Investigation of dislocations by STEM in a scanning electron microscope

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Dislocations have significant effects on the properties of crystalline solids. Therefore, the characterization of dislocations with respect to their type, density and distribution is highly important. Transmission electron microscopy (TEM) is commonly used for dislocation analysis. Burgers vectors of individual dislocations **b** can be determined by exploiting the **g·b**=0 criterion where the sample is oriented in two-beam conditions **g**, and extinction of the dislocation contrast is utilized to determine the dislocation Burgers vector. Based on the reciprocity theorem, bright-field scanning transmission electron microscopy (BF-STEM) can be also applied for diffraction contrast analysis of defects if suitable imaging conditions are chosen [1]. Up to now, BF-STEM defect analyses were restricted to transmission electron microscopes operated at electron energies of 100 keV and above. However, modern scanning electron microscopes can be also equipped with a STEM detector making them capable of analyzing TEM samples. Two-beam conditions can be set up by either making use of a segmented HAADF-STEM detector [2] or with an on-axis CCD-camera positioned under the specimen to acquire transmission electron diffraction patterns. The latter approach was employed in this study using a Thermo Fisher Helios G4 FX instrument which is also equipped with double-tilt specimen holder for TEM specimens.

In this work we have investigated dislocations in a magnetic steel sample and in a single-crystalline indium nitride (InN) layer grown along the [001] direction on a Si (111) substrate. Fig. 1 shows 30 keV cross-section BF-STEM images of the InN layer and corresponding transmission electron diffraction patterns (TED). Two different two-beam conditions, (-120) in Fig. 1a,c and (002) in Fig. 1b,d are set up. Two dislocations marked by arrows in Fig. 1a show strong contrast under (-120) two-beam conditions. The line direction of the dislocations is parallel to the [001] growth direction. The dislocations completely vanish under (002) two-beam condition as seen in Fig. 1b. Hence, their Burgers vector must be perpendicular to the [001] line direction indicating that the dislocations are edge dislocations. The dark spots on the BF-STEM images are artifacts from sample preparation. As far as the magnetic steel sample is concerned, imaging is in general facilitated in the field-free operation mode of scanning electron microscope as opposed to the in-lens mode in TEM imaging where any change of sample or aperture positions leads to severe misalignment. Our work shows that defects analyses can be successfully performed in a scanning electron microscope even at moderate specimen thicknesses at 30 keV. This considerably extends the applicability of STEM imaging in scanning electron microscopes.

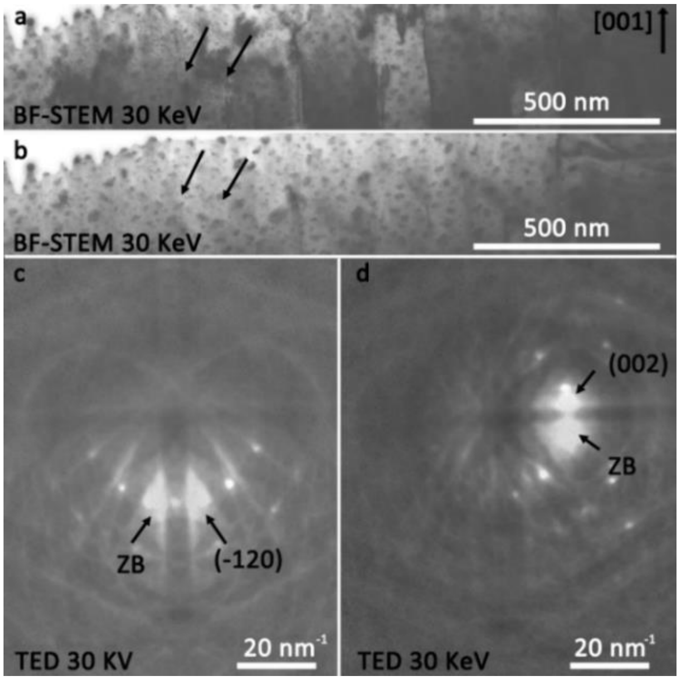

Fig. 1 (a,b) BF-STEM images and (c,d) corresponding TED patterns of InN. ZB indicates the zero-order beam.

1. Maher, D.M., Joy, D.C., Ultramicroscopy 1 (1976) 239-253.

2. Sun, C., Muller, E., & Gerthsen, D. A new method to orient samples by STEM in a scanning electron microscop e, European Microscopy Congress 2016.

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