LASER-ASSISTED ROLLER IMPRINTING OF NANO STRUCTURES WITH REAL-TIME MONITORING OF REPLICATION DEGREE

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INTRODUCTION
Nanoimprinting lithography (NIL) is a promising technology that is used for fabrication of micro- to nanometer-scale structures [1]. Since the invention of NIL, many variations have been proposed and developed. Roller nanoimprinting, that is one of the variations, can fabricate the nanostructures continuously with a roller mold. Compared to flat nanoimprinting, roller nanoimprinting has advantages of patterning on large-area substrate in short time and lower pressing force [2]. Because of these advantages, roller nanoimprinting is expected to be used for replication of patterns onto flexible substrate such as thermoplastic films. Flexible substrate with micro- to nanometer-scale patterns can be applied to large-area optical films such as antireflection films or light-excitation films and to next-generation flexible displays or sensors.

However, it is generally difficult to replicate patterns completely with conventional roller nanoimprinting. One of the reasons is that thermoplastic polymer has a glass transition temperature (Tg), below which its viscosity is high and above which that becomes drastically lower. In conventional roller nanoimprinting, thermoplastic film is fed between a heated roller mold and a counter roller. The reflow in which the polymer surface is heated until demolded and the nanostructures are destroyed due to the surface tension is occurred immediately after demolding.

In this study, we propose and demonstrate a laser-assisted roller nanoimprinting. Figure 1 shows the schematic of the system. First, the laser locally heats the nanostructured mold through the transparent counter roller and film at the first-half region of the contacting area and the nanostructures are replicated. Second, at the last-half region, the film is cooled under Tg by the roller that has been originally cold. Finally, the replicated nanostructures are demolded from the mold. By using this method, the nanostructures can be completely replicated and demolded.

Furthermore, we also apply real-time monitoring method of replication degree. When mold patterns are irradiated with laser, the light reflects and diffracts. The diffracted light intensity is monitored in nanoimprinting process. When the film is filled into mold patterns, the diffracted light intensity changes [3]. With measuring the diffracted light intensity, replication degree can be monitored in real time. This technology enables to clarify replication mechanism. By feeding back the signals corresponding to the replication degree, not only replication phenomena during laser-assisted imprinting but also optimal parameters for the fabrication can be clarified.

Figure 1. Schematic of laser-assisted roller imprinting system with real-time monitoring of replicated degrees.

EXPERIMENTAL AND RESULTS
Laser-assisted roller imprinting
Laser-assisted roller imprinting was demonstrated. Film was put between a roller mold and a glass roller. Heating laser was scanned by Galvano mirror and the roller mold was heated linearly. We used Ni mold with 500-nm-pitch line-and-spaces, polymethylmethacrylate (PMMA, Tg: 90 °C) as a film, and Nd:YAG laser (λ=1064 nm) with average power density of 1.3 kW/cm² and diameter of 300 µm.
Figure 2 shows replicated PMMA surface and its SEM image. In this experiment, the feeding speed of laser was 0.5 mm/s, i.e., replication speed was 10 mm²/s. However, according to our preliminary experiment, if the power of laser is double, the replication speed would become 50 times faster. It can be explained that higher power and shorter irradiation results in higher temperature gradient inside mold and substrate and needs smaller energy to heat the surfaces over Tg.

![Replicated PMMA surface and its SEM image](image)

**Figure 2. Replicated PMMA surface and its SEM image.**

**Real-time monitoring of replication degree**

Real-time monitoring of replication degree by laser was demonstrated. PMMA film was put between a roller mold and a polycarbonate plate, and monitoring laser was irradiated behind the plate. We heated a whole roller mold. During nanoimprinting process, we measured diffracted light intensity. By moving the irradiation point along with feeding direction, the replication degree at each point can be investigated (Figure 3).

He-Ne laser ($\lambda=632.8$nm) was used as a monitoring laser. We used the line-and-space pattern that has 600 nm pitch and 300 nm depth. Pressing pressure was set at 2.7 MPa that is the same as that for roller imprinting experiment. Feeding speed was set at 5.0 mm/s. Figure 4 shows the diffracted light intensity at each irradiation points with roller mold at room temperature and heated at 120 °C.

With roller heated at 120 °C, the concaves of patterns were filled with film. Because the difference of light-distance between the light reflected at the concaves and at the convex parts corresponds to the wavelength, they were considered to be interfered and enhanced each other. On the other hand, at room temperature, the spaces between the mold concaves and film surface are remained. As a result, the two kinds of light were interfered and weakened each other.

![Schematic of difference of diffracted light intensity at each point in real-time monitoring of replicating degree](image)

**Figure 3. Schematic of difference of diffracted light intensity at each point in real-time monitoring of replicating degree.**

![Diffracted light intensity in each irradiation point with mold at room temperature and 120 °C](image)

**Figure 4. Diffracted light intensity in each irradiation point with mold at room temperature and 120 °C.**

**CONCLUSION**

We demonstrated laser-assisted roller nanoimprinting and real-time monitoring of replicating degree respectively. The laser-assisted roller imprinting realizes high-throughput and low-energy replication of nanostructures. The real-time monitoring method can clarify the filling and reflowing mechanism during the process. When the signal from the real-time monitoring was fed back, the conditions of laser-assisted roller imprinting can be optimized and applied to various nanostructures or different polymers or film thickness.

**REFERENCES**

