Experimental and theoretical study on the demolding mechanics in imprint process

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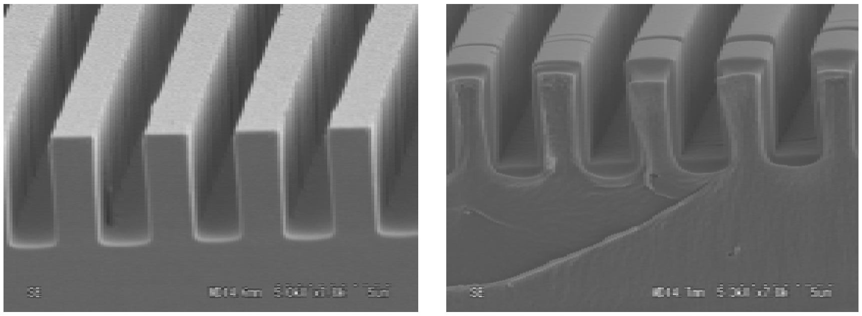
Demolding is one of the most important issues in nanoimprint lithography. Although several reports are found about the demolding process(1), the mechanics have not been discussed in detail. In this report the dependence of the demolding force on the resist thicknesses is investigated by both experiments and simulation analysis.

A silicon mold with 2 μm line and space pattern is used. The improved alternate Si etching process is used in order to suppress the side wall scalloping(2) because the side wall roughness must be greatly influenced to the demolding characteristics. An example of the fabricated Si mold is shown in Fig. 1(a). It is found that the Si mold with smooth side wall is obtained. After the surface treatment by fluorinated self-assembled monolayer (SAM) the mold is pressed to a PMMA film on a silicon substrate. The press conditions are 160ºC, 10MPa for 5 min. Then, the temperature is decreased to 100 ˚C by the first cooling step and to 40 ˚C by the second cooling step. The time of the first cooling step, t_1, is varied and that of the second cooling step is kept 13 min. After the cooling the press pressure is released and the demolding force is measured by a force gauge. An example of the imprinted PMMA pattern is shown in Fig. 1(b). A good PMMA pattern is obtained. Since the resist is pressed by the side wall of the mold pattern, the measured demolding force is normalized by the total side wall area. The experimental results are shown by the solid line in Fig. 2. The first cooling step time is 15 min. The demolding force decreases as the PMMA thickness increases. The side wall press force by the resist shrinkage is simulated by a simple model as shown in Fig. 3. In this model the left side and the bottom of the PMMA film is fixed and the other edges are free. The PMMA film is shrunk by the cooling under the boundary condition. The simulation result is shown by the dashed line in Fig. 2. The dependence on the PMMA thickness agrees to the experiment qualitatively. It is considered that a large stress which is produced at the bottom boundary is relaxed when a thick PMMA film is used. The normalized demolding forces are shown in Fig. 4 for the fast (t_1=2 min) and slow (t_1=60 min) cooling rates. Note that the normalized demolding force increases as the PMMA thickness increases for the slow cooling rate. Although the reason can not be explained in the present time, it is obvious that the demolding characteristics depend on the cooling process.

(1) Y. Hirai, et al., *J. Photopolym. Sci. Technol*., **14**, 457 (2001).
(2) H. Kawata, et al., Microelectron. Eng., **84**, 1140 (2007).



(a) **(b)**

Fig. 1 Fabricated Si mold (a) and imprinted PMMA pattern (b)

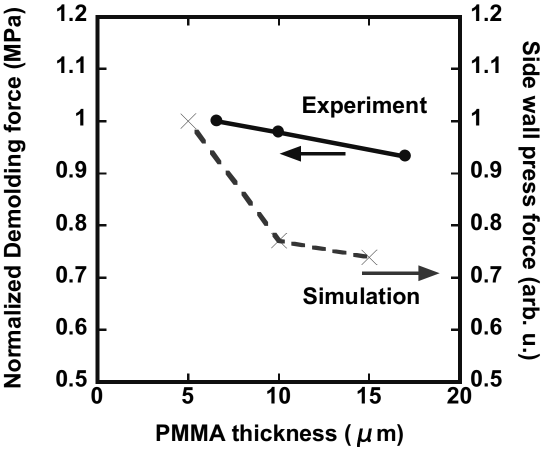
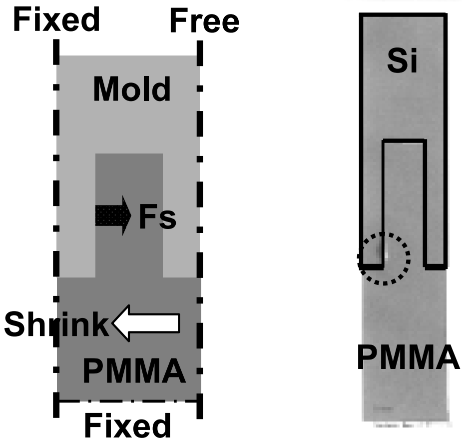


Fig.2 The dependence of both the normalized demolding force and side wall press force on PMMA thickness.



(a) **(b)**

Fig.3 Simulation model (a) and example of the simulation result (b). The side wall press force is concentrated to the left pattern edge shown by the circle in (b)

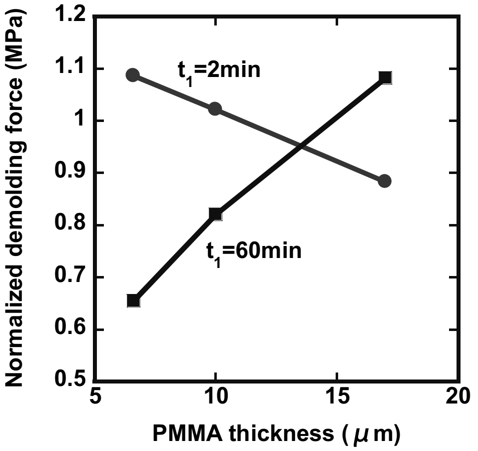


Fig.4 The dependence of the normalized demolding force on PMMA thickness for fast cooling rate of 2 min and slow cooling rate of 60 min.