Measuring the clearing dose on positive resists

Beamfox Proximity (1.2) – Application Note

Beamfox Proximity provides state-of-the-art proximity effect correction (PEC) for electron-beam lithography (EBL) in a user-friendly software package. To obtain the best results in your exposure, you only need to specify

1. The material layers in your sample (including the resists).
2. The dose required to clear the resist.

Beamfox Proximity defines the clearing dose of positive-tone resists as the minimal dose required to fully remove the resist on very large areas. After correction, a dose factor will be assigned to every polygon in the converted pattern, which is multiplied by the clearing dose to ensure that all features in the desing gan be properly resolved following the exposure. The electron propagation can be accurately simulated by Beamfox Proximity, however the clearing dose cannot be simulated, since it depends on the materials and conditions of a specific application, which may vary from case to case.

In this application note, we describe how to extract the clearing dose in the simplest and most accurate way for Beamfox Proximity. As an example, we use a positive-tone resist (ZEP 520A from Zeon Chemicals [1]) and a gallium arsenide substrate. We use 100 keV electron-beam lithography (Elionix ELS-7000G) and develop our resist in N-amyl Acetate at room temperature for 60 s. As a general guideline, we suggest reading the datasheet provided by the resist manufacturer to learn about the expected clearing dose.

Now, we prepare a pattern, which contains a single square. The most suitable size for the side of the square is roughly nine times the backscattering radius β of the electrons in the point-spread function. In GaAs at 100 keV, $\beta \simeq 12\ \mu$m, thus a square of $100 \times 100\ \mu m^2$ would work well. If β is not known, run Beamfox Proximity to simulate your specific case, using the stack of material and acceleration voltage required. At the end of the simulation, a value of β can be found under the Point Spread Function sub-menu on the left panel.

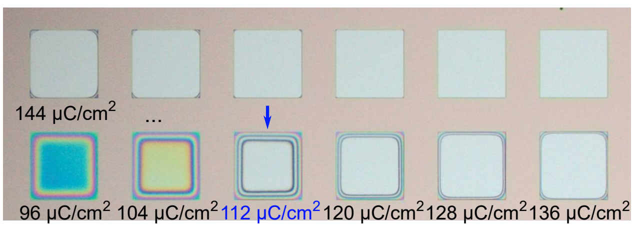

Figure 1: Optical microscope image of the developed test pattern. Each square is $100 \times 100\ \mu m^2$ in size. The uniform dose used for each square is also shown. The clearing dose and the corresponding square are indicated in blue.

In the ebeam system, expose the square patterns multiple times increasing the dose in small steps (recommended step size: 5–10% of the target dose). The dose range and step size can be chosen based on the resist and the time available for exposure. After development (it is important to use exactly the same conditions that will be used in the final exposure), the squares can be imaged under an optical microscope. Figure 1 shows the optical microscope image of the developed squares at different doses. As expected, the center of the square develops much faster than the sides, due to proximity effects. As the dose increases, the residual thickness of the resist is reduced. This can be seen also using a surface profiler (see Fig. 2). The clearing dose is the first dose that completely removes the resist in the center. In our experiment $D_c = 112\ \mu C/cm^2$.

We recommend exposing the Beamfox Proximity corrected patterns using the clearing dose given by this approach, and repeating the exposure with a few more doses higher than the initial value. Over time, the clearing dose might vary due to the aging of the resists or the developer. More specifically, if the thickness of the resist increases, the clearing dose would also increase. Typically, we use a value of D_c which is 10% higher ($D_c = 120\ \mu C/cm^2$) to ensure the complete removal of the resist. For best results, we also suggest repeating this operation periodically to ensure the most accurate measurement of the clearing dose.

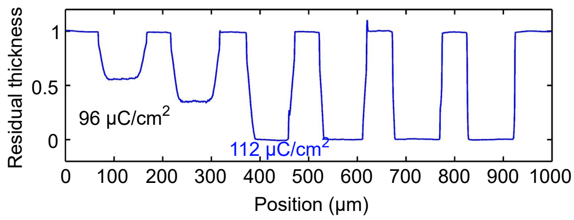

Figure 2: Residual thickness after development measured with a surface profiler. The clearing dose leaves a fully developed square.

Finally, we briefly describe the concept of clearing dose for negative-tone e-beam resists. Version 1.2 of Beamfox Proximity treats the dose requirement of negative resists the same as positive resists. However, the proximity correction method used for positive resists might not always yield satisfying results for negative resists. For negative resists we define the clearing dose as the crosslinking dose, i.e., the dose that completely crosslinks the resist, leaving the thickness unchanged after development. Such a dose can be identified with the same method, simply looking for the first dose where the resist is fully crosslinked. When performing corrections in Beamfox Proximity, it is necessary to change the equalization level to 1 in Advanced options. The value of 0.5 is the default for positive resists and corresponds to mid-point equalization. For a discussion on the equalization levels in PEC, see Ref. [2].

[1] http://www.zeon.co.jp/.

[2] R. Wüest, Dissertation, ETH Nr. 17146, Electrical Engineering, ETH Zurich, Zurich, Switzerland, 2007.