Large-Area Nanostructures by Laser-Scanning Imprinting

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Nanoimprinting is a mass fabrication method for nanostructured polymer.[1] The cycle time of conventional nanoimprinting is long because the polymer and mold are heated and cooled from their outside. It was demonstrated that the method in which only the surfaces of the substrate and mold are heated leads to a short cycle time.[2] We proposed a laser-assisted imprinting in which the mold consists of two layers; a light-transparent layer and thin light-absorption layer.[3] However, these methods are difficult to apply in a large area because the power of the laser is limited. In this study, we demonstrate a laser-scanning imprinting (Fig. 1). The surface of the polymer is heated and melted. The melted polymer fills the nanostructures of the mold. After the laser irradiation, the imprinted polymer is cooled, solidified, and demolded. This method leads to not only imprinting large-area patterns but also imprinting arbitrary pattern areas of the mold.

We used Nd:YAG laser (diameter of the beam: 300 μm, average power density: 1.4 kW/cm^2), a polymethyl-methacrylate (PMMA) film (thickness: 75 μm, deflection temperature under load: 90 ˚C), a 625-μm-thick quartz substrate (transmittance: 96%) as the light-transparent layer and a 3-μm-thick diamond-like carbon (DLC) film (absorptance: 78%) as the light-absorption layer. The size of the mold was 20×20 mm^2. The pattern of the mold was 500-nm-pitch line and space, and the height was about 200 nm (Fig. 2(a)). Pressure was applied between the PMMA and mold before laser irradiation by screws attached between two aluminum alloy plates sandwiching them. The plate on the mold had a hole to transmit the laser. The pressure was 8 MPa, which were calculated from the screw torque, and the irradiation time was 125 ms. The laser was also scanned in a line at a speed of 8 mm/s and in an area of 10×10 mm^2 through lines with 0.8 mm intervals at a speed of 8 mm/s.

Figures 2(b,c) shows SEM images of the imprinted PMMA. The area with the diameter of about 1 mm was imprinted, which corresponds to a scanning speed of 8 mm/s. Figures 3(a,b) shows SEM images of the PMMA imprinted by scanning the laser in a line. The width of the imprinted line was about 1 mm, which is almost similar to the diameter of the PMMA imprinted by irradiating laser at a target point. Figs. 3(c,d) shows SEM images of the PMMA imprinted by scanning the laser in an area with a size of 10×10 mm^2 in 20 s. In Fig. 3(c), no boundary between the scanned lines was observed, which indicates that an area with arbitrary size can be imprinted by the laser-scanning imprinting.

[1] S. Y. Chou, P. R. Krauss and P. J. Renstrom, Appl. Phys. Lett., 67(1995)3114-3116.
[2] S. Y. Chou, C. Keimel, and J. Gu, Nature, 417(2002)835-837.
[3] T. Sato, K. Nagato, J. Choi, T. Hamaguchi, M. Nakao, Proceedings of IEEE Nano 2011.

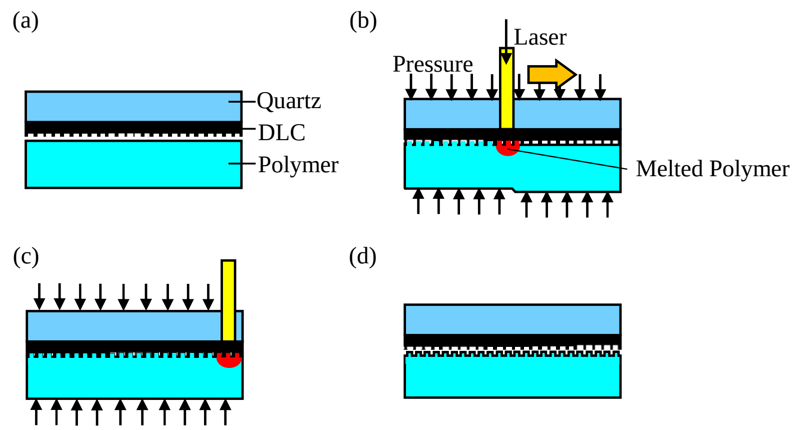

Figure 1: Schematic of the procedure of the laser-scanning imprinting, (a) preparation of the mold and polymer, (b) scanning laser, (c) solidification of polymer, (d) demolding.

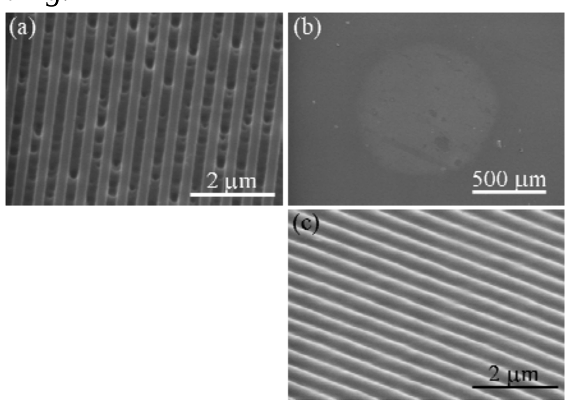

Figure 2: SEM images of the mold and PMMA imprinted with the irradiation time of 125 ms, (a) the mold (top view), (b) irradiated area of the imprinted PMMA (top view), (c) magnified image (tilt: 45 ˚).

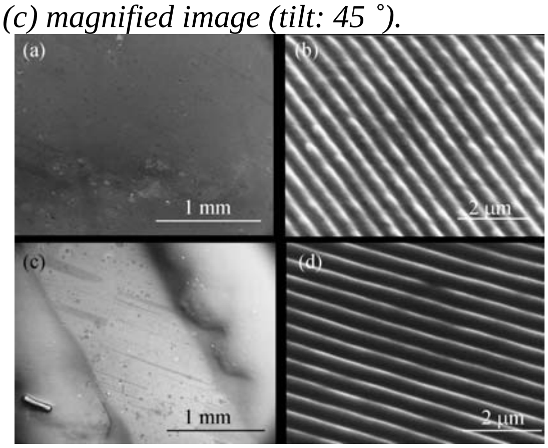

Figure 3: SEM images of the PMMA imprinted by scanning in a line (a) the irradiated area (top view), (b) magnified image (tilt: 30 ˚), and in an area (c) the irradiated area (top view), (d) magnified image (tilt: 30 ˚).