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# EFTEM- and STEM-EDXS Spectral Imaging of "Hidden" Si-based Semiconductor Device Defects

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As semiconductor devices continue to shrink, so do the critical defects or flaws that arise during the fabrication process. The failure analysis community must keep pace with these smaller defects with its tools and techniques. Here, it is demonstrated how one may go beyond the "traditional" analytical techniques of three-window Energy-Filtered TEM (EFTEM) mapping and spot-EDXS analysis in the characterization of small "hidden defects" within Si-based semiconductor devices.

EFTEM spectral imaging (SI) utilizes a series of aligned energy filtered images stacked along an energy loss axis. This technique is very quick and has a high degree of spatial resolution per image, but has relatively poor energy resolution which is dependent on the width of the energy selecting slit [1]. In a typical failure analysis, one is often less concerned with the exact details of chemical make-up of the defect, but rather where it is, and roughly what it is, i.e. an oxide, a nitride, etc. These criteria make EFTEM SI a technique of choice for typical small semiconductor defect analyses.

An FEI Strata 400S DualBeam FIB, fitted with an OmniProbe in-situ lift-out apparatus was used to prepare a TEM cross-section sample from a Si-based semiconductor device die. 30kV Ga ion milling was used to prepare a roughly 2μm thick sample which was extracted and mounted onto a Cu OmniProbe TEM grid. Subsequent milling was performed at 30kV, 16kV, and 5kV with each step creating less amorphous surface damage to the sample. A final 2kV amorphous damage clean-up on each side of the sample was used as the final thinning step [2]. The TEM, EFTEM, and STEM imaging was performed using a Philips/FEI CM300 (S)TEM with a field emission gun operated at 300kV. It is equipped with a model 2002 Gatan Imaging Filter and a Noran X-ray detector. The acquisition and analysis software used in the present work is the Gatan Digital Micrograph software and the Noran System Six software.

An EFTEM SI composed of EFTEM images acquired over about 15 minutes using a 5eV energy window ranging from 50eV to 750eV was acquired from an area of a semiconductor device with a suspected defect as shown in a conventional TEM micrograph in figure a). By scrolling through the images, or slices of the EFTEM spectral image, one quickly finds a region of high contrast likely corresponding to a roughly 20nm particle. Three of these slices were summed to create a "super-slice" corresponding to a 15eV wide window centered on 90eV energy loss shown in figure b). EELS sum spectra extracted from the designated areas labeled 1 and 2 in figure b) corresponding to the apparent particle and its embedding material are shown in figure c). Through a quantification procedure, one finds that region two is roughly $SiO_2$ and from the particle one finds $Si_{63}O_{37}$. Assuming that the particle is pure Si embedded in $SiO_2$, a density-composition calculation suggests that the particle is roughly one-third the thickness of the TEM cross-section sample.

An alternative analytical spectral image using STEM-EDXS was acquired from the same area as a)-b). The STEM-EDXS spectral image was acquired utilizing the Noran System Six

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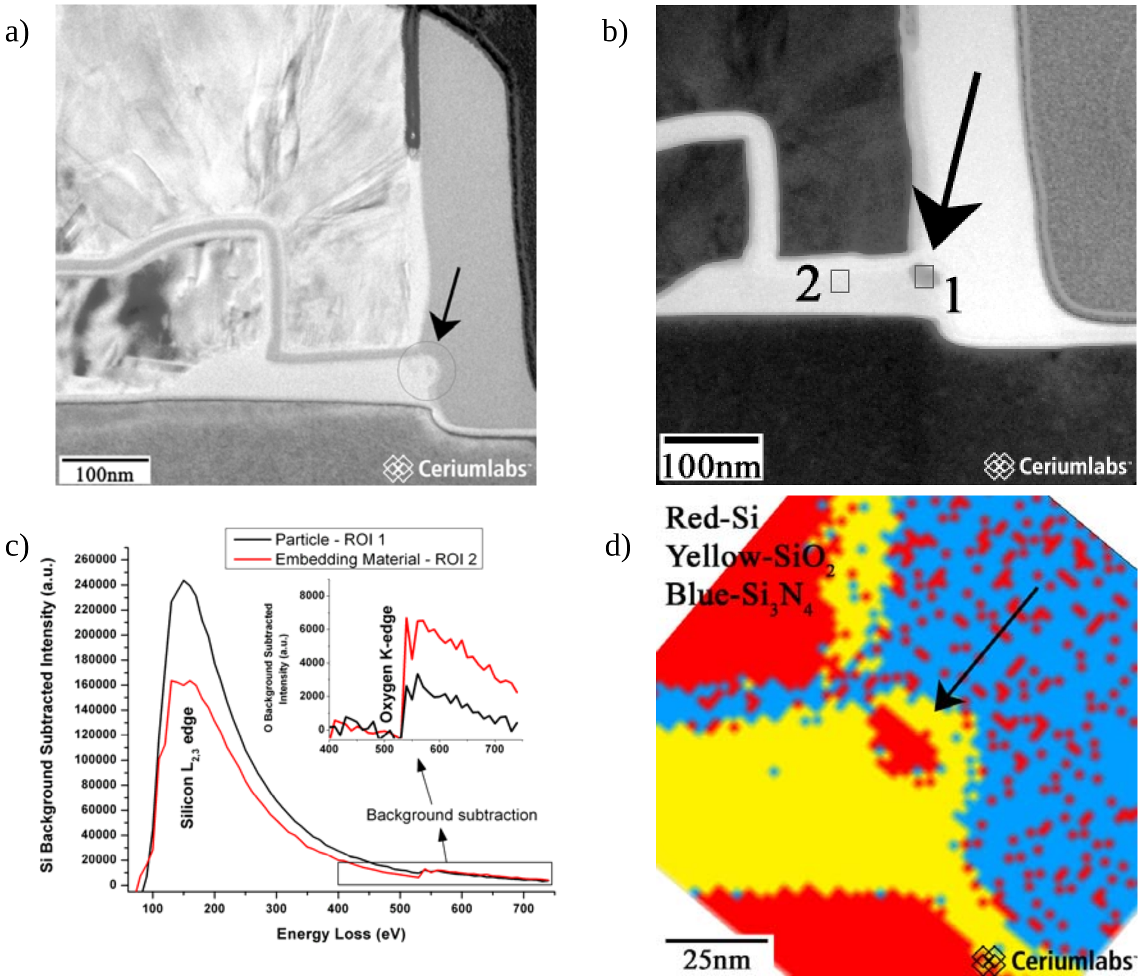
software/hardware package with which phase maps were extracted using the multi-variant statistical analysis routines within the “Compass” package [3]. Three of these phase maps are superimposed in figure d) which is also consistent with the particle likely being pure Si embedded in a $SiO_2$ layer.

Through analysis with Analytical TEM, semiconductor based defects that have typically been hidden from view in conventional TEM can now be readily observed and analyzed using TEM based spectral imaging techniques.




a) Conventional TEM bright field suggesting the presence of a defect, b) Image extracted from an EFTEM spectral image showing strong contrast between the particle and embedding medium, c) Extract EELS sum spectra from ROI 1 and 2 in figure b) showing the particle is stronger in Si and weaker in O than the embedding medium and d) superimposed STEM-EDXS phase maps also indicating the particle is likely Si.

References

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[4] The authors wish to thank Tim McGrady for providing this sample for analysis.