

Get more out of EELS spectra: noise reduction, original background-removal functions and component analysis

Martial Duchamp*, Chris B. Boothroyd, András Kovács and Rafal E. Dunin-Borkowski

Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons (ER-C)
and Peter Grünberg Institute (PGI), Forschungszentrum Jülich, D-52425 Jülich,
Germany

*contact e-mail: martial.duchamp@gmail.com

Abstract

Thin films of hydrogenated amorphous Si (a-Si:H) are used as active absorber layers in solar cells deposited on steel foil by roll-to-roll processing [1]. In order to improve the efficiency of such solar cells, the nature of the defects that act as charge recombination centres and decrease the internal electric field in the active Si layer needs to be understood. We have used electron energy-loss spectroscopy (EELS) in the transmission electron microscope (TEM) to study *n-i-p* thin film Si solar cells grown on steel foil or glass substrates. For a solar cell in which an intrinsic a-Si:H layer is sandwiched between 10-nm-thick n-doped and p-doped a-Si:H layers, we assess whether core-loss EELS can be used to measure the diffusion of B from the *p* to the *i* layer. The difficulty of such measurements results in part from the fact that the energy-loss near-edge structure from the Si L edge interferes with the B K edge at 188 eV. In addition, the Si L_{2,3} edge cross-section is five times larger than that of the B K edge. We use dedicated EEL spectrum acquisition and fitting procedures to reduce the detector noise and to separate the B K edge contribution from the Si fine structure for B concentrations as low as 1 at. %. We compare the shape of the measured B K edge with real space *ab initio* multiple scattering calculations and show that it is possible to separate the weak B K edge peak from the much stronger Si L edge fine structure by using log-normal fitting functions. Line profiles of B concentrations measured using core-loss EELS are compared with secondary ion mass spectrometry (SIMS) profiles recorded using two different ions energies from the same sample. We also assess whether changes in volume plasmon energy can be related to the electrically active B concentration and/or to the density of the material and whether variations of the volume plasmon line-width can be correlated with differences in the scattering of valence electrons in differently doped a-Si:H layers [1, 2].

In a separate experiment, we study the chemical compositions of defective regions in thin film Si solar cells using energy-dispersive X-ray spectroscopy

and EELS in the scanning TEM. We use nanometer-resolved chemical analysis to reveal the presence of ZnO in micrometer-long defective regions. We apply an unmixing algorithm to the EELS measurements to determine the chemical compositions of the defective regions objectively, without introducing artefacts from fitting procedures. The resulting spectral components, which are inferred to correspond to Si, ZnO and SiO₂ + C signals. The results obtained using this spectral decomposition procedure indicate that the defective regions in the Si layer are filled with ZnO, which diffuses along voids that propagate from the bottom of the absorber layer up to the top ZnO contact [3].

References

- [1] C. B. Boothroyd, K. Sato and K. Yamada, *Proceedings of the XII International Congress on Electron Microscopy, edited by L. D. Peachey and D. B. Williams, Seattle, Washington, 12-18 August 1990, (San Francisco Press, San Francisco, 1990), p. 80*
- [2] M. Duchamp, C. B. Boothroyd, M. S. Moreno, B. B. van Aken, W. J. Soppe and R. E. Dunin-Borkowski, *Journal of Applied Physics* **113** (2013), 093513
- [3] M. Duchamp, M. Lachmann, C. B. Boothroyd, A. Kovács, F.-J. Haug, C. Ballif and R. E. Dunin-Borkowski, *Applied Physics Letters*, **102** (2013), 133902