Quantitative characterization of mechanical properties and residual stress in nanoimprinted polymer films at the microscale

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Nanoimprint is an important nanofabrication technique that has been widely adopted in various electronic and biomedical applications. However, a series of previous studies have found that defects during nanoimprint process, such as polymer adhesion[1], shape collapse[2] and brim wrinkle[3] limited the commercial application of the nanoimprint technique. In thermal nanoimprint, the molecular dynamics studies have reported that polymer films can flow and deform more easily at higher imprint temperature [4]. However the imprinted polymer structures usually are generated from complicated polymer flow pattern due to complex topography as compared with flat polymer thin films. The variations in flow rates and flow directions within the polymer resist film will result in the distribution of polymer chain orientations and consequently internal stresses. Quantitative studies of residual stress in nanoimprinted polymer micro- and nanostructures are seldom reported.

Nanoindentation has been developed as an easy-to-use mechanical property characterization method at the nanoscale[5]. It has been widely used in scientific and industrial applications because of the advantages of high sensitivity, high accuracy, easy-prepared samples and wealthy mechanical information. In this work, we utilized nanoindentation to study the mechanical properties of nanoimprinted PMMA patterns under various processing parameters (Fig.1). We find that the elastic modulus at a fixed position of a PMMA pillar increases with the nanoimprint temperature and imprint depth (vertical displacement of mold protrusions) (Fig. 2), which might be due to the accelerated flow of polymer chains at an elevated temperature. The quantitative measurements of optical birefringence in nanoimprinted polymer structures due to stress-optical effects corroborate the nanoindentation results (Fig.3). Our results also indicated that the mechanical inhomogeneity could be minimized if the imprint temperature was controlled at around 433K for PMMA nanoimprinting. The quantitative measurements of mechanical properties and residual stress of nanoimprinted polymer structures provide deeper insight in optimizing nanoimprint processing parameters to mitigate defects in nanoimprint lithography.

References

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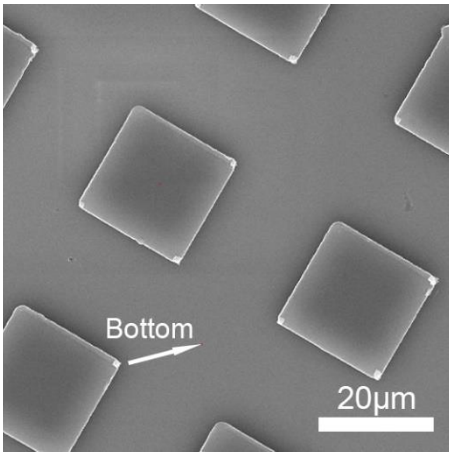

Fig.1 The SEM image of the imprinted PMMA square array. The arrow points at the indentation spot.

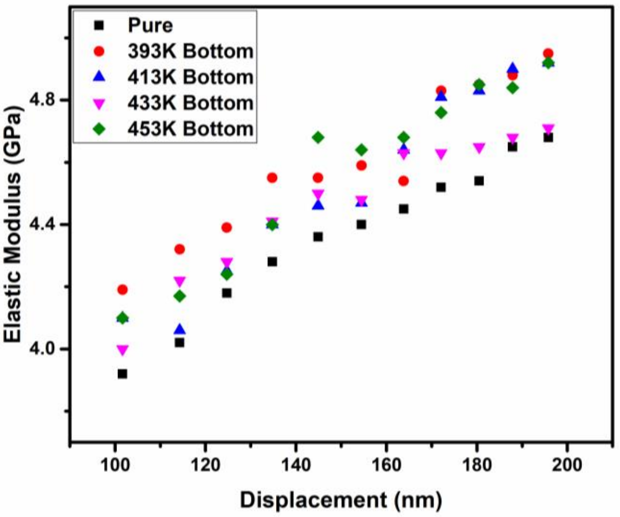

Fig.2 The elastic modulus of a polymer structure imprinted at different temperatures and with different imprint depths (vertical displacements of mold protrusions). The modulus increases with the increase of imprint depth and temperature.

0.9492 1.4823 1.6859 1.9971

Fig.3 Images of optical retardance in polymer microstructures patterned by nanoimprint at different temperatures (from left to right: 393K, 413K, 433K, and 453K). The average value of the optical retardance, which is proportional to the internal stress through the stress-optical effect, increases with the imprinting temperatures. The image also shows the internal stress is nonuniformly distributed, with the highest stress occurs at the locations with the largest polymer flows, namely the edges of the polymer microstructures.