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Analysis of roll-stamped light guide plate fabricated with laser-ablated stamper

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ABSTRACT

LGP (light guide plate) is one of the major components of LCD (liquid crystal display), and it makes surface illumination for LCD backlit. LGP is a transparent plastic plate usually produced by injection molding process. On the back of LGP there are micron size patterns for extraction of light. Recently a roll-stamping process has achieved the high mass productivity of thinner LGPs. In order to fabricate optical patterns on LGPs, a fabricating tool called as a stamper is used. Micro patterns on metallic stampers are made by several micro machining processes such as chemical etching, LIGA-reflow, and laser ablation. In this study, a roll-stamping process by using a laser ablated metallic stamper was dealt with in consideration of the compatibility with the roll-stamping process. LGP fabricating tests were performed using a roll-stamping process with four different roll pressures. Pattern shapes on the stamper fabricated by laser ablation and transcription ratios of the roll-stamping process were analyzed, and LGP luminance was evaluated. Based on the evaluation, optical simulation model for LGP was made and simulation accuracy was evaluated. Simulation results showed good agreements with optical performance of LGPs in the brightness and uniformity. It was also shown that the roll-stamped LGP has the possibility of better optical performance than the conventional injection molded LGP. It was also shown that the roll-stamped LGP with the laser ablated stamper is potential to have better optical performance than the conventional injection molded LGP.

1. Introduction

The liquid crystal display (LCD), one of the most widely used type of displays, is not self-illuminating and hence requires a backlight unit (BLU) as a background light source. The structural components of a BLU are light-emitting diodes (LEDs), a light guide plate (LGP), a diffuser film, prism films, and a reflective film. Of these, the LGP is an optical component that converts a point light source into a surface light source with optical micro-patterns positioned on the opposite surface of the outgoing light. In the case of LGPs in displays of mobile devices, ultrathin films (0.23 mm) have recently been used, whereby micro-patterns (≤50–60 μm) should be formed to hide dot patterns. In general, all dot patterns have the same geometry, and the luminance uniformity of surface light emission is controlled by adjusting the distances between dots [1–3].

Chemical etching, LIGA-reflow, and laser ablation are commonly used methods for fabricating patterns on stampers to form optical patterns on the LGP. Chemical etching and LIGA-reflow processes have an advantage over laser ablation in that they result in cleaner patterned surfaces. However, they involve time-consuming and cost-intensive processes of stamper production. In a study aimed at developing a method to reduce the time and cost for stamper production, Park et al. [4] optimized luminance uniformity by directly machining V-groove patterns on the LGP by using a CO_2 laser. Kim et al. [5] achieved an optimal luminance uniformity by engraving spherical patterns within the LGP by using a Nd:YAG laser. Owing to a staggering number of patterns on the LGP, which ranges from hundreds of thousands to tens of millions, it is not desirable in terms of productivity to machine each pattern directly on the LGP. Therefore, in this study, we applied a roll-stamping pattern transfer technique (Lawrence, Li [6]), whereby circular micro patterns (32.5 μm of diameter) were formed on a metal stamper using Nd:YAG laser processing and transferred under heat and pressure.

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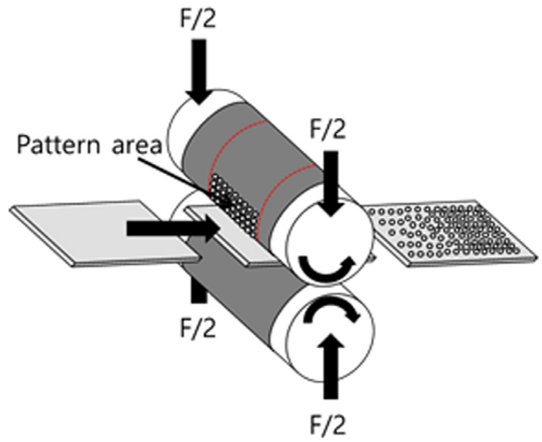

Fig. 1. Schematic of the roll-stamping process (F represents roll force, i.e., the pressure exerted by the roller).

Fig. 1 shows a schematic of the roll-stamping process. An example of a study using this method is one by Lan et al. [7], who demonstrated the feasibility of mass production of large-area LGPs based on a roll-to-flat process by investigating the transcription ratio using polycarbonate. Ahn et al. [8] performed molding experiments using roll-to-roll and roll-to-plate replication techniques, with the roller speed and embossing pressure being factors determining the transcription ratio of the patterns formed on the LGP. Using roll-to-roll processing, Yeo et al. [9] identified the roller temperature, embossing pressure, roller speed, and pattern density as process parameters affecting the transcription ratio of the patterns formed on the LGP. Sahli et al. [10] performed finite-element simulations of a roll embossing process by varying the geometry of the optical patterns in conical and semicircular shapes, and they found that the latter was superior to the former in terms of the filling rate.

In the present study, we measured the transcription ratio of the optical patterns and the luminance of the LGP in a preliminary experiment performed to evaluate LGP molding, and we tested the analysis method by comparing the results of the aforementioned preliminary experiment with those of corresponding optical simulations. Finally, to evaluate how the transcription ratio affects luminance and luminance uniformity, four different cases of roll forces were investigated (Cases 1–4) by conducting molding experiments and optical simulations.

2. Experiment and optical simulation conditions

2.1. Experiment

As the LGP substrate material, we used polycarbonate (PC, CCL +LGP, i-components Inc.), which is widely used for thin plate-type LGPs. SEM image of laser ablated micro-patterns on the stamper is shown in Fig. 2. The formation principle of ring shape around the crater is described in detail in references [11–13]. The parameters used for laser ablation are summarized in Table 1. Laser ablated micro-patterns on the stamper(a, left), imprinted micro-patterns formed on the LGP(b, left), and the graph of the measured cross-sectional profile are shown in Fig. 3. The dimension of LGP used in the present study is 180 mm (length) × 110 mm (width) × 0.6 mm (thickness), and the BLU contains 21 LEDs.

Important factors for increasing the luminance uniformity of LGP, one of its optical properties, include the geometry of the micro-pattern, density distribution, and transcription ratio. In order to reduce the cost and time for fabricating the stamper, we used a ring-shaped overflow left around the rim after laser processing as the embossing micro-pattern. The average outer and inner diameters and pattern height of the micro-pattern are 32.5 μm, 21.0 μm, and 4.10 μm, respectively. The density distribution of the micro-pattern was set in accordance with the design parameters for the injection molding of an 8-inch LGP. More detail description of the density is given in Section 2.2. As defined in Eq. (1), the transcription ratio is the ratio of the depth of the optical pattern formed on the LGP (h) to the height (H) of the micro-pattern of the stamper.

$$\text{Transcription ratio } (\%) = \frac{Depth\ of\ pattern\ (\mathrm{h})}{Height\ of\ stamper\ (\mathrm{H})} \times 100 \quad (1)$$

When fabricating the LGP via the roll-stamping process, the transcription ratio of the optical micro-pattern was controlled by adjusting the roll force (F). Uniform roll force was applied from

Table 1
Parameters of laser ablation.

Laser parameters	Value	Unit
Laser type	Fiber laser (200 ns)	
Wavelength	1070	nm
Power	30	W
Pulse frequency	30	kHz
Pulse duration	0.5	sec
Number of pulses per feature	About 1500	

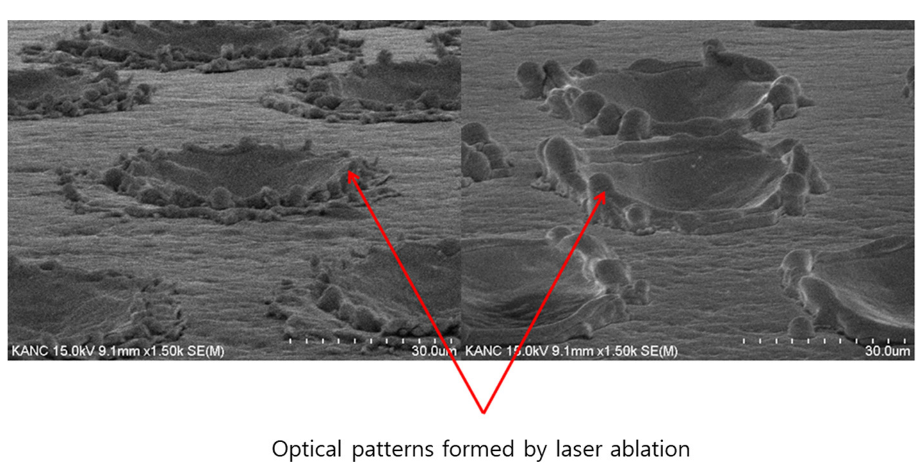

Fig. 2. SEM micrograph of micro-pattern on the stamper.