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Dislocation imaging via the virtual dark-field technique using the precession electron diffraction data

Dexin Zhao and Kelvin Xie

Texas A & M University, United States

Dislocation is an important plasticity carrier in metallic systems [1]. Imaging dislocations is a critical step to understand the deformation mechanisms. Transmission electron microscopy (TEM) serves as a powerful tool to visualize dislocations directly [2]. Two-beams bright-field and weak beam dark-field (WBDF) are two common methods to reveal dislocations and to calculate the corresponding Burger vectors [3]. However, tilting is required to excite specific diffraction spots and to satisfy the two-beam condition, from which the effort is non-trivial. In some cases, certain diffraction spots cannot be easily excited, considering the limited tilting angles inside TEM (usually $\pm 40^{o}$).

To overcome the above challenges, in this work, we applied precession electron diffraction (PED) to acquire micrographs and using virtual apertures to reveal the dislocations [4–6]. With PED, diffraction patterns are able to be collected pixel-by-pixel, with a nano-scale step size of the scanned area; dislocation images could be reconstructed from these diffraction patterns virtually. From previous studies [7,8], we demonstrated the virtual bright-field (VBF) technique (reconstructed dislocation image from the center spot of diffraction pattern) could better illuminate dislocations with more uniform background and stepper intensity via averaging out dynamical effect. In this study, instead of only using the center spot (direct beam), we used diffraction spots (diffracted beams) to reconstruct the virtual dark-field (VDF) dislocation images. Here, we chose a 3%-strained pure Mg as the model material. The target grain was firstly tilted to the [2-1-10] zone axis, and a regular TEM bright-field (BF) image was taken (Fig. 1a). To reveal the dislocation characters, careful tilting experiments were then performed near the zone axis of the examined grains, and $\mathbf{g}\cdot\mathbf{b} = 0$ invisibility criterion was used to illuminate <*a*> and <*c*> components separately (Fig. 1b and c). The **g**-vectors we used to illuminate dislocations are **g** = [0-110] (two-thirds of <*a*> components) and **g** = [0002] (all <*c*> components). To demonstrate the PED capability, we acquired a PED map with a 10 nm step size in the same area and generated a VBF image using center spots of the diffraction patterns (Fig. 1d). Moreover, we used [0-220] and [0004] diffraction spot to reconstruct VDF image of <*a*> and < c > components. The diffraction spots we selected are away from the center spot to increase the signal-to-noise ratio. After comparing with the regular TEM DF images (Fig. 1b and c), the VDFs are shown to correctly illuminate <*a* >and< *c* > components (Fig. 1e and f), but without any need for additional specimen tilting in TEM. A few examples of <*a*> dislocations (origin line) and <*c*> dislocations (green line) were highlighted in both conditions. In conclusion, we have demonstrated dislocation imaging could be much simpler with PED via the VDF technique as the effort-demanding tilting step could be avoided.

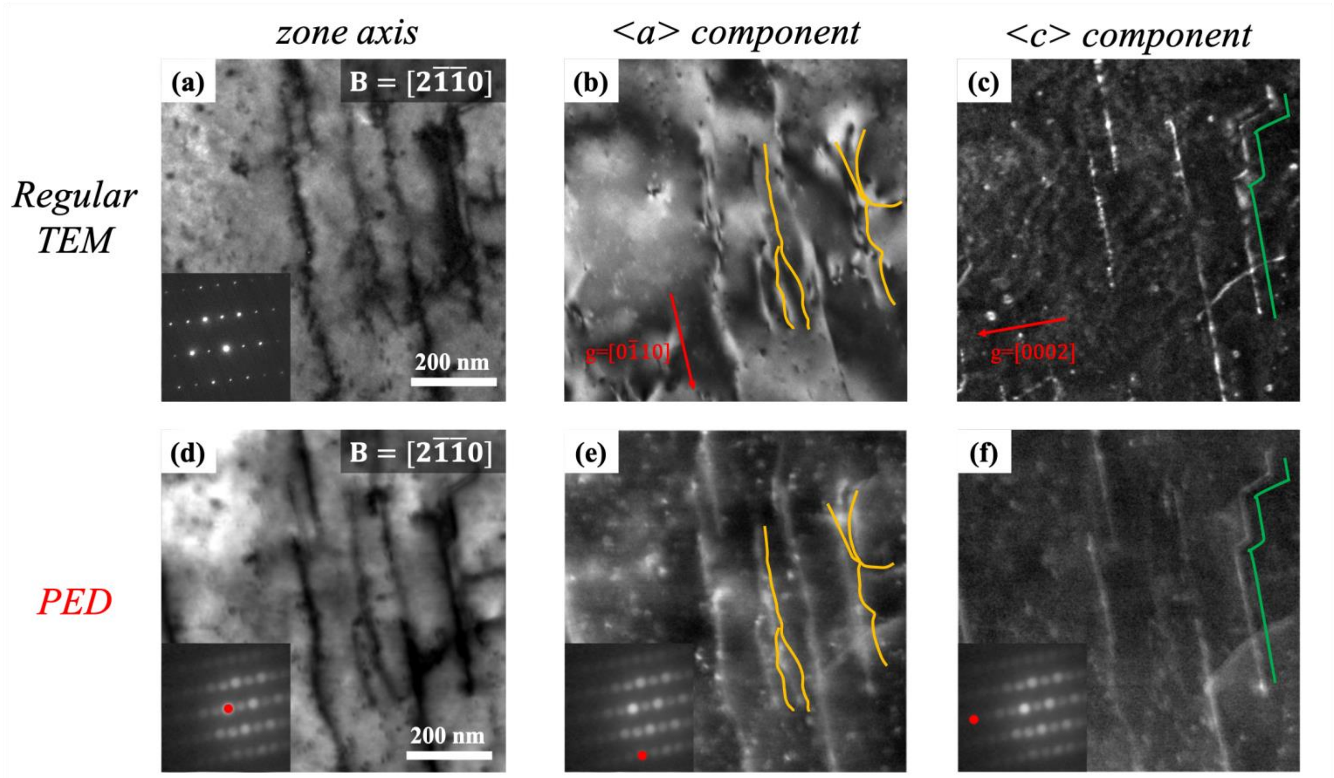

Figure 1. Regular TEM dislocation (a) zone axis bright-field (BF) and (b-c) weak beam dark-filed (WBDF) micrographs revealing the and components in pure Mg. Precession electron diffraction (PED) (c) zone axis virtual bright-field (VBF) and (e-f) virtual dark-field (VDF) imaging and components in pure Mg. Red discs are the spots used to reconstruct the virtual image. A few examples of dislocations (origin lines) and dislocations (green lines) were highlighted.

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