattern fabricated by modified LIGA with thermal reflow process was tested to this new optical design of LGP. The manufacturing process using LIGA-reflow is made up of three stages as follows: (i) the stage of lithography, (ii) the stage of thermal reflow process and (iii) the stage of electroplating. The continuous micro-lens patterned LGP was fabricated with injection molding and its test results showed the possibility of commercial use in the future.

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

1. Introduction

It is very well known that LCD (liquid crystal display) becomes popular in mobile display market. LCD unit consists of liquid-crystal panel, electric circuit and BLU (Back Light Unit). Among them, liquid-crystal panel consists of color-filter, orientation layer, liquid-crystal layer and TFT (Thin Film Transistor). BLU consists of reflection film, LGP (Light Guide Plate), BEF (Brightness Enhancement Film) and protection sheet as shown in Fig. 1 (Nagahara *et al.*, 2001). The main function of LGP, one of the most important components of BLU, is to make plane light source out of line source (CCFL) or point source (LED) (Lin *et al.*, 2000; Lin *et al.*, 1996). The LGP in existing navigators [Fig. 2] has printed individual diffusion optical pattern at the bottom, which is usually made by etching process. However, as shown in Fig. 3, the etched pattern on it has very rough surface due to its fabrication process. The light through the LGP has high ratio of scattering and rather high loss to reach the surface. Consequently, there are certain limitations in enhancing the efficiency of LCD-BLU using etched pattern. In other words, LGP having high luminance is difficult to be developed, even though precise control of individual optical pattern is achieved. The shape uniformity and surface roughness of individual optical pattern are two main problems.

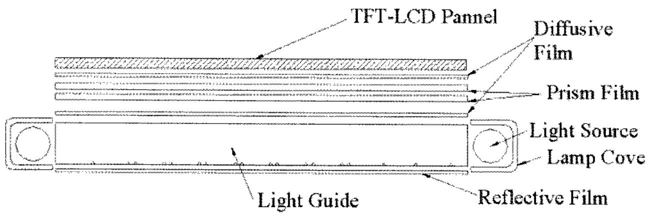


Fig. 1. A schematic diagram of LCD-BLU.

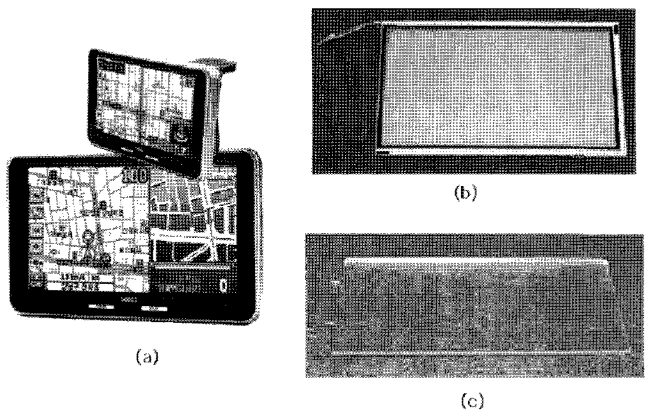


Fig. 2. Photographs of LCD-BLU for navigator system.

*Corresponding author: khyoon@dku.edu

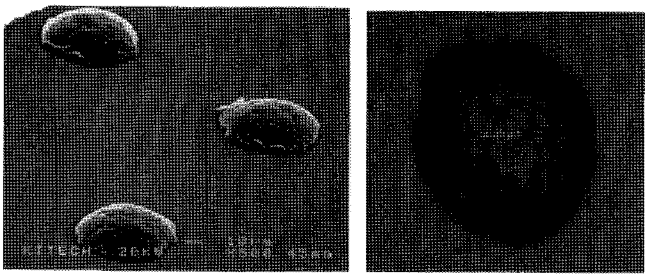


Fig. 3. Microscopic and SEM images of etched dots on LGP surface.

In the present study, to overcome the limitation of existing etched pattern the continuous micro-lens pattern of 200 μm was applied to the LGP for navigation use. UV LiGA technique that enables to optimize the special optical shapes and to control the surface roughness with several nanometer level. (Ruther *et al.*, 1997; Hwang *et al.*, 2005; Malek *et al.*, 2004; Popovic *et al.*, 1998; Wu *et al.*, 2002)

2. Continuous micro-lens

The individual optical pattern that is used in existing LGP is shown in Fig. 4. Most of them are hemisphere shaped optical pattern made by etching. As written in the introduction, the main difficulty is to control their exact patterned shape and is impossible to increase the aspect ratio due to the characteristics of etching process. An alternative method is the application of machine processed V-grove pattern that is currently introduced to LGP's for medium sized-notebooks and monitors. However, when about 4,000 V-groves of 50-100 μm pitch are reproduced, the problem of uniformity occurs between V-groves. Besides, as it uses expensive equipment, not only its processing cost is high but also flexibility is low. In order to overcome these problems, UV-LIGA and reflow processes were carried out to link neighboring photoresists to make the final shape of continuous micro-lens as shown in Fig. 5(b) and (c). Because such continuous micro-lens uses semiconductor process, it is relatively easy to control the patterned shape and to achieve similar or better optical efficiency than other patterns.

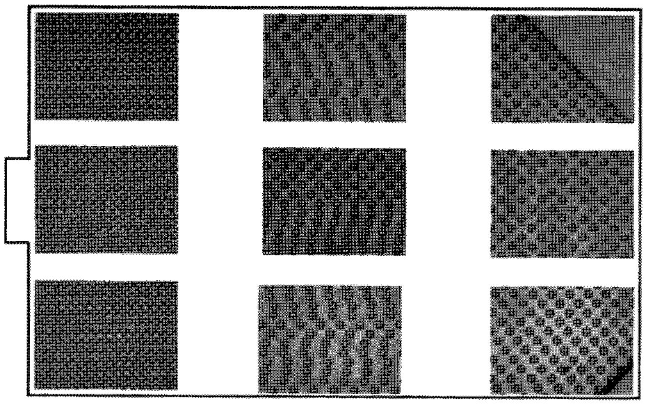


Fig. 4. Examples of etched dots of current LGP for navigator system.

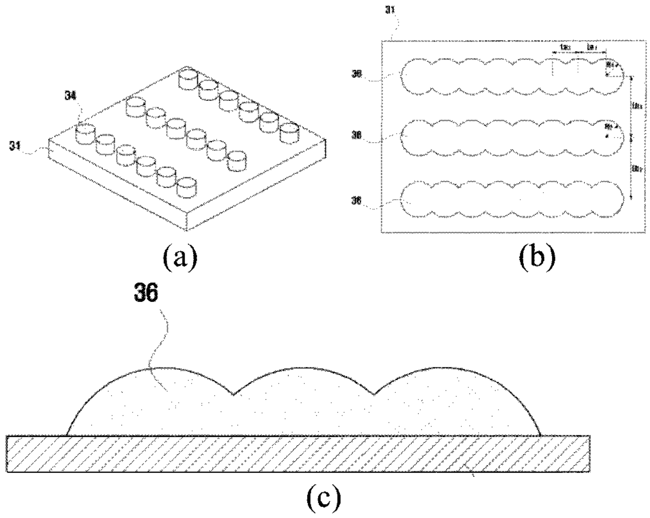


Fig. 5. A schematic diagram of continuous micro-lenses.

3. Optical analysis of 7 inch BLU

In order to design 7 inch BLU for navigator, the present study adopted the continuous micro-lens of 200 μm in diameter and adjusted luminance by controlling the density of optical pattern. An example of an existing LGP uses 100 μm size etching pattern, as shown in Fig. 4, and adjusts luminance by controlling the density of pattern (97,020 pieces of etched dots). To obtain higher luminance 934,751 pieces of continuous micro-lenses was used in the present design. SPEOS (OPTIS Corp.), an optical analysis program, was used for the optical analysis of newly designed LGP. And optical analysis model was

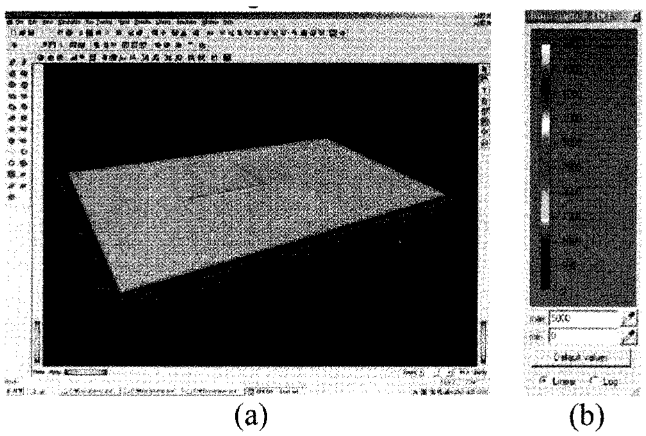


Fig. 6. (a) A simulation model of continuous micro-lens patterned LGP by SPEOS and (b) a scale bar of spatial luminance.

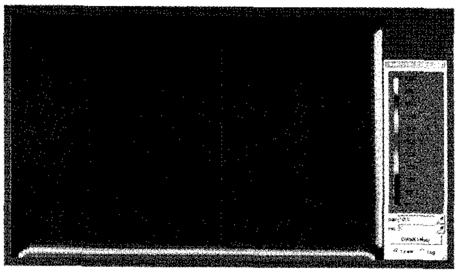


Fig. 7. A simulation result of spatial luminance in positive etched-dot patterned LGP.

"L"-shaped CCFL structure from entire LGP structure as shown in Fig. 6(a). It consisted of a BLU of 3 mm regular thickness and a reflection sheet at rear side. The resin used for current LGP was PMMA, i.e., MGSS grade resin of Sumitomo Corp., and its refractive index was 1.49. Under the above conditions, an analysis model using SPEOS for the LGP was completed as shown in Fig. 6. The present analysis used continuous micro-lens that had same pattern density and diameter. And the height of each micro-lens was adjusted later. The results of simulation for the spatial luminance that measures radiation flux passing through unit site from photometric view point are shown with a scale bar as in Fig. 6.

4. The results of optical analysis

For the case of existing 7 inch LGP for navigator, the nominal height of individual optical pattern was fixed as 15 μm and the diameter was fixed as 100 μm. Its contrast could be secured uniformly to 0.12 but average luminance showed low value of 1,580 nit. Uniformity of luminance was 78% and optical efficiency was about 24%. As shown from the simulation results current etched-dot patterned optical design was relatively easy to maintain the luminance uniformity, but showed rather low average luminance. Thus, in the present study, an optical design with continuous micro-lens was carried out to improve the problems of etched patterns.

Fig. 8(a) shows simulation results using the continuous micro-lenses of 200 μm in diameter and 15 μm in height. The contrast was 0.24, average luminance was 3,794 nit, luminance uniformity was 62% and optical efficiency was about 51%. Average luminance increased almost 2.5 times compared with existing etched-dot patterned LGP, but the uniformity decreased significantly. The average luminance using continuous micro-lenses was very promising, however, the target height of lenses should be determined by simply changing the height in the simulation. Usually the ratio of the height to the diameter is called as aspect ratio (AR) for hemispherical lens. So, for the first case, the aspect ratio was 0.075 (AR=0.075).

Fig. 8(b) shows the results when the height of continuous micro-lenses was set at 20 μm (AR=0.10). The contrast was 0.12 similar to existing etched-dot patterned LGP, average luminance was 4,640 nit, luminance uniformity was 79% and optical efficiency was about 61%. Both average luminance and uniformity increased as the aspect ratio increased.

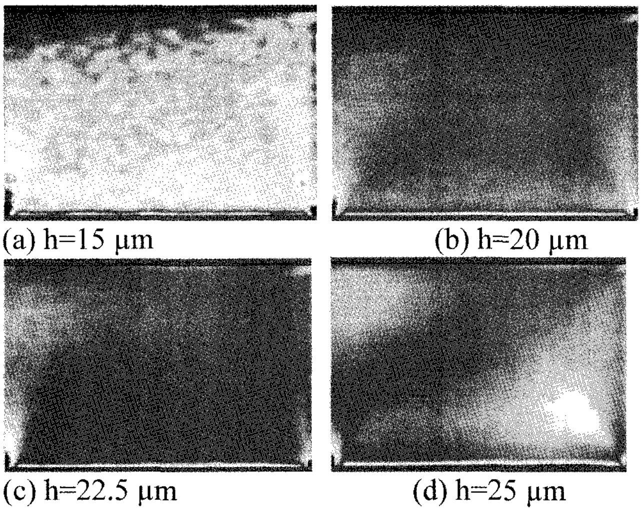


Fig. 8. Simulation results of spatial luminance from continuous micro-lens patterned LGP (h=height of optical pattern).

Fig. 8(c) shows the results when the height of continuous micro-lenses was set at 22.5 μm (AR=0.1125). The contrast was also 0.12, average luminance was 4,956 nit, luminance uniformity was 78% and optical efficiency was about 64%.

Fig. 8(d) shows the case 25 μm (AR=0.125). The contrast was 0.27, average luminance was 5,536 nit, luminance uniformity was 58% and optical efficiency was about 71%.

To summarize the above simulation results of optical analysis as shown in Table 1 average luminance tends to increase as the height of optical pattern becomes higher. However, luminance uniformity decreased again, as the height of optical pattern was higher than 25 μm. The results of higher than 30 μm are not shown here. As a result of simulation, the optimal height of continuous micro-lens pattern should be between 20 and 25 μm in

Table 1. The simulation results of luminance data of micro-lens patterned LGP

	etching	continuous			
height of optical patten (um)	15	15	20	22.5	25
contrast	0.12	0.24	0.12	0.12	0.27
average luminance (nit)	1,580	37,94	4,640	4,956	5,536
luminance uniformity (%)	78	62	79	78	58
Coefficient of light utilization (%)	24	51	61	64	71

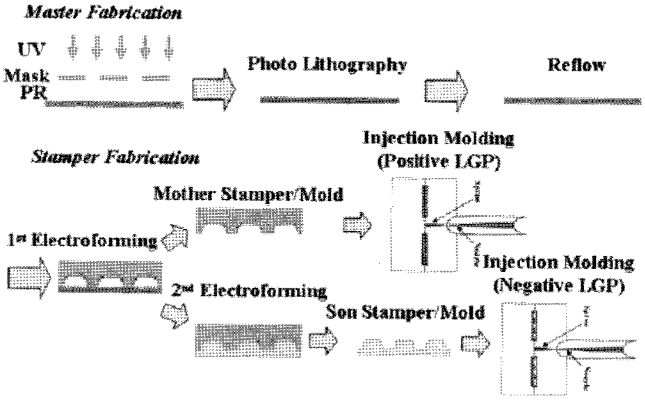


Fig. 9. A schematic diagram of LIGA-reflow process.

Table 2. The process conditions of LIGA-reflow

process name	condition
Spin coating	1,000 rpm
	30 sec
Soft bake (oven)	95°C
	50 min
Relaxation	25°C
	30 min
Exposure	300 mJ/cm^2
Development	25°C
	4 min
Reflow (oven)	140°C
	5 min

order to get high enough uniformity maintaining high average luminance. Finally, 200 μm of diameter and 22.5 μm of height (AR=0.1125) were selected as target values of micro-lenses for the experimental work of LIGA reflow process.

5. Mold fabrication using LIGA reflow

In the mold fabrication process LiGA-reflow was used as a main scheme. The process was in the order of (i) photo lithography stage, (ii) reflow stage and (iii) electroplating stage, as shown in Fig. 9.

The process conditions of LIGA-reflow are listed in Table 2. The film mask was made by the CAD file containing the optical design pattern as shown in Fig. 10. In this study, 500 μm thick Si wafer 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. PR (Photo-Resist) of 14 μm in thickness was exposed to UV light using film mask, and it was developed by using developing solution to make desired struc-

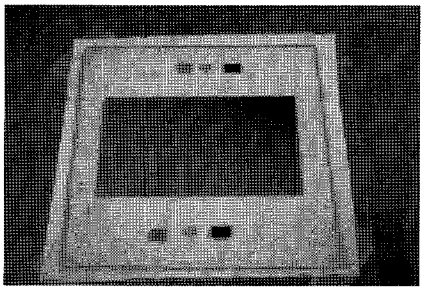


Fig. 10. A photograph of film mask used.

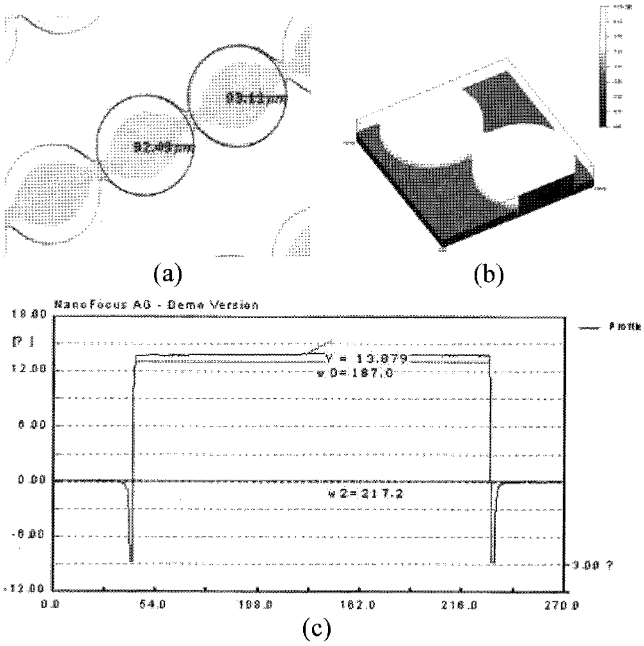


Fig. 11. The images and measurement results of cylindrical PR pattern for continuous micro-lenses. ((a) microscope image, (b) and (c) the results of 3D-profiler measurement).

ture. The exposure power was 300 mJ/cm^2 and development time was 4 min. Finally, PR structure in Fig. 11 was obtained through photo lithography stage. Fig. 11(a) shows the result of optical microscope measurement and Fig. 11(b) and (c) are the results of 3D-profiler measurement. The final PR structure had 13.88 μm of height, 217 μm of diameter and formed definite column(or cylindrical) shape, as expected.

The critical reflow process was undergone to place the pre-structure in the convection oven at 140°C for 5 min, which is higher than the glass transition temperature (Tg) of PR. The developed PR structure changed to the shape of continuous micro lens by surface tension. Such LIGA-reflow process, unlike other processes, is a simple method to make micro-lens shape. And, the surface roughness of several nano-levels could be obtained. Fig. 12(a) is the optical microscope photo to show how the column shaped PR changes into micro-lens shape after reflow process.

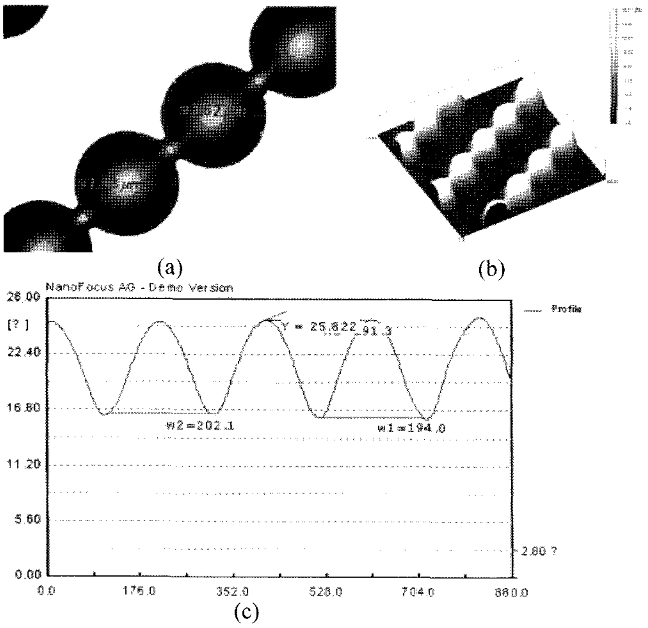


Fig. 12. The images of positive re-flowed PR from ((a) microscope, (b) and (c) 3D-profiler).

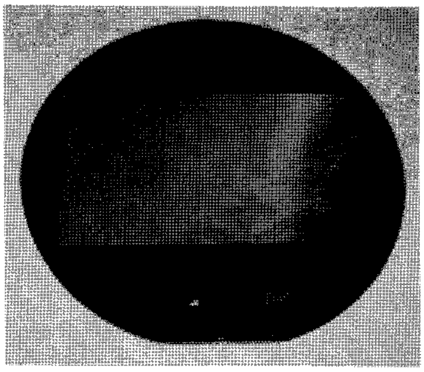


Fig. 13. A photograoh of re-flowed PR for navigator system.

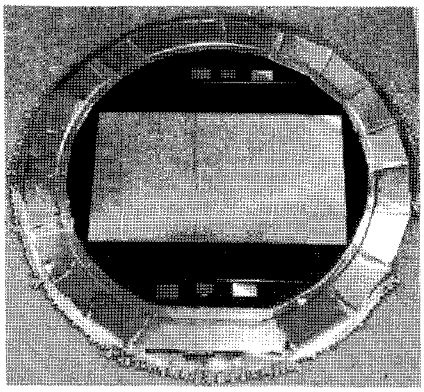


Fig. 14. A photograph of electroplated mold (or stamper).

Fig. 12(b) and (c) are the results measured by 3D-profiler. The produced continuous micro-lens shape has 25.8 μm of height and about 200 μm of diameter. The height of the continuous lenses were slightly higher than target value. The final PR structure produced by these processes is shown in Fig. 13.

After the reflow process, the opposite shape of a PR structure was obtained through the electroplating process, and the electroplated mold (or stamper) was used in injection molding. The electroplated stamper was made by Digital Matrix's electroplated machine. The Electroplating was conducted at 55°C, pH of 4.2 and at low current density in order to minimize the internal stress and to obtain 500 μm of uniform thickness. For finishing processes the stamper was back-polished and cut into right size. The final micro mold equipped with positive patterned stamper is shown in Fig. 14. The SEM image of the surface of electroplated stamper is shown in Fig. 15.

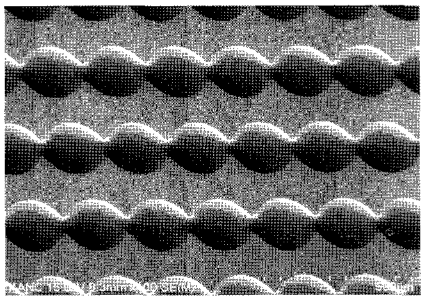


Fig. 15. SEM image of continuous micro lens on the surface of a mold used.

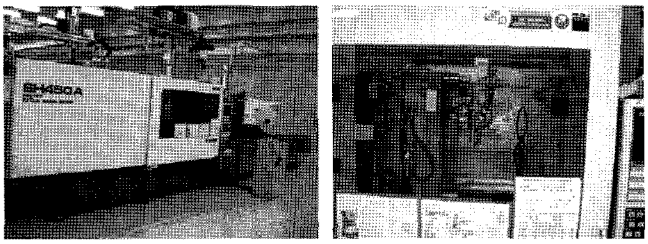


Fig. 16. Photographs of (a) injection molding machine (L.G, SH450A) and (b) injection mold (7", 1 cavity).

6. Injection molding and luminance evaluation

The injection molding machines used to mold the sample LGP was SH450A (450 ton) of Sumitomo Corp. as shown in Fig. 16(a) and (b). And the micro injection molding experiments were done in the clean room (Class 10,000). Injection time was set to 2 seconds and injection velocity in the cavity section was 100 mm/s. The melt temperature was 265°C, mold temperature was 60°C and the packing pressure was maintained as 100% of the one at the end of fill for 3 seconds. From the injection molding carried out under above conditions 7 inch/1-cavity LGP sample was produced as shown in Fig. 17.

After the injection-molded LGP sample was assembled to existing BLU frame, its luminance was measured with

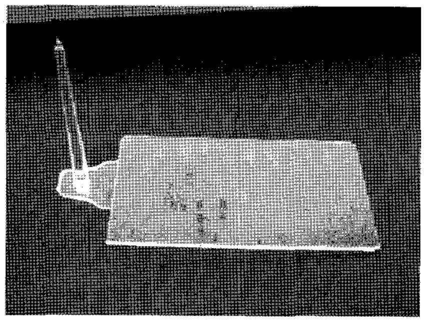
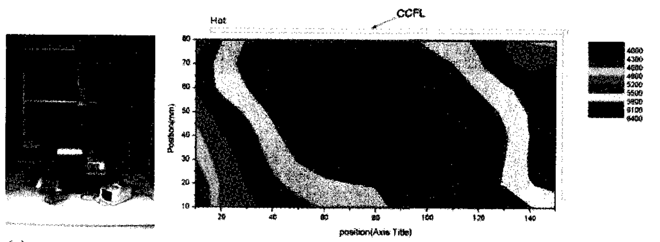


Fig. 17. A final injection-molded LGP sample for navigator system.



(a) (b)

Fig. 18. A photograph of (a) BM7 and of (b) the results of luminance measurement of micro-lens patterned LGP.

BM7 as shown in Fig. 18(a). As a result, 5,244 nit of average luminance was obtained as shown in Fig. 18(b). 5,244 nit is the value between the simulation results of 22.5 μm and 25 μm. The reason why the experimental value of average luminance was lower than simulated one was that the transcription ratio of injection-molded micro-lens pattern could not reach to 100%.

7. Conclusions

When the optical pattern of continuous micro-lens type made by LIGA reflow was introduced to replace existing etched-dot pattern, it was proved that much higher optical efficiency could be obtained than etched pattern. Furthermore, it was demonstrated that the production of LGP mold with continuous micro-lens pattern using UV-LIGA and electro-plating can be applied to other BLU systems in future use.

References

Hwang, C.J., Y.B. Ko, S.Y. Ha, G.H. Lee and Y.M. Heo, 2005, Micro injection mold fabrication with modified LIGA micro-lens 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. Microeng.* **10**, 395-400.

Lin, L., C.J. Chiu, W. Bacher and M. Heckele, 1996, Micro-fabrication 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.

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.

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

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