CHARACTERIZATION OF TEST STRUCTURES FOR E-BEAM LITHOGRAPHY FOR ESTIMATION OF PROXIMITY EXPOSURE PARAMETERS

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1. Introduction

The nowadays trends in Electron Beam Direct Write lithography (EBDW) dictate significant decrease in the lateral resolution together with enormous increase in the density and complexity of patterned structures. However, EBDW suffers from the so called proximity [1] effects that limit the resolution [2]. Density- or proximity-based observations are needed, because isolated, dense and critical-shape features having independent process windows, must be compared for process characterization. The main goal is turning these data into information that quickly assists in the characterization, quantification and “centering” the process windows across multiple dimensions and pattern combinations, including taking correct optimization actions. The pattern geometry of the resist layer is a direct response of the resist to the electron irradiation and its pre- and post-processing. In order to predict the resulting geometry of an exposed pattern in the resist, we should be able to know the dissolution behaviour of the irradiated polymer in the developer. This process additionally includes a large amount of uncertainties due to highly nonlinear behavior of complicated thermo-hydro-kinetic processes. Proximity-effect corrections of the exposure data based on experimental measurements [3] should be incorporated. To achieve this, a method which optimizes the Point Spread Function (PSF) for the proximity effect correction must be implemented especially in the case of large and complex chips [4].

2. Experimental

The EBDW lithography experiments have been carried out on the ZBA 10 (30keV mode, thermal emission cathode), ZBA 21 (20keV) and ZBA 23 (20 and 40keV modes, LaB_6 cathode) variable shaped e-beam pattern generators. In order to obtain the necessary information needed for the optimization of the exposure control PSF, several lithography tests were used, some of which will be shortly described here and some results taken from these experiments will be presented.

The so called Exposure Wedge (EW) test serves for the construction of the sensitivity (characteristic) curve and to extract the contrast gamma value of the resist. By this test we obtain the dependency of the remaining resist thickness to the applied exposition dose within large-area exposures (see Figures 1-3). Moreover, optimized and reproducible resist pre- and post- exposure process parameters can be estimated (best gamma value). In other words this results in possible highest contrast and minimal dark erosion of the resist and also to minimizing all non-linear secondary effects in the resist. Process homogeneity can also be controlled using the “EW” test-pattern exposed at various locations (e.g. in a linear matrix) over the whole substrate.

The Exposure Test (ET) serves to visualization of the e-beam scattering effects (together with the development bias) in the resist/substrate stack. Based on the measurements on the ET tests we can extract the Dose-to-Line curve, which is the relation of the optimized dose to the desired line-width (see Figure 4). The optimum dose for the desired line width is further obtained by measurement on the lines exposed with various incrementally changing doses.
In order to tune the PSF parameter set with respect to the suggested model, the so-called Duty Ratio Test (DRT) is used to reconstruct the measured native deformation effect of the patterns. The line width changes of a single line are measured after this line enters the increasingly dense arrays of lines (of the same width) with a variable duty ratio. The tuning is sensitive mainly to the short-range α parameter. Using this test pattern enables one also to extract the “Base-Dose” value for the given process.

3. Results and Discussion

The results obtained from two e-beam resists are shown here, namely from the PMMA E2041 (positive tone) and from the HSQ Fox-12 (negative tone), respectively, as these two resists are similar in their sensitivity parameters. In the first step the data from the EW tests are presented. The measurements were carried out using the standard profilometry technique (Talystep, Alphastep). The remaining resist thickness *vs.* the exposure dose was measured and the contrast (characteristic) curves for both resists were obtained. The nominal film thickness was 100 nm for the HSQ and 350 nm for the PMMA, and for both resists the dependencies at various e-beam energies are presented. Figures 1-3 show the contrast curves for the PMMA and HSQ, respectively, obtained from the EW measurements. For both PMMA and HSQ we have used standard and optimized pre- and post-exposure processes, where the resists show the highest contrast. Figure 1 shows characteristic curves for PMMA resist/glass stack at 20, 30 and 40 keV energies, respectively, and Figure 2 presents the characteristic curves for PMMA on different substrate materials (Si substrate, borosilicate and quartz glass mask) at 40keV e-beam energy (exposed on ZBA 23).

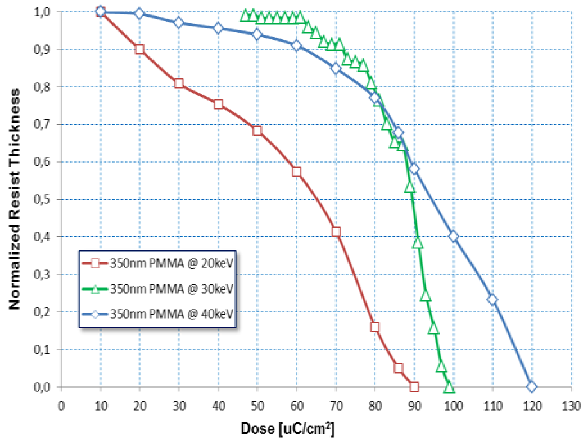

Fig 1. Characteristic curves for PMMA (on glass) at various e-beam energies.

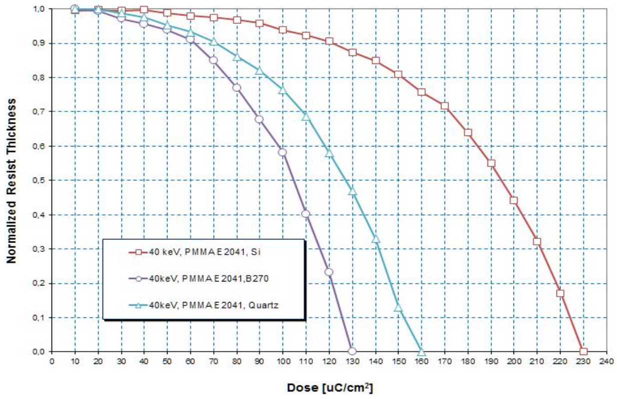

Fig 2. Characteristic curves for PMMA (on different substrate materials) at 40keV energy.

Figure 3 shows the characteristic curves obtained from the EW tests for the HSQ resist on Si substrate at various e-beam energies.

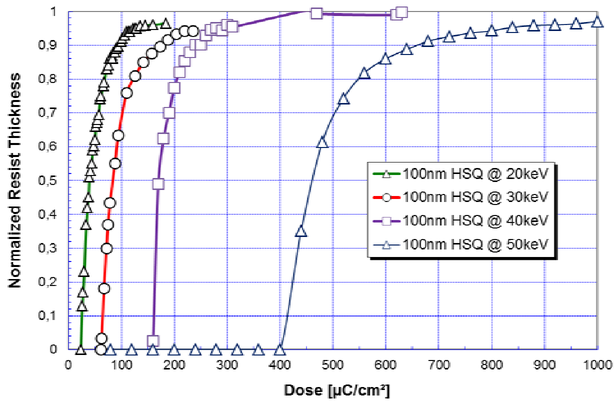

Fig 3. Characteristic curves for HSQ (on Si substrate) at various energies.

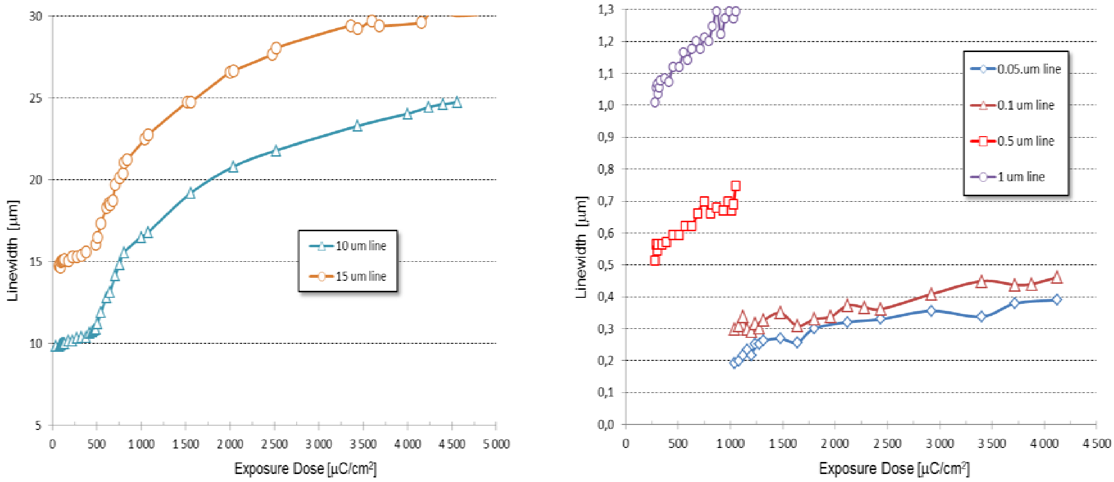

Fig 4. Exampe of typical experimental line correction curve taken from the ET test.

In Figure 4 an experimental line correction curve at 40keV e-beam energy is shown for several isolated line widths (namely 0.05, 0.1, 0.5, 1, 10 and 15 μm lines), obtained from the ET measurements. Here results from the PMMA resist (350nm) on quartz glass are shown. As can be seen, in the case of 10 and 15 μm lines (on the left) a nice plateau can be seen, above which a strong influence of backscattered electrons plays role. On the other hand, for lines widths below 1 μm (on the right) proximity corrections are needed to achieve desired line width for the nominal dose.

4. Conclusion

The carried out measurements and analysis of the results help us very much in obtaining important information about the resists and exposure processes. The obtained information enables us to practically verify the suggested methods of parameters extraction for a reliable exposure model.

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