Characterizing Nanoimprint Profile Shape and Polymer Flow Behavior using Visible Light Angular Scatterometry

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The line profile shape and the flow dynamics of polymer under the nanoimprint process are examined using visible light angular Scatterometry. It is shown that the noninvasive optical angular scattering technique can serve as an accurate metrology tool for characterizing nanoimprint line profiles as well as estimating the polymer residue thickness unlike other noninvasive tools such as CD-SAXS.[1] A nanoimprint female mold with 365 nm pitch is used to generate nanoimprint samples of 950 K PMMA on Si substrates at a temperature of 180 °C and a pressure of 6 MPa. The mold pitch was estimated by locating the angle of diffraction in the $+1^{st}$ order of reflected light from an incident red HeNe laser beam (633 nm wavelength). The same laser source was used to obtain all the scatterometry data from various imprint samples by varying the angle of incidence from 20^o to 80^o and measuring only the $zero^{th}$ order reflected intensity for each angle. A linear regression solution algorithm is employed to retrieve the line profile and residue thickness by fitting the measurement data to a rigorous electromagnetic diffraction model (RCWA). Samples with both thick and thin residue layers are considered. In figure 1 reflectance scatterometry data and results are shown for two samples prepared by depositing 620 nm and 220 nm layers of PMMA prior to the imprint process. The reflectance model fit to the data is better in the case of the thin PMMA sample. The larger fit error in the thick PMMA sample suggests a non-uniform residue layer which might be resulted from the mold bending on the thick PMMA during imprinting. Unlike the thick sample, a slightly non-linear sidewall slope was found to best fit the thin PMMA sample. Results are also compared to the SEM images revealing good accuracy.

In addition the relatively lower cost optical technique can be used to monitor the flow behavior of polymer under annealing also referred to as the “melting” behavior. Such study has been attempted recently using CD-SAXS where a profile model with linear sidewalls has been used. In this paper a nonlinear sidewall model is used revealing more faithful representation and insight over the polymer flow behavior. Two SEM images are shown in figure 2 for the thin nanoimprint sample described above. The sample is cut in half where one half is measured without heating and the second half is measured after heating on a hotplate for 2 min at 100 ^oC, which is slightly above its glass transition temperature (95 ^oC). After the heating a more pronounced nonlinear sidewall profile was found while only slight change in height and top line width. This observation offers a new insightful look at the polymer flow behavior. In figure (2), the scatterometry measurements and results are compared to the SEM images captured indicating good accuracy.

The two types of studies conducted in this paper show that low-cost visible light angular scatterometry could be a strong metrology tool for physical characterization of polymer nanostructures and for studying the nature and dynamics of the nanoimprint process under different conditions such as polymer thickness, temperature, and pressure. Real time scatterometry in future studies are expected to yield more conclusive findings.

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[1] R. L. Jones, et. al., “Real-time shape evolution of nanoimprinted structures during thermal annealing,” *Nano Lett. 6(8), pp. 1723-1728, 2006.*

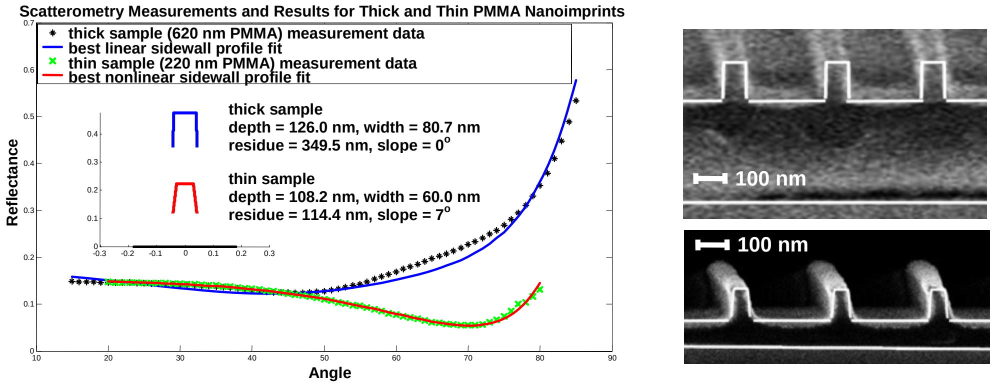

Figure 1 – Scatterometry measurements and modeling results for a thick and thin PMMA nanoimprint samples from the same mold (left figure). The profile models (white lines over SEM images on the right) show a good fit with the grating profiles in SEM cross-sectional images. The thin PMMA sample appears to be shorter and with a slight slanted and nonlinear sidewall. The residue layer in both cases is estimated with good accuracy. For the thick sample, the larger difference between the model reflectance curve and the data suggests a nonlinear residue layer. Such issues do not arise when a thin PMMA layer is used. The data indicates that the scatterometry method offers a high sensitivity to detect the thickness of polymer residue layer as well as grating dimensions.

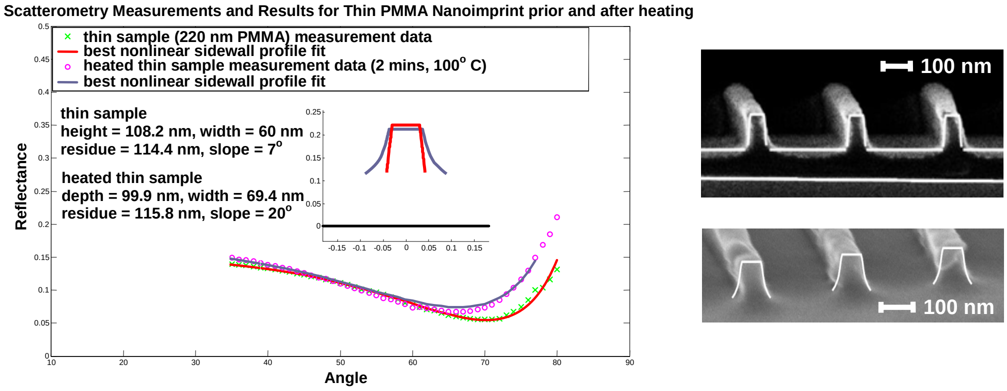

Figure 2 – Scatterometry measurements and modeling results for the thin PMMA nanoimprint sample above (left figure). The nonlinear sidewall profile models show a good fit with the grating profiles in the SEM cross-sectional images. A reduction of 8.3 nm to the grating height and an addition of 9.4 nm to the line width were measured. The sidewall slope was found to increase from 7° to 20° and to exhibit stronger nonlinearity after heating. The residue layer has not change significantly due to a short exposure to heat. A larger difference between the model reflectance curve and the data is found after heating. This can be related to larger variations and uniformities in the profiles of the patterned lines as revealed by the SEM images.