Investigation of Proximity and Development Process Effects for Large Area Dense Nano-Pattern Applications

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Increasing interest for nano features with improved fidelity and uniformity over large areas demands optimal process conditions. For electron beam lithography common challenges are proximity and process effects, the scattering of the electrons in the resist and substrate material and 3D effects during the resist development and pattern transfer. Proximity effect based on electron scattering and its correction (PEC) is widely investigated and methods and software exist for adjusting the exposure doses at every point of exposure area with high performance. However lithography on high density material such as GaAs or InP in combination with high pattern density show layout scenario dependent CD non-uniformities even after PEC. Here we study the root cause with experiments and simulation for different resist processes to separate the effects of energy deposition and resist development process. One of the main challenges for such study is accurate and reproducible SEM metrology. We are using a clever layout and automated SEM image analysis based on Hough Transform[1]. Experimental details are summarized in Figure 1. Figure 1 (c) shows the CD variation from center to edge for different base doses. For the best obtained base dose of 600µC/cm² the radius is dropping from 78 nm at the edge to 71 nm in the center and the holes in the center are connected. Simulation of absorbed energy shows that PEC did adjust the feature edges to a uniform absorbed dose which should result to a uniform CD. To explore the root cause of the CD variation, we have changed the development process to 5 sec of development time. Fig 1 (d) shows that the CD non-uniformity is decreased and the process window is improved. To understand the effect, Fig 1 (e) compares the development rate curves of the two development processes. Using 3D lithography simulation software Fig 1 (f) shows that at these background doses development rate in the unexposed areas of pattern leading to a higher lateral development rate variation between center and edge for the 30 sec development. The 5 sec development shows less lateral development rate leading to better CD uniformity and larger process window. A larger exposure latitude (more stable process) is found for the shorter development times. The results are consistent with the presented resist simulations. Similar investigation will be presented for the same development times at colder development temperatures and different resist thicknesses.

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* This project is supported by TUBITAK under project numbers 114F204 and 113F282.

[1] *O. Göktaş et al., Microelectronic Engineering 177 (2017) 6, http://dx.doi.org/10.1016/j.mee.2017.01.006*

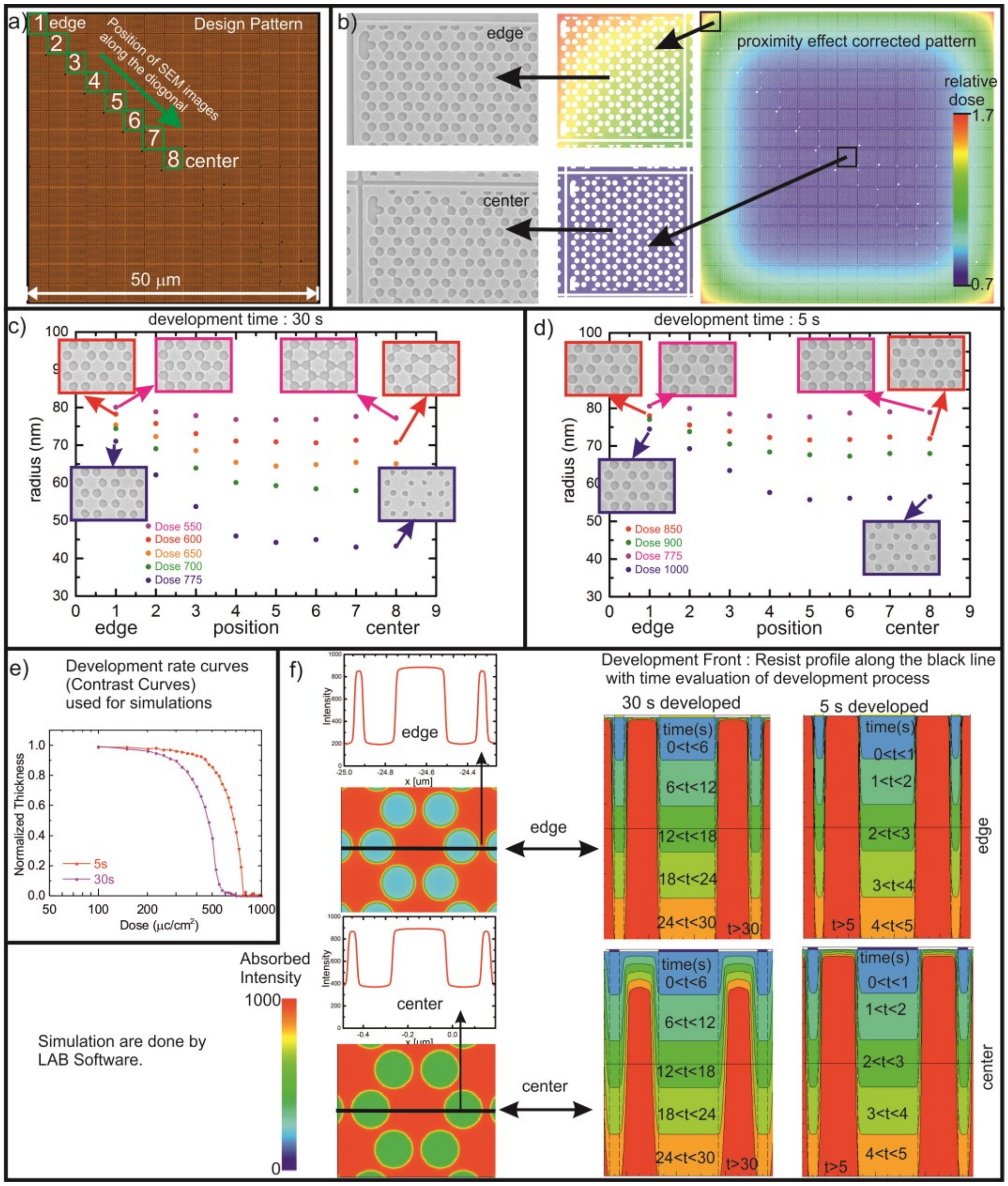

Figure 1: (a) The pattern is 50μm x 50μm honeycomb array of holes with radius of 80 nm and pitch of 200 nm. The position of the SEM images for metrology is indicated. (b) The pattern is PEC corrected using BEAMER software. After the PEC, the pattern is exposed for the varying dose values by 100keV electron beam PMMA resist on GaAs substrate, developed for 5 s and 30 s, followed by evaporation of thin Ti/Au metal layer and lift-off. Then patterns are inspected under SEM, images taken along the diagonal of the patterns, measurements are performed and mean radius of the holes is calculated using automated SEM image analysis (Göktaş et al.[1]). (c) The mean radius of the holes for the 30 s developed pattern and (d) for 5 s developed pattern. (e) Normalized thickness of the resist versus dose (Contrast Curve) for 5 s and 30 development times. (f) 3D simulation performed by LAB software showing absorbed intensity at the edge and center and the resist development front over time for the 5 s and 30 s developments which clearly demonstrates higher lateral development for 30 s.