E-beam Energy Dissipation in Complex Solid Targets

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Photomask is the enabling technology for photo-lithography, allowing for ever-shrinking transistor size in IC's. In the last decade, all masks for critical IC layers have been written in shaped-beam electron lithography tools. In these tools, a tightly focused 50 keV e-beam of rectangular shape strikes a mask blank surface.

The mask blank generally consists of thin layers of resist and metal on top of a massive quartz substrate. Primary and secondary electrons travel in this structure, and some of them collide inelastically with resist molecules, causing resist exposure. Consequently, the electron energy loss distribution in the resist defines the exposure resolution. Modeling of this process is notoriously difficult, given the complexity of the physics involved, with millions of participating particles. At the outset, we used the MONSEL[1] programs, which simulate electron scattering in solids. MONSEL allows for solid targets of various materials arranged in multiple layers, with a normal or tilted incident e-beam. Basically, MONSEL computes SE and BSE yields of the targets. During execution, MONSEL creates raw data files which store the energies and coordinates of all the electrons modeled, whose numbers come in millions.

We have developed search-and-sort add-on software for MONSEL post-processing. This new software, BS4, sifts through the raw data files, computes each individual electron energy loss at collision points, and organizes the loss data in a way that allows the computation of the total energy distribution.

BS4 allows for numerical output describing the energy loss distribution in the mask structure. Figure 1 shows results of the test run, for the axial energy loss distribution in pure Quartz, computed with MONSEL-BS4 and with the well-known Everhart-Hoff formulae.

The next chart (Figure 2) shows the axial energy density distribution in a generic mask with resist/Cr-layer/Quartz structure. This chart shows two important effects: (1) low energy density, or under-exposure in ~10…20 nm under the resist surface (this may cause "resist skinning" effect); and (2) a spike in the energy density very near the Cr-surface, caused by overlapping of in-coming and Cr-backscattered electrons (may cause "resist foot" effect).

Figure 3 shows radial energy density distribution in mask resists of 200 and 300 nm thickness.

The thicker resist shows wider background exposure, as electrons experience more collisions in the thicker resist.

BS4 allows computation of multi-layered energy density distributions, useful in mask heating modeling (Fig. 4).

Overall, the BS4 software, in conjunction with MONSEL, is a useful new tool for e-beam/solid state interaction modeling.

Reference

1. J. Villarrubia, N. Ritchie, J. Lowney,
   in Proceedings of SPIE, vol. 6518.

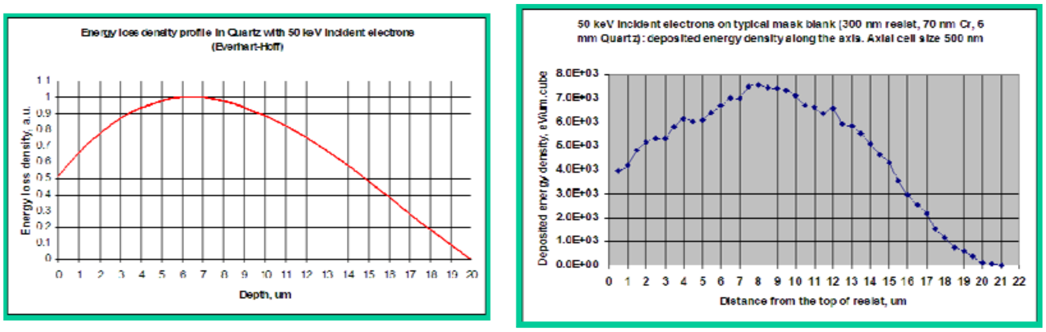

Figure 1. Energy loss distribution in Quartz, computed with MONSEL-BS4 (l) and Everhart-Hoff formulae (r).

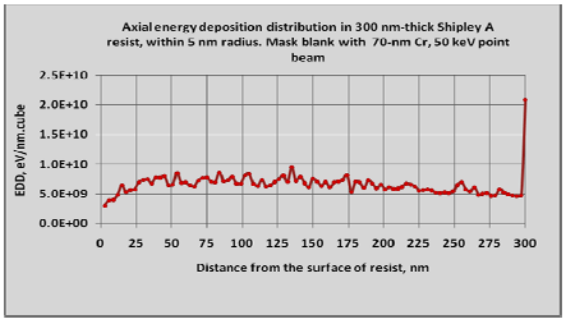

Figure 2. Axial energy density distribution in resist.

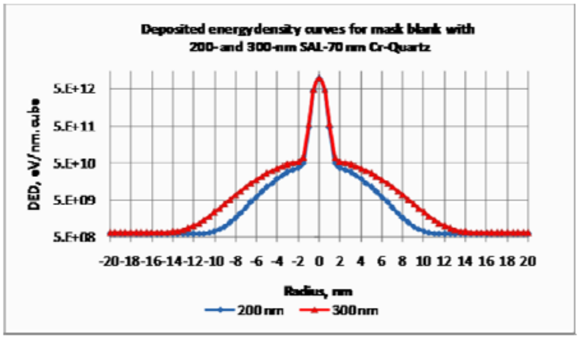

Figure 3. Radial energy density distribution in resist.

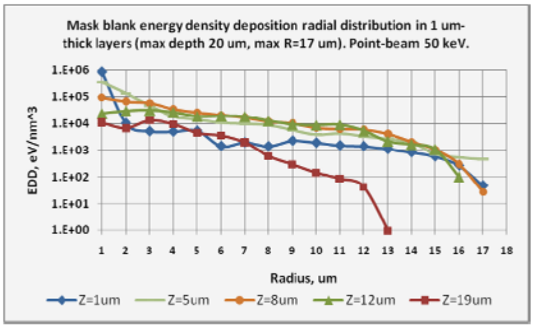

Figure 4. Radial, multi-layer energy density distribution in mask.