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Atomic-Resolution Secondary Electron Imaging

AC-STEM with Secondary Electron (SE) imaging provides the unique capability of evaluating specimen surface morphology with atomic-resolution.

Introduction

Aberration Corrected Scanning Transmission Electron Microscopy (AC-STEM) is now widely used in material science research, product process control, and device failure analysis for a wide variety of different materials. The aberration-corrected electron probe scanned across a thin specimen provides atomic-resolution imaging not only from transmitted electrons (TE - HAADF, BF, ABF…), but also from secondary electrons (SE) emitted from the surface of the specimen. AC-STEM SE imaging provides a unique method of characterizing material structure including important depth information.

Discussion

When surface information of a thin specimen is desired, STEM SE imaging can be utilized. This includes tasks such as particle morphology, CD measurements, and defect inspection to name a few. In the case of defects, it is often important to understand their location within the thickness of a (S)TEM specimen. Investigations based solely on transmitted electron information can often be inconclusive especially in the case of 3-D structures since TE images only provide a projection of the entire thickness of the sample. In Figure 1, the BF-STEM (TE mode) image on the left, shows a brighter region above a threading dislocation induced V-defect at the ITO/GaN EPI interface. This contrast is indicative of a region having lower average Z, but it is impossible to distinguish whether the feature is simply filled with lighter material such as Carbon or is a void. However, SE imaging provides the conclusive answer. Since SE are emitted from very shallow depths in the sample (<50nm), changes in topography such as edges are observed to have higher SE yields (brighter) than the surrounding material. This sensitivity to subtle surface topography provides important surface details that are otherwise lost in TE images. In the corresponding SE image on the right of Figure 1, the brighter edges of the feature clearly identify it as a void at the center of the defect.

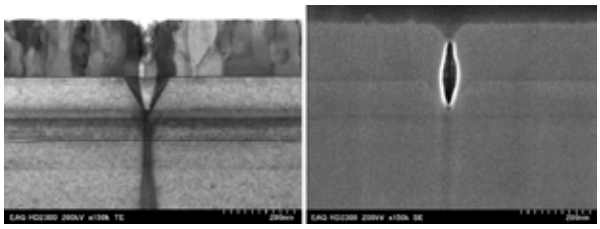


Figure 1: BF-STEM and SE images of voiding metal/EPI interface above a threading dislocation. Left: BF-STEM in TE mode; right: STEM-SE mode

The images in Figures 2-4 demonstrate atomic-resolution imaging (SE/HAADF/BF) of Si nanoparticles using a Hitachi HD-2700 AC-STEM. Figure 2. provides HAADF-STEM and SE overview images of a cluster of Si nanoparticles on a carbon support film. Since the SE image has much greater surface sensitivity than the HAADF image, it provides valuable surface morphology as well as depth information for each particle in the specimen. One larger particle was tilted to [110] zone axis and

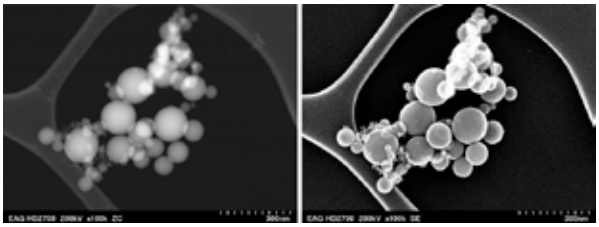


Figure 2: Overview images of Si nanoparticles on carbon support film. Left: HAADF-STEM (ZC mode); right: STEM-SE mode

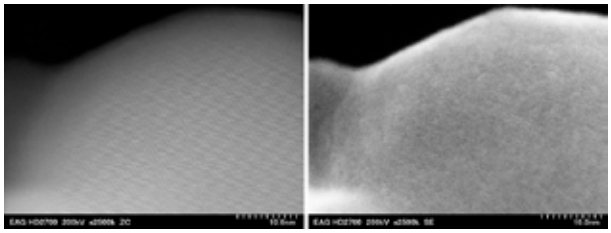
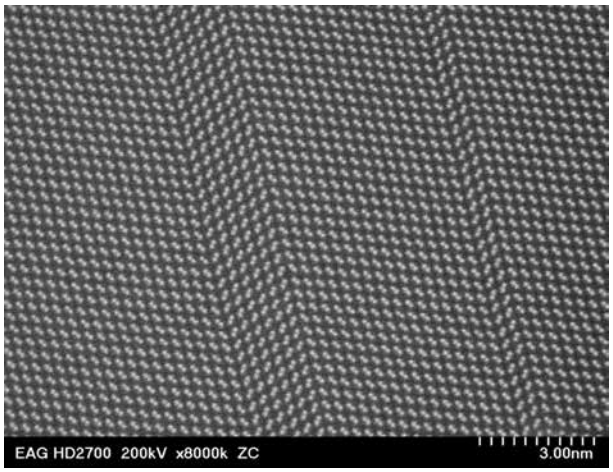


Figure 3: High-resolution images of a particle on [110] zone axis. Left: HAADF-STEM (ZC mode); right: STEM-SE mode



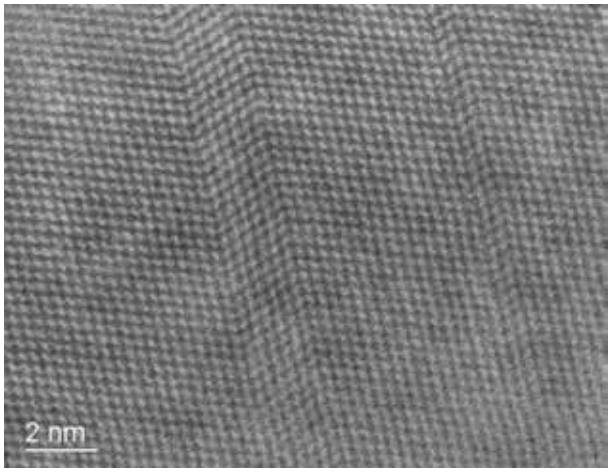


Figure 4: Ultra-high-resolution images at Si twin boundaries. upper: HAADF-STEM (ZC mode); lower: STEM-SE mode

higher magnification HAADF-STEM and BF-STEM images (Figure 3) reveal twin boundaries. Figure 4 shows ultra-high-resolution HAADF-STEM and SE images acquired at the twin boundaries. The SE image clearly shows Si atom columns and the location of the twin boundaries on the particle surface.

Conclusion

An SE detector in an AC-STEM provides SE imaging capability with atomic resolution. Ultra-high-resolution imaging of a thin specimen's surface as well as depth evaluation of 3D structures can be very important to solving complex atomic scale issues. This SE imaging capability is suitable for a variety of applications: semiconductor CD measurements, catalysts, device failure analysis, etc. At Eurofins EAG, our state-of-the-art instrumentation combined with extensive materials expertise, can provide critical information about your samples helping you launch your products faster and more efficiently. Contact us today to learn how we can help.