Electron beam optimization using self-developing resist for large write-field electron beam lithography

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In electron beam lithography (EBL) of large scale nanostructures, a large write-field combined with high beam current allows much shorter writing time, as well as stitching-error-free exposure of the pattern within such a large field. For dedicated EBL systems (such as Vistec EBPG5000Plus), focus and stigmation are compensated across the entire write-field, though the compensation alone was shown insufficient to obtain uniform exposure and additional hardware modification was proven necessary [1]. For EBL system based on SEM (such as Raith 150^{TWO}) that is much less expensive and more available than dedicated EBL systems, exposure pattern at write-field corners is always significantly deformed and enlarged because the beam is finely adjusted only at the write-field center. This issue becomes more serious for large write-field and large aperture (high beam current), which are essential for large scale EBL. Here we propose to use self-developing resist nitrocellulose, for which patterns show up right after exposure without ex-situ development, as a kind of feedback on the beam distortion and enlargement at field corners, in order to manually carry out focus and stigmation optimization. Our procedure is to write dot or line at different locations, examine them using SEM at high magnification, modify the working distance (focus) and stigmation parameters, repeat the task until we achieve a relatively uniform shape/size distribution of the patterns across the entire write-field (see Figure 1). That is, when the beam is optimized this way, the beam spot is considerably smaller near the corner at the cost of larger spot at the write-field center.

Figure 2 shows the contrast curve for nitrocellulose, which has been previously used as ion beam resist [2]. As seen, nitrocellulose is not a useful electron beam resist because of the very thick residual layer even at very high exposure dose. However, such a residual layer wouldn’t prevent it from being used as an in-situ feedback for electron beam optimization. As a proof of concept, we exposed identical patterns at the center and four corners of a large write-field of 1 mm^2, and examined the pattern at high magnification after exposure. As expected and shown in Figure 3a-b, when the beam was well adjusted at high magnification, the central pattern was well defined, whereas the corner one was very blurred. Then we adjusted the working distance, till we saw equally well defined pattern at the field center and corner, which was obtained by increasing the working distance by 37 µm (Figure 3c-d). Under such optimal condition, we exposed PMMA resist, and achieved ~40 nm line-width within the entire 1 mm^2 write field (not shown). In addition to working distance, stigmation can also be optimized; and other self-developing resists such as AlF_3 can be used as well. They are currently under study.

[1] V. A. Guzenko, J. Ziegler, A. Savouchkina, C. Padeste and C. David, Microelectronic Engineering, 88, 1972 (2011).
[2] M. W. Geis, J. N. Randall, T. F. Deutsch, N. N. Efremow, J. P. Donnelly and J. D. Woodhouse, J. Vac. Sci. Technol. B, **1**, 1178 (1983).

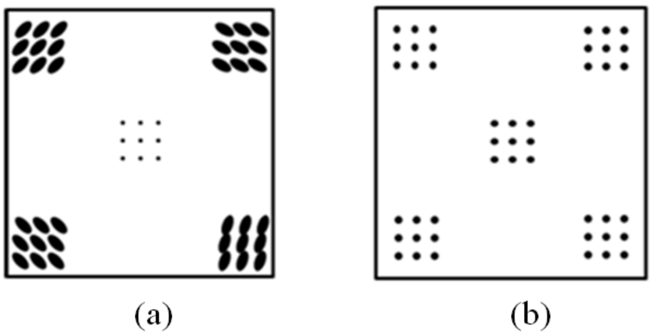

Figure 1. Schematic electron beam optimization: (a) Central spot optimized at high magnification, typically to sub-5 nm beam spot size; (b) Globally optimized by adjusting working distance and stigmation for uniform beam size/shape distribution (e.g. ~20 nm across the entire write-field).

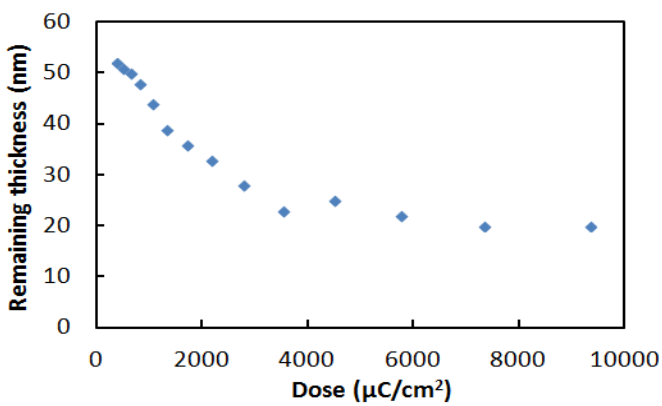

Figure 2. Contrast curve of nitrocellulose exposed at electron beam energy of 20 keV, without ex-situ development.

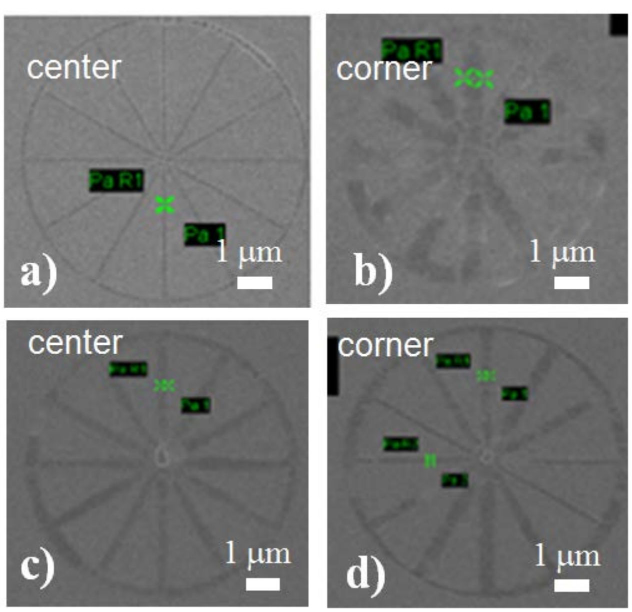

Figure 3. Line pattern exposed in nitrocellulose resist: (a) Well-focused at 8 mm working distance, center; (b) same as (a) but at write-field corner; (c) De-focused by +37 µm, center; (d) same as (c) but at write-field corner. Write-field size is 1 mm^2.