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# Fabrication of a prism structure on light guide plates with UV roll-to-plate imprinting process

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As the demand of multiple functions optics devices fabrication, conventional methods such as injection molding and hot embossing to fabricate light guide plates (LGPs) with the prismatic structure become difficult and unsuitable; so we developed a roll-to-plate UV imprinting lithography (RPIL) process for fabricating the prismatic structure on light guide plates (LGPs). Using the proposed process, the prismatic structure on the LGP achieved a formability rate 97%, and the luminous gain rate of the imprinted LGP exceeded 1.6, this is almost the same as that of 3M's prism film. This study demonstrates the potential of our proposed process for fabricating the prismatic structure on the LGP.

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*Keywords:* Imprint lithography, Transparent mold, Light guide plate

## 1. Introduction

In general, liquid crystal displays (LCDs) are not active emission devices. The light supply for LCDs rely on a backlight module (BLU) composed of a light source, a light guide plate (LGP), optimal films such as prism films and others. The function of the prism is to reshape the backlight's luminance distribution by collimating the light by the refraction of rays on the surface of the one-dimensional micro prism, thereby enhancing the on-axis luminance[1]. Usually, prism films are fabricated using the roll-to-roll UV curing process[1-2], and then are cut to the required size by tooling. 3M's prism was first used in the BLU industry to enhance luminance; a layer of UV curing resin with a prismatic structure imprinted by the roll-to-roll process was coated on the substrate of polyethylene terephthalate (PET) film. The resulting optical performance depended on the refractive index of the material and the replication rate of the process. Wang's investigation [1] showed that UV resin's refractive index has a higher on-axis luminous, and this luminous decays when the resin's refractive index exceeds 2.0. Although different manufacturing processes have been proposed and studied [3-5] for improving the replication rate, the roll-to-roll manufacturing process is a better method for obtaining high replicated rates, because it can obtain high and uniform replication rates using rollers with precision prismatic structures manufactured by the precision lathe supply on-axis pressure and direct UV light exposure system. However, this process is only suitable for continuous and flexible substrates. The industrial trend to anticipate the integration of the BLU components is one of the reasons for BLU assembly issues. The sole function of the LGP is to propagate light rays uniformly over the entire display area. In Feng's research[6], LGPs with the prismatic structures on its surface fabricated by injection molding have multiple functions of ray transmission and on-single axis brightness enhancement. This study is devoted to the development of a suitable process for the fabrication of LGPs with prismatic structure. The most suitable is the roll-to-plate imprinting lithography (RPIL) process that integrates the advantages of the roller and UV light exposure systems through the mold directly to fabricate prismatic structures on the LGP at room temperature and low pressures. Optical analyses will be performed to investigate the optical effects of the prismatic structure on the LGP with different refractive indices. Experiments using the RPIL process will then be conducted to verify the results of optical analyses. The on-axis luminance performance will be measured by assembling LGPs with a prismatic structure into the BLU, and the experimental results will be compared with the analysis data regarding the dual prisms brightness enhancement rate.

## 2. Optical simulation

### 2.1 Setup of the optical model

The prismatic structure in this study refers to 3M's prism structure that has a V-cut shape with an apex angle of 90°, a width of 50 µm, and a height of 25 µm. It is also expected to simulate the imprinted and curing of the UV resin after the RPIL process directly on the LGP. Fig. 1 shows a layer of the prismatic structure on the LGP for performing optical analysis. The thickness of the LGP and the UV resin are 0.8 mm and 10µm respectively, and the width of the V-cut shape is 50µm. Trace pro software was adopted for the optical simulation in this study. To achieve greater computer efficiency and reduce calculation time, an optical model was set with a partial BLU (2 mm × 2 mm), and light was emitted from the side into the LGP, as shown in Fig. 2(a). In the figure, the ray detector is placed above the optical model, and the surface of the detector will detect rays from the optical model. The imprinted model of the cured layer was fabricated by the RPIL process and was directly attached to the LGP, as shown in Fig. 2(b). A refractive index adopted for the UV resin was between 1.49 and 2.2, which allows the investigation of the effects of different refractive indices on the brightness enhancement gain rate.

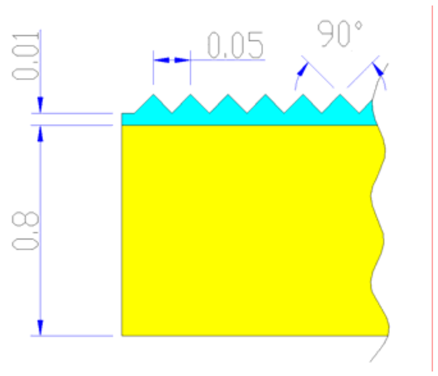



*Fig. 1 Single layer of prismatic structure on the LGP, in mm.*

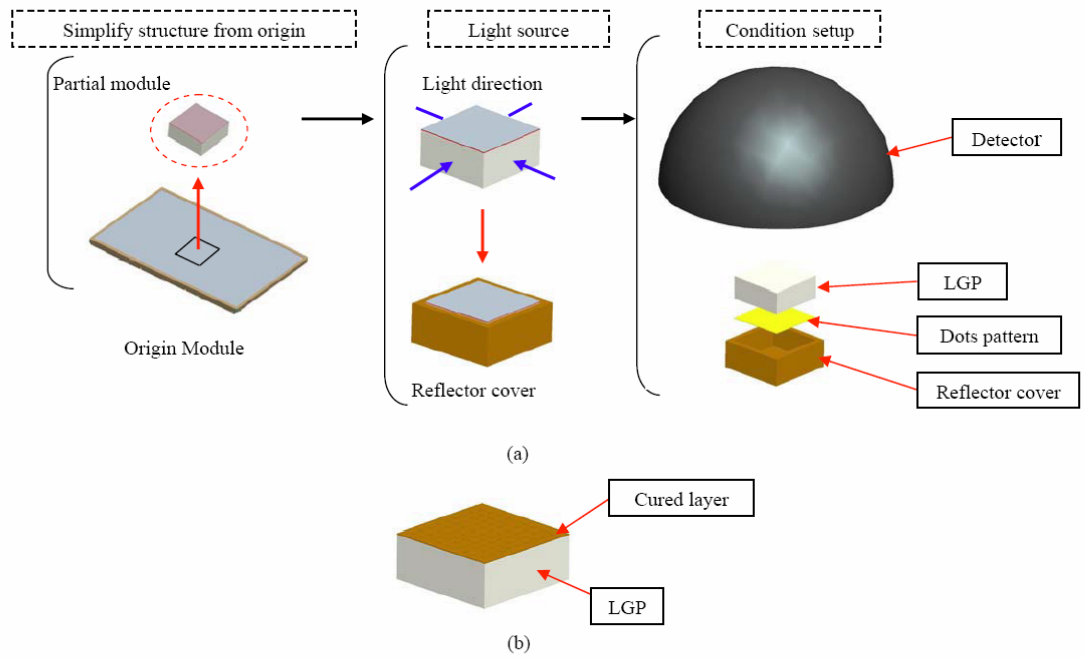



*Fig. 2 (a) Model of optical simulation setup (b) The imprinting layer is attached to the LGP.*

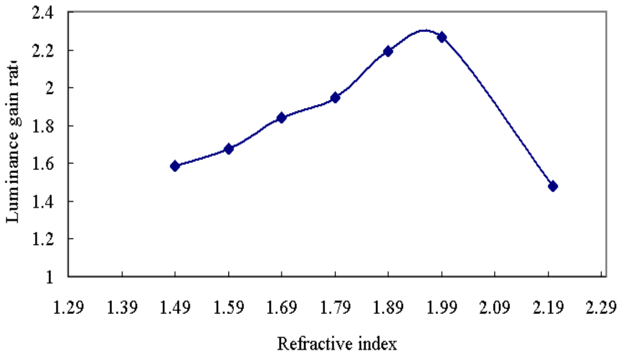
### 2.2 Analysis of simulated results

The BLUs that are equipped with the LGP-imprinted a prismatic structure with a resin refractive index ranging from 1.49 to 2.2 are simulated to obtain the results of the luminous intensity and gain rate distribution, as shown in Fig. 3. The results show that the gain rate is higher with increasing refractive index of the resin until refractive index exceeds 2.0.

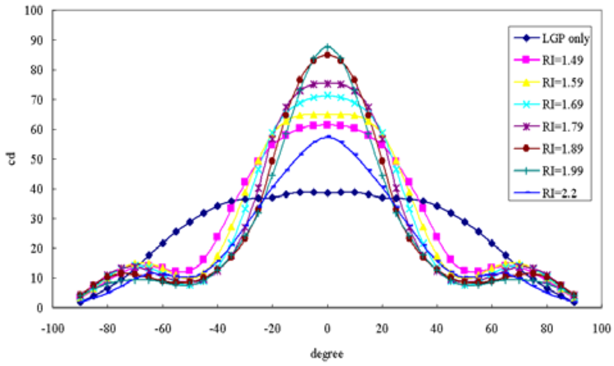
## 3. Experimental method

### 3.1 Development of roll-to-plate UV imprinting lithography (RPIL) process

This study aims to develop the RPIL process and to evaluate its feasibility for fabricating a prismatic structure on the LGP. The system includes a roller system, a UV light unit, a loading system, and a flexible mold, as shown in Fig. 4. UV light needs to be passed through the mold to harden the resin and enable line contact of the rolling process. Therefore, we selected a flexible, transparent polycarbonate (PC) having a thickness of 0.5mm as the substrate. In order for the mold to replicate the prismatic structure from the steel plate made by micromachining, the steel plate was coated with a layer of the release agent, and the substrate was coated with UV cure resin in a restricted area. The fabrication of a flexible, transparent mold with a prismatic structure was completed by UV exposure, as shown in Fig. 5. LGPs that were cut from extruded polymethylmethacrylate (PMMA) with a thickness of 0.8 mm were used as the substrate in this experiment. The flexible mold was fixed in the release mechanism, and the substrate was attached to the chassis with an air sucker.



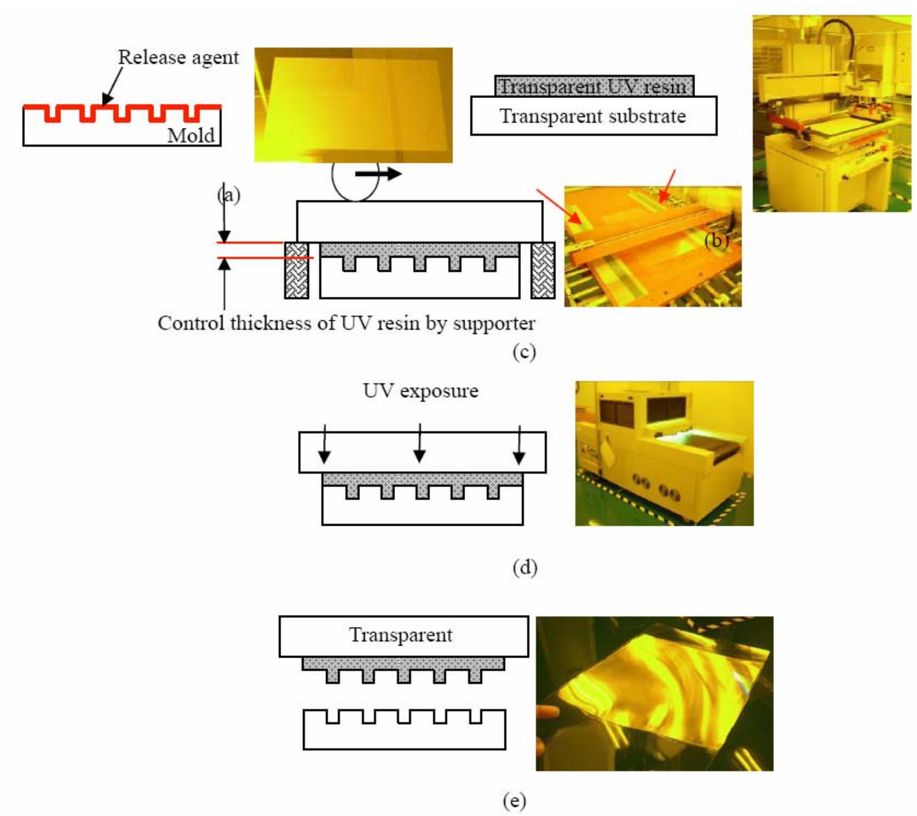

a




*RI= Refractive index

b

*Fig. 3. (a) The gain rate distribution of LGP with single layer of prismatic structure. (b) The angular distribution of the luminous intensity.*




*ig. 4 Schematic diagram of the manufacturing process of the flexible mold. (a) Model of steel plate coated with a layer of release agent. (b) Substrate coated with UV resin by screen printing machine. (c) UV resin thickness controlled by support plates. (d) UV exposure using the UV light source. (e) The transparent mold released from the model.*

The RPIL process is shown in Fig. 6 and is described as follows:

(a) The flexible mold makes contacts with the UV resin placed above the substrate when the release mechanism is lowered.

(b) The roller is lowered until it is stopped by a supporter and maintains a steady force.

(c) The movement of the roller is parallel to the surface of the substrate, and the UV light is emitted from behind the roller.

(d) The flexible mold is released from the substrate when the release mechanism is raised, and then microstructures related to the mold of microstructures have to be fabricated on the substrate.

To evaluate the feasibility of the developed RPIL system for fabricating the prismatic structure on the LGP, a series of imprint tests were performed following the setup of the process for analysis. The UV resin with a refractive index of 1.49 was used to fabricate the prismatic structure on the LGP. The surface profiler was used to verify the formability between the steel plate and the prismatic structure of the first and second layers.

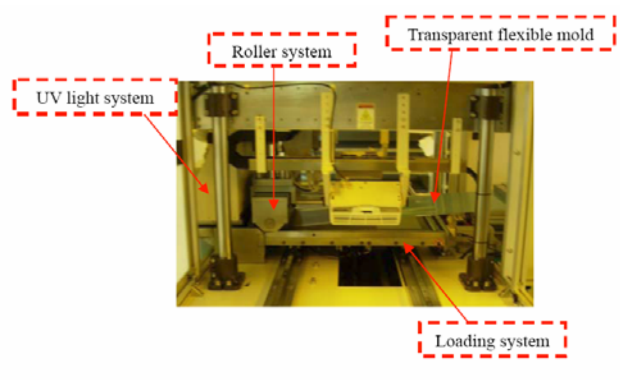



*Fig. 5 Photograph of the RPIL system.*

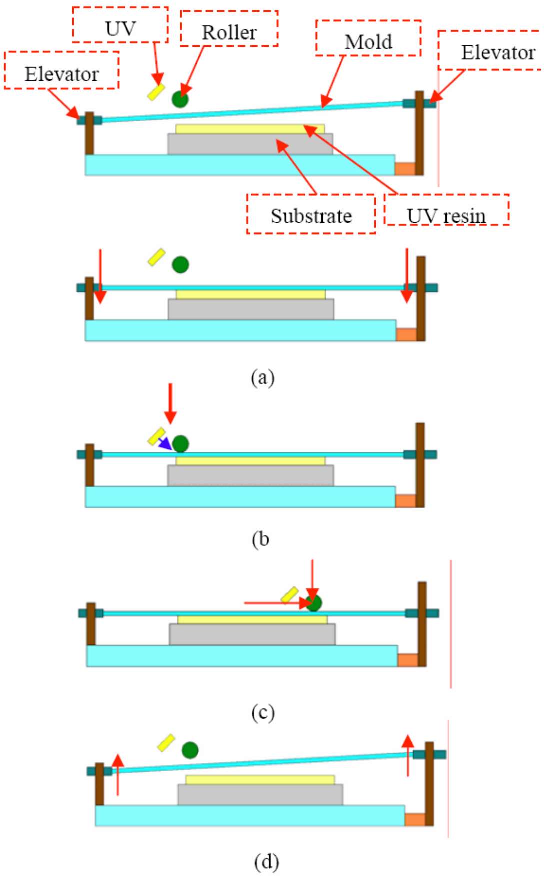
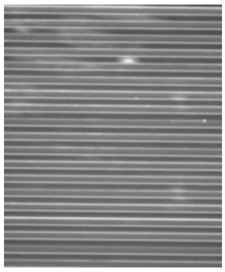



*Fig. 6 Schematic diagram of the RPIL process. (a) The elevator moves lower to make the contact between mold and UV resin. (b) The roller and UV light unit move lower until it is stopped by the supporter and maintains a steady force. (c) The movement of the roller is parallel to the surface of the substrate, and the UV light is emitted from behind the roller. (d) The flexible mold is released from the substrate when the elevator is raised, and then microstructures relative to the mold of microstructures was fabricated on the substrate.*

### 3.2 Experiment results

As shown in Fig. 7, the LGP with the prismatic structure has been successfully replicated from the flexible mold using the RPIL process. The dimensions and optical characteristics of the structure were measured. The results show that the formability of the prismatic structure between the steel plate and the first layer exceeds 97%. In order to measure the on-axis luminance gain rate, the raw LGP plate and the LGP with prismatic structure were assembled into a backlight module and on-axis luminance were measured by the optical color analyzer, respectively. The gain rate is the luminance of the BLU with the LGP of the prismatic structure divide by the raw LGP, the on-axis luminance gain rate is above 1.6. The results are almost the same as that of the analysis data, and hence, we can confirm that our analysis results are accurate. A potential application of this proposal process is the fabrication of the prismatic structure on the LGP.

a



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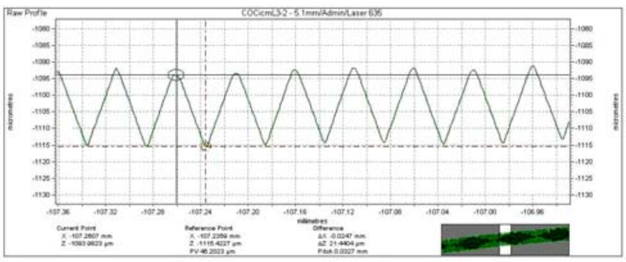

c

*Fig. 7. (a) The first layer of prismatic structure on the LGP. (b) OM image of the prismatic structure of the first layer. (c) Measurement of the prismatic structure by surface profiler.*

## 4. Conclusions

In this study, we presented an effective process for the fabrication of a prismatic structure on the LGP using a roller system and an UV light exposure system through the transparent mold directly. This process takes advantage of the uniform pressing pressure and fast curing of the UV imprinting. Through optical analysis, the refractive index of the UV resin should be within the range 1.49-2.0. In our experiments, the formability of the prismatic structure fabricated by the RPIL process reached a rate of 97%, while the on-axis luminous gain rate of the prismatic structure on the LGP obtained using the resin with refractive index 1.49 was above 1.6. The experimental results were compared with the results of optical analyses and were confirmed to be accurate, demonstrating that this process has the capacity to fabricate the prismatic structure on the LGP.

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