Three-dimensional elemental analysis of semiconducting devices by EDS Tomography

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Recently, semiconducting devices are designed to be three dimensional (3D) stacking structures for high integration and performance [1]. The 3D structural analysis is essential for new device development and failure analysis [2]. Energy dispersive X-ray spectroscopy (EDS) tomography is getting popular for 3D characterizations of a sample, since the method enables us to clarify the atomic species and 3D structure of a sample simultaneously. In addition, recently, the X-ray detection sensitivity has been drastically improved with multiple large-sized detectors. In the previous X-ray detection system composed of two EDS detectors, the detectors locate symmetrically with respect to the tilt axis of the sample holder in TEM. Therefore, EDS tomography has two types of limitations for 3D quantitative elemental analysis. First, some of the generated X-rays are blocked by the sample holder or supporting mesh in specific tilting angle range. Second, the generated X-ray can be absorbed by the sample itself. These can lead to the incorrect results in 3D quantitative elemental analysis using EDS tomography. The purpose of this study is to make a new EDS detection system for EDS tomography without the shadowing effect and obtain 3D elemental maps from semiconducting devices using the new system.

The electron microscope used for our experiments was an aberration corrected 300 kV TEM (JEM-ARM300F) with dual SDDs. In order to avoid the shadowing effect, one detector is located on the tilting axis of the sample holder. By using this single SDD, we have confirmed that there was no shadow by the sample holder in the obtained EDS tomogram. This experiment was performed using the paint film sample. This detection system was applied to a finFET, which is a typical 3D tri-gate semiconductor device. Figure 1 shows slices normal to the X, Y and Z directions extracted from the obtained 3D elemental volume map of the finFET samples. The tilting angular range for obtaining this EDS tomogram was from +64 to -64 degree with 4 degree increments. The acquisition time of each map was only 3 minutes by using a large-sized SDD whose solid angle was more than 1.1 sr. In the maps, germanium, titanium, tungsten, oxygen, nitrogen and silicon were detected. The position of the Y-cut slice map is indicated in the corresponding Z-slice map shown below the Y-cut slice map by a yellow line. The germanium stressor (yellow), tungsten electrode (green) and the silicon channel (blue) are clearly seen in the Y-cut slice map (a). The nitrogen (magenta) located between the channel and electrode was obtained in the 3D elemental maps. We can conclude that the EDS tomography is useful to analyze 3D elemental structures of modern semiconducting devices.

[1] D. Hisamoto et. al., IEDM Tech. Dig., (1998) p. 1032
[2] M. Hayashida et. al., Microsc. Microanal. 21. 3 (2015) p. 1609

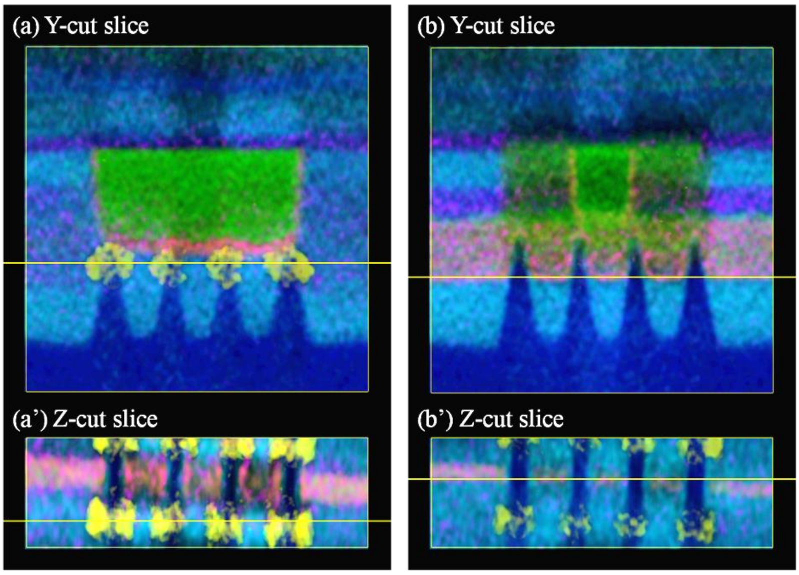

Figure 1 Y and Z slice maps from the elemental map reconstructed by EDS tomography. The Z-cut slice is parallel to the wafer surface. Positions of the Y-cut and X-cut slices are indicated by yellow lines shown in the corresponding Y and Z slice maps. The germanium in the stressor, the tungsten in the electrode and the silicon in the channel and substrate are colored yellow, green and blue, respectively.