Electron scattering simulation for subsurface metrology in scanning electron microscope

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According to shrinkage of semiconductor device dimensions, critical-dimension (CD) measurement techniques using a scanning electron microscope (SEM) have been improved to meet the demand for higher accuracy and precision in semiconductor fabrication processes. Conventional SEM measurements have been performed using secondary electron enhancement at the edges of patterned structures. However, alternative measurement techniques are requested for the subsurface structures often encountered in the fabrication of emerging new devices. In this study, we modified an electron-scattering simulator MONSEL, which was developed at NIST [1], to simulate a flat sample with a subsurface structure and classified emitted electrons according to their generation processes. By using this simulator, we evaluated the CD bias of the subsurface pattern.

Figure 1 shows the sample geometry. The sample consists of a 5-nm-thick a-C film on flat W and Si pattern. The electron-beam irradiation onto the sample generates secondary electrons (SEs) and backscattered electrons (BSEs). We classified the emitted electrons on the basis of their generation process as shown in Fig. 2. SE1 is generated from a-C film by the incident electrons, but SE4 is generated from a-C film by the backscattered electrons from W and Si patterns. Figure 3 shows the simulated SE and BSE profiles at irradiation energy of 2 keV. The components forming these profiles are also shown with the dotted lines. Although the yields of SE4 (generated by BSE2) and BSE2 show a material contrast between the W and Si, those of SE1 and BSE1 are almost constant and then become an offset component of the total yields. Since the yield of BSE1 is much smaller than that of SE1, a higher contrast is obtained for the BSE profile. Therefore, we found that the BSE profile is suitable for CD measurement of the subsurface pattern under even a several-nm thin layer.

Figure 4(a) shows the simulated BSE profiles at two different irradiation energies and taper angles, θ (Fig. 1). The BSE yield increases with irradiation energy, which agrees with the reported results [2]. The two profiles for 1 keV are almost the same, but those for 5 keV show different behaviors. The BSE profile at 20º with higher irradiation energy shows a smooth edge due to the BSEs from the tapered W. This causes the increase in CD bias between the 100-nm top width of W and the measured CD. Figure 4(b) clearly shows the increase in CD bias at 20º with increasing irradiation energy. However, the contrast also increases with increasing irradiation energy. These results show that controlling the irradiation energy is necessary for obtaining accurate CD measurements of a flat sample with a tapered subsurface pattern.

1. J. R. Lowney, Scanning **18**, 301 (1996).
2. L. Reimer, *Scanning Electron Microscopy* (Springer-Verlag, 1998) p144.

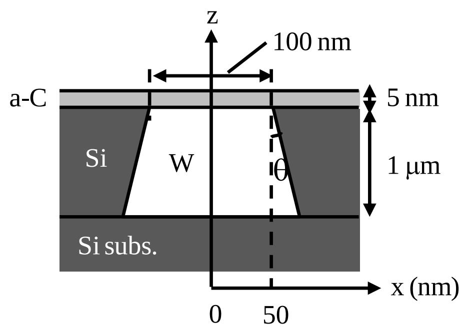

Fig.1. Sample geometry

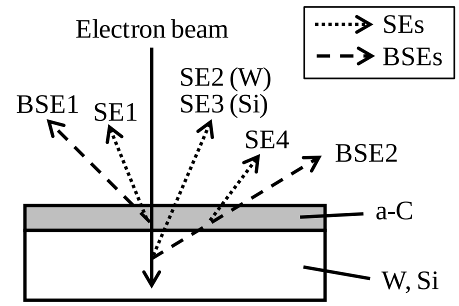

Fig.2. Classification of secondary electrons (SEs) and backscattered electrons (BSEs) on basis of generation process

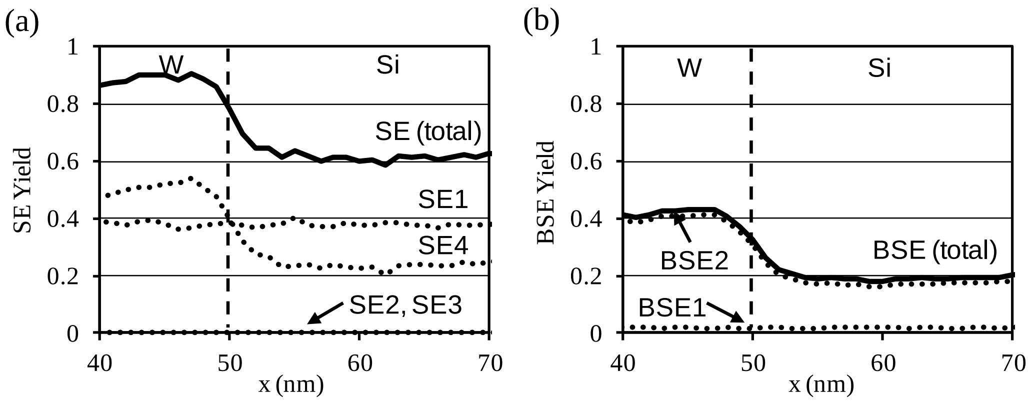

Fig.3. Simulated SE and BSE profiles (solid line). The irradiation energy and taper angle θ are 2 keV and 0º, respectively. The components forming the SE and BSE yields are also shown (dotted line).

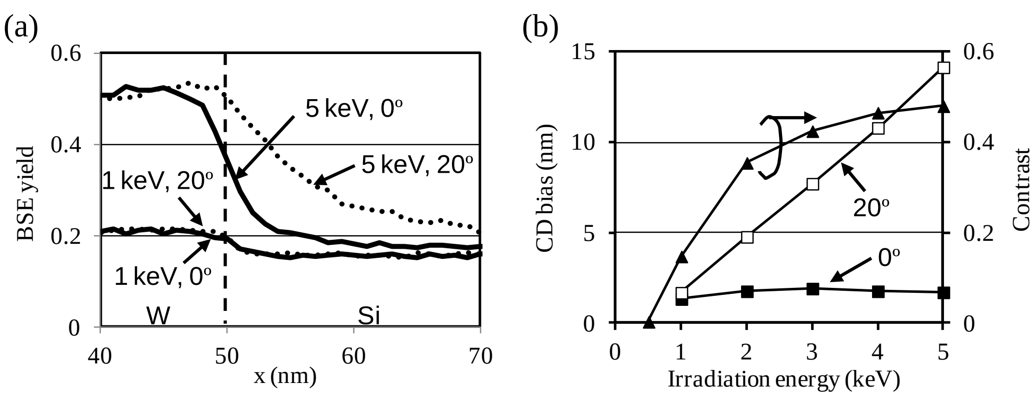

Fig.4 (a) Simulated BSE profile at irradiation energies of 1 and 5 keV, and taper angles θ of 0º and 20º. (b) CD bias between 100-nm top width of W and measured CD (threshold 50%) as a function of irradiation energy. The contrast (equal to Michelson contrast) between the W and Si regions is also shown.