Three-dimensional observation of dislocations in ferromagnetic iron using magnetic-field-free electron tomography

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Specimens in conventional transmission electron microscopy are placed in between the objective lens pole piece and therefore exposed to a strong magnetic field about 2 T. For a ferromagnetic specimen, magnetization of the specimen causes isotropic and anisotropic defocusing, deflection of the electron beam as well as deformation of the specimen, which all become more severe when the specimen tilted. Therefore electron tomography on a ferromagnetic crystalline specimen is highly challenging because tilt-series data sets must be acquired without changing the excitation condition of a specific diffraction spot. In this study, a scanning transmission electron microscopy (STEM) tomography method without magnetizing a ferromagnetic specimen has been developed for three-dimensional (3D) visualization of dislocations in iron, which is a typical ferromagnetic material. Magnetic-field-free environment down to 0.38 mT at the specimen position is realized by demagnetizing the objective lens pole piece of a commercial STEM instrument. By using a spherical aberration corrector with the magnetic-field-free environment, an "aberration-corrected Low-Mag STEM mode" with no objective lens field reaches a convergence semi-angle ~1 mrad and a spatial resolution ~5 nm, and shows an adequate performance of imaging dislocations under a two-beam excitation condition for a low-index diffracted beam. The illumination condition for the aberration-corrected Low-Mag STEM mode gives no overlap between the direct beam disk and neighboring diffraction disks. An electron channeling contrast imaging technique, in which an annular detector was located at a doughnut area between the direct beam and the neighboring diffracted beams, was effectively employed with the aberration corrected Low-Mag STEM mode to keep image intensity high enough even at large specimen-tilt angles. The resultant tomographic observation (Fig. 1) visualized 3D dislocation arrangements and active slip planes in a deformed iron specimen [1].

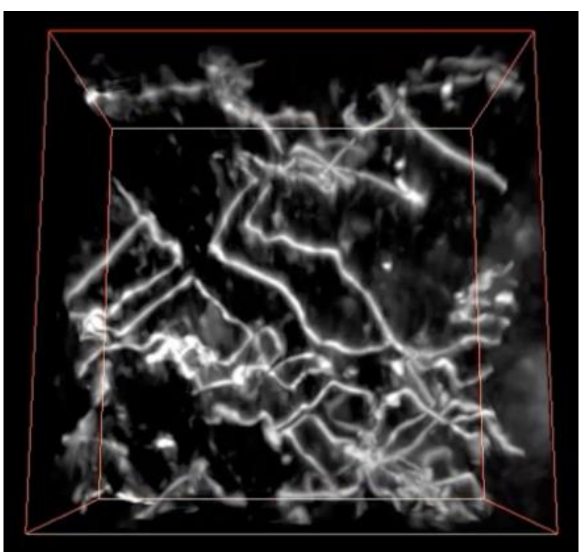

Fig. 1. A 3D reconstructed view of dislocations in a deformed iron specimen [1]. The reconstructed volume is 1043 nm x 1043 nm x 600 nm and the pixel size is binned to 2.98 nm from the original size of 1.49 nm.

[1] Hasezaki K. L. et al., Ultramicroscopy, 182, 249-257 (2017).

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