A FIB Micro-Sampling Technique for Three-Dimensional Characterization of a Site-Specific Defect

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In characterization or failure analysis of new materials and semiconductor devices, the requirements for three dimensional observation and analysis are rapidly increasing. We discuss techniques for specimen preparation, three-dimensional observation, and elemental analysis of semiconductor devices that we developed using a system consisting of a dedicated focused ion beam (FIB) instrument and a scanning transmission electron microscope (STEM). The system utilizes a FIB-STEM compatible specimen holder with a specially designed rotation mechanism, which allows 360° rotation of a specimen on a conical stage (needle stub) around the ion beam axis of the FIB system and 360° rotation perpendicular to the electron beam in the STEM1,2. A piece of sample (micro sample) is extracted from a specific-site by the micro-sampling technique3,4 and mounted on the needle stub. Instruments used in the study are the Hitachi FB-2100 FIB system with a micro-sampling attachment and the HD-2300 field emission 200kV STEM.

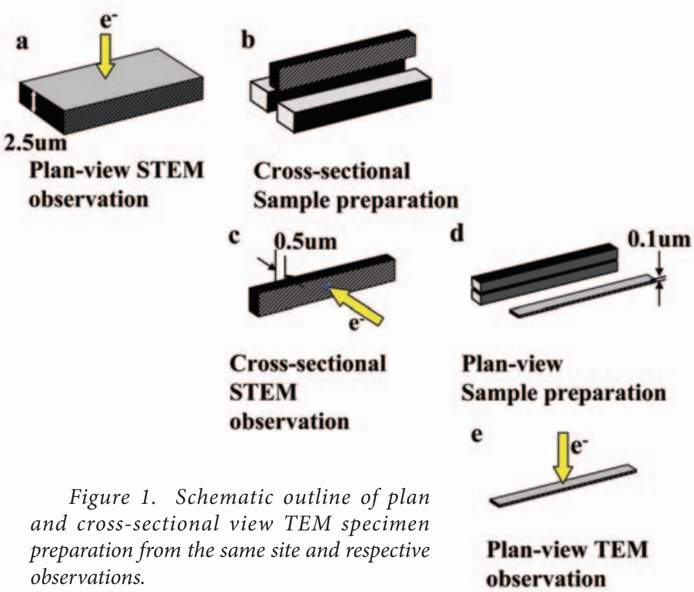

Figure 1. Schematic outline of plan and cross-sectional view TEM specimen preparation from the same site and respective observations.

Plan-view, cross-sectional and plan-view observations of an SRAM device

The micro-sampling technique allows cross-sectional and plan-view STEM sample preparation from the same initial material at a pre-specified location. Figure 1 shows an outline of the plan for cross-sectional view, STEM specimen preparation from the specified site and subsequent observations. First, a plan-view micro-sample with a thickness of 2.5 micron is prepared in the FIB system and is observed with the 200kV FE-STEM (a).

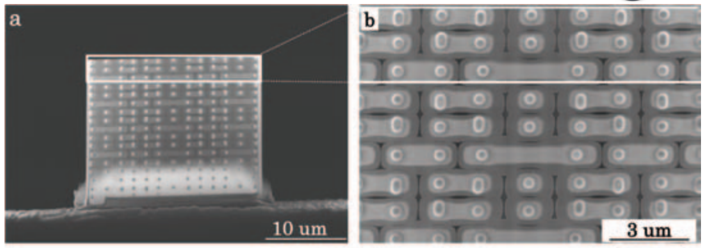

Figure 2. DF-STEM images of a plan-view sample observed at the accelerating voltage of 200 KeV. a.) The entire micro-sample, b.) enlarged image.

Since STEM imaging has less chromatic aberration than TEM imaging at the same kV, the image quality in the STEM does not suffer degradation, even with a 2.5 micron thick sample. Next, a 0.5 micron thick cross-sectional sample is prepared from the plan-view sample and analyzed in the STEM. Finally, a precisely located, thin, plan-view sample is extracted from the cross-sectional sample using the patented micro-sampling technique (d). The plan-view STEM image is observed and the sample may now be fully characterized for defects utilizing all of the analytical accessories the instrument is capable of supporting.

The method described above was applied to characterize an inter-level via (or plug) of an SRAM cell in a microcomputer chip. To begin with, a micro-sample of about 2.5 micron thick was prepared for plan-view STEM observation. Figure 2 shows the dark-field (DF) STEM images of the plan-view sample (a) and its magnified image (b). The position of the plugs and wiring can be clearly observed. Next the upper part of the specimen, the square masked area, is cut out for cross-sectional sample observation. The cross-sectional DF-STEM image of the sample with a thickness of 0.5 micron is shown in Fig.3. Along both sides of the plugs we see dark contrast areas that are openings or gaps.

Subsequently, the sample is thinned to a final thickness of approximately 0.1 micron. Figure 4a shows a plan-view DF-STEM image corresponding to the area observed in the cross-sectional STEM image. Figures 4b and c are enlarged images of the left and center plugs, respectively. The plugs are fringed with the bright contrast of a Ti/TiN barrier metal layer. There are differences in shape and peripheral structure of both plugs. In Fig.

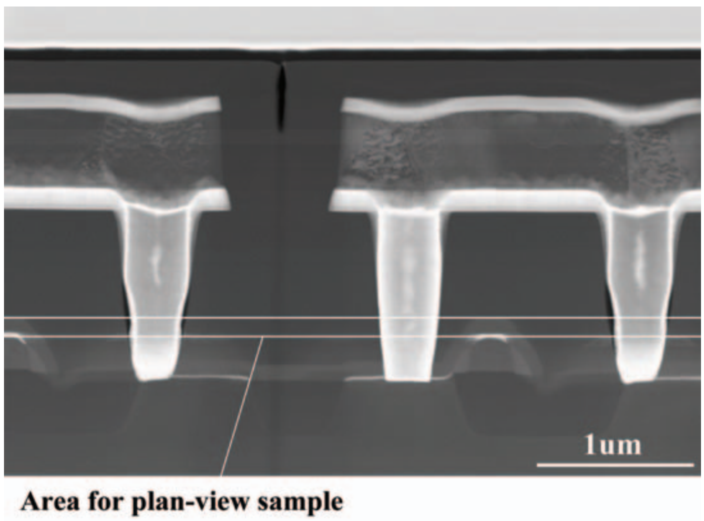

Figure 3. Cross-sectional DF-STEM image of an SRAM device specimen with a thickness of 0.5 microns, observed at 200 KeV.

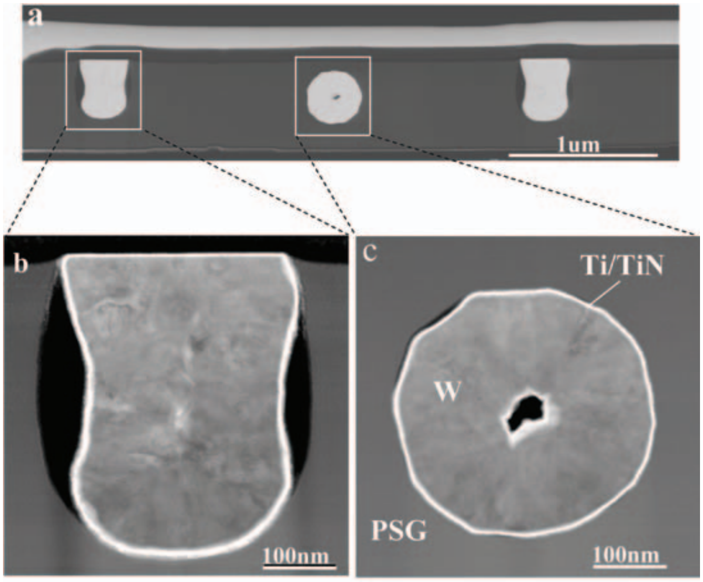

Figure 4. Plan-view DF-STEM images observed at 200 KeV: a.) DF-STEM image corresponding to the area observed in the figure 3 cross-section STEM;. b.) and c.) enlarged images of the left and center plugs.

4b, there are openings between the phospho-silicate glass (PSG) insulating layer and the plug. It can be surmised that the PSG shrank when it was dried after the Ti/TiN layer was deposited.

FIB micro-pillar sampling technique for 3D STEM observation of DRAM Devices

For this method, a piece of sample in the shape of a pillar (micro-pillar sample) is extracted at a pre-specified site for characterization by the FIB micro-sampling method. Figure 5 shows the procedure for this method. The extracted micro-pillar

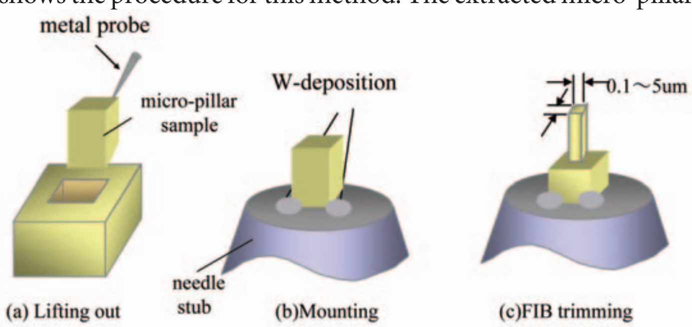

Figure 5. Schematic flow for the FIB micro-pillar specimen preparation technique.

sample (a) is transferred and mounted onto a needle stub (b). The sample is further shaped into a pillar of ~ 0.1-5 microns square and 10 to 15 microns long (c), and then transferred to the STEM for high angle annular dark field (HAADF) STEM, bright field STEM, and secondary electron microscopy (SEM) image observation at 200kV to obtain the three-dimensional and cross sectional structure of the specific-site. The geometry of the sample, and the needle stub, allows observation of the sample over a wide range of angles. In this manner, the specific site location is further refined for additional FIB milling as required to produce a final specimen. For a Si device, it takes less than 30 minutes to prepare a micro-pillar sample. A secondary electron (SE) image of a micro-pillar sample from a Si device mounted on a needle stub is shown in Fig. 6. The specific site can

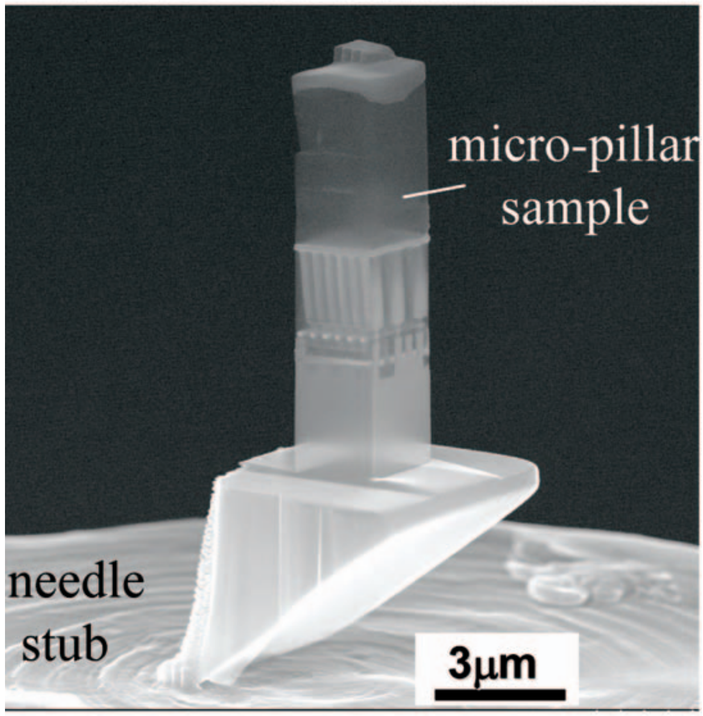

Figure 6. SE image of a micro-pillar specimen from a Si device mounted on a needle stub.

be located for further FIB milling, if required. Figure 7 shows a portion of a hemi-spherical grain (HSG) capacitor observed by SE (a), high angle annular dark-field (HAADF) STEM (b) and bright-field (BF) STEM (c) images. The shape and fine structure of the capacitor are observed three dimensionally.

Figure 8 shows high resolution STEM images of atom columns in a pillar-shaped Si single crystal specimen with a size of about 150nm x 150nm. Figure 8(a) and (b) were observed using the [110] and the [1-10] diffraction directions respectively. A crystal lattice image of the Si (111) plane with the distance of 0.314nm is observed clearly.

We have described a method for three-dimensional characterization of a specific-site defect, using the Hitachi FB-2100 FIB system equipped with a micro-sampling attachment and the Hitachi HD-2300 dedicated FE STEM. This method was applied for the structural characterization of SRAM and DRAM cells. The results revealed that the micro-sampling technique enabled

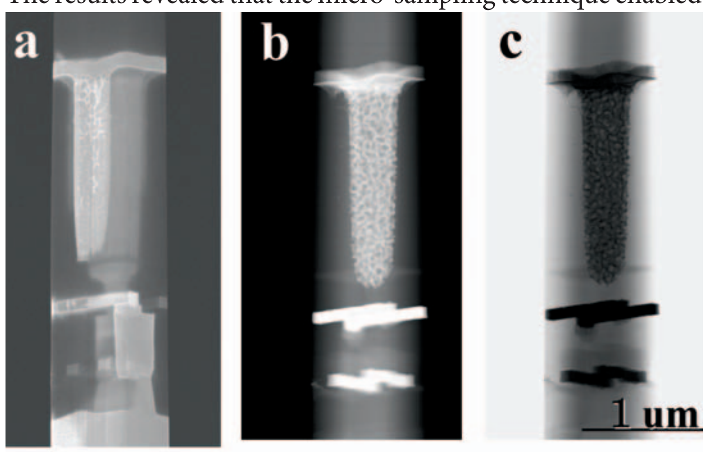

Figure 7. SE (a), DF-STEM (b), and BF-STEM (c) images of a 1 micron wide by 0.5 micron long square pillar.

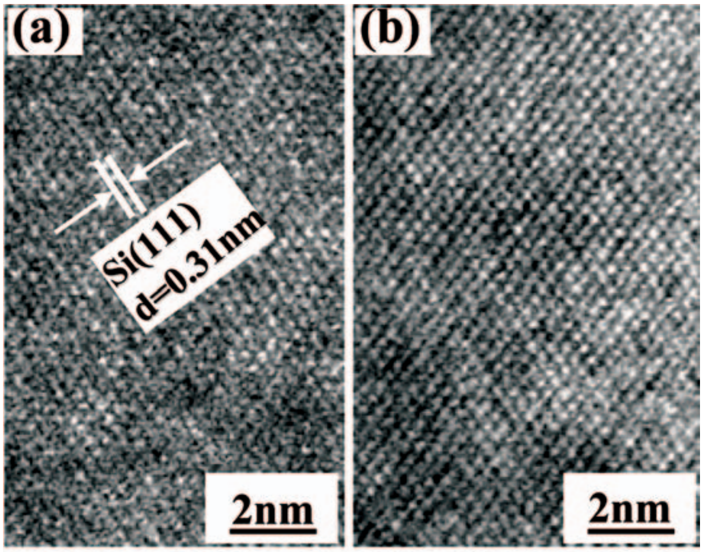

Figure 8. High resolution STEM images of a pillar-shaped Si single crystal specimen of about 150 nm x 150 nm. a.) [110] operating reflection, b.) [1-10] operating reflection.

the observation of the three-dimensional structure of specific sites at atomic resolution and the technique can be applied to the failure analysis or evaluation of a wide range of materials. ■

References

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