Roller nanoimprint lithography

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An alternative approach to flat nanoimprint lithography (NIL)—roller nanoimprint lithography (RNIL) is demonstrated. Compared with flat NIL, RNIL has the advantage of better uniformity, less force, and the ability to repeat a mask continuously on a large substrate. Two methods for RNIL are developed: (a) rolling a cylinder mold on a flat, solid substrate; (b) putting a flat mold directly on a substrate and rolling a smooth roller on top of the mold. Using our current roller nanoimprint system, sub-100 nm resolution pattern transfer has been achieved. © *1998 American Vacuum Society.* [S0734-211X(98)18606-7]

I. INTRODUCTION

Nanoimprint lithography (NIL) is a new lithographic method that offers a sub-10 nm feature size, high throughput, and low cost.[1,2] In previous NIL experiments, an entire flat mold is pressed simultaneously into a polymer cast on a flat substrate. Here, we demonstrate an alternative approach to flat imprint lithography—roller nanoimprint lithography (RNIL). We report the design and construction of a roller nanoimprint system, the development of two methods for roller nanoimprint, and the demonstration of sub-100 nm patterns by RNIL. Previously, roller presses were used in the cement industry[3,4] and was used to imprint into flexible thin films that can conform to the shape of the roller. However, the pressed feature size in these applications is a micron or larger and they are not used as a lithography method.

II. ROLLER NIL MACHINE DESIGN

Our roller press consists of a roller, a movable platform, and a hinge (Fig. 1).[5] The roller is a hollow metal tube with a halogen bulb mounted inside. It has a thin wall and a small thermal mass, and therefore can be heated and cooled quickly. The flat platform that holds a sample can be heated by a strip heater inside, and has two ball-ring rails underneath allowing the platform to move back and forth freely in the direction vertical to the roller. The hinge is for applying a constant force between the roller and the sample. Pressure can be adjusted by applying different weight to the top hinge. The mold can either be bent into a cylinder shape or be put directly on the sample. During RNIL, the roller rotates around a fixed axis, while the platform slides underneath the roller.

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III. TWO METHODS FOR ROLLER NANOIMPRINT

We have developed two methods for RNIL (Fig. 2). One method is the cylinder mold method. The cylinder mold was made by bending a thin metal film mold around a smooth roller. In particular, a compact disk master made of 100 μm thick of Ni with 700-nm-wide tracks was used. The substrate is a flat Si wafer of 0.5 mm thickness with 220 nm polymethylmethacrylate (PMMA) cast on top. During roller NIL, the mold is pressed into the PMMA resist, and the rotation of the roller pushes the sample forward.

The second method, the flat mold method, uses a flat Si wafer mold of 0.5 mm thickness with intrusions of 190 nm period and 180 nm height, placed directly on the substrate. A smooth roller is rotated over the mold and the slight deformation of the flat mold under the pressure of the roller imprints patterns in the resist.

In both methods, the roller temperature is set well above the glass transition temperature, T_g, of the resist, while the temperature of the platform is set below the T_g. Therefore, only the area in contact with the roller has a temperature higher than T_g, making the resist in that area flow and being imprinted with patterns. This is different from flat nanoimprint, where the entire resist, heated above T_g, is imprinted simultaneously and the pressure is applied until the resist is cooled down, becoming hardened.

IV. RESULTS AND DISCUSSION

In either roller NIL method, we have been able to duplicate the mold pattern into the PMMA resist continuously. In the first method, the compact disk master we used had mesa patterns of 700 nm width (Fig. 3). After roller nanoimprint, atomic force microscope (AFM) images showed that the trenches imprinted in PMMA are 700 nm wide, 60 nm deep (Fig. 4). Due to the AFM tip size effects, the imprinted AFM image has rounded sidewalls. In the second method, the flat mold has a large area grating pattern of 190 nm period and

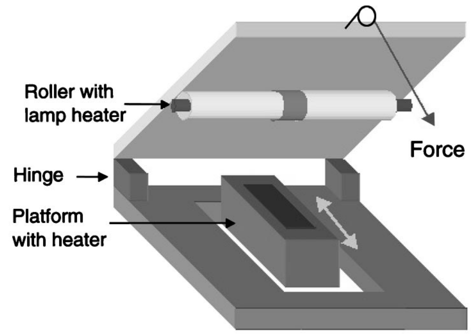

FIG. 1. Schematic of a roller nanoimprint system, consisting of a roller, a movable platform, a hinge, and heaters.

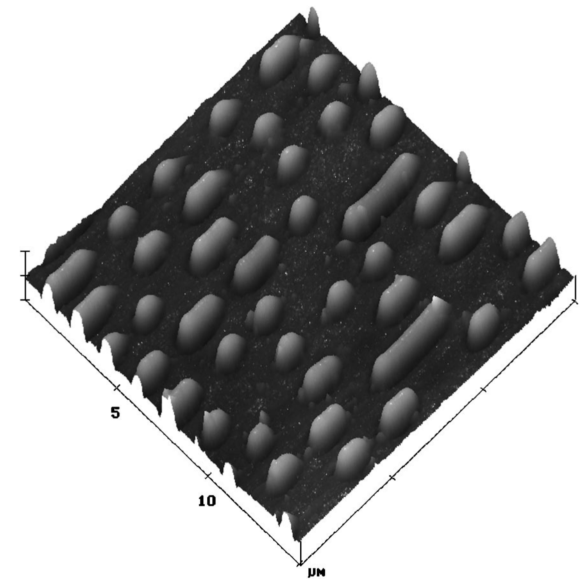

FIG. 3. AFM graph of a compact disk mold before bent into a cylinder: 700 nm tracks pattern on the surface of compact disk.

180 nm height.[6] After RNIL we obtained a large area grating with 190 nm period and 40 nm depth. The width of the PMMA grating is 70 nm (Fig. 5). The sloped PMMA sidewall and the shallow trench are due to the AFM tip size effect.

The RNIL processing conditions have been investigated. The temperature of the platform was varied between room temperature and 200 °C, and the temperature of the roller was varied between 120 and 200 °C. The scan speed of the roller ranged from 0.5 to 1.5 cm/min, and the estimated pressure was changed from 300 to 4800 psi. The pressure was estimated from the total force and the total contact area (the sample width times the contact length). The total force ranged from 10 to 20 lbs. The sample width was from 0.25 to 2 cm, and the contact length, which is a function of the pressure, was about 2 mm.

The temperatures and pressures for the two roller NIL methods are different because the molds are different in both material and feature size. We found that for the cylinder mold method, the best result can be achieved when the platform temperature is around 50 °C and the roller temperature is at 170–200 °C. For the flat mold method, the best temperature for pattern transfer would be around 70 °C for the platform and 170–200 °C for the roller. Furthermore, it is found that the temperature and pressure are related. Increase of the platform temperature would decrease the viscosity of the PMMA, therefore less imprint pressure is required. The roller temperature seems not critical to the press as long as it ranges from 160 to 200 °C.

We found that when the platform temperature is too high, or the roller moving speed is too fast, or the pressure is not

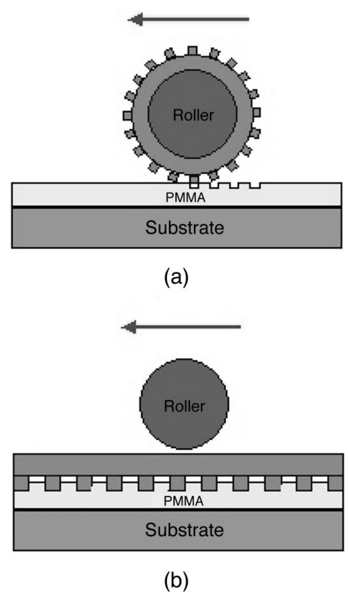

FIG. 2. Two ways for roller nanoimprint: (a) imprints using a cylinder mold: bending a compact master disk into cylinder shape, mounting it around the roller, and rolling the roller on the substrate; (b) imprints using a flat mold: putting the mold directly on the substrate, and rotating the roller on top of the mold.

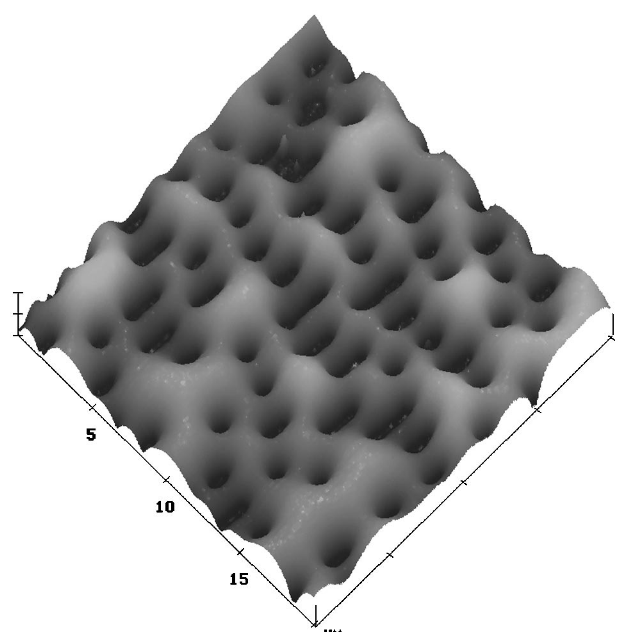

FIG. 4. PMMA imprinted by a cylinder mold, showing sub-100 nm accuracy in pattern transfer.

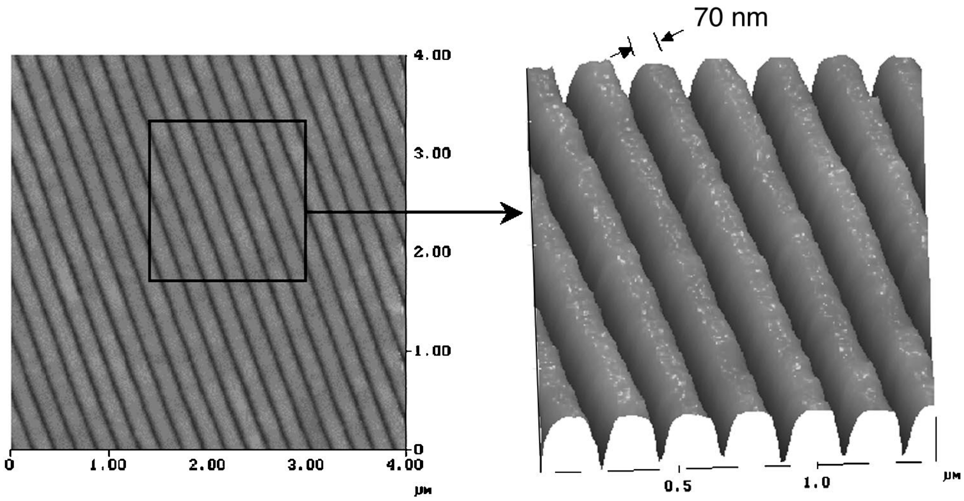

FIG. 5. PMMA imprinted by a flat mold: it has large area grating with 190 nm period and 40 nm depth, showing a sub-100 nm resolution.

sufficient, the imprint quality becomes poor. At high platform temperature (e.g., higher than 100 °C for PMMA), once the pressure is removed, the imprinted pattern deforms quickly due to the low viscosity. At fast roller speed or at lower pressure, the resist may not have enough time to change its shape, depending upon the resist viscosity.

Inspection using optical microscope and AFM showed that RNIL has few air bubbles, even when imprinted in atmosphere, perhaps because the roller pushes the air out.

During flat nanoimprint, the whole area of the sample is imprinted at the same time. Unevenness in sample thickness or a small dust particle in one place can affect the uniformity of a large surrounding area. But for RNIL, only a line area is in contact for a given time, significantly reducing the effects of thickness unevenness and dust on surrounding area. However, the actual uniformity depends on the RNIL machine being used. We are still improving our RNIL machine.

Finally, We would like to point out that both the RNIL machine and the process need further improvements for a better uniformity, smaller feature size, and larger area.

V. SUMMARY

A roller NIL machine was designed and constructed. Two methods for roller nanoimprint lithography have been developed with one using a roller mold and the other using a flat mold and a smooth roller. In both methods, sub-100 nm resolution has been achieved. Our results indicate that roller NIL is an attractive alternative approach, offering a much simpler NIL machine, higher throughput, and lower cost.

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