Impact of Resist Shrinkage on De-molding Process in NIL

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Introduction) De-molding is one of the most important process in nanoimprint lithography because fatal defects are induced due to adhesion between resist and mold. Several numerical simulation works have been reported and they help to understand and optimize the de-molding process. However, impact of the resist shrinkage on the de-molding process has not been discussed in details. In this work, we simulated the resist shrinkage process during resist curing and investigate the resist separation process from the mold. Also, we discuss about the de-molding forces due to resist shrinkage by numerical simulation work.

Simulation) Before de-molding process, the resist shrinks by thermal or UV cure process. The ratio depends on resist materials but it sometimes becomes up to several present. When the shrinkage occurs, inner stress is induced the resist which makes the resist separation from mold. The stress distribution may depend on geometrical feature such as aspect ratio of the patter or mold configuration.

To investigate the resist separation process due to shrinkage, isotropic shrinkage is concerned. The criteria of the resist separation from the mold due to inner-stress is as follows:

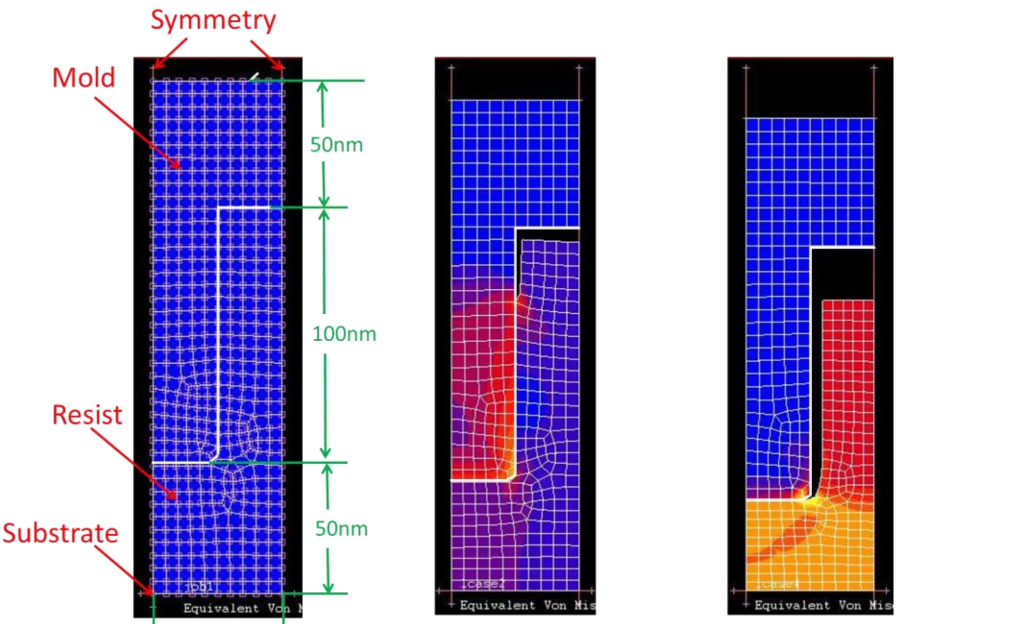
$$(\sigma_n/P_n)^2+(\sigma_s/P_s)^2 \quad >1 \qquad (1)$$

,where σ_n is normal stress at the boundary, σ_s is shear stress, P_n is the critical normal stress and P_s is the critical shear stress[1)]. We use conventional FEM simulator MSC-marc based on continuum mechanics to analyze resist reparation due to resist shrinkage and estimate de-molding force subsequent de-molding process.

Result and discussion) Figure 1 shows resist profiles due to increment of the resist shrinkage. As the increment of the shrinkage, the separation of the resist from the mold starts at the top side of the resist pattern and propagates down to the bottom (Fig.1 a → b→c). The geometrical features due to resist separation depend on the shrinkage and critical adhesion stress. Figure 2 shows relation between mold displacement and de-molding forces for various starting geometrical status after shrinkages were completed for each statues in Figs.1 a, b and c, respectively. The maximum de-molding forces are almost the same for various pre-separation statuses due to resist shrinkages. The result shows that the resist shrinkage does not significantly effect on the de-molding process subsequently occurs after resist shrinkage. This is because the maximum de-molding force is determined by the separation force from the residual layer as discussed in the ref.2. Nevertheless, the per separation due to resist shrinkage and the de-molding forces might depends on the pattern geometry such as aspect ratio, residual thickness, and slope of the side wall, which are under investigations in currently.

References

1) M. Ortiz and A. Pandolfi, Int. J. Numer. Meth.Engng. 44(1999), 1267
2) T. Shiotsu, et al., J. Vac. Sci. Technol B, 31 (2013) 06FB07.



a)No Separation (no shrinkage)
b)Top and part of sidewall separation (0.62% shrinkage)
c) Top and sidewall separation (1.48% shrinkage)

Fig.1. Resist profile due to shrinkage. The displacement is expanded 10 times in x-y directions.
(50nm Line & Space, Pattern height: 100nm, Resist: PAK-01, Critical Stress :P_n=P_s=100kPa, E=5 MPa)

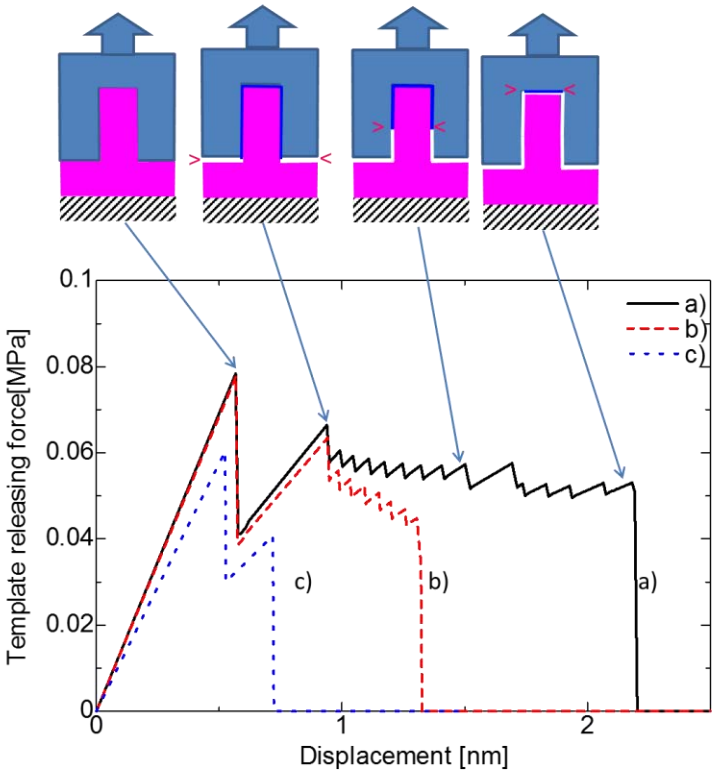


Fig.2 Force curve for mold displacement
a): No Separation, b): Top and part of sidewall separation, c): Top and sidewall separation