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Heat transfer analysis during a curing process for UV nanoimprint lithography†

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Abstract

A heat transfer analysis during the curing process in UV-Nanoimprint lithography was carried out. To imprint nano/micro patterns into a large-area target glass such as LCD panels, a mold with a poly-urethane-acrylate layer is often used, on which layer the micro/nano patterns are inscribed for the UV-NIL process. After UV resin is coated between the target glass and the flexible mold, the UV resin is cured by exposing UV light on the resin. In the curing process, heat from the phase change of the resin and the radiation by UV lamp would induce a temperature change and thermal distortion of the mold. In this study, we measured the temperature change of the flexible mold, and established an analytic model of the heat transfer. From the result, we derived the thermal properties of the PUA layer, and a thermal resistance layer between the PUA and the cured resin layer.

Keywords: Nanoimprint; Mold; UV Resin; Thermal change

1. Introduction

UV-Nanoimprint Lithography (UN-NIL) has been researched as an alternative process for manufacturing LCD panels [1]. The conceptual processes of the UV-NIL process are shown in Fig. 1. After UV-curable resin is laminated on the panel glass, a mold is aligned by using a machine vision system with respect to fiducial marks on the panel-glass and the mold.

The mold has an additional poly-urethane-acrylate (PUA) layer, on which nano/micro patterns are inscribed. On the aligned position, we induce some pressure to assemble two panels. Then, UV light is radiated to cure and solidify the resin and the nano/micro patterns on the surface of the mold will be transferred into the panel glass. The mold and the panel-glass should be aligned in touch with the UV-resin in the alignment and curing process. The UV resin usually is viscoelastic in its liquid phase, and it shrinks in 10% volume during the curing process. Thus, it may induce some stress on the mold and panel-glass after the curing process [2].

The UV resin also generates some heat during phase change. The heat may cause temperature change and thermal distortion in the mold and the target panel. The heat transfer problem in the UV-NIL process is different from the problem in photolithography. In the case of photolithography, the UV resin can be cured by UV light without any contact with the mold or mask, and the heat is transferred to air or through the target panels. In the case of UV-NIL, however, the resin is laminated between the mold and panel-glass. Thus, the heat generated during the curing process will transfer through the mold and

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the panel-glass directly. The temperature change may cause thermal deformation on both panels. In previous research, Kim [3] simulated heat transfer in the curing process of UV-NIL. The heat generation ratio was predicted from physical properties of a mold, silicon wafers and a UV-resin.

In this work, we focus on heat transfer in the curing process of UV-NIL for LCD. We carry out two experiments to observe the heat transfer during the curing process. We measure temperature change of the mold and the panel using thermocouples attached on the surfaces of the mold-glass and the panel-glass. Then, we simulate the heat transfer of the curing process based on the experimental results. We analyze heat transfer using FEA analysis. The thermal properties of the PUA layer and the cured resin layer are calculated to match the simulation to experimental results.

2. Experimental results

A mold and a glass panel for the UV-NIL process are made of transparent LCD glass to transmit the UV. The thickness of the both glasses is 0.67 ㎜. The thickness of the PUA layer on the layer is about 30 ㎛. The size of the mold is 370mm by 470mm, and the size of the glass-panel is 300mm by 400mm.

We attached thermocouples to measure the temperature changes on the panels in the curing process. The thermocouples A and B are attached on top of the mold and the bottom of the target glass panel, respectively. The experimental setup including thermocouples is depicted in Fig. 2.

To compare the effect of the PUA layer on the mold, we performed two experiments. In the first case, a mold with a PUA layer and a target glass panel was used for the curing process. In the second case, we used another glass panel instead of the mold; the alternative mold panel had no PUA layer. By comparing these two experiments, we could obtain the thermal effect of the PUA layer in the curing process. In both cases, the UV resin was filled between the panels

We executed the experiments for 10 minutes while we recorded the temperature change of the mold and the panel. After we started experiments, we turned on UV-light at 30 seconds and observed the change of temperature. We turned off the light at 210 seconds and recorded the temperature change until 600 seconds.

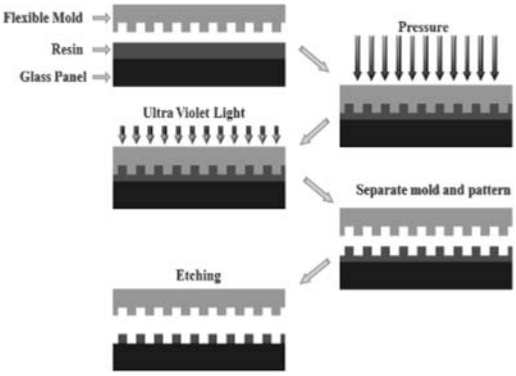

Fig. 1. Schematic diagrams of Nano imprint lithography.

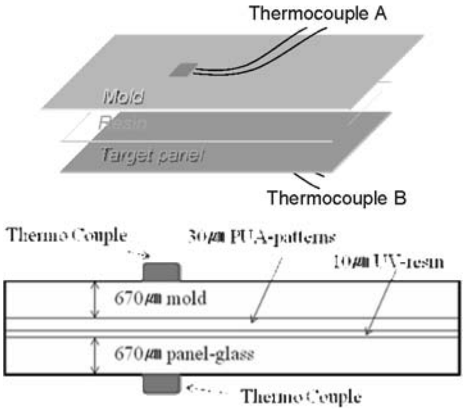

Fig. 2. Experimental setup.

The temperature changes of both experiments are presented in Fig. 3 and Fig. 4, respectively. In the first case where we used a mold with a PUA layer, we could observe that the temperature change at the bottom of the glass panel increased very quickly after turning on the UV light. Although the UV light was being turned on until 210 seconds, the temperature started to decrease from 70 seconds. We inferred that the heat generation of the resin ended at around 70 seconds, and that the period from 30 seconds to 70 seconds represented the actual curing time.

In contrast, the temperature change on top of the mold glass increased slowly until the UV light was turned off. The maximum temperature of the thermocouple A was 23.5 °C

On the other hand, the second experiment showed a different temperature change. In this case, the temperature change of thermocouple A was much faster than thermocouple B. The maximum temperature of the thermocouple A was about 25 °C

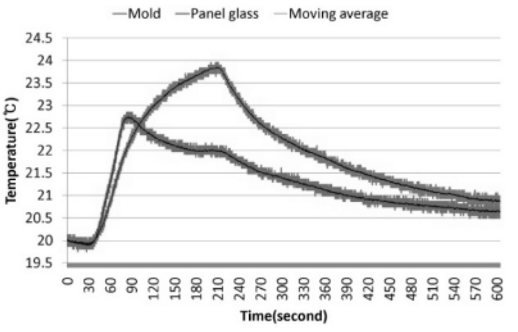

Fig. 3. Temperature change of a mold with a PUA layer and a target glass-panel.

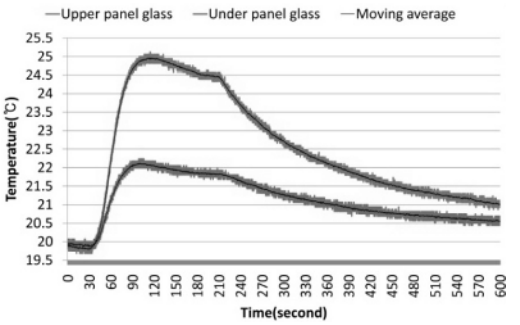

Fig. 4. Temperature change of a glass-panel without PUA layer and a target glass-panel.

The temperature changes of both experiments were different from each other. The temperature change on top of the mold in the second case was faster than that in the first case. The heat by resin curing could be transferred more easily through the alternative mold in the second case than in the first case. Thus, we could infer that the PUA layer acted like an insulation layer against the heat transfer. However, as shown in Table 1, the thermal conductivity of PUA is the same order of magnitude with an LCD glass, though its thermal capacity is twice bigger than the glass. That means the heat insulation effect by the PUA layer is not enough to explain the temperature change in the experiment.

3. Heat transfer analysis

We simulated the transient heat transfer in order to analyze the heat transfer experiments. The analysis was done by using the FEA software, ALGOR. This analysis can provide heat transfer parameters during the curing process: the variation due to convectional boundary condition; thermal resistance between PUA and the cured resin; heat generation ratio of the resin.

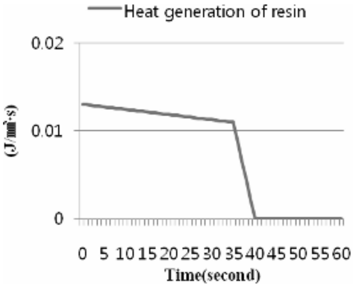

Fig. 5. Heat generation by UV resin during curing process.

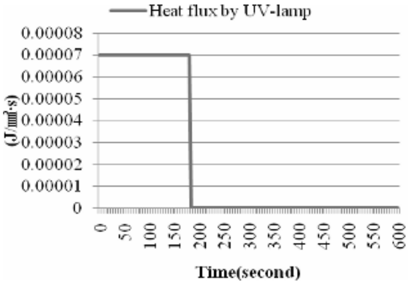

Fig. 6. Heat flux curve by UV-lamp radiation.

We assumed two heat sources for the simulation. The first heat source was heat generation by the UV-resin during the curing process. Another heat source was radiation from the UV-lamp.

In the experimental results, the heat was generated for 40 seconds from 30 seconds to 70 seconds in the curing process. In the simulation we started the curing process from 0 second and applied the heat generation from 0 second to 40 seconds. The heat generation curve is shown in Fig. 5. We modeled the influence of the radiation of UV-lamp as heat flux. We assumed that the heat flux activated from 0 second to 180 seconds when the UV lamp was turned on. The heat flux curve is shown in Fig. 6. The detailed values of the heat generation profiles were determined to match the simulation result and the temperature change of the experiments.

The simulation used a layered mesh modeling, where every node in the contacted surface is bonded with each other except the resin layer and the PUA layer. In addition to modeling each layer which is suggested in Fig. 2, we modeled a thermal resistance layer between the resin and the PUA layer in simulating heat transfer. We assumed that these two layers did not have conformal contact with each other but had air gaps between them. In previous research [4], the shrinkage of the resin and the gas generated during the curing process could make air gaps in part of

Table 1. Thermal properties for the heat transfer analysis.

	Mass density	Thermal conductivity	Specific heat
Mold	2.37g/㎤	0.1J/s· m· ℃	0.81J/g· ℃
PUA	1.00g/㎤	0.1J/s· m· ℃	2.00J/g· ℃
Glass panel	2.37g/㎤	0.1J/s· m· ℃	0.81J/g· ℃
Thermal Resistance between the resin and the PUA layer			0.1W/㎡· ℃

Table 2. Convection coefficients h with respect to the temperature of the glass panel T_g.

T_g (℃)	h (J/s·℃·㎟)	T_g (℃)	h (J/s·℃·㎟)
0	-0.00002032	21	0.00001248
15	-0.00001712	22	0.00001424
18	-0.00001424	25	0.00001712
19	-0.00001248	40	0.00002032
20	0		

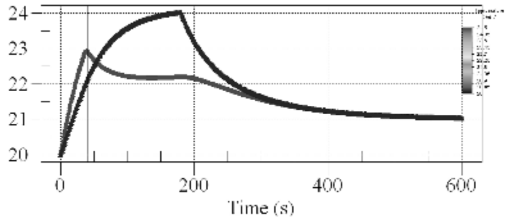

Fig. 7. The simulation result of temperature change with the mold and the target glass panel.

the layer. The detailed thermal properties for the heat analysis are presented in Table 1.

We also set the boundary condition between the glass and the environment. The heat transfer coefficients by the convection are presented in Table 2, where the coefficient depends on the change of the surface temperature of the mold and the target panel.

The simulation results of temperature change are shown Fig. 7. The temperature changes are simulated on the position of thermocouples A and B in the experiments. If the thermal resistance layer did not exist, the simulation could not show similar temperature change to the result of the first experiment in curing process. Thus, we could infer that the thermal resistance layer between the PUA and the resin layers should be considered in the heat transfer analysis for the curing process of the UV-NIL.

4. Conclusions

We analyzed the heat transfer during a curing process of UV-NIL. Temperature changes on top of the mold and under the bottom of the glass panel were measured by installing thermocouples. From the experimental results, we found that the PUA layer acted as an insulation layer against the heat transfer.

Based on the results of the experiments, the heat transfer was simulated to obtain temperature change by the resin curing. From the analysis, we could infer the thermal properties of the PUA layer, thermal resistance between the resin and the PUA layer, heat flux from UV-lamp and coefficients of convection load.

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