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Dislocation Imaging by Precession Electron Diffraction

Dexin Zhao and Kelvin Y. Xie

Texas A&M University, College Station, Texas, United States

Dislocation is a major plasticity carrier, which also dictates the mechanical properties, in metallic systems[1]. Transmission electron microscopy (TEM) is a powerful technique to allow for the visualization of dislocations. Both two-beam condition and low-index zone axis imaging (multiple-beam condition) have been used to reveal dislocations. However, both techniques have drawbacks. In the two-beam condition, some dislocations are invisible due to the $g \cdot b = 0$ criterion, thus limits the holistic illumination of dislocations. Regarding the low-index zone axis imaging, more dislocations could be illustrated, but the dynamical effect usually overwhelms the contrast from the dislocation lines.

In this work, we employed precession electron diffraction (PED) as a tool for dislocation imaging. PED is a diffraction-based technique, where pixel-by-pixel diffraction patterns of the whole scanned area are acquired. The experimentally acquired diffraction patterns are then compared to those in the database to offer crystal orientation and elastic strain information at the nanoscale[2–6]. Here, we realize the beam precession could also be utilized to potentially generate high quality micrographs with enhanced dislocation contrast. One major result of beam precession is to average out the dynamical effect in TEM micrographs and to show high-quality kinematical information[7]. To demonstrate such capability, we used a deformed AZ31 magnesium alloy as the model material. The crystal was tilted to the $[11\bar{2}0]$ zone axis and bright-field images were first taken. In the example shown in Fig. 1a, the dislocations are visible, but the contrast is low (appearing to the eyes) due to the strong dynamical effect of the beam-crystal interaction. In the same area, we then acquired the PED map and formed the virtual bright-field (VBF) image using the direct beam. Since the volumes that contain dislocations scatter the incident electron beam more strongly, this leads to a lower intensity of the direct beam. Thus, dislocation lines appear to be dark in contrast (Fig. 1b). Compared to the zone-axis bright-field micrographs, the dislocations illustrated by PED exhibit much-improved contrast. Even with only 0.3° precession, most of the dynamic contrast has been eliminated. To further compare the dislocation clarity in the above two techniques, intensity profiles from the same region are plotted (Fig. 1c). Dislocations are better illuminated in the PED micrograph in the following three ways: (1) a more uniform background, (2) a much brighter background, and (3) much steeper intensity difference from dislocations to the background. We also noted the precipitates are better resolved in PED, as shown by the white arrow in Figs. 1a and 1b. In conclusion, we have demonstrated PED is a powerful characterization technique that could remove the dynamical effect and better reveal dislocations under the multiple-beam conditions.

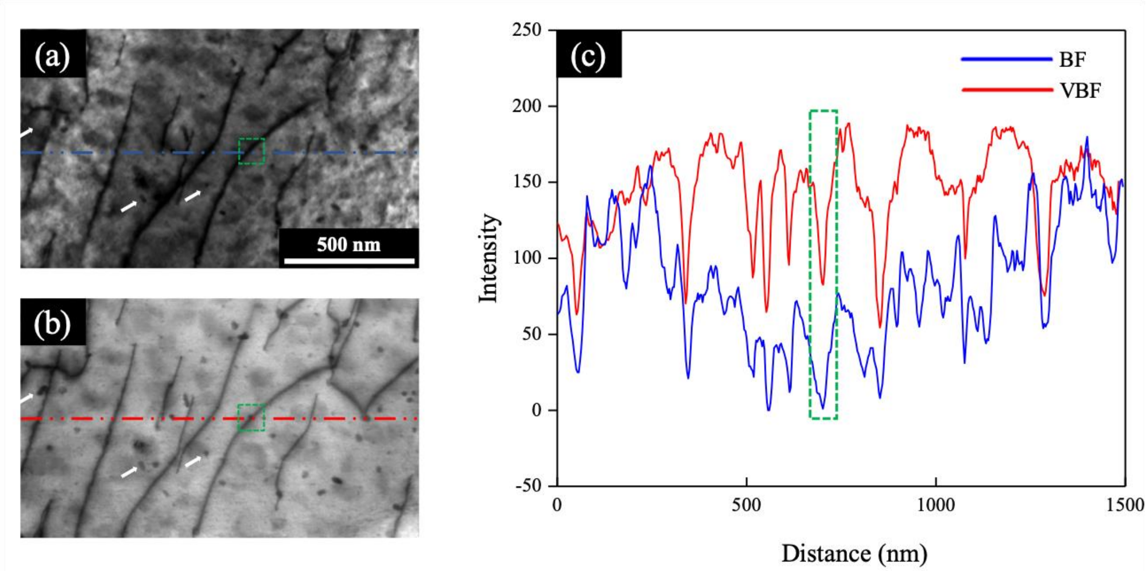

Figure 1. (a) Bright-field (BF) and (b) virtual bright-field (VBF) image of dislocations in an Mg AZ31 alloy and (c) corresponding intensity profile for the two dash lines in the BF and VBF images

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