Roll-to-Roll Liquid Transfer Imprint Lithography for Patterning on a Large-area Roll

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Roll-based nanoimprint lithography (Roll-NIL) has been studied and developed for the fabrication of nanopatterns on large and flexible film substrates. Most Roll-NIL systems use a roll wrapped by a thin nanostamp or a nanopatterned belt[1,2]. The fabrication of a roll with nanopatterns formed on its surface should be done beforehand for Roll-NIL. As the size of the film substrate increases, the nanopatterned roll should be longer. However, it is difficult to fabricate nanopatterns onto such a large-area roll. First, because most patterning processes were developed with wafer substrates, it is challenging to apply these processes to roll surfaces. Second, the resist cannot be coated onto the roll stamp via a spin coater. The dip coating of the resist on the roll surface was studied as an alternatives to spin coating[3,4]. However, it was found to be difficult to dip a large-area roll with a length of a few hundreds of mm into a resist container.

To solve the problem of coating a large-area roll (up to 1,000 mm length), this paper uses liquid transfer imprint lithography (LTIL). LTIL can transfer nanopatterns from a small-area roll (stamp) to another large-area roll (substrate). LTIL has been developed for flat substrates with flat or roll stamps[5,6]. The advantage of LTIL is that there is no need to coat a resist onto the large-area roll itself. After coating the resist onto a donor, the stamp takes approximately half of the resist from the donor through contact and separation. The resist on the stamp can then be transferred onto an acceptor (the large-area roll in this case). During the process of transferring to the acceptor, the resist forms an inverse shape to the patterns of the stamp. Figure 1(a) shows the transfer of the resist from the master roll (stamp) to the substrate roll (acceptor) by contact and synchronized rolling. The UV source inside the master roll illuminates UV light onto the contact area and cures the resist line by line during the process. Because the substrate roll is larger than the master roll, this process should be repeated in the axial and circumferential directions, as shown in Fig. 1(b).

A roll-to-roll system is developed to demonstrate the proposed process. A substrate roll with a maximum length of 1,000 mm can be loaded onto the system. The master roll consists of a transparent quartz tube with an effective length of 200 mm. The UV source installed inside of the master roll can illuminate a line of focused UV light to cure the resist. The nanopatterns can be fabricated on the surface of the master roll itself, or a nanopatterned flexible sheet can be attached to the surface of the master roll. For the experiment, we created a polydimethylsiloxane (PDMS) replica from a nanopatterned silicon template. The size of the PDMS replica is 144 mm by 96 mm. There are nanolines of a width, pitch, and depth of 150 nm, 400 nm, and 300 nm, respectively. Polyurethane-acrylate (PUA) resist was spin-coated with a thickness of 600 nm to a donor 150 mm by 150 mm in size. After temporarily attaching the donor to the surface of the substrate roll, the master roll (with the PDMS replica) comes into contacts with the substrate roll under 5 kgf load, and both of rolls synchronously rotate with a linear velocity of 0.4 mm/s. Half of the resist is then transferred from the donor to the surface of the master roll. As the next step in the LTIL process, the master roll is moved to a certain position of the substrate. The two rolls are then pressed again and synchronously rotated with a linear velocity of 0.12 mm/s, as shown in Fig. 2(a). By repeating this process 56 times (considering the lengths and circumferences of the two rolls), the nanopatterns can be fabricated onto all surfaces, as shown in Fig. 2(b). The transferred nanopatterns (vertical lines) were measured via scanning electron microscopy (SEM), as shown in Fig. 2(c).

This work seeks to verify the possibility of the LTIL process from a small roll to another large roll. By repeating this process, we fabricated nanopatterns on a roll which was 1,000 mm long. This work can serve as a reasonable solution to produce a nanopatterned large-area rolls which can be used in the mass production of functional nanopatterned films.

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