# Variable shape E-beam writing: proximity effect simulation and correction of binary and relief structures

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## ABSTRACT

This contribution deals with a proximity effect simulation and proximity effect correction tools that are intended mainly for shaped electron beam exposures at relatively low energies (e.g. 15 keV) where, generally, the long-range electron scattering region and the short-range one are not well separated. The presented tools handle both binary and relief (multi-level) structures. The simulation is provided in two steps. First, the density of absorbed energy in the resist layer is calculated using double Gaussian distribution function with a library of pre-calculated different-size stamps that improves the speed of the algorithm. Second, the resist development process is simulated using the resist sensitivity curve including the resist contrast and the clearing dose as basic parameters. Validation of the algorithm was performed on several real-case e-beam exposures.

## PROXIMITY EFFECT

During the e-beam writing, several effects occur, which can significantly change the desired resolution of designed patterns [1, 2]. The final pattern is mostly affected by two scattering effects in resist layer and substrate: forward scattering and backscattering. Due to this electron scattering effects, the exposed patterns can be significantly broader than the designed. This phenomenon, called proximity effect, causes that areas adjacent to the exposed ones receive nonzero electron dose and thus pattern can vary from the intended size.

## PROXIMITY EFFECT SIMULATOR

Proximity effect correction requires knowledge of the energy density absorbed in electron resist layer during the exposure by electron beam. The proximity effect can be described by the two Gaussian functions model [3]. If a rectangular shaped beam is used for pattern generator then distribution function can be calculated as numeric integration of individual pixels in stamp. It means that stamp consists of number a*b beams with cross section size of one pixel and the distribution function can be generated for individual stamps of different sizes as following. The distribution function is calculated as sum or difference of pre-calculated stamps saved in library and it prevents from calculating a big number of Gaussian functions, this leads to a higher speed of calculation. Proximity effect simulator (PES) were created and thus the density of absorbed energy in resist layer for designed binary and relief structures can be plotted (Fig.1 and Fig.2). Variables from Gaussian distribution calculated in previous papers [4] were used as input parameters for PES.

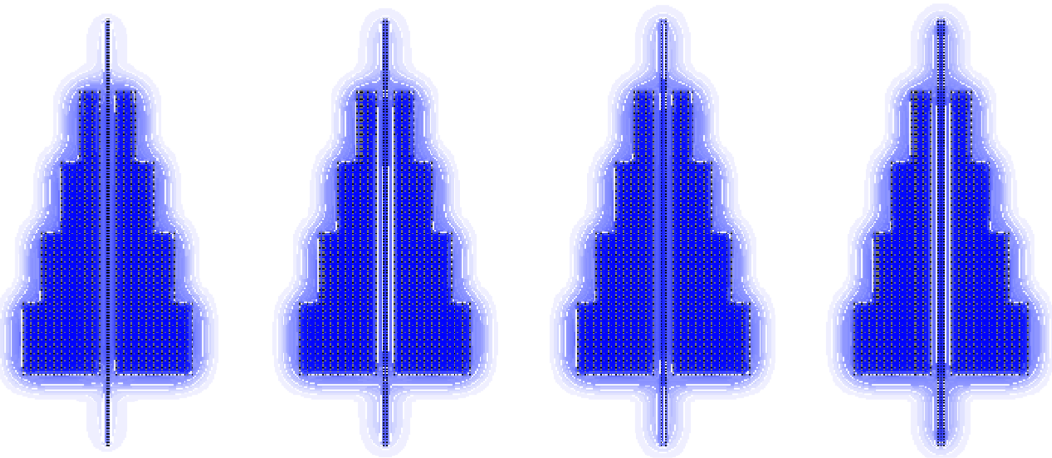

*Figure 1: The density of absorbed energy for binary testing pattern.*

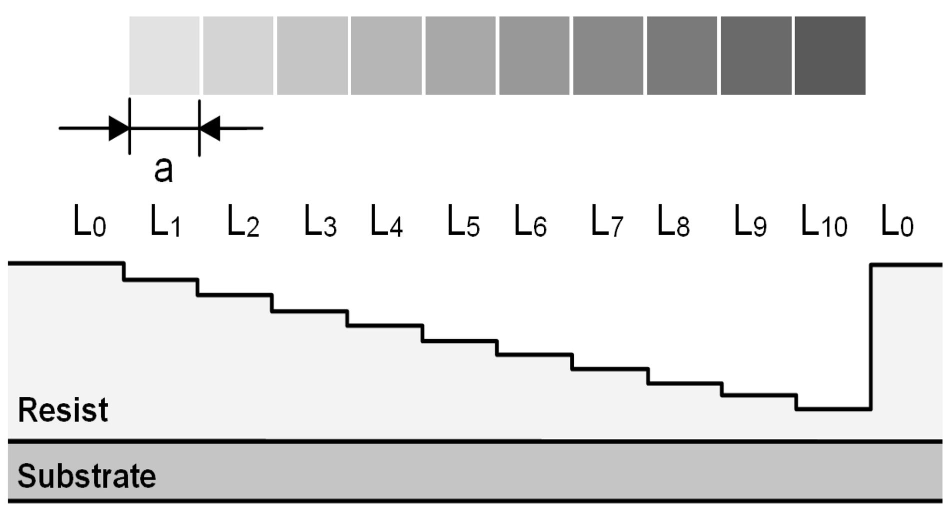


*Figure 2: The model of relief structure for simulation created from ten lines (a=1,0 μm) exposed with linearly increasing dose.*

In order to simulate the exposed structure profile, it is necessary to obtain the resist sensitivity curve. The resist contrast and clearing dose were used as input parameters for profile simulation of designed structures (Fig. 3).

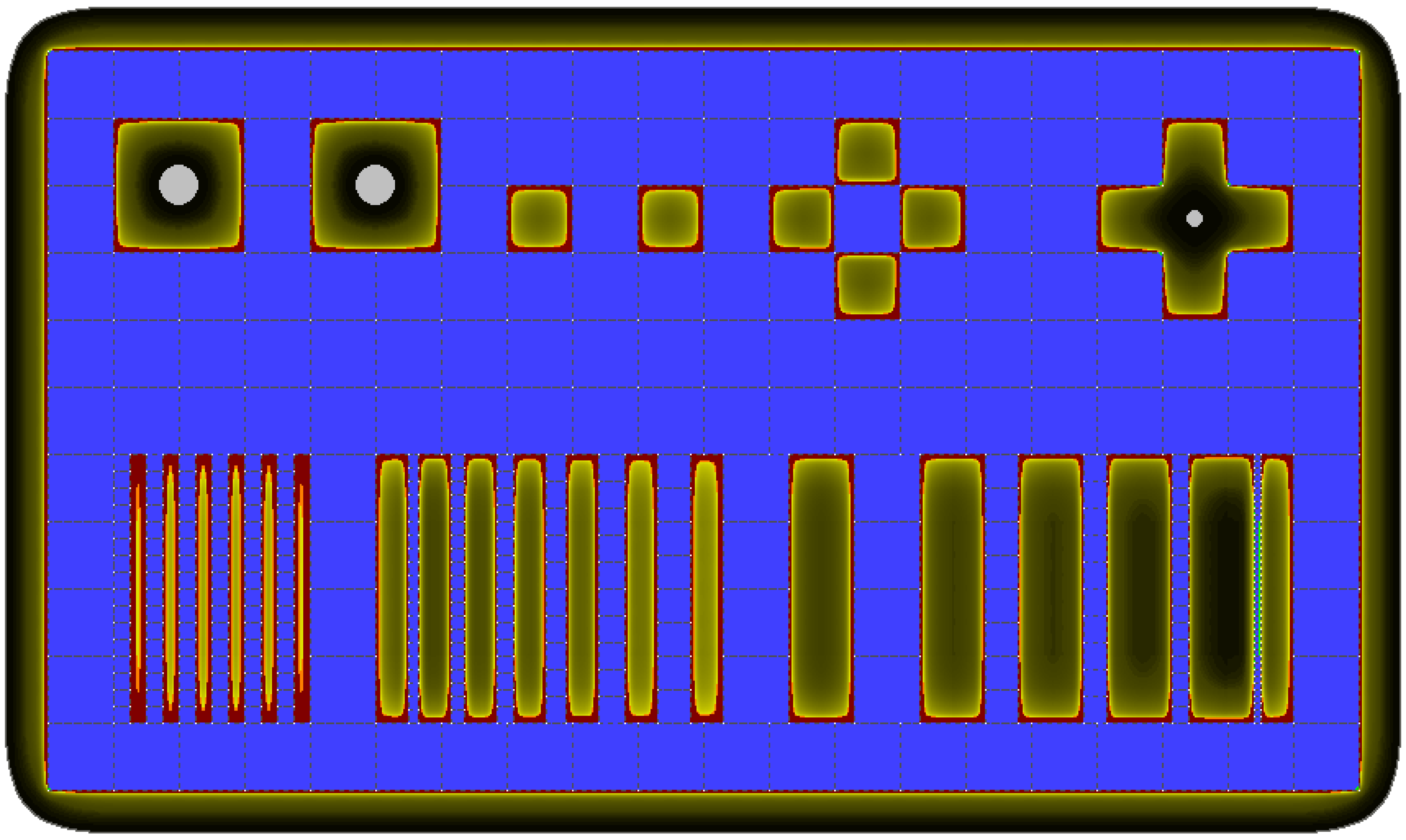

*Figure 3 : The simulation of depth for binary testing structures.*

## CONCLUSION

In the present paper the simulations of proximity effect were carried out on binary structures, where dimension of exposed structures is critical as well as on relief structures where the precise control of thickness plays crucial role. The dose distribution and developed resist profile were simulated in PES software. After that real binary and relief structures were prepared in PMMA layer on silicon substrate. The e-beam writer Tesla BS600 working with fixed energy of 15 keV and variable size rectangular shaped beam [5] was used as pattern generator. The real profiles were compared with the simulated ones (Fig. 4 and Fig. 5) and so validation of the algorithm was performed. Finally, testing patterns were exposed with proximity effect correction algorithm and tool for offline proximity effect compensation were tested.

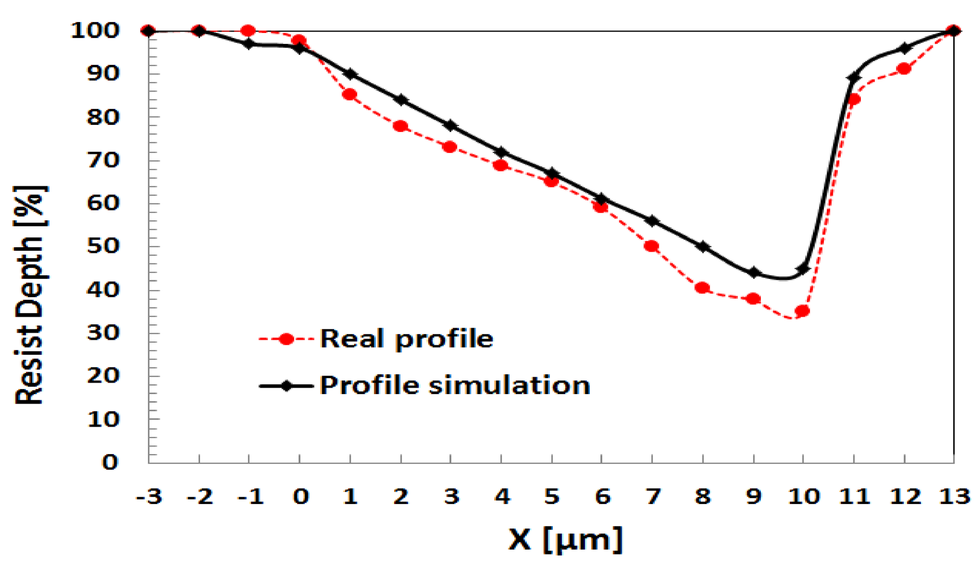


*Figure 4: The profile simulation of relief structure in comparison with real measured profile.*

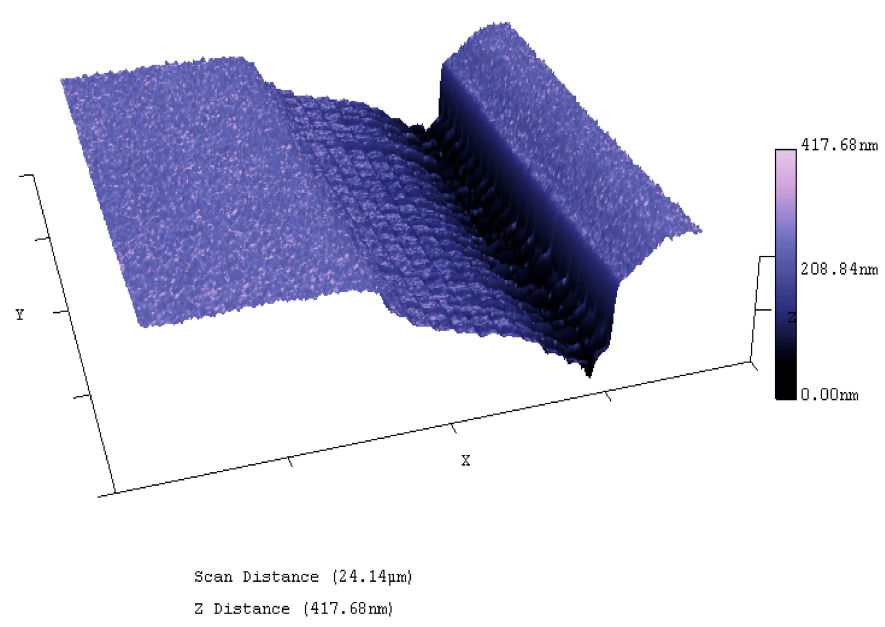


*Figure 5: AFM image of relief structure.*

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