doi:10.1017/S1431927620017389
Microsc. Microanal. 26 (Suppl 2), 2020

High Resolution Imaging of Dislocations Using Weak Beam Dark Field STEM

Jiashi Miao

Ohio State University, Columbus, Ohio, United States

Conventional transmission electron microscopy (CTEM) with parallel beam illumination has been widely used to study dislocation structures. Due to resolution limitation, it is hard to use strong beam CTEM imaging to reveal narrowly dissociated dislocations, which are frequently observed in alloys with low stacking fault energy. The development of weak beam dark field (WB DF) TEM [1] made it possible to achieve high resolution imaging of such dislocation structures in CTEM mode. Recently, a high resolution method of imaging dislocations in STEM mode: weak beam dark field (WB DF) STEM, was developed [2]. Fig. 1 a) schematically illustrates the systematic row convergent beam illumination condition in STEM mode. Fig. 1 b) and c) show the difference between strong beam and weak beam imaging in STEM mode. Under the strong beam condition, the center of 1**g** (**g** being the diffraction vector) diffraction disc is set to fulfill the Bragg condition, while under the weak beam condition, a high order diffraction disc such as 3**g**, 4**g**, etc., is set to satisfy the Bragg condition. In this WB DF STEM imaging method, an objective aperture is used to select the first order diffraction (1**g**) disc for imaging as shown in Fig. 1 c). Previous experimental study shows that dislocation characterization such as **g** · **b** and **g**· **R** visibility analysis, can be conducted in WB DF STEM [2]. This WB DF STEM method can offer the same high resolution as WB DF TEM in imaging dissociated dislocations [2].

In this study, WB DF STEM images were simulated using CTEMsoft [3] to investigate optimal imaging conditions. Fig. 2 a) shows examples of simulated dark field STEM images of a dissociated edge dislocation with a dissociation distance of 5 nm in copper under imaging conditions varying from strong beam to weak beam. The stacking fault plane is parallel to (111) plane. The full edge dislocation has a Burgers vector of a/2[-101], which dissociates into two Shockley partial dislocations with a Burgers vector of a/6[-1-12] and a/6 [-211] respectively. A systematic row diffraction vector of (-202) is used in the simulation. Under this diffraction condition, both partial dislocations are visible, while the stacking fault is invisible. The simulation was conducted using a beam convergence angle of 9 mrad and an accelerating voltage of 200 kV. The thickness of TEM foil is 100 nm. The accumulative intensity profiles across the simulated images of the dissociated dislocation are given in Fig. 2 b). The locations of two partial dislocations are indicated using two red dash lines in Fig. 2 b). The simulation results in Fig. 2 b) show that the dissociation distance measured from the intensity peaks in the simulated images decreases with the increase of deviation parameter (s). The distances between the intensity peaks and the locations of dislocation cores also decrease with the increase of deviation parameter. Under the strong beam condition (s = 0), the measured dissociation distance is 16.5 nm, which is much larger than the real dissociation distance (5 nm), indicating large errors in measuring dissociation distances using strong beam conditions. Under the (**g**□3**g**) weak beam condition in Fig. 2 a), the center of 3**g** diffraction disc is set to satisfy Bragg condition and the deviation parameter at the center of 1**g** is equal to 0.151 nm^{-1}. The measured dissociation distance from the simulated WB DF STEM image is 5.5 nm. With the further increase of the deviation parameter to 0.226 nm^{-1}, the measured dissociation distance decreases to 5.2 nm, which is 4% larger than the real dissociation distance. Fig. 2 c) shows the variation of measured dissociation distances with the increase of deviation parameters. Similar simulation results were obtained on dissociated screw dislocations. Current study showed that high resolution imaging of dislocations can be achieved using WB DF STEM method in imaging conditions with properly selected deviation parameters. The effects of other imaging parameters including beam convergence angles, accelerating voltages etc., on WB DF STEM images were also examined. Practical examples and guidelines of using WB DF STEM in studying engineering alloys will be given [4].

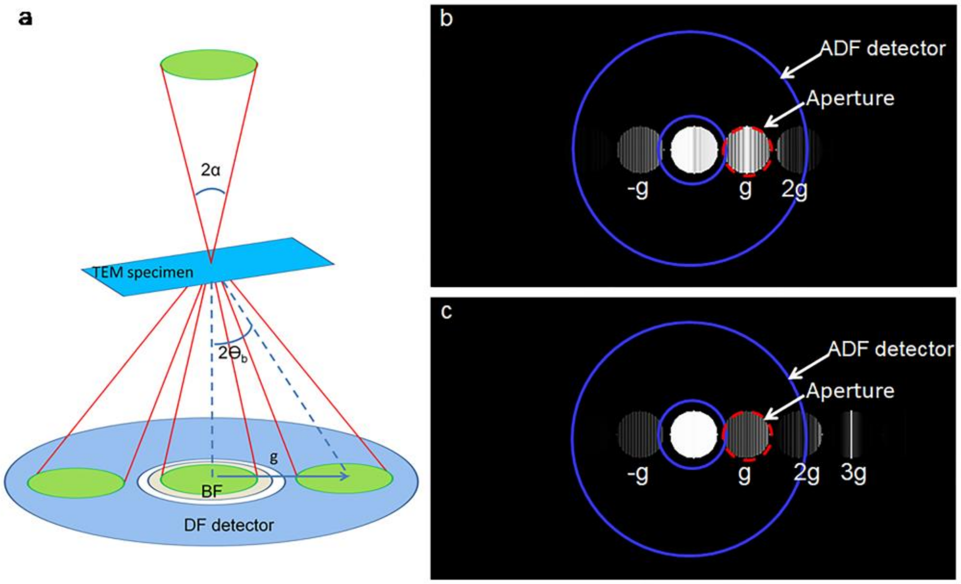

Figure 1. a) schematic illustration of the systematic row convergent beam illumination in STEM mode; b) illustration of the experimental set-up for strong beam STEM imaging; c) illustration of the experimental set-up for WB DF STEM (g.3g) imaging.

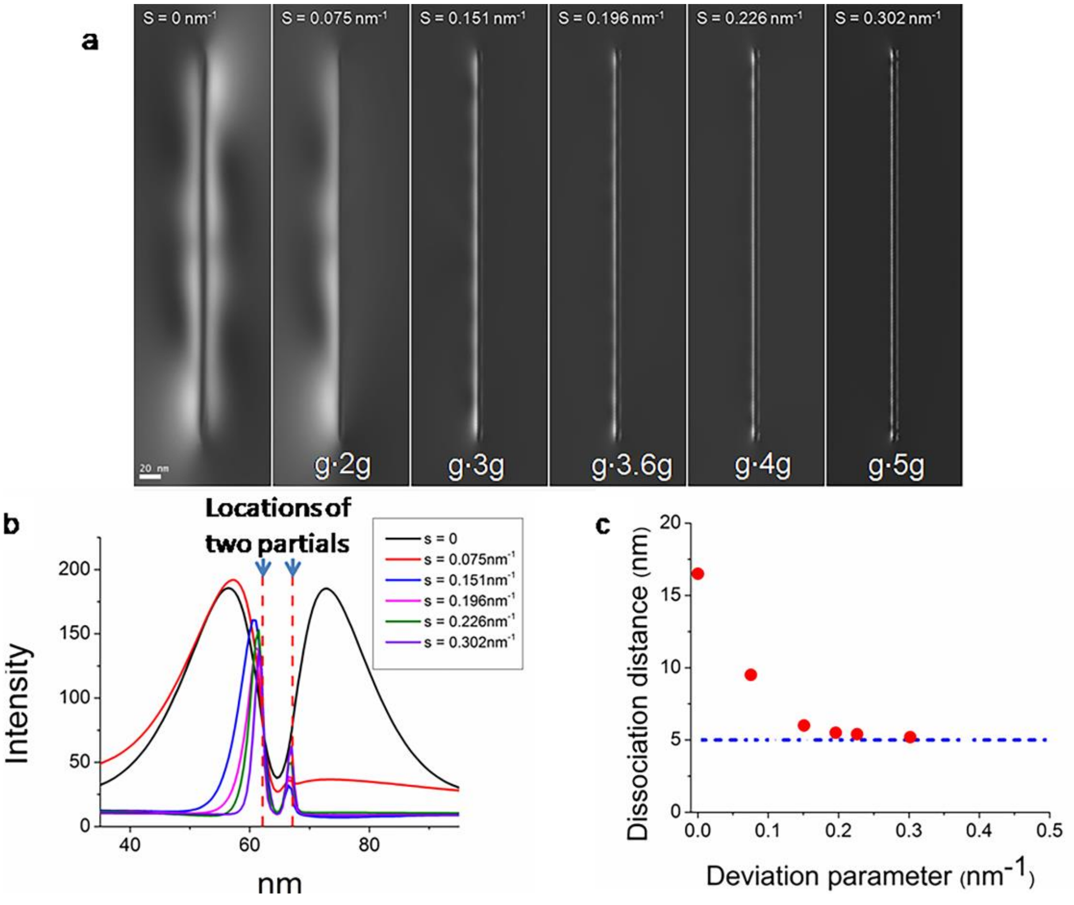

Figure 2. a) simulated dark field STEM images of a dissociated edge dislocation under different imaging conditions; b) accumulative intensity profiles across the simulated dissociated dislocation images with the locations of two partial dislocations highlighted using red dash lines; c) the variation of dissociation distances measured from the simulated images with different deviation parameters.

References

[1] D.J.H. Cockayne, I. L.F. Ray and M. J. Whelan, Philosophical Magazine A 20 (1969), p.1265.
[2] J. Miao, S. Singh, J. Tessmer, M. Shih, M. Ghazisaeidi, M. De Graef and M.J. Mills, Microscopy and Microanalysis 24 (2018), p.2202.
[3] M. De Graef, Microscopy and Microanalysis 16 (2010), p.246.

[4] The author is grateful to Prof. M. De Graef (CMU) and Prof. M.J. Mills (OSU) for helpful discussions.