Pattern exposure order dependence in hydrogen silsesquioxane

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Pattern order dependence is observed and characterized in electron beam lithography (EBL) exposed hydrogen silsesquioxane (HSQ) resist. Previously, HSQ has been reported to have a time delay effect[1] which could auto-correlate to pattern order depending on the time required to expose the pattern. However, this observed effect is different, whereby the HSQ is sensitive to exposure order and location, is repeatable over time, and not a function of delay time.

6% HSQ is spun coat at 5000 RPM, 2000 RPM/sec, 60 sec on 35 mm square silicon substrates, yielding a final film thickness of 102 nm. The sample is immediately exposed, without any baking, by 100 kV EBL at 2 nA beam current at a dose of 200 uC/cm^2. Samples are developed in MF-319 (2.3% TMAH) for 70 sec, followed by DI water rinse for 60 sec. The HSQ film is exposed with 10 X 10 arrays of 10 um squares with 1 um spacing in a controlled order as shown in Figure 1. For example, in Pattern A, the square in the (row,column) = (2,2) is exposed first and then rows are exposed left to right and top to bottom. Pattern A is exposed first, followed immediately by Pattern B and C, each spaced apart by 10 mm.

The developed patterns are imaged by SEM and shown in Figure 1. In each case, it can be observed that the first exposed square appears significantly lighter, due to lower HSQ film thickness, than adjacent squares. This is confirmed by AFM data, and Figure 2 shows the initial square in Pattern C has a height of 42.7 nm compared to adjacent squares with thickness of 57.9 nm. It should be clarified that it is expected for corner squares in the array to have lower thickness compared to squares in the center, due to the final deposited energy density caused by the well know proximity effect[2]. However, because the overall pattern is symmetric, square (2,2) should have the same final deposited electron energy, and thus final resist thickness as square (9,9) in Pattern A. Correspondingly, squares (9,2) and (2,9) in Pattern B, and squares (5,5) and (6,6) should be matched as pairs in thickness. It is furthermore observed, that the squares that immediately follow the initial square in exposure order, also have lower thickness than their symmetric counterparts (e.g. (10,1) in Pattern B compared to (1,10)). HSQ has a known sensitivity to pre-exposure bake conditions[3] and it is hypothesized that the observed thickness dependence on pattern order is caused by local heating by the electron beam. The observed dependence will be further modeled and characterized in this work.

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[1] D. A. Westly, D. M. Tennant, Y. Aida, H. Ohki, and T. Ohkubo, J Vac Sci Technol B 29 (2011).
[2] T. H. P. Chang, J Vac Sci Technol 12, 1271 (1975).
[3] W. Henschel, Y. M. Georgiev, and H. Kurz, J Vac Sci Technol B 21, 2018 (2003).

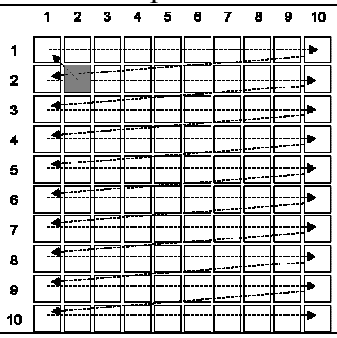
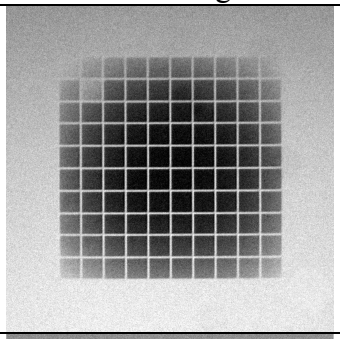
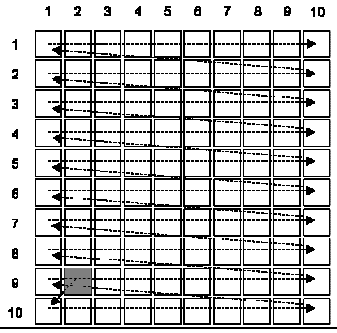
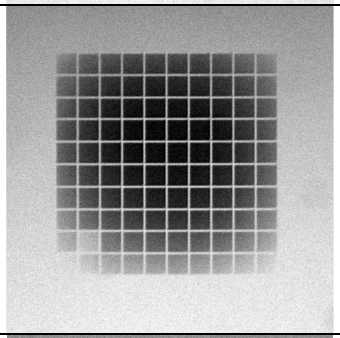
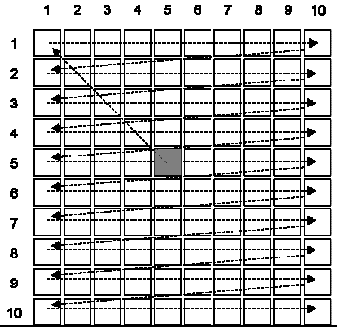
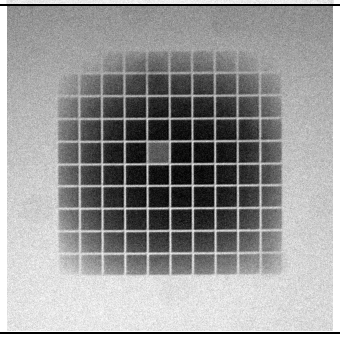
	Pattern exposure order	SEM image
Pattern A		
Pattern B		
Pattern C		

Figure 1: 10 X 10 arrays of 10 um exposed HSQ squares on silicon substrate with 1 um spacing. Pattern exposure order in left column, with initial square shaded in gray, and corresponding SEM image in right column.

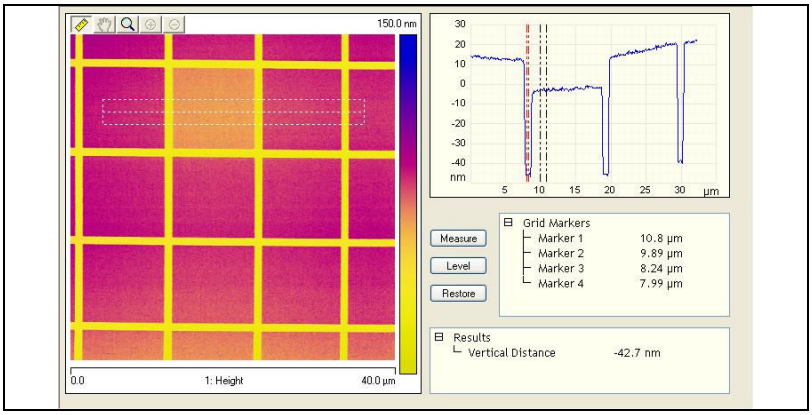


Figure 2: AFM data of Pattern C from Figure 1. The lighter color square corresponds to the initially exposed 10 um square with a height of 42.7 nm compared to adjacent squares with heights of 57.9 nm.