Impact of side wall angle of mold pattern on release force in nanoimprint lithography

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Introduction

A Mold release process is one of the important processes in nanoimprint lithography. Due to adhesion and friction between the mold and resist, the resist pattern is stretched and fatal defects are induced. To eliminate the defect, reduction of the resist stretching force namely mold release force is one of the effective approaches. Various works have been reported by chemical and mechanical approaches. We had been reported on the side wall angle of the mold cavity pattern[1)], however the variation of the angles were not sufficient to discuss the effects in quantitatively. In this paper, we study the impact of the side wall angle on the mold release force by experimental and computational works.

Experiment and discussion

Si molds having various side wall angles are fabricated using dry etching process based on the BOCSH method using Ar and SF_6 gases. After the side wall passivation layer was deposited, where the passivation layer was partially remained at the corner of the pattern cavity. Then, the passivation layer and the Si substrate are etched simultaneously. The etched depth becomes deeper than that of the both sides of the pattern cavity due to residual passivation layer. After the deposition and the etching process are alternately repeated, the side wall angle is controlled by the period of each step. Figure 1 demonstrates the Si molds with various side wall angles θ. Using the molds, the release forces from PMMA resists (Mw=350k, 3.0 μm) are measured in experimentally. On the other hand, the adhesion and friction forces between Si and PMMA are experimentally evaluated by prove microscope to obtain physical properties. The SiO_2 ball tip is indented to thin PMMA layer and detaching force as adhesive force and lateral static sliding force as static friction force are extracted in experimentally. The extracted ratio of the P_s / P_n is around 7 to 40, in experimentally for PMMA/SiO_2 interface. Computational work is also done using the extracted parameters to estimate the release force. A small displacement is applied to the mold step by step. The resist is separated from the mold interface when the applied normal and sheer force per unit area (σ_n and σ_s) exceeds critical value as $(\sigma_n / P_n)^2 + (\sigma_s / P_s)^2 > 1$, where P_n is the critical normal force (adhesion) per unit area and P_s is the critical shear force (static friction) per unit area[2)]. Release force, when the resist is completely separated from the Si surface is calculated by numerical simulation[3)] using finite element method (FEM).

Result and discussion

Figure 2 shows mold release forces for various side wall angles of the mold. The experimental results show the release force decreases as the decrement of the side wall angle, but it remains a certain value below around θ=80 degree. On the other hand, the computational work also shows the same results below critical slope angle for various the P_s / P_n ratios. The release force is restricted by the critical friction force in vertical side wall angle, but the impact is weakened as the side wall angle decreases . Below the critical angle, the release force is restricted by the adhesion force at the flat portion of the mold. The result successfully expresses the experimental results and the mechanism is explained by computational works.

References

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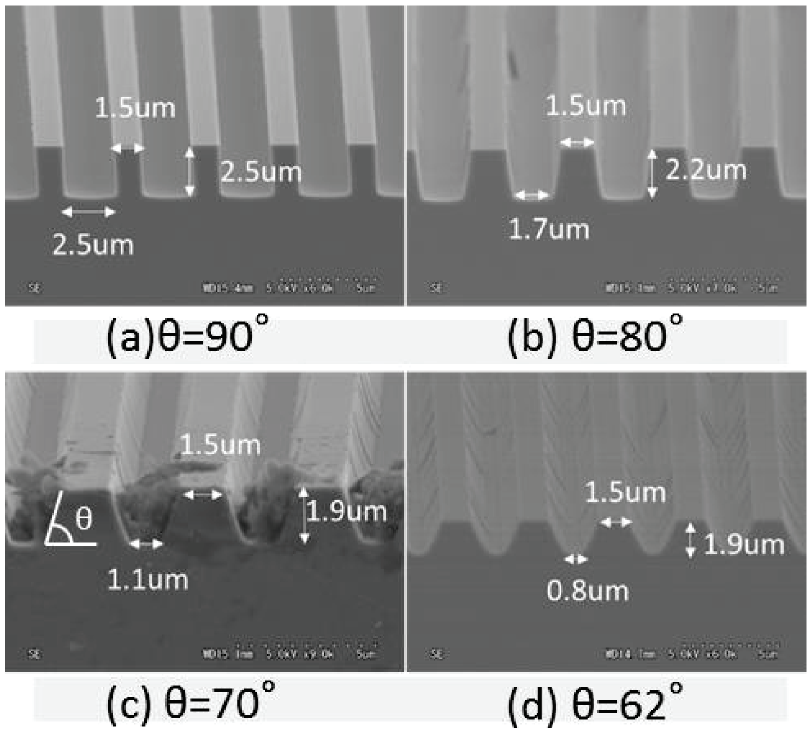

Figure.1. Si molds with the side slope wall angle θ of the patterns.

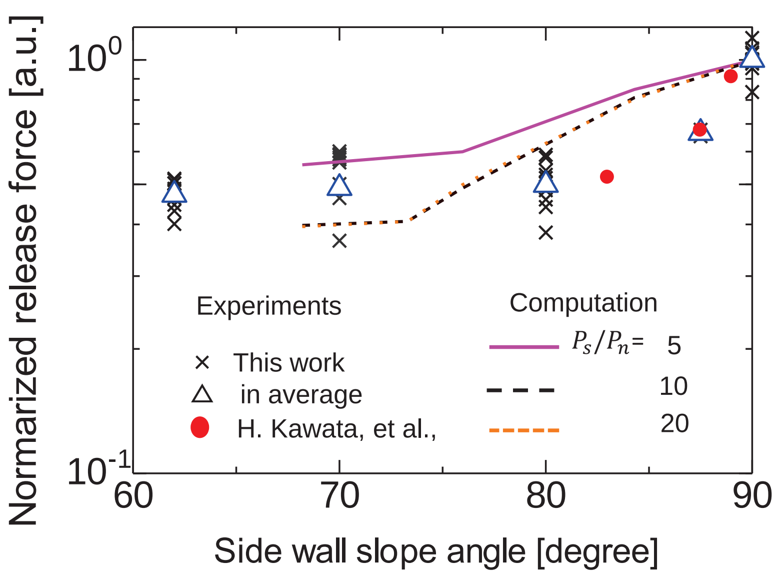

Figure 2. Dependence of release force on the side wall slope angle.
(Crosse, dots: Experimental works; Solid and dashed lines: Computational works).