Improving pattern fidelity in helium ion beam lithography using pixel dose optimization

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Keywords: Helium ion beam lithography, EUV lithography, Chemically amplified resist, Modelling

Scanning Helium ion beam lithography (SHIBL) with a sub-nanometer beam probe size at the sample surface is a promising technology for high-resolution lithography with high pattern density [1]. The advantages of SHIBL compared to e-beam lithography are higher sensitivity and a lower proximity effect. Remarkably, there are unique similarities in the activation response of resists to He-ions and extreme-ultraviolet (EUV) photons in EUV lithography (EUVL). Both primary beams produce low energy secondary electrons (SEs) and are not hindered by proximity effects. Recently Maas et al. experimentally demonstrated these similarities and suggested SHIBL as a promising method for pre-screening chemically amplified resists (CARs) prior to their final performance evaluation in an EUV scanner [2].

Here, we present a heuristic resist activation model for single-pixel dose SHIBL. The model employs a point-spread function (PSF) to account for all contributing factors in the resist activation. Ion shot noise impact is modeled with Poisson statistics. We show a good agreement between the model and our experimental single-pixel dose SHIBL results for line-and-space (LS) and contact hole patterns. The results for a desired LS pattern are shown in Figure 1. Our model indicates pattern fidelity in sensitive CAR is not only limited by ion shot noise; instability of the He-ion source emission and post-exposure resist processing can also play important roles. Moreover, we introduce optimized-pixel-dose SHIBL to improve critical dimension uniformity (CDU), line width roughness (LWR), exposure latitude and throughput gain. Figure 2 shows the graphical illustration of our pixel dose optimization calculations. First, from a desired binary pattern (Figure 2(a)) we construct a target dose profile (Figure 2(b)). The target dose profile is calculated according to the capabilities of the exposure tool (e.g. resolution, beam step size, scanning beam electronics, etc.) and the resist properties (i.e. dose-to-clear). The model then finds iteratively a solution to an optimization problem in which we seek to minimize the discrepancy between the target dose profile and the realized dose profile. The solution provides the optimal ion doses at each pixel to achieve the best pattern fidelity (Figure 2(c)). In this approach, we calculate an optimum ion dose map for a given binary pattern such that the pattern’s edges are exposed at the steepest part of the PSF to improve resist-pattern contrast and to minimize ion shot noise effect. Pixel dose optimization is advantageous to single-pixel exposure when the feature size is larger than the FWHM of the PSF. We discuss this by comparing our modeling results for single-pixel and optimized-pixel-dose SHIBL exposure modes for a desired LS pattern. We show that pixel-dose optimization could reduce LWR by ~45% (~1.3 nm) with a concurrent 20% dose reduction.

Figure 1. (a) Comparison between the calculated resist activation maps and the experimental results (SEM images) on CAR for different He doses for a 50 nm-full-pitch LS pattern. The blue-color-line on the gray scale bar indicates the dose-to-clear. Decent resemblance between each calculated resist activation map and its corresponding experimental result can be seen. (b) Comparison between the experiments and calculations for line width as a function of the He-dose, where a good agreement is obtained.

Figure 2. Graphical illustration of the calculation steps involved in our pixel dose optimization. (a) A binary map of a desired 50 nm-FP LS pattern. (b) The calculated optimal ion dose map for the desired LS pattern based on the capabilities of the exposure tool and the resist properties. (c) The calculated optimal ion dose map for the region indicated by the red-color-dashed rectangle in Figure 2(c). Here, each gray color represents the required number of ions for each pixel.

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