High Density Nanostructure Fabrication by Electron Beam Lithography

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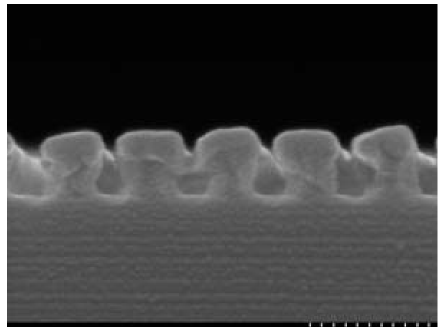
Despite of the fact that fabrication of individual nanostructures by Electron Beam Lithography (EBL) has been increasingly successful over the last years, generation of high-density nanostructures is still challenging. The resolution of fabrication of high density nanoscale features is affected by several factors, such as the proximity effect and the post exposure degradation of the resist. To reach the ultimate quality of the EBL process, a detailed understanding and optimization of both the exposure and development stages is required.

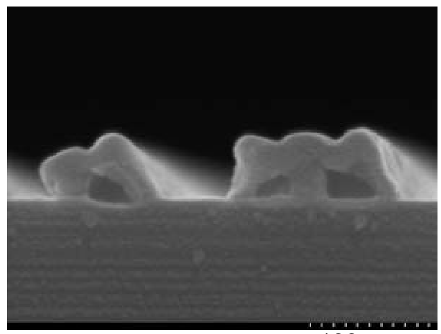
Employing the Raith150 EBL system, we have investigated the influence of process conditions on the resolution of sub-50 nm features. For this purpose we have developed an efficient methodology to obtain cross-sectional profiles for lines and gratings in PMMA, and visualized the profiles by SEM (see Fig. 1 below). The control factors of our primary focus are the exposure dose, the development time, and temperature of development, from room temperature down to –5°C.

To understand and improve the fabrication process we have applied our theoretical model, which represents the entire EBL process. Firstly, our model describes electron-resist interaction, which includes the travelling of primary, secondary and backscattered electrons in a resist (PMMA) on the top of a substrate material. As a result, a distribution of the probability of the main chain scission is obtained. Next, we use this probability to apply the Poisson distribution, and obtain the local concentrations of PMMA fragments of various weights. These distributions of fragments are employed as the input of a detailed kinetic diffusion-drift model that describes the interaction of the developer with PMMA. We have investigated numerically the various regimes of resist dissolution and employed these to interpret our experimental results. By this we were able to formulate recommendations on improving the quality of deep nanoscale EBL.

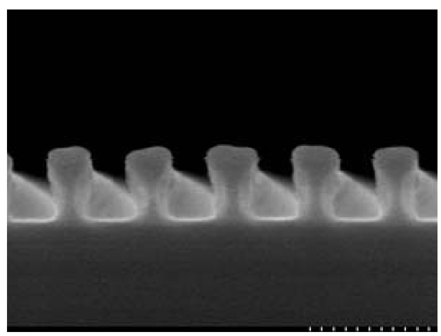
As an example, Fig. 1 illustrates some of challenges towards fabrication of high density, high resolution nanostructures. Our detailed theoretical analysis of the major stages of the EBL process allows for an efficient optimization of the exposure dose, development time, and temperature.



(a) 100 nm



(b) 100 nm



(c) 100 nm

Fig. 1. (a) SEM image of the cross-sectional profile of a grating fabricated in PMMA with the exposure electron energy of 10 keV, and room temperature development. Although the grating pattern has been resolved, the inter-wall space is too narrow for practical applications. (b) A similar cross-sectional profile obtained with an increased exposure dose. The width of the interline trenches has increased, but the walls have collapsed. (c) Cross-sectional profile obtained for similar exposure conditions as in (b), but with cold development conditions (–5° C). In this example, both exposure and development steps have been successfully optimized.