User-specific design and manufacturing of flexible micro- and nano-devices by utilizing continuous mechanical machining protocols

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ABSTRACT

In the nanopattern manufacturing process based on the conventional face-to-face principle, which undergoes an etching process followed by optical lithography or nanoimprinting (NIL), in order to variously change the period, shape, dimension, etc. of the nanopattern to suit a specific use, the mold Individual fabrication and complex tuning of process conditions are inevitably involved. In this study, Piezo actuated One-dimensional vibration-driven Patterning and Dynamic Nano-Inscribing based on the principle of plastic deformation based on one-to-one contact as a continuous nanoproduction technology that can perform user-customized variable shape nanopatterning more easily and with high scalability. We intend to develop and present the original process technology and verify its high productivity and applicability.

Keywords: Nanopatterning, Nanoinscribing, Flexible substrate, Polymer deformation

1. INTRODUCTION

Because the nanopatterning process changes the physical and chemical properties of a material only with a certain nanopattern arrangement on the surface without changing the composition of the material, it is actively improving or replacing the performance in various ready-made fields. Applications and demand are increasing. However, conventional nanopattern manufacturing processes such as photolithography or nanoimprinting require pre-processing of a mask or mold suitable for a specific shape and cycle, which is a major cause of increase in cost and process time.

Therefore, in this study, based on the principle of continuous machining, Piezo actuated One-dimensional vibration-driven Patterning; POP and Dynamic Nano Incribing; DNI direct processing nanopatterning technology is presented. The POP, DNI process is a micro-nano pattern direct processing technology due to pure mechanical plastic deformation and does not require pre-processing or additional materials such as vacuum process. In addition, since it is a line-to-face process based on the principle of continuous machining on a soft flexible film, there are few restrictions on the material and shape of the substrate, and at the same time, it is easy to mass-produce a large area. Furthermore, multi-dimensional nanopatterns can be easily produced through multi-dimensional repetition of the engraving path, and pattern transfer to a desired target substrate can be easily performed by combining it with the soft lithography process. In this study, as an example of application, we would like to show an application case in which a wide-angle improvement effect is obtained while maintaining external coupling efficiency by easily attaching a 2D nanopattern patch fabricated based on the fusion process to a flat-panel polymer LED (PLED).

2. EXPERIMENTAL PROCESS

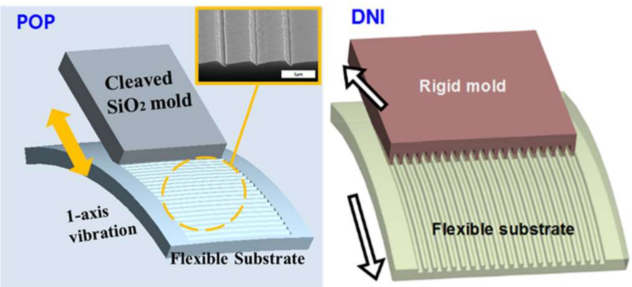

Figure 1. POP process schematic and SEM image of prismatic grating pattern fabricated from a flat-edge rigid mold / DNI process schematic.

For the POP process, any flat rigid edge can be used as mold by fixing it to the arm of the system, aligning its edge to be parallel to the flexible substrate (typically 30-45° to substrate). While maintaining the proper distance between the mold and the substrate, the substrate is transported in the horizontal direction. Thereby POP utilizes high-frequency periodic indentation of a rigid tool on the continuously fed flexible substrate, which is driven by high-speed single-axis vibration of a piezo actuator (vibration frequency up to 500 Hz at 150V) through the pulse width modulation (PWM) control. By adjusting the angle of the mold arm, POP can produce a prism pattern with various angle as shown in Fig. 1, and by adjusting the vibration frequency and horizontal feed rate, POP can produce nanopatterns having various periods without complicated processes.

For the DNI process, rigid micro-nano grating patterned mold is fixed at the arm with appropriate angle. The edge of the mold is in direct contact with the surface of a desired substrate, and the substrate is transported in the horizontal direction (0.1-10 mm/s) under an appropriate temperature (RT-150 °C) and pressure (1.5, 2, and 2.5 N). The patterning shape and depth can be readily tuned by controlling the angle of the mold arm, pressing force and temperature during engraving, and substrate sliding speed. Furthermore, when patterning is performed after fixing the mold by rotating the mold at an arbitrary angle with respect to the substrate transport direction, it is possible to continuously manufacture slanted patterns with variable periods and variable shapes using the same mold.

3. RESULTS & DISCUSSION

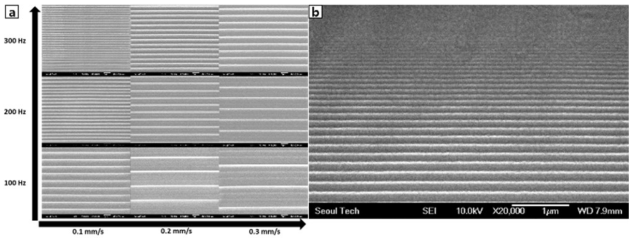

Figure 2. (a) POP SEM image matrix of vibration frequency of the piezo and the transfer speed of the substrate. (b) SEM image of variable period POP pattern.

The patterning period using the POP process can be variously tuned without complicated processes by controlling the vibration frequency of the piezo and horizontal feed rate of the substrate. Fig. 2a shows that the POP can produce nanopatterns with various period and accurate period control is possible. Also fig. 2b shows that a pattern with a variable period can be fabricated by changing the vibration frequency of the piezo stack in real time during the process.

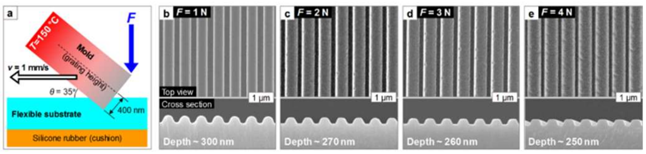

Figure 3. DNI SEM image according to force change.

Fig. 3 shows the change in pattern depth and shape at different DNI process conditions. In the DNI process, patterns having various shapes and depths can be continuously manufactured using the same grating mold (period of 700 nm) by adjusting the mold arm angle, pressure and temperature, and the substrate feed rate.

Based on the above experimental results, we developed a re-attachable ionomer nanopattern (RAIN) that can be repeatedly attached to and detached from a surface of any shape (Fig. 4). First, multidimensional nanopatterns can be easily made through the DNI process. After transfer to an elastomeric pad for use as a soft nanoimprinting stamp, the ionomer film is roll-imprinted at a low temperature of ~60-70°C to fabricate a flexible and highly transparent RAIN. The superior adhesion resulting from ionic interactions uniquely realizes RAIN's conformal adhesion and pristine detachability to universal targets under ambient conditions, which is particularly useful for nanopattern-based individual wearables and mobile devices.

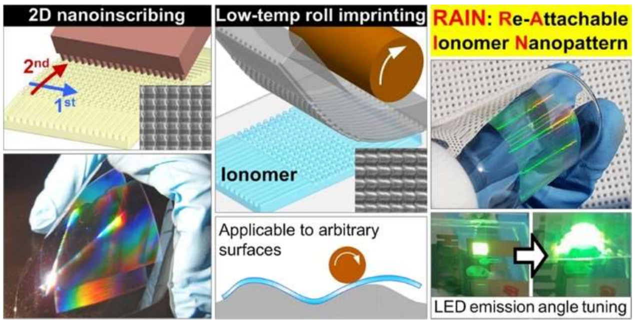

Figure 4. Schematic drawing of the continuous 1D and 2D nanograting fabrication and low-temperature roll imprinting of the PDMS stamp.

4. CONCLUSION

Both POP and DNI perform nano-patterning based on the face-to-face process principle, that is, contact with the edge of the mold, so it is easy to expand the pattern area by performing press-fitting or engraving as many strokes as desired without being constrained by the area of the mold disc. In addition, complex nanopatterns with various shapes and dimensions can be easily fabricated through the multidimensional combination of POP and DNI strokes. This high-productivity manufacturing technology of user-customized nanopatterns is expected to be applicable to many applications designed specifically for personal use, such as wearables and mobile devices.

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