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Nanoimprint Lithography Using Novolak Photoresist and Soft Mold at Room Temperature

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1. Introduction

Nanoimprint lithography [1]-[10] has attracted considerable attention from the viewpoint of low cost fabrication because exposure systems are not required. Up to now, polymethylmethacrylate (PMMA) films and hard molds were often used in nanoimprint lithography.[1]-[9] Concerning dry etching, novolak photoresist[9] is superior to PMMA because the etching rate of novolak photoresist is lower than that of PMMA.[11] With regard to molds, it is expected that use of soft molds as well as hard molds will expand applications of nanoimprint lithography.

In this paper, we report on the successful demonstration of nanoimprint lithography using novolak photoresist and a soft mold such as a soft polyester sheet on which two-dimensional square grating with a pitch of 1000 nm and a height of 300 nm is formed. By combining pressing and successive developing of the novolak photoresist, two-dimensional (2-D) square grating on a soft polyester sheet was successfully transferred onto the novolak photoresist. By using the patterned novolak photoresist as an etching mask for reactive ion etching (RIE), holes with a radius of 450 nm and a depth of 320 nm were obtained on the thermally oxidized 320-nm-thick SiO_2 layer.

2. Fabrication

First, a 320-nm-thick SiO_2 layer was formed on a Si substrate by thermally oxidizing the Si substrate. As the novolak photoresist, 600-nm-thick OFPR-800 (TOKYO OHKA KOGYO CO., LTD.) was spin coated on the SiO_2/Si substrate followed by prebaking to control its viscosity. As illustrated in Figure 1, a soft polyester sheet was pressed with a stainless column onto OFPR-800 on the SiO_2/Si substrate at room temperature. This polyester sheet has 2-D square gratings with a pitch of 1000 and a height of 300 nm. Also, a duralumin plate, a stainless plate, and a Si substrate were used to obtain parallel and flat contacts of the polyester sheet and OFPR-800. After the pressing, OFPR-800 was developed by dipping the wafer in NMD-3 (TOKYO OHKA KOGYO CO., LTD.) and was rinsed for 1 min with running pure water at a flow rate of 5 ml/s. Before RIE, OFPR-800 was postbaked for 5 min at 120°C. Finally, by using the patterned novolak photoresist as an etching mask, the SiO_2 layer was etched for 6 min by RIE using CHF_3 gas with a flow rate of 5 sccm, a pressure of 0.03 Torr, and an RF power of 200 W.

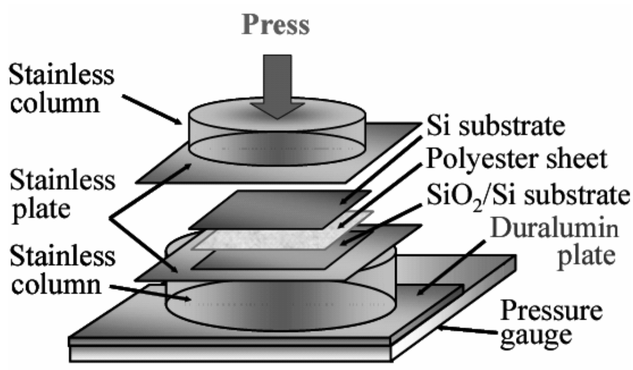
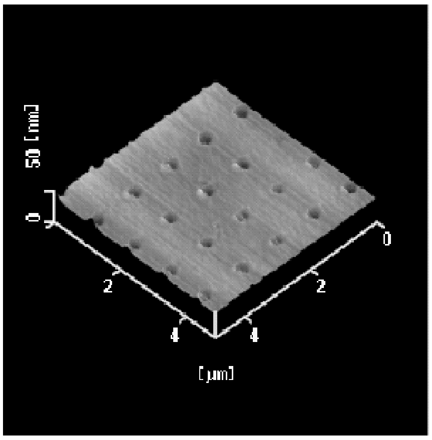


Fig. 1 Schematic of pressing a mold to novolak photoresist on a SiO_2/Si substrate.

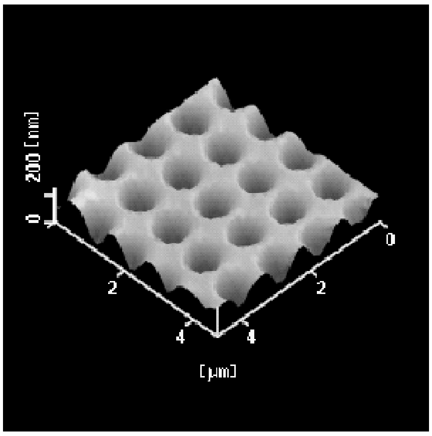
3. Experimental Results and Discussions

Figure 2 shows atomic force micrographs (AFMs) of the surfaces of OFPR-800 after prebaking for 1 min at 40°C and pressing for 1 min at 130 kgf/cm^2: (a) without developing, (b) with developing for 10 s, and (c) with developing for 20 s. From Fig.2, it is found that the developing rate for the valleys (60 nm/s) is much higher than that for the flat areas (40 nm/s). This difference in the developing rate is probably caused by the following two reasons: (1) chemical bonds in the novolak resin in the valleys, which were pressed regions, get weaker than those in the flat region due to a difference in the pressures, and (2) liquid tends to attack valleys rather than flat areas, as observed in rivers, and NMD-3 dissolves the valleys much faster than the flat areas.

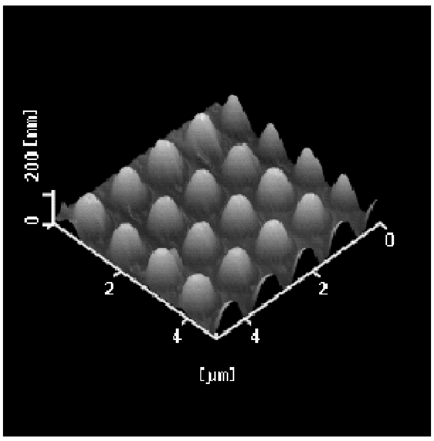
To achieve sufficient resistance for RIE, OFPR-800 was prebaked for 5 min at 120°C, pressed for 1 min at 97.5 kgf/cm^2, and developed for 3 min. Corresponding to a harder prebaking condition (5 min at 120°C) than that in Fig.2 (1 min at 40°C), the developing time was extended from 10 s to 3 min; the developing rates decreased from 60 nm/s to 3.3 nm/s for the valleys, and from 40 nm/s to 2.6 nm/s for the flat areas, respectively. Even though process conditions were different from those in Fig.2, holes with 600 nm wide and 130 nm deep were clearly formed by combining pressing and developing. These results suggest that developing OFPR-800 is useful for transferring fine patterns to OFPR-800 from a soft mold. It is interesting that a developing process worked well even though an exposure process did not exist in the present process in this letter. Because maximum thickness of OFPR-800 after postbaking was 140 nm, the holes were not formed down to the SiO_2 surface. However, the remained OFPR-800 at the bottom of the hole was only 10 nm thick, this remained OFPR-800 was easily removed by RIE.



(a)



(b)



(c)

Fig. 2 Atomic force micrographs (AFMs) of the surfaces of OFPR-800 after prebaking for 1 min at 40°C and pressing for 1 min at 130 kgf/cm^2: (a) without developing, (b) with developing for 10 s, and (c) with developing for 20 s.

Figure 3 shows a scanning electron micrograph (SEM) of the surface of the SiO_2/Si substrate after RIE followed by removal of OFPR-800. Holes with a radius of 450 nm and a depth of 320 nm were successfully obtained by RIE on the thermally oxidized 320-nm-thick SiO_2 layer. This result indicates that OFPR-800, which was patterned by pressing followed by developing, has a high resistance to RIE.

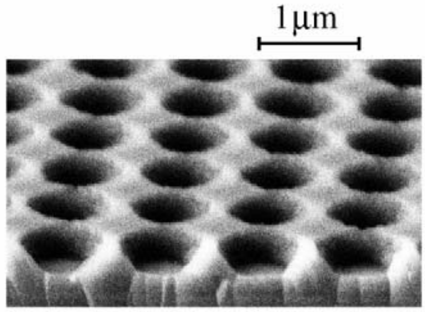


Fig. 3 Scanning electron micrograph (SEM) of the surface of the SiO_2/Si substrate after RIE followed by removing OFPR-800. Holes with a radius of 450 nm and a depth of 320 nm were formed on the thermally oxidized 320-nm-thick SiO_2 layer.

4. Conclusions

Nanoimprint lithography using novolak photoresist and a soft mold was successfully demonstrated by combining pressing and developing of the novolak photoresist. It is found that developing of the novolak photoresist is useful for a soft mold such as polyester. It is also revealed that the novolak photoresist, which was patterned by pressing followed by developing, has high resistance to RIE.

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