Visualization of 2D dopant distribution in energy selected secondary electron image by 200 kV scanning transmission electron microscope

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The secondary electron image (SEI) is sensitive to the potential of the sample surface. Therefore, SEI reflecting the surface potential at the p-n junction [1] and SEI contrast reflecting the carrier concentration in semiconductor [2] were reported. And a 200 kV transmission electron microscope (TEM) is popularly used for characterization of semiconductor, since the device size is getting smaller to be nanometer scale and the resolution of the conventional scanning microscopes (accelerating voltages are 1-30 kV) is insufficient for modern device structure. In this paper, we report that the energy selected SEI visualizes the dopant distribution of a Si wafer using a field emission scanning TEM (FE-STEM), whose resolution is enough for analysis of nanometer-sized devices.

We used an FE-STEM/TEM (JEM-2800), equipped with an Everhart-Thornley type SEI detector above the upper pole of the objective lens. Figure 1 shows a scheme of the SEI detector and two electrodes. These electrodes are used to separate the energy of SE. The E1 eliminate SE, whose energy is < -E1, on contrary, the E2 reflect back SEs < -E2. Sample we prepare has known dopant concentration to clarify the relation of SEI contrast and dopant concentration. The dopant for a Si wafer was arsenic (As), whose concentration was pre-observed by secondary ion mass spectrometer (SIMS). The cross sectional sample was prepared by Ar^+ ion milling (ION SLICER™).

Figure 2 show the SEIs of cross sectional Si wafer at (a) E1 = -5.4 V and E2 = -40 V and (b) E1 = 0 V and E2 = -11 V. Figure 3 shows the SEI intensity profiles of Figs 2 (a) and (b) and a profile of As concentration by SIMS (red line). The intensity profile (green line), from Figs. 2 (b), monotonously decreases from the surface toward the p-type region, and becomes constant at depth of 300 nm. This tendency is similar to As concentration profile (red line) by SIMS. The SEI catches the contrast of a concentration as low as the detection limit of SIMS (0.1 ppm). That is, the energy-selected SEI has enough sensitivity for dopant concentration. Another profile, from Fig. 2 (a) (violet line), shows a different behavior. The doped region shows dark contrast and small dip at the beginning of depletion layer. From the applied voltages for E1 and E2, the image in 2 (a) is formed with SEs > 5.4 eV and > 40 eV. The contrast of this image shows that the energy selected SEI may have capability to image the specific characters of semiconducting materials such as a depletion layer.

Finally, we can conclude that the SE imaging performed at 200 kV FE-STEM may realize simultaneous acquisition of contrast of dopant concentration, high resolution imaging and elemental analysis, which are the functions preferred in characterizations of semiconducting materials and devices.

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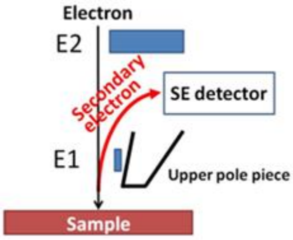

Fig.1

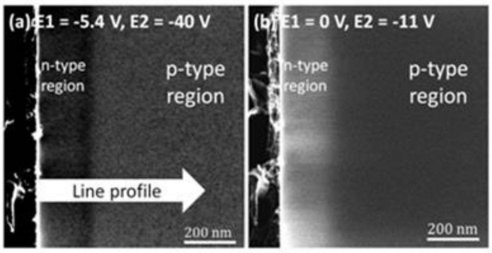

Fig.2

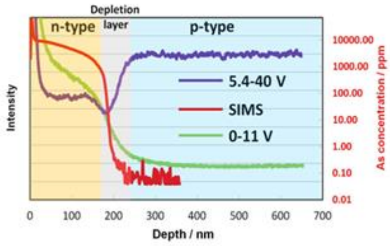

Fig.3