Monte Carlo simulations to study FEBID and EBL resolution limits.

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We study lithography processes for the 1 to 20 nm range, using focused-electron-beam-induced deposition (FEBID) and resist-based electron beam lithography (EBL). What the two techniques have in common is the interaction of electrons with a particle-sensitive layer (adsorbed gas layer or resist) and the underlying substrate. As a result of the electron exposure, molecules in the particle-sensitive layer are dissociated (FEBID) or chemically modified (EBL), allowing the definition of a pattern on the substrate. The spatial- and energy-distribution of electrons (primary, secondary, backscattered) in the particle-sensitive layer determine the ultimate writing resolution for FEBID and EBL. To predict the resolution, Monte Carlo (MC) methods are most suitable, mimicking the statistical nature of electron scattering[1] (see Fig. 1). Here we present the latest results obtained using the GEANT4 platform-based MC code developed by E. Kieft and E. Bosch[2]. This approach, based upon Dielectric Function Theory for inelastic electron scattering and general GEANT4 framework for defining targets and detectors geometries predicts not only the backscattered electron yields correctly, but also the secondary electron (SE) yields. The strength of the method is illustrated by two practical examples.

First, the simulation of the spatial distribution and energy spectra of electrons arising from 300 keV electrons incident on ultra-thin membranes is considered. Various membrane thicknesses and materials with and without a deposit on top (Fig. 2) are taken to predict the spatial resolution of the FEBID process and the FEBID growth[3]. The conclusion is that the role of the SE is significant and strongly determines FEBID growth as soon as there is at least some deposit on the membrane. We show that most of the SE generated reach the surface through the deposit while the membrane itself (thickness and material) becomes of less importance.

The second example is the simulation of electrons generated by 100 keV electron exposure of a resist layer (SiO_2, resembling HSQ), enabling prediction of the resolution of the exposure step in EBL. The simulated energy deposited by electrons as a function of depth in the resist layer is shown in Fig. 3. For a resist thickness of 100 nm (Fig. 3b) the deposited energy is seen to increase with depth, then assumes a maximum and then slightly decreases. This correlates with the experimentally observed dependence of the sensitivity on the layer thickness of HSQ resist[4]. As for sub-10 nm lithography it is expected that ultra-thin resist layers are required, we show in Fig. 3c that the deposited energy in the 10 nm thick surface layer is essentially constant compared to the variation in deposited energy at larger depths.

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3 W.F. van Dorp, C.W. Hagen, P.A. Crozier, P. Kruit, Nanotechnology 19, 225305 (2008).
4 V. Sidorkin, A. Grigorescu, H. Salemink, E. van der Drift, Microelectron. Eng. 86, 749 (2009).

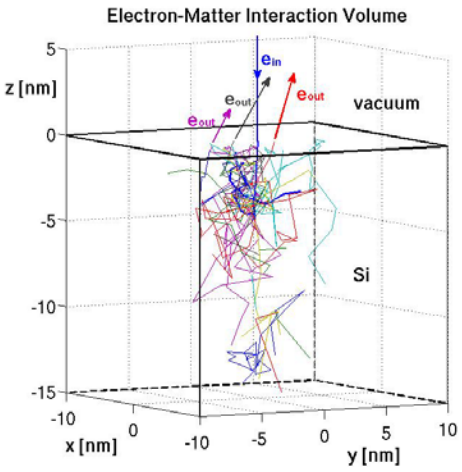

Fig 1: Simulated secondary electron generation. The interaction volume can be studied by using a large number of primary electrons. Some of the secondary electrons end up at the sample surface. The rest loses all their energy within the substrate (or resist).

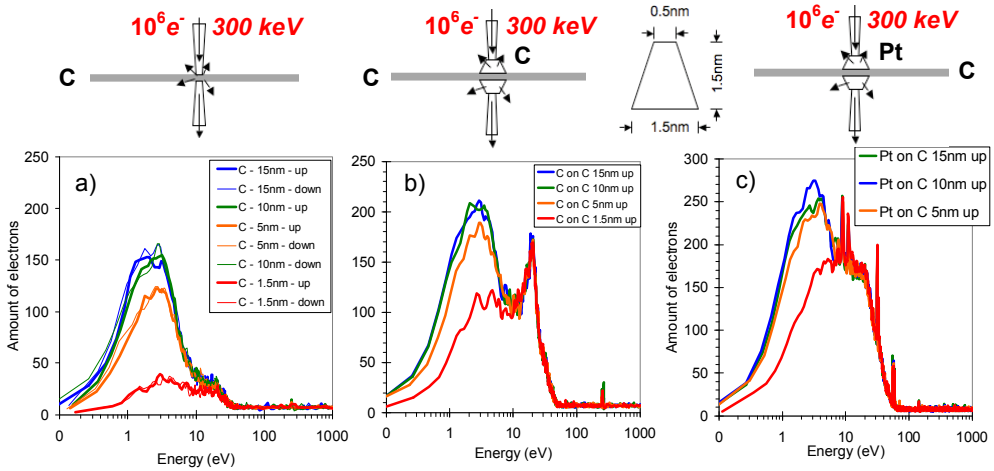

Fig 2: Energy spectra of the emitted electrons for different C membrane thicknesses. One million primary electrons of 300 keV were incident on the top surface. a) No deposit on the membrane. b) C dot deposited on the top (Note the dimensions of the dot in the sketch on the right). c) Pt dot deposited on the top.

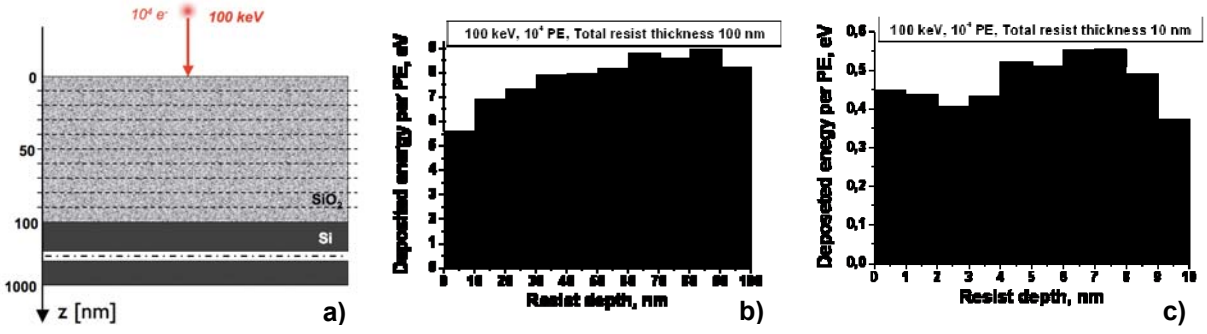

Fig 3: Deposited electron energy distribution inside a SiO_2 resist layer on a Si substrate for 10^4 primary electrons of 100 keV, incident on the top surface. a) Modeling scheme; b) Results for 100 nm total resist thickness; c) Results for 10 nm total resist thickness.