Effect of Ultrasonic Vibration on Microstructure Hot Glass Embossing Process

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Abstract

Hot glass embossing is a novel technology to manufacture microstructures for Field Emission Displays. By this technology, microstructures on the mold could be embossed on the glass surface with high quality and lower cost. Although effect of ultrasonic vibration on micro-formability of glass material has been studied in some previous research, no consideration has been performed with pyramid array which possesses small tip angle. The aim of this work is to utilize ultrasonic vibration with frequency of 35 kHz and amplitude of 3 μm to improve the filling ability of K-PSK100 glass into pyramid shaped-microcavities. This study also proposed to use an impression mold to enhance the filling ability for the glass. Experimental data showed that micro-formability of glass material could be improved 17 % under effect of ultrasonic vibration and more 3 % as using the impression mold.

Keywords: ultrasonic vibration, hot glass embossing, pyramid array, impression mold

1. Introduction

Hot glass embossing technology is one of novel methods to produce microtips in Field Emission Displays with high quality and low cost. Especially, micro-formability of glass material could be improved significantly with the assistance of ultrasonic vibration. A conventional hot glass embossing process usually consists of four stages: heating, embossing, annealing and de-molding, respectively. The only difference between the conventional process and the ultrasonic vibration-assisted one is in the embossing stage. As shown in Fig. 1, in this stage, an ultrasonic vibration source with high frequency which is located at the top of the upper mold, will be transfered to the glass. The high energy of ultrasonic vibration rapidly increases the temperature of the glass and the mold. The temperature rise caused by ultrasonic vibration not only leads to the reduction of required embossing force, but also to improve the micro-replication ability of the glass.

Unlike metals and polymers materials, very few researches have been studied effects of ultrasonic vibration on hot glass embossing process. Tsai et al. [1] recently conducted hot embossing experiments to examine the effect of ultrasonic vibration on glass micro-replication. Furthermore, Hung et al. [2] reported that embossing forces reduced markedly when applying ultrasonic vibration into hot glass embossing process. Recently, Nguyen et al. [3] has performed some experiments to study effect of some parameters on force reduction under effect of ultrasonic vibration by using different embossing speeds, changing various embossing temperatures and extending the applying time of ultrasonic vibration.

Although the previous researchers have shown the effect of ultrasonic vibration on improving forming ability of glass material, the microstructure size was quite large (hundreds of micrometers) and microstructures shape was still simple (V-rack).

Besides that, though the filling ability of the glass could be better with the assistance of ultrasonic vibration, it is difficult to make the final shape of microstructures be closed to the desired shape. One of the reasons was that all previous experiments used flat lower mold. Under the embossing force during the embossing stage, the glass not only went upward to fill into the microcavities on the upper mold, but also moved horizontally. This would make the amount of the glass fill into the microcavities less. Therefore, the purpose of this work is to utilize the energy of ultrasonic vibration to improve the filling ability of the glass material into the microcavities which were shaped as pyramid array with the size of several micrometers. This study also proposed a new design for the lower mold as an impression mold. The findings of this research could be used to optimize design parameters of the mold to achieve the best filling ability for glass material.

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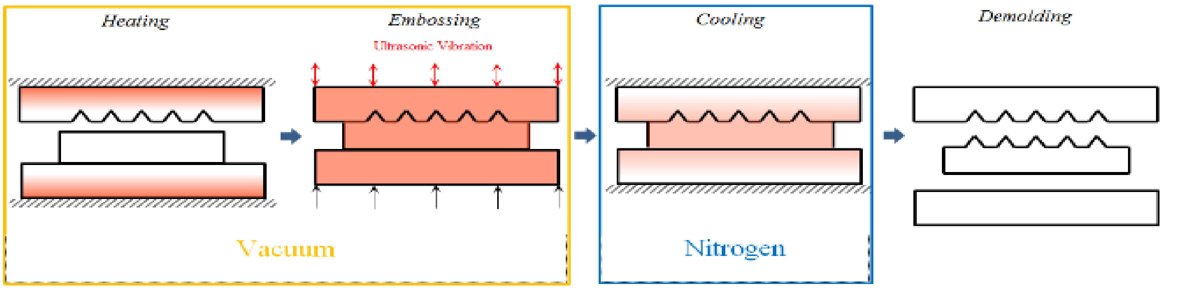

Fig. 1. Stages of ultrasonic vibration-assisted hot glass embossing process

2. Experiments

2.1. Materials

In this study, K-PSK100 optical glass supplied by SUMITA OPTICAL GLASS, INC. was used. Plate specimen (20 × 20 × 1 mm) was applied for all experiments (Fig. 2). Thermal and mechanical properties of this glass, which were provided by the manufacturer, are listed in Table 1.

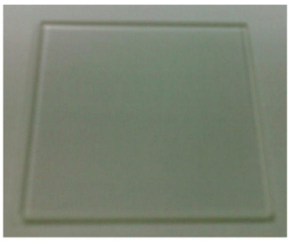

Fig. 2. Glass plate specimen

Table 1. Thermal and mechanical properties of K-PSK100 optical glass [4]

Young's modulus	70 GPa
Poisson's ratio	0.262
Density	3.24 g/cm^3
Transition temperature T_g	390 ˚C
Annealing temperature A_t	415 ˚C
Thermal expansion coefficient	11.4×10^{-6} / ˚C
Thermal conductivity	0.715 W/m.K
Specific heat	679 J/kg˚K

All molds used for hot embossing experiments were made of stainless steel SUS304. As shown in Fig. 3, in order to fabricate microstructured-upper mold, a pyramid array was replicated from the master mold made in Tungsten Carbide (WC) material onto the surface of the flat original upper mold [5]. Size of pyramid array is shown in Fig. 4.

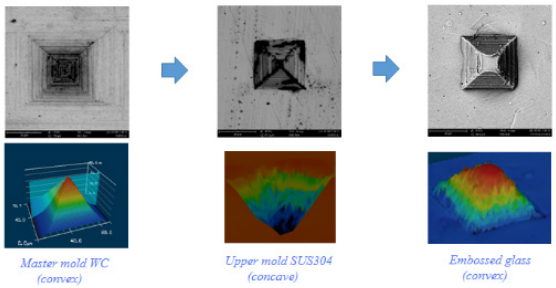

Fig. 3. Fabrication principle of microstructured mold

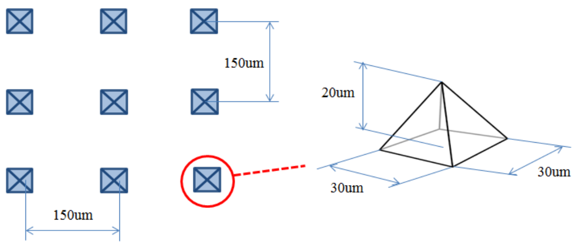

Fig. 4. Size of pyramid array

During embossing process, sticking phenomenon could appear between the glass and the mold. To avoid this phenomenon, Diamond-like-carbon (DLC) layer was coated on the surface of the mold. The original and coated molds are shown in Fig. 5.

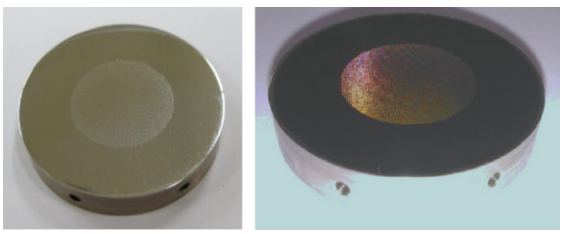

Fig. 5. Microstructured-upper mold before (left) and after (right) coated

Moreover, in order to investigate effect of lower mold geometry on the final height of microstructures, two kinds of lower molds were also suggested, flat and impression lower molds (Fig. 6).

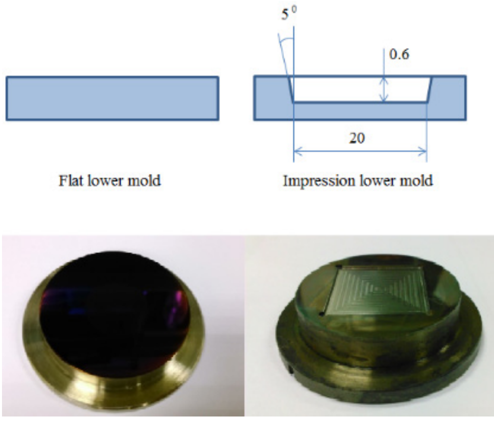

Fig. 6. Flat (left) and impression (right) lower molds

All hot embossing experiments were performed using an apparatus that was developed by members of the Advanced Forming Laboratory, Department of Mechanical Engineering, National Chiao Tung University, Taiwan (Fig. 7). The specifications of this apparatus are shown in Table 2.

Table 2. Specifications of hot embossing apparatus [6]

Ultrasonic frequency	35 kHz
Ultrasonic power	900 W
Maximum amplitude	12 μm
Maximum temperature	700 °C
Temperature accuracy	± 1 °C
Embossing speed	0.05 – 200 mm/min
Displacement accuracy	5 μm
Maximum load	10 kN
Load accuracy	±0.5 N
Degree of vacuum	2.5 torr
Maximum molding area	ϕ 85 mm

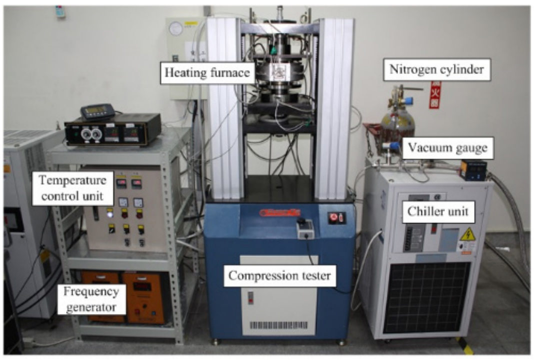

Fig. 7. Hot embossing apparatus

2.2. Experiments

Using plate glass specimen, pyramid-structured upper mold, flat and impression lower molds, microstructure hot embossing experiments were performed to study effect of lower mold shape on filling ability of glass material into microcavities. Conventional hot embossing experiment was first performed. The steps of this experiment are described as follows:

Step 1: Glass specimen was placed between two molds after being cleaned.

Step 2: Both molds were heated to 430 °C, and then held to ensure that the temperature distribution in the glass specimen was uniform.

Step 3: The upper mold was fixed while the lower mold continued to emboss the glass at a constant speed of 0.1 mm/min until the embossing displacement reached 0.3 mm.

Step 4: Step 3 was held so that stress in the glass relaxed completely.

Step 5: Finally, both the glass and the molds were cooled to room temperature, and the glass then was released from the molds.

After conventional experiment, the ultrasonic vibration-assisted experiment was carried out. The steps of this experiment were basically similar to those of the above experiment, except for the step 3. In step 3, ultrasonic vibration (amplitude of 3 μm and frequency of 35 kHz) was applied to the upper mold while the lower mold continued to emboss the glass at a constant speed of 0.1 mm/min until the embossing displacement reached 0.3 mm.

4. Results and Discussions

After hot embossing experiments, microstructures on the upper mold were replicated on the glass surfaces (Fig. 8). Using Scanning Electron Microscope (SEM), images of pyramid structures were obtained and compared in Fig. 9.

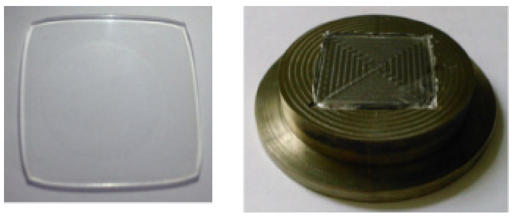

Fig. 8. Embossed glass using flat (left) and impression (right) lower molds

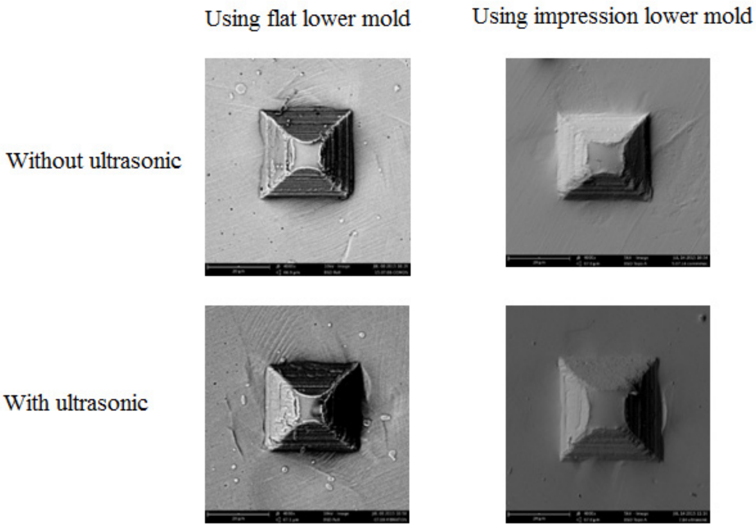

Fig. 9. SEM images of pyramid structures

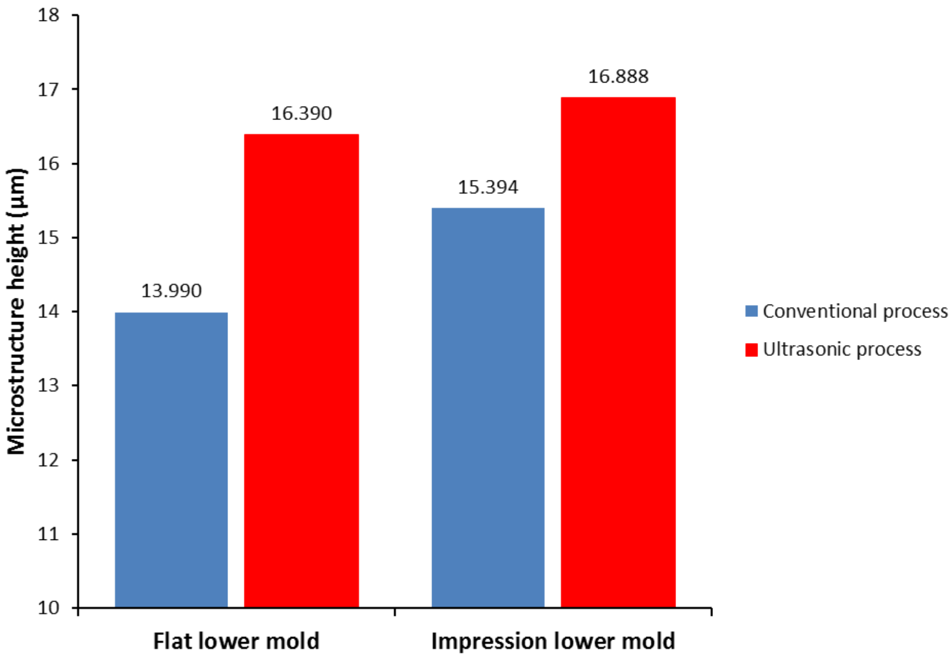

Fig. 10. Pyramid height after experiments

As shown in Fig. 10, experimental data illustrated that the filling ability of the glass could be improved significantly with the appearance of ultrasonic vibration. Compared to the conventional case, the final height of pyramid increased 17 %, from 13.990 µm to 16.390 µm. This can be explained by the heating effect of ultrasonic vibration. Energy of ultrasonic vibration was mostly converted into heat, which then caused the local temperature rise at the interface between the glass and mold. Therefore, the glass material could move and fill into the microcavities more easily.

Moreover, experimental data shown in Fig. 10 also illustrated that the shape of the lower mold could improve the filling ability of the glass. Compared to the case of using flat lower mold, using impression lower mold could help the final height of pyramid increase 3 %, from 16.390 µm to 16.888 µm. This could be explained by the following reason. In case of using flat mold (open mold), beside the vertical displacement to fill into the microcavities in the upper mold, the glass also flew through horizontal direction. The higher the embossing temperature, the more the horizontal displacement, which would obstruct the glass to fill up into the microcavities. This obstacle could be solved by using impression lower mold. Although horizontal displacement of the glass still exists, most of material will flow into the microcavities.

5. Conclusion

This work studied effect of ultrasonic vibration on the filling ability of K-PSK100 glass substrate into pyramid-structured cavities during the hot embossing process assisted by ultrasonic vibration with frequency of 35 kHz and amplitude of 3 μm. Experimental data illustrated that filling ability of the glass would be better (17 %) with the assistance of ultrasonic vibration. Besides effect of ultrasonic vibration, using impression lower mold could improve the filling ability of the glass into the microcativies efficiently (3 %). This finding could be a basis to continue carrying out effect of some process parameters on final shape of microstructures, such as amplitude and frequency of ultrasonic vibration, embossing temperature, vibration-applied time, etc. Besides that, this finding could be used to study effect of geometry parameters of the lower mold on optimizing filling ability of glass material.

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