Dose to clear in EBL: comparison of Monte Carlo predictions with experiment

In electron beam lithography (EBL), defining dose to clear is a key factor for successful exposure when using a new substrate or changing beam voltage. This is especially important for optoelectronics laboratories where the substrate material compositions to be exposed are changed frequently. An experimental dose calibration is usually necessary to establish the optimum process conditions for new materials. A trial exposure, resist development, and measurements are needed in order to find the required dose. In this paper, we attempt to predict dose to clear by simulations, and to verify the results experimentally. If successful, such predictions would save a lot of efforts and expensive EBL time.

Monte Carlo simulation of the point-spread function (PSF) was performed for a set of commonly used substrate materials, using similar simulation conditions. The absorbed energy in the resist varies because electron scattering is dependent on the underlying substrate. The relative dose to clear for the different materials were calculated by numerical integration of the simulated PSF’s, taking the value for bare silicon as the reference. Two types of Monte Carlo models were used: one implementing the common continuous slowing down approximation (CSDA) and another applying advanced discrete loss approximation (DLA). In the DLA every scattering event is simulated separately; in the CSDA model all events are averaged using Bethe formula.

Experimental dose calibration tests were performed to find the dose to clear for the various substrate materials. The dose to clear was measured using partial development of the e-beam resist, which is more accurate than full development. The exposures were run with a 100 keV EBL system. Simulated and experimental results for the different materials are presented in Fig. 1. It was found that predictions by CSDA model could provide a trend, while DLA model was quantitatively accurate. This demonstrates that DLA Monte Carlo simulations can be used to avoid or reduce the need for experimental dose calibration.

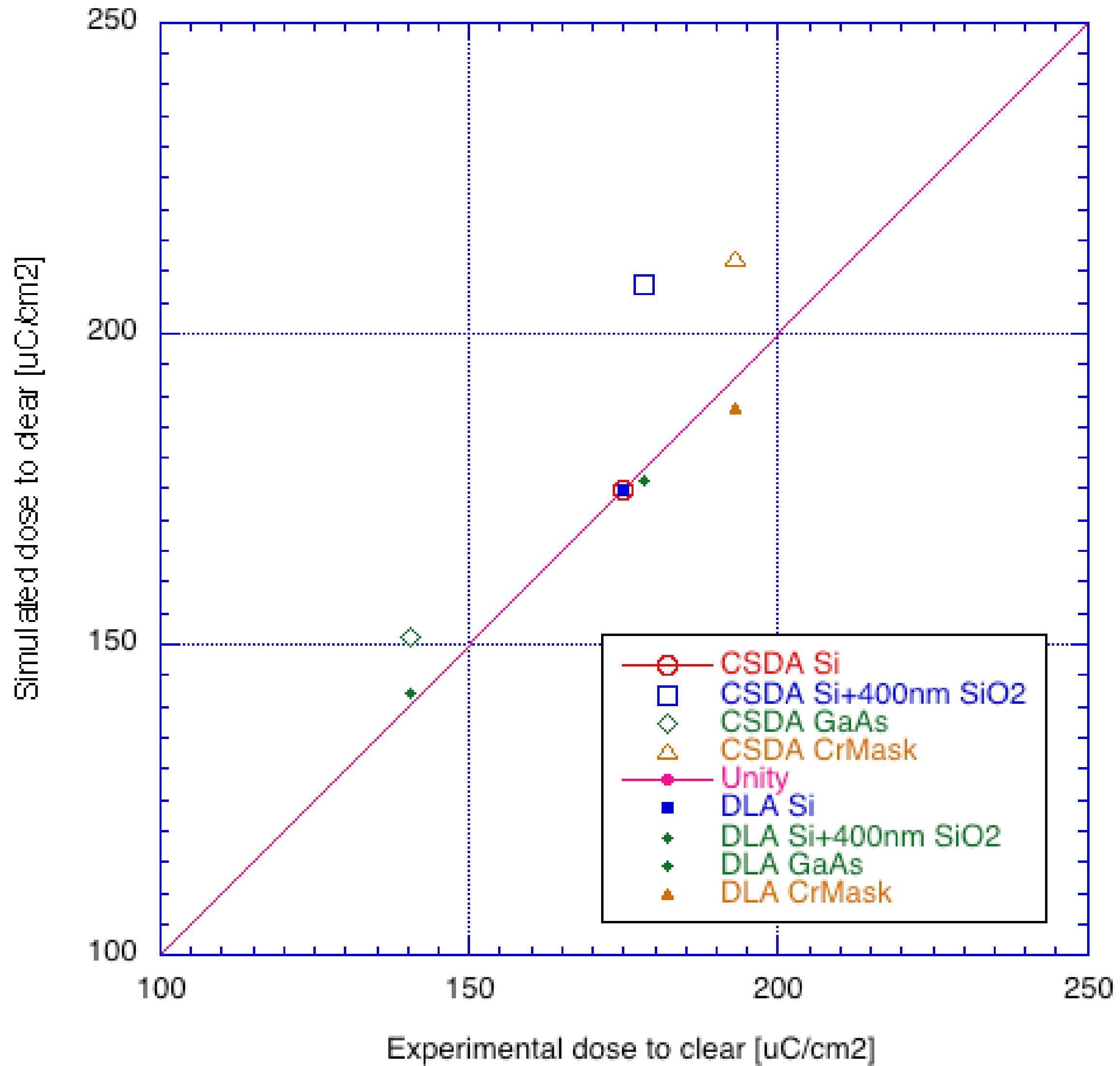

Figure 1. Dose to clear for various substrate materials predicted by CSDA and DLA Monte Carlo modeling, and by experiment. The DLA model accurately predicts the required dose to clear and so avoids the need to establish this experimentally.