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IT-10-P-2123 3D electron tomography analysis of silicon nanoparticles in SiC matrices by quantitative determination of EELS plasmon intensities

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Silicon nanoparticles (NPs) embedded in insulating or semiconducting matrices has attracted much interest for the third generation of photovoltaics, “all-Si” tandem solar cells. This study is to show how silicon NPs are distributed in 3D on a silicon carbide thin film using the electron tomography technique in the transmission electron microscopy (TEM). [2]

We first have assessed Si NPs distributions in such SiCx sample with a low degree of crystalline using bright field (BF) TEM tomography (figure 1) and found an average nearest neighbour spacing of two NPs of about 12nm. For more crystalline NPs, the projection requirement is no more fulfilled and only those Si NPs that are both crystalline and oriented to a Bragg reflection are detectable. [3] Therefore, in this case, conventional BF TEM signal is unsuitable for electron tomography and we applied spectrum imaging (SI) techniques: EELS SI imaging and EFTEM SI imaging. Since Si and SiCx have different plasmon energies, [4] we can extract Si plasmon and SiCx plasmon images from the spectrum images. We observed that only a proper fit of the plasmon spectrum with subsequent extraction of Si and SiCx plasmon images results in the correct Si ad SiCx distribution (figures 2 and 3), whereas just EFTEM images taken from windows around the Si and the SiC plasmon energy resulted in overlaps in the image.

For both, STEM and EFTEM SI signals, in figure 2 and 3, we are able to detect the entire population of NPs. In figure 3, the stripes like contrast inside of crystalline NPs shown in the BF TEM image persist in plasmon images. This is due to parallel beam illumination in EFTEM SI mode thus making the STEM SI imaging more suitable for tomography of these NPs. In Figure 2, for STEM SI, the contrast evolution during the tilting is thickness dependent, thicker part of the sample gives stronger contrast in the extracted plasmon images, and this nonlinear thickness effect can be corrected by introducing attenuation coefficient. [5]

In summary, to study the 3D distribution of Si NPs in SiCx matrix, we compared three signals from BF TEM, STEM and EFTEM SI signals. In order to overcome the non-linearity of contrast change during the tilting process, STEM-SI signal in combination with quantitative treatment of the plasmon spectra shows clear Si NP contrasts and overcomes limits set by the projection requirement.

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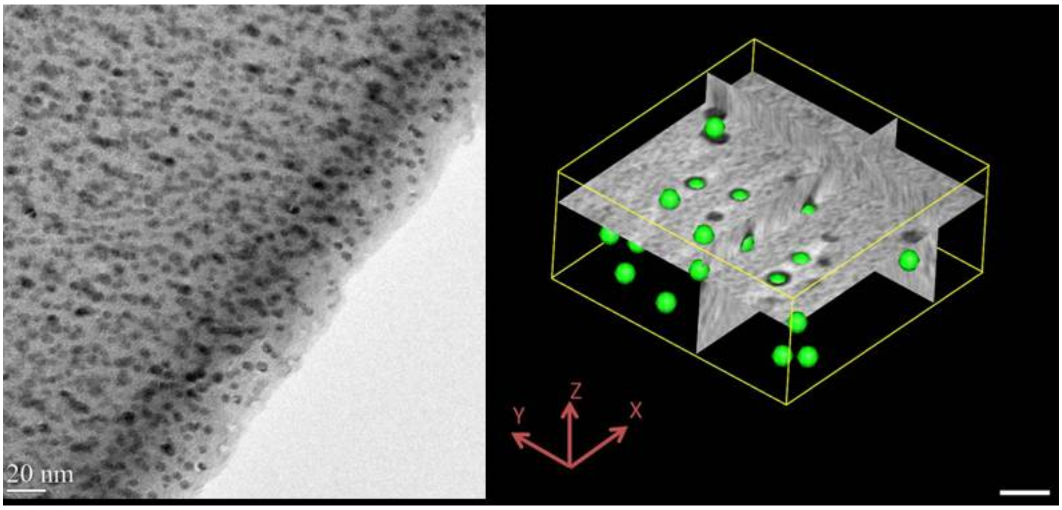

Fig. 1: Figure 1. (Left) 2D BF TEM image of Si nanoparticles embedded in amorphous Si riched SiC:H matrix, (Right) 3D model view of Si nanoparticles distributed in matrix, green spheres indicate Si nanoparticles, and reconstructed X, Y and Z images are also shown in the volume. Scale bar is 10 nm.

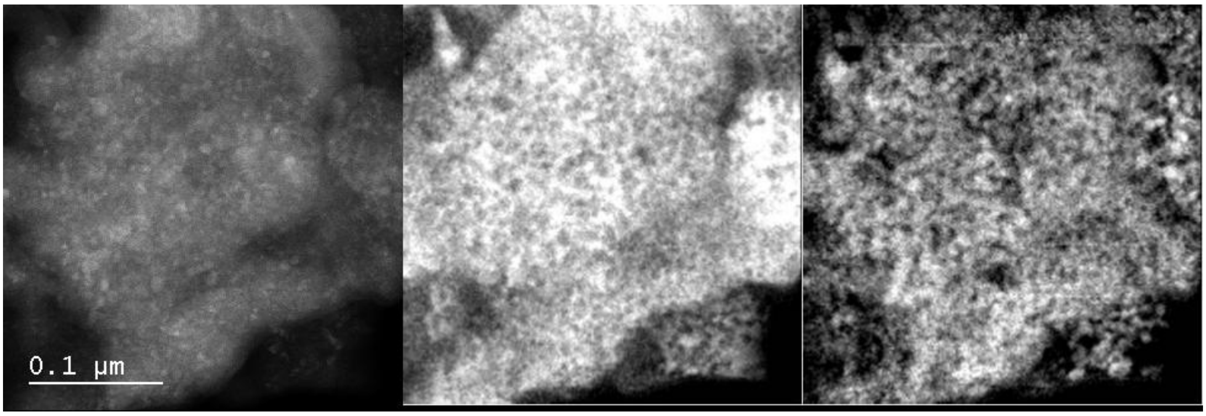

Fig. 2: Figure 2. (Left) 2D STEM-ADF image of Si nanoparticles embedded in SiCx matrix, (Middle) Si plasmon image, (Right) SiC plasmon image. Both plasmon images are extracted from STEM SI data set.

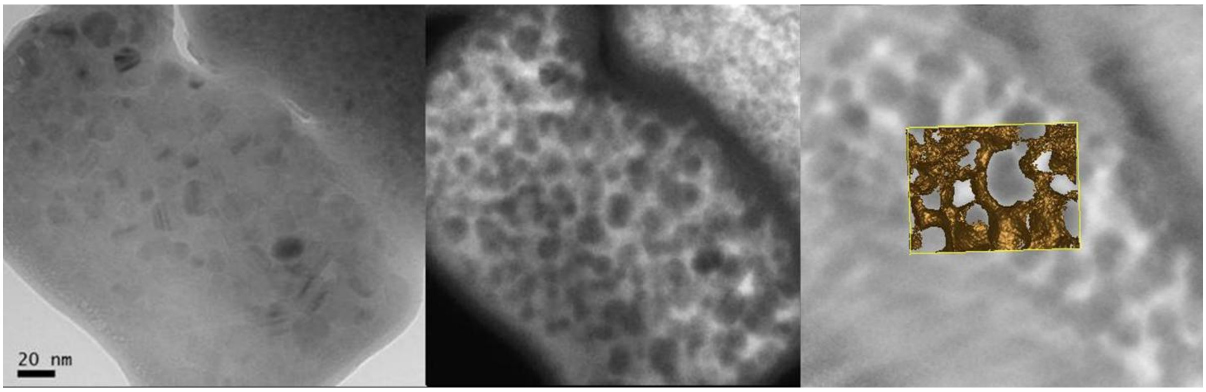

Fig. 3: Figure 3. (Left) 2D BF TEM image of Si nanoparticles embedded in SiCx matrix, (Middle) Si plasmon image, (Right) Reconstructed tomogram and the formation of Si networks were shown in the volume by using the isosurface. Plasmon images are extracted from EF TEM SI data set which is acquired with a 2 eV energy slit at 17 eV (Si).