Nanoimprint Process Optimization for PMMA

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Primary CNF Tools Used: Nanoimprint NX-2500, P7 Profilometer, Oxford 81/82, MVD100, AFM, SEM

Abstract:

Nanoimprint lithography (NIL) has the capabilities of having high resolution, producing features that are sub-10-nm and is also cost-effective compared to lithography techniques with same resolution, such as electron-beam lithography. To achieve such benefits, nanoimprinting parameters must be optimized, such as imprint temperature, pressure, polymer physical properties, residual layer thickness, and etch depth of mask, among others. Within the parameters explored, optimal thermal nanoimprint lithography (T-NIL) guidelines were achieved with polymethyl methacrylate (PMMA), a well-understood electron-beam resist, on Si wafers on the Nanonex NX-2500 with one non-uniform density pattern and a uniform grating pattern. For widest pattern conditions, optimal T-NIL parameters occurred around 250°C with an imprint time of 210 seconds using 50K PMMA, for a 180 nm deep mask.

Summary of Research:

While there are many factors that affect the optimization of nanoimprint lithography, a crucial factor is the temperature of imprint. To achieve an optimal imprint, the polymer needs to be in a viscous state where it can flow completely into the desired pattern being imprinted. For an optimal temperature to achieve such a polymer state, the glass transition temperature, T_g, needs to be taken into consideration [1]. Optimal imprinting begins approximately 70°C to 80°C above T_g so that the polymer is not just in a rubbery state but in a viscous state [1,2]. As for polymethyl methacrylate (PMMA), PMMA has a T_g of approximately 105°C [1]. Therefore, an ideal imprint temperature was determined to be 250°C for a pressure of 200 PSI.

PMMA comes in varying molecular weights such as 950K, 495K, and 50K, each with different polymer chain lengths with 950K PMMA having the longest and 50K PMMA having the shortest. In Figure 1, with an imprint time of 210s, both 50K and 495K PMMA have adequate imprints while 950K PMMA is still not ideal.

UV exposure was considered for enhancement, because when PMMA is irradiated, scissions occur within the polymer chains, reducing the average molecular weight [3]. With polymer chain scissions, the T_g is affected, enhancing nanoimprinting conditions. A wafer with 950K PMMA was flood exposed at $\lambda_{UV} = 220$ nm with 12 mW/cm^2 UV followed by an imprint time of 120s, and the results are shown in Figure 1. There is a significant increase in the percent filled compared to the 950K PMMA with no UV exposure imprinted for longer time. Figure 2 exemplifies a typical defect with non-ideal imprinting parameters; PMMA filled in half of the width of the line, not filling completely into the pattern on the mask. Figure 3 shows a scanning electron microscope (SEM) image after Si RIE etching of a PMMA nanoimprinted pattern. The image highlights two problems that must be avoided, specifically, incomplete removal of the residual layer, and complete removal of the PMMA mask during RIE etching. Roughness in the bottom surface was due to incomplete residual layer etching in O_2 plasma of the PMMA, prior to the full SF_6 RIE etch. Complete removal of the PMMA mask due to poor selectivity led to further roughness on the top surface of the structures on the final stages of the Si etch.

A uniform grating pattern with a pitch of 800 nm and trenches with sizes of 541 nm was also explored. Figure 4 is a SEM image of a typical area after optimal nanoimprinting with 200 PSI, 250°C, and for 210s on an 82 nm PMMA coated wafer. While there were large areas that were imprinted fully, some defects were found over some portions of the sample.

Conclusions and Future Steps:

In the parameter space explored in this research, optimal nanoimprinting for non-uniform density patterns for PMMA on Si wafers were determined. These conditions require a temperature of at least 250°C with a pressure of 200 PSI. Print time for 100-400 nm layer thicknesses of 50K PMMA can be 120s for feature sizes from 5 μm

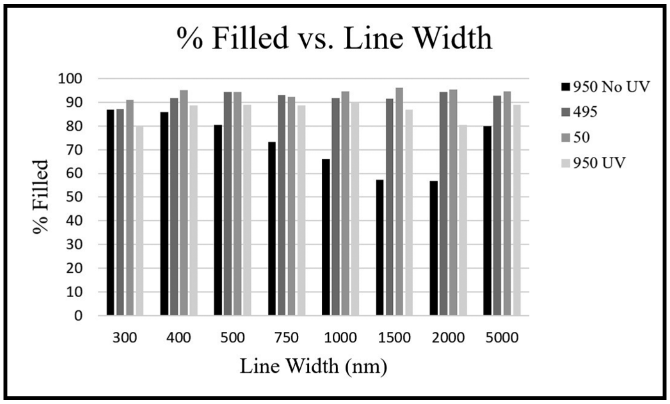

Figure 1: Graph comparing the percent of imprint pattern filled for varying molecular weights of PMMA along with prior UV exposure before imprinting for 950 PMMA for each line width of a non-uniform pattern.

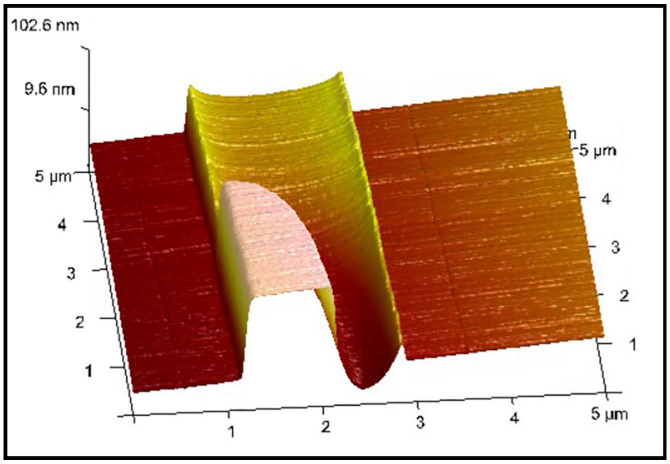

Figure 2: AFM image of a common partially filled line after nanoimprinting when imprinting is done at not optimized parameters.

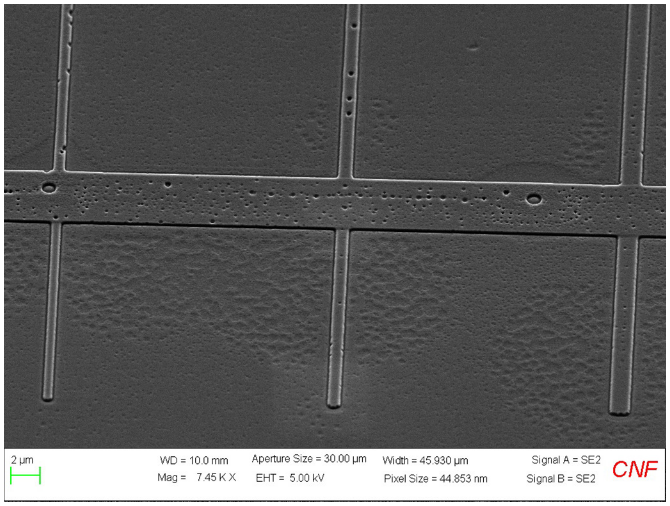

Figure 3: SEM image of after pattern transfer through RIE. Roughness on bottom was due to incomplete residual layer etch.

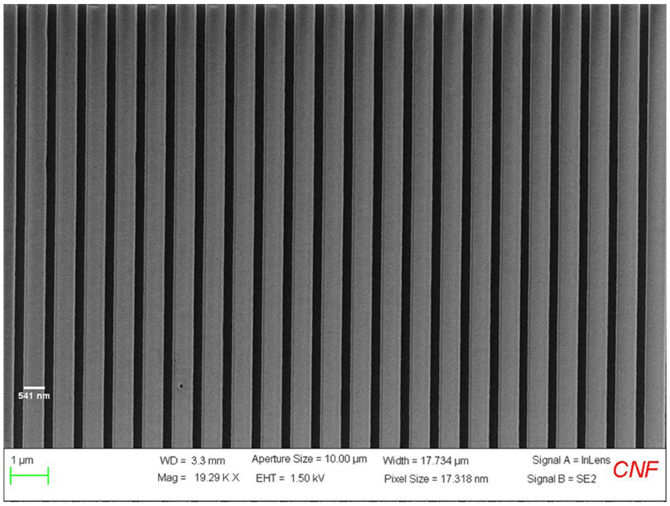

Figure 4: SEM image of a uniform grating pattern after being imprinted with a pitch of 800 nm and feature sizes of 541 nm.

to 300 nm, while 210s is required for 495K PMMA layers. For optimal printing at 950K PMMA, we have determined that 12 mW of UV at $\lambda = 220$ nm for 6s leads to optimal patterning. Uniform printing of the grid pattern was achieved over large areas; however, some areas of the wafer still contained non-uniformities within the pattern. Additional work is required to reproduce large features above 20 μm. We plan to explore printing with 50K PMMA with UV exposure. Furthermore, careful consideration must be given to the depth of pattern transfer during the nanoimprint etch steps, due to PMMA being a poor mask in reactive ion corrosion (RIE).

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