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Research paper

Fabrication of the grid pattern on a roll mold by electron beam direct writing

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ABSTRACT

Roll to roll-nanoimprint lithography (RTR-NIL) has received a great deal of attention as a technique for the fabrication of next generation devices. The most important part of RTR-NIL is a roll-shaped mold, which is difficult to manufacture because of its cylindrical shape. Therefore, we have developed fabrication methods for a seamless roll mold substrate, using single point electron beam (EB) direct writing, where the substrate is rotated in a vacuum. We have already developed a fabrication method for parallel lines and dot patterns with sub-100 nm in the direction of rotation in a previous study. However, a grid pattern is required for transparent electronics, and a method of writing a line perpendicular to the direction of rotation has not yet been demonstrated. In this study, we attempted writing in the vertical direction from two angles, using electronic and mechanical methods. As a result, we succeeded in fabricating grid patterns by writing the dots between two parallel lines using an electronic method and tilting the roll using a mechanical method. We obtained sub-1 μm and 7.2 μm grids for the electronic and mechanical methods, respectively.

1. Introduction

In recent years, with the widespread use of wearable terminals, printed electronics have attracted attention as a manufacturing technique. Printed electronics is a technology integration of printing device manufacturing and flexible device technologies, and is applied in various fields, such as energy, home electronics, and medical care; examples are smartphones, solar cells [1–3], and organic LEDs. Transparent electrodes are built into these terminals. A transparent electrode is fabricated by metal wiring on a transparent plastic substrate. In particular, grid-like transparent electrodes are often used for touch panels. Usually, the capacitance method is adopted for the touch panel. The touch position detection on the capacitance method touch panel is performed by detecting an extremely minute capacitance change in the electric field, occurring between the fingers and the X and Y axes sensor, requiring grid-like metal wiring. Nanoimprint lithography (NIL) [4] is a suitable manufacturing technique. NIL uses a mold with nanopatterns and UV curable or thermosetting resins. The process is simple; first, the resin is dropped on the mold and pressed against a substrate and is transferred. Second, the resin is cured by exposing it to UV light or by the application of heat. The mold is then released from the substrate, leaving a duplicated nanopattern on the transferred substrate. Using these simple steps, NIL can be used to fabricate nanoscale patterns.

Among them, Roll to Roll-NIL (RTR-NIL) [5–7] has received great attention as a technique for the fabrication of next generation devices. RTR-NIL is a technology that allows continuous transfer of patterns by making the mold cylindrical rather than a conventional flat surface, and its speed is very fast, e.g., 18 m/min [8].

The most important part of RTR-NIL is a seamless roll-shaped mold. To manufacture a roll mold without a seam, the roll substrate is directly cut with a blade or laser [9], or by using step-and-rotated UV-photolithography [10]. However, it is difficult to obtain sub-1 μm resolution in both methods. Recently, a manufacturing method to connect the seams has been reported [11]. Self-organized structures have no seams and the size of the pattern is very fine [12]. However, it is difficult to design the pattern shape. Therefore, there is a need for a fabrication method that can produce seamless roll molds with sub-100 nm resolution that facilitate intricate design.

We previously developed a technique for EB direct rotation exposure as a precision seamless machining method. This technique exposes the resin that has been coated on the surface of the roll, with a single point EB while rotating the roll [13]. Similar methods have also been investigated by other researchers [14,15]. We succeeded, in the previous study, in creating parallel line and dot patterns with sub-100 nm size in the direction of rotation, such as dots and line & space [16,17].

However, a grid pattern is required for transparent electronics, and a method of writing a line in a direction perpendicular to the direction of rotation has not yet been created. We attempted to write vertical lines

Abbreviations: EB, Electron beam; NIL, Nanoimprint lithography; RTR-NIL, Roll to roll-nanoimprint lithography.

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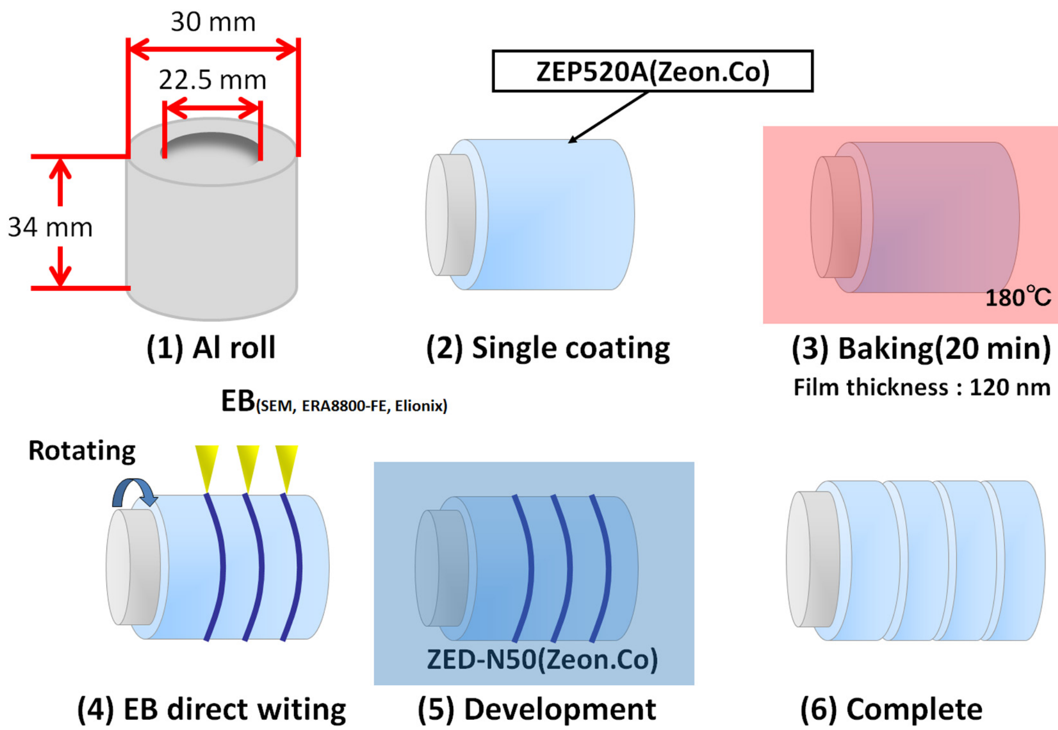

Fig. 1. Fabrication of the roll mold.

using electronic and mechanical methods using single point EB direct writing. In this paper, we report two kinds of writing methods for vertical lines; by writing the dots between two parallel lines using an electronic method, and tilting the roll in a mechanical method.

2. Experimental setup

Fig. 1 shows the standard process of EB direct writing with a rotating roll mold. A 34-mm-long aluminum cylinder with an outer diameter of 30 mm and an inner diameter of 22.5 mm was used as the substrate for the roll mold. ZEP520A (Zeon Corp., Tokyo), a positive EB resist with a dedicated ZED-N50 developer, was used as the EB resist [18]. To obtain a thin coating, the ZEP520A was diluted by 50% by adding ZEP-A thinner. The roll mold substrate was dipped in the diluted ZEP520A resist at a speed of 3 mm/s, kept in the solution for 5 s, and then pulled out at a speed of 0.2 mm/s [Fig. 1(2)]. Next, the sample was baked at 180 °C for 20 min [Fig. 1(3)]. The resulting ZEP520A layer had a thickness of ~120 nm. Next, we mounted the roll substrate on rotating equipment that was installed in the EB writing system. A scanning electron microscope (SEM, ERA-8800FE; Elionix Inc., Tokyo) with a blanking system was used for the EB writing [Fig. 1(4)]. To fabricate the nano-pattern, the roll mold was rotated in the circumferential direction and the EB was simultaneously switched on and off (chopping) by controlling the blanking signal. The EB was focused at a single point on the surface of the roll mold and the nano-pattern was produced by revolving the roll while the EB was switched on and off [17]. After the roll substrate was developed in ZED-N50 and rinsed in 2-propanol (IPA) [Fig. 1(5)]. And, it is complete [Fig. 1(6)].

2.1. Writing characteristics when writing dots between two parallel lines

We firstly examined the drawing characteristics when drawing dots between two parallel lines from the following two viewpoints: the drawing characteristics when the dose was changed and the drawing characteristics when the unit drawing length was changed.

Fig. 2 shows the writing pattern. The writing method is as follows: First, the top line, then a row of dots was written. Finally, the bottom line was drawn. The machining conditions were as follows; acceleration voltage of 10 kV; EB dose of 510–1275 μC/cm^2, unit drawing lengths of 45.3 and 181 nm; EB currents of 40 and 100 pA; and rotating speeds of 0.25 and 0.5 rpm. The beam diameter was ~10 nm. The vacuum pressure during EB writing was less than 5.0×10^{-4} Pa.

Fig. 2 illustrates the writing of the dots between two parallel lines (an electronic method) and tilting the roll (a mechanical method).

2.2. Writing the dots between two parallel lines for the electronic method

Fig. 3 shows the design pattern example for a grid pattern. The writing method of the lattice pattern is as follows. First, the top line, then the rows of dots were written. During this time, we controlled the chopper

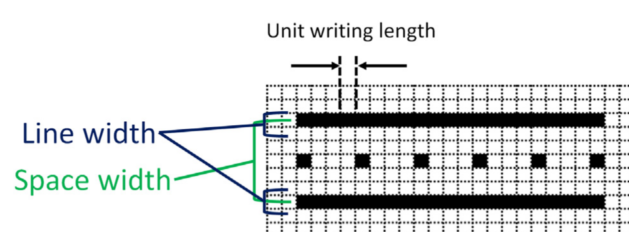

Fig. 2. Design pattern.

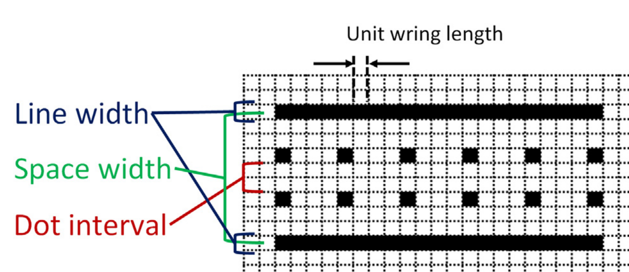

Fig. 3. Design pattern example.