Development of Direct Surface Forming Process

Kwanghwan Cho and Kyunghwan Yoon

Department of Mechanical Engineering, Dankook University
San 8, Hannam-Dong, Yongsan-Ku, Seoul, Korea, 140-714

Abstract

The backlight unit(BLU) is used as a light source of TFT liquid-crystalline-display (TFT-LCD) module. In this backlight unit, one of important components is the light guide, which is usually made of transparent polymers. Currently the screen-printing method is mainly used for the light guide as a manufacturing process. However, it has limitation to the flexibility of three-dimensional optical design. In the present paper a new alternative manufacturing method for the light guide with low-cost is proposed. This manufacturing method is named as direct surface forming (DSF), which is very similar to the well-known hot embossing except for partial contact between mold and substrate. The results of this new manufacturing method are presented in terms of processing condition, dimensional accuracy, productivity, etc.

Key Words : Back light unit, Direct surface forming(DSF), Light guide, Thin-film-transistor Liquid-crystalline-display (TFT-LCD)

1. Introduction

Recently the market share of the thin-film-transistor liquid-crystalline-display (TFT-LCD) is growing rapidly in display device market. In order to lead market share many LCD makers have been making their efforts to develop the TFT-LCD module, which consists of TFT-LCD panel, backlight unit and housing, not only with thinner and wider panel but also at lower cost. In considering these factors, the backlight unit is being focused on as one of target components. The backlight unit is used in TFT-LCD module as a light source. As shown in Fig. 1 the backlight unit consists of light source, light guide, housing and several optical films such as reflective film, prism film, and diffusive film. The function of backlight unit is to make the light from light source, which is usually a fluorescent lamp or light-emitting diode(LED), transferred into the screen of TFT-LCD module and to make the intensity of the transferred light as high and uniform as possible. In order to achieve this goal, the light guide is a very important component in backlight unit, which is usually made of polymethyl methacrylate (PMMA). The light guide should have the micro-optical pattern which is based on optics in order to change the direction in which the light travels. The order of this micro-optical pattern is about 10~100 μm. An example for 3-dimensional micro-optical pattern of light guide designed by reflective method is shown in Figure 2. The angle, depth and pitch of pattern may not be uniform to achieve the maximum performance.

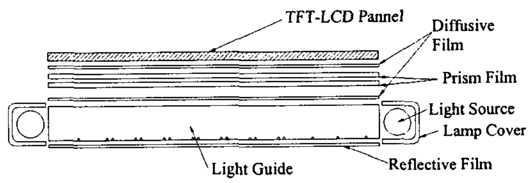


Figure 1. The structure of backlight

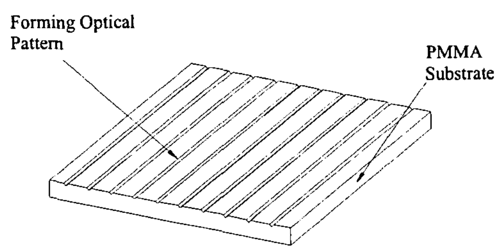


Figure 2. An example of 3-D optical pattern designed by reflective method(light guide)

Currently screen-printing method is usually adopted for the mass production of making the micro-optical pattern in light guide of most TFT-LCD modules. The printed ink makes the light scattered in order to obtain the uniform intensity of the light in the screen of the TFT-LCD module. Although this manufacturing method seems to be very simple, it has several weak points such as the limitation of optical pattern design, absorption of small amount of light by printed ink, productivity, manufacturing cost, and so on. The other manufacturing technologies for making micro-optical pattern include V-cutting, injection molding, hot embossing, etc., which have also their own advantages and disadvantages [1]. However, these technologies are not proper for large-sized TFT-LCD module(18" or larger).

In this paper a new alternative manufacturing method to the screen-printing method is proposed for large-sized TFT-LCD module, which is called the direct surface forming (DSF). The DSF is similar to the well-known hot embossing except for partial contact between mold and substrate [2-5]. The DSF is to make micro-optical pattern directly on the flat rectangular substrate of PMMA by using mold with locally heated micro-optical pattern [6-7]. The light guide can be deigned not by using scattering of light but by using the refraction and reflection of the light through this manufacturing technology. This manufacturing technology can allow flexibility for optical system design and accurate transcription of micro-optical pattern with low cost, which should be advantages of manufacturing technology.

2. The DSF Process

This concept of partial contact between mold and substrate is different from that of hot embossing technology as shown in Fig. 3.

DSF molding machine consists of press, heating element, cooling channel, mold and stopper. At the first step for DSF molding, the mold is heated by heating element up to specified temperature. Then the press makes mold move down to the pre-heated substrate of PMMA and the mold stops by stopper. The contact between mold and substrate makes PMMA substrate heated locally up to temperature high enough to make PMMA flow locally for making micro-optical pattern. Only very low pressure is required for making transcription of the micro-optical pattern onto the substrate of PMMA compared with hot embossing, which results from meting locally only the surface of PMMA substrate and decreasing the viscosity of PMMA very fast while hot mold surface starts to touch PMMA substrate.

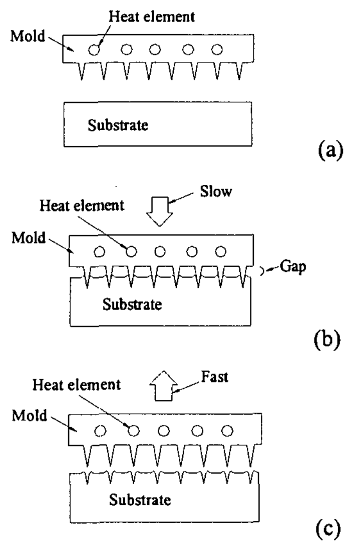


Figure 3. Schematic diagram for DSF technology; (a) initial heating of a mold, (b) partial contact and (c) retraction of a mold

The advantages for this new manufacturing technology are as follows:

- Increasing the intensity of light on the screen of TFT-LCD module because DSF does not use ink material that can absorb light.
- Increasing the productivity because of low level of energy consumption during the manufacturing due to local heating.
- Decreasing the manufacturing cost because molding machine and mold for DSF can be made with relatively low price in comparing with those for other technologies due to very low pressure required for molding.

3. Experimental Results

For the first feasibility study of DSF, a mold for the light guide of 70 mm × 70 mm × 3 mm has been made as shown in Figure 4(press-type mold). An initial DSF molding machine equipped with the mold is in Figure 5. Commercial PMMA plate(Mitsubishi) is used as a substrate [8]. The micro-optical pattern used in this experiment is V-groove with depth of 50 ~ 300 μm, angle of 30 ° and pitch of 0.5 ~ 2 mm.

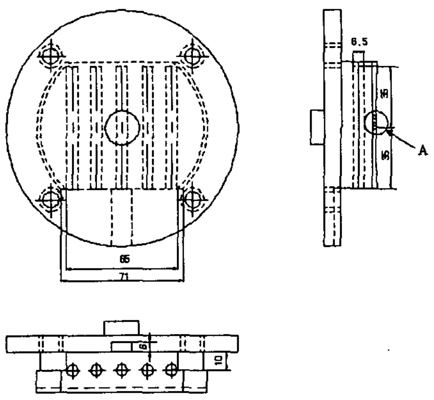


Figure 4. Molding machine and press-type mold for DSF; press-type mold for DSF

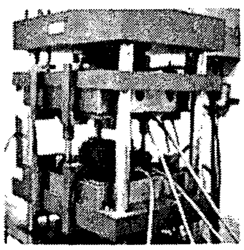


Figure 5. Picture of DSF molding machine

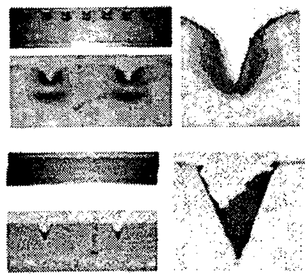
Table 1 shows the list of processing conditions with various pressure and temperature in order to find feasible and optimal processing condition. Figure 6 shows two experimental results for cross-sectional views of transcribed bad V-groove and good V-groove. As shown in Figure 6 (a), large deformation occurs on the surface of V-groove because of low processing temperature. On the other hand, the deformation can be negligible near the micro-optical pattern at the elevated temperature ($T \geq T_g + 70$ ℃)), as shown in Figure 6(b). In addition, pressure has been proven to be not a critical factor for DSF technology from these results of preliminary experiments. In this experiment, the applied pressure is only 0.2 atm. That means that the pressure due to gravity is high enough to transcribe perfectly V-groove on the substrate at the elevated temperature

From this experiment, the following results have been found:

- Mold temperature ($T \geq T_g + 70$ ℃) should be much higher than the recommended temperature of the mold for hot embossing, which is slightly higher than glass transition temperature of used substrate.
- There exists a warpage of light guide after ejection because of local and differential heating and cooling, which results from viscoelastic behavior of PMMA.

Table 1. Processing conditions for experiments with press mold

	Pressure(MPa)	Upper Mold Temp.(℃)	Depth(mm)
1	0.17	135	0.840
2	0.07	135	0.460
3	0.05	130	0.425
4	0.03	130	0.340
5	0.01	130	0.050
6	0.02	151	0.383
7	0.02	167	0.272
8	0.02	170	0.520
9	0.02	188	0.242



(a)

(b)

Figure 6. The cross sectional view of manufactured micro-optical pattern by press-type mold; (a) Case 4 (bad groove) and (b) Case 8 (good grove)

For the second feasibility study, several experiments have been performed with a knife-type mold, as shown in Fig. 7. The angle of knife-type mold is changed from 30 ° to 74 ° for applying to light guide with more realistic micro-optical pattern. In this study, our goal is to determine optimal processing temperature and pressing time.

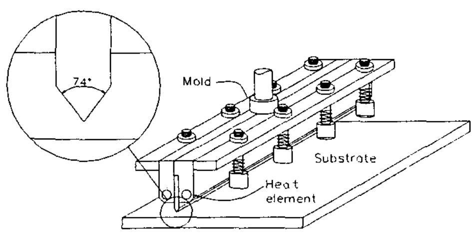


Figure 7. A knife-type mold used in the feasibility study of DSF.

The first effort is focused on finding an optimal processing temperature with given pressure of 0.2 atm, pressing time of 20 seconds and depth of 200 ㎛. In the second feasibility study, the obtained optimal temperature of a knife is 215 ℃. This temperature is the minimum value to transcribe the shape of V-grove. Figure 8 shows experimental results for cross-sectional view of transcribed V-grooves at various temperature.

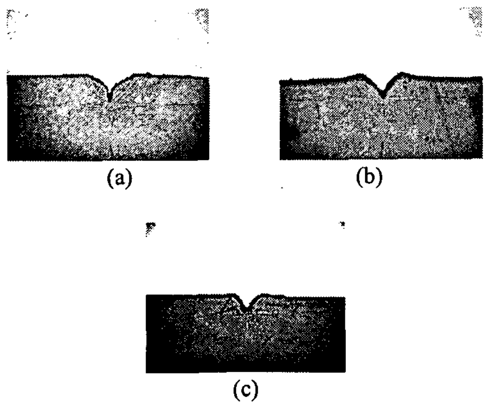


Figure 8. 3-different micro-optical patterns formed by knife-type mold; (a)low temperature (180℃),(b) optimal temperature(215℃) and (c) high temperature(230℃)

The second effort is focused on determination of the pressing time according to depth with given pressure of 0.2atm and optimal temperature of 215 ℃. The pressing time depends on the depth of V-groove because the deeper groove needs more amount of heat. Table 2 shows the results of relationship between the depth of V-groove and the pressing time for desirable shape of V-groove.

Table 2. Optimal pressing time according to the depth of V-groove with knife-type mold (temperature at the knife tip: 215 ℃)

Case	Depth(㎛)	Pressing Time(s)
1	130	10
2	160	15
3	200	25
4	240	35

Figure 9 shows the cross-sectional view of transcribed V-grooves for different nominal depth and pressing time to achieve desired shape.

For a final stage of feasibility study, the complete light guide of 15.1 inches has been made. In this study, the knife-type mold with variable depth, constant pitch and constant angle of 74 ° is used for DSF technology. After this process, significant warpage occurs in the PMMA substrate because of local and differential heating and cooling. This local and differential heating and cooling induces thermally induced-stress, which may results in deformation of PMMA substrate. Therefore, this thermally induced stress should be considered and minimized. To get rid of warpage an annealing process must be adopted as a post-process. In this feasibility study, the annealing process is performed in the oven with temperature of 130 ℃ for 20 minutes.. After the annealing process shrinkage of about 5% in planar direction is found. In order to avoid the reduction of size of light guide the PMMA substrate of 5 % larger size can be used. The DSF molding machine may need vacuum device to grip the substrate firmly for reduction of warpage during pressing.

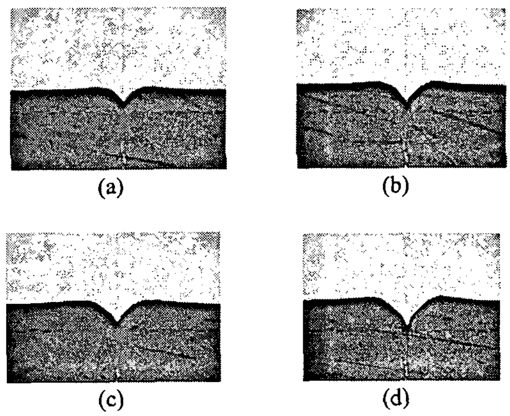


Figure 9. Molded pattern for different nominal depths (D: depth and T: pressing time); (a)D=130 ㎛, T=10s, (b)D=160 ㎛, T=15s, (c)D=200 ㎛, T=25s and(d) D=240 ㎛, T=35s

To evaluate the quality of final light guide made by DSF technology, local brightness is measured at several positions, shown in Fig. 10, to calculate average brightness and uniformity. Table 3 shows comparison for the brightness of final light guides made by DSF technology and screen-printing technology, respectively. The uniformity used in Table 3 is defined as follows:

- Uniformity(5 Positions)=Max. / Min.
- Uniformity(13 Positions)=(Max. − Min.) / Avg. × 100

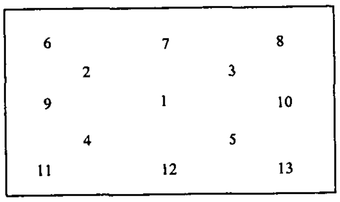


Figure 10. Positions for measuring brightness of a backlight unit

Table 3. Measured brightness of light guides both by DSF and by screen-printing(1 [nit] = 1 [cd/m^2])

Position	Brightness by DSF	Brightness by Screen-Printing
1	1101.52	1211.05
2	1402.86	1226.94
3	1444.86	1211.05
4	1567.44	1189.48
5	1483.45	1211.05
6	984.95	1329.09
7	1320.01	1172.46
8	1121.83	1335.90
9	1418.75	1117.18
10	1512.96	1161.11
11	1230.34	1272.34
12	1581.06	1156.57
13	914.70	1267.80
Average(5Positions)	1400.02	1209.91
Average(13 positions)	1314.21	1220.15
Uniformity(5 positions)	50.70	17.93
Uniformity(13 positions)	1.42	1.03

The average brightness of light guide made by DSF is 100 nits higher than that by screen-printing method, while the uniformity of light guide by screen-printing method is much better than that by DSF. From the optical simulation result by ASAP, however, the brightness of light guide by DSF is 30 % higher than that by screen-printing method with the almost same uniformity. If the more accurate device is used in the DSF technology such as stopper for precise depth control, temperature controller and time controller for pressing time, then light guide made by DSF will be much close to designed one by simulation of ASAP with more accurate shape of V-groove in PMMA substrate, which means the quality of light guide made by DSF will be much better than that made by screen-printing method.

Further work is undergoing to apply the DSF process for mass production.

4. Conclusions

The DSF has been proposed and demonstrated successfully as new manufacturing technology for a large-sized light guide in TFT-LCD module, which is a substrate of PMMA with micro-optical pattern. The advantages for this new manufacturing technology are as follows:

- Increasing the intensity of light on the screen of TFT-LCD module because DSF does not use ink material that can absorb light. In this study, increment of the intensity is up to 10~20 %.
- Increasing the productivity because of low level of energy consumption during the manufacturing due to local heating. In this study, we can determine the optimal mold temperature of 215 ℃ for PMMA material.
- Decreasing the manufacturing cost because molding machine and mold for DSF can be made with relatively low price in comparing with those for other technologies.

The disadvantage for this new manufacturing technology is to need the secondary process, that is, annealing stage to avoid thermally induced warpage due to local heating and cooling after processing by DSF.

References

(1) R. Wimberger-Friedl, ANTEC Proceedings, New York,476(1999)
(2) H. Becker and C. Gärtner, Electrophoresis, 21, 12(2000)
(3) H. Becker and T. Klotzbücher, Proceedings of 3rd International Conference on Microreaction Technology, Frankfurt, April 18-20(1999)
(4) H. Becker and U. Heim, Proceedings of MEMS, Orlando, 228(1999)
(5) M. U. Kopp, H. J. Crabtree and A. Manz, Current Opinion in Chem. Biol., 1, 410(1997)
(6) Y. J. Juang, L. J. Lee and K. W. Koelling, Polym. Eng. Sci., 42, 539(2002)
(7) Y. J. Juang, L. J. Lee and K. W. Koelling, Polym. Eng. Sci., 42, 551(2002)
(8) L. Yu, Y. J. Juang and L. J. Lee , ANTEC Proceedings, Orlando, 612(2000)