Three-dimensional analysis of plastic strain propagation in metallic materials by 3D-EBSD

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Metallic materials such as steel and iron base alloy have been widely used as base materials supporting infrastructure in human society. In order to discuss deformation and fracture behaviour of metallic materials, it is important to understand propagation of plastic strain and deformation in a crystal grain or in the vicinity of grain boundary because the materials consist of many crystal grains. As a three-dimensional analysis technique, 3D-EBSD is very useful to take three-dimensional crystal information and has been applied to metallurgical study [1]. In 3D-EBSD measurement, cross sectioning with FIB and orientation mapping with EBSD are carried out alternatively, and then three-dimensional images are reconstructed with a series of obtained EBSD maps. In this study, 3D-EBSD technique was applied to analyze propagation of plastic deformation in metallic materials.

A well polished small nickel plate (10mm×10mm×1mm) was annealed in a vacuum furnace for 3hr at 973K, and then a small impression was made with a Vickers indenter, which has a diamond tip in the form of a square based pyramid, on a surface of the plate. A weight of 10g was loaded on the indenter. The impression was smaller than 2μm in depth under the loading condition. 3D-EBSD measurement was carried out with an integration instrument of FE-SEM, FIB and EBSD: Carl Zeiss 1540EsB and Oxford-HKL NordlysF. In this instrument, cross sectioning and orientation mapping are automatically controlled by acquisition software: HKL fast acquisition. Figure 1 shows snap shot images during EBSD and FIB machining. In the experiment, EBSD maps were obtained from 30μm×30μm area. A pixel size of the EBSD maps was 200nm×200nm. Every cross section had a thickness of 200nm. In order to extract information of plastic deformation from EBSD maps, the misorientation angle of deformed crystal was calculated with a rotation matrix [2].

Figure 2(a) shows a two-dimensional contour map of misorientation angle obtained at a depth of 1.8μm from a surface of the nickel plate on which a small impression is indented. The observed area includes a growth twin of crystals A and B as shown in Fig. 2(a). The deformed region around the impression has a larger misorientation angle than five degrees. The region near the centre of the impression, however, has a smaller misorientation angle than one degree. This indicates that severe plastic deformation occurs at the place touching the face of the pyramid shaped indenter, and that little deformation occurs at the apex of the indenter. Figure 2(b) shows a three-dimensional map reconstructed with a series of the contour maps obtained by 3D-EBSD measurement. In the three-dimensional map, it was found that the nickel crystal is slightly deformed and still has a misorientation angle of several degrees at a depth of 10μm from the surface. This indicates that the plastic deformation made with the indenter arrives at the region five times as deep as the depth of the impression. Figures 3(a) and 3(b) show cross sectional views of the three-dimensional map across and along the twin boundary, respectively. Plastic deformation of the crystal shows anisotropic propagation, and propagation of plastic deformation is obstructed at the twin boundary. It is considered that the anisotropic propagation is caused by restriction that a slip plane and a slip direction in nickel crystals possessing fcc structure are {111} and <-110>, respectively, and that a twining plane having the same index as a slip plane of {111} is responsible for relaxation of the plastic deformation. Thus, 3D-EBSD is a powerful technique to visualize three-dimensional propagation of plastic deformation and strain, and the obtained results should contribute to crystal plasticity studies.

References

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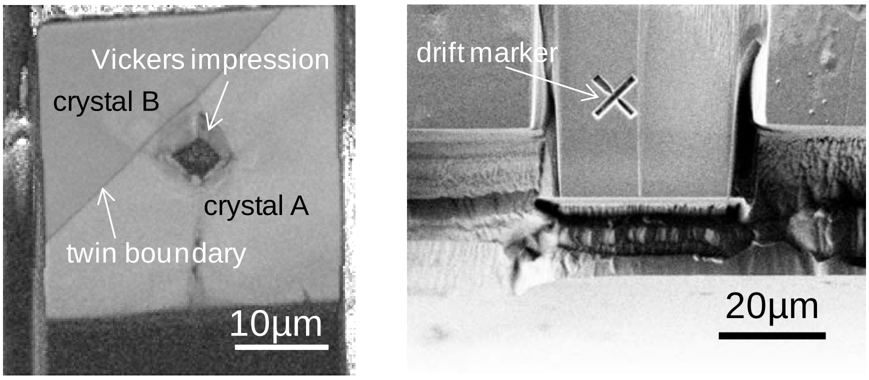
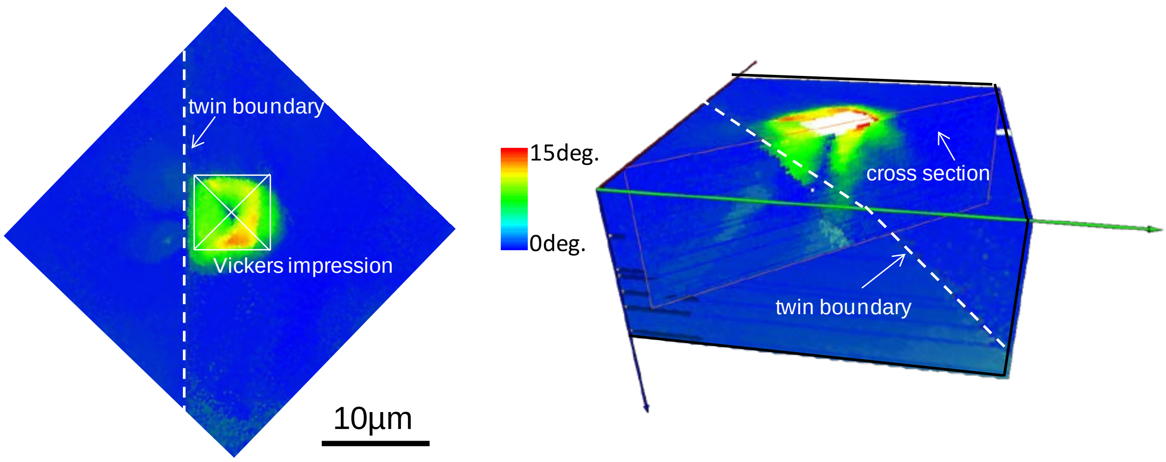


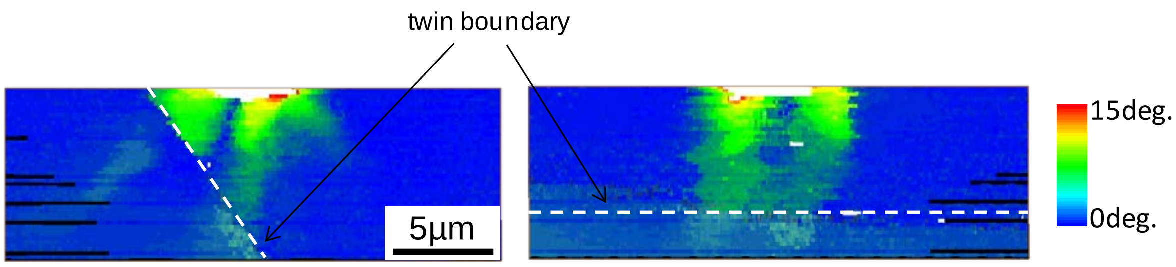
EBSD position FIB position

Figure 1. *A snap shot images during EBSD and FIB machining. Observed region has two crystals which are in twin relation. A Vickers impression and a twin boundary are arrowed in EBSD position. A cross mark observed in FIB position is a marker for drift correction.*



(a) cross section at a depth of 1.8µm (b) 3D reconstructed image

Figure 2. *Contour map images of misorientation angle, (a) 2-dimentional contour map at a depth of 1.8µm from the surface of nickel plate (b) 3D reconstructed image. The white dotted lines in figures indicate twin boundary.*



(a) across the twin boundary (b) along the twin boundary

Figure 3. *Cross sectional view of 3D reconstructed contour map of misorientation angle. A cross sectional image across the twin boundary shows that the twin boundary obstructs propagation of plastic deformation.*