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Electron imaging with an EBSD detector

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ABSTRACT

Electron Backscatter Diffraction (EBSD) has proven to be a useful tool for characterizing the crystallographic orientation aspects of microstructures at length scales ranging from tens of nanometers to millimeters in the scanning electron microscope (SEM). With the advent of high-speed digital cameras for EBSD use, it has become practical to use the EBSD detector as an imaging device similar to a backscatter (or forward-scatter) detector. Using the EBSD detector in this manner enables images exhibiting topographic, atomic density and orientation contrast to be obtained at rates similar to slow scanning in the conventional SEM manner. The high-speed acquisition is achieved through extreme binning of the camera—enough to result in a 5×5 pixel pattern. At such high binning, the captured patterns are not suitable for indexing. However, no indexing is required for using the detector as an imaging device. Rather, a 5×5 array of images is formed by essentially using each pixel in the 5×5 pixel pattern as an individual scattered electron detector. The images can also be formed at traditional EBSD scanning rates by recording the image data during a scan or can also be formed through post-processing of patterns recorded at each point in the scan. Such images lend themselves to correlative analysis of image data with the usual orientation data provided by and with chemical data obtained simultaneously via X-Ray Energy Dispersive Spectroscopy (XEDS).

1. Introduction

Since the very first micrographs generated from data obtained using automated Electron Backscatter Diffraction (EBSD) or orientation imaging microscopy (OIM) [1], the appreciation of the ability of these maps to illuminate salient features of microstructure has steadily grown. Much of the early focus was on the quantitative crystallographic orientation data behind the images; but, the basic ability to form microstructural images from the OIM data has drawn many researchers unfamiliar with crystallographic orientation to EBSD. However, even with the speed of modern EBSD systems, the collection times required to obtain the orientation data precludes the use of OIM mapping as an imaging tool in the conventional sense.

One challenge for EBSD work is locating a suitable area on the sample for collecting EBSD data. As a highly tilted sample ($\sim 70^{\circ}$) with a smooth surface is preferred for producing good EBSD patterns, imaging the surface of the sample with traditional secondary electron imaging (SEI) or backscattered electron imaging (BEI) is difficult. To alleviate this challenge, EBSD detectors often have diodes mounted at various positions near the perimeter of the phosphor screen. These diodes capture electrons scattered in a forward direction due to the sample tilt and are thus generally termed forward-scatter detectors (FSDs). An FSD enables an operator to quickly collect a high-intensity and high-contrast image of the tilted sample surface. Thus, the sample can be surveyed using FSD imaging to locate a region for characterization via full EBSD analysis.

Day and Quested [2] showed the benefits of collecting multiple images of the same sample area using multiple diodes. They noted that these images differed from each other and proposed that they could be combined to create composite color images of the microstructure. While Day and Quested focused on the ability of these detectors to provide orientation contrast, others have shown that FSD imaging also shows atomic density (Z) contrast [3] and/or

Abbreviations: BEI, Backscatter Electron Image; BSD, Backscattered Electron Detector; CCD, Charge Couple Device; EBSD, Electron Backscatter Diffraction; FIB, Focused Ion Beam; IQ, Image quality as it pertains to the band-to-background contrast in an EBSD pattern; FPS, Frames per second; FSD, Forward-scattered Electron Detector; OIM, Orientation Imaging Microscopy; PRIAS, Pattern Region of Interest Analysis System; ROI, Region of Interest; SE, Secondary Electron; SED, Secondary Electron Detector; SEI, Secondary Electron Image; SEM, Scanning Electron Microscope; STEM, Scanning Transmission Electron Microscope; T-EBSD, Transmission Electron Backscatter Diffraction; TEM, Transmission Electron Microscope; TKD, Transmission Kikuchi Diffraction; VFSD, Virtual Forward-scattered electron Detector; WD, Working Distance; XEDS, X-Ray Energy Dispersive Spectroscopy

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topographic contrast. The balance between the different contrast mechanisms changes depending on the position of the diode relative to the phosphor screen or more importantly relative to the point of incidence of the beam on the sample. For example the contrast differs when the detector unit is fully inserted compared to when it is retracted [4]. One of the drawbacks of using multiple FSDs is that each diode requires signal amplification in order to form an image. Thus, when multiple diodes are used either multiple amplifiers are needed or the images must be obtained sequentially through the same amplifier; thus, the benefits of multiple FSD detectors are often not fully realized.

As an extension of a study on image quality (IQ) mapping [5], Wright and Nowell explored using the EBSD camera itself as a set of multiple FSDs [6]. In essence, each pixel of the camera operates as an individual FSD. If the intensity at a specific pixel is recorded at each point during a scan then this data can be used to form an FSD-like image of the scan area. These initial studies [6] were performed using patterns recorded at each point during a scan using a typical camera operating condition (96×96 pixel patterns). The recorded patterns were further reduced in software to a 3×3 array of pixel bins. The intensities recorded within bins at each point in the scan grid were then used to form a set of individual microstructural images as shown in Fig. 1. As with multiple diodes, these images clearly showed differences arising from differences in the positions of the bins from which the images were formed.

The terms synthetic-BSD, virtual-FSD (VFSD), hybrid-FSD, and PRIAS (Pattern Region of Interest Analysis System) have all been used to describe the use of the EBSD detector as a set of multiple FSDs. Recently, there has been renewed interest in this type of imaging [7–9]. As in the Wright and Nowell [6] study, these studies have all been performed post-acquisition using patterns saved at each point of the scan grid during a conventional OIM scan. Indeed, this has given more impetus for saving of patterns during an OIM scan. One advantage of the CCD cameras used in modern EBSD systems is that they can be binned down in hardware to increase the collection efficiency of the EBSD detector and the speed of operation. Thus, instead of using an individual camera pixel as an FSD, a bin of pixels can serve as an FSD. This enables rapid imaging of the sample surface prior to performing EBSD analysis similar to FSD imaging.

2. Materials

The following materials are used in this study. They were selected so as to emphasize the effectiveness of the imaging technique to emphasize different elements of the microstructure. The working distance (WD) used for each sample is also listed.

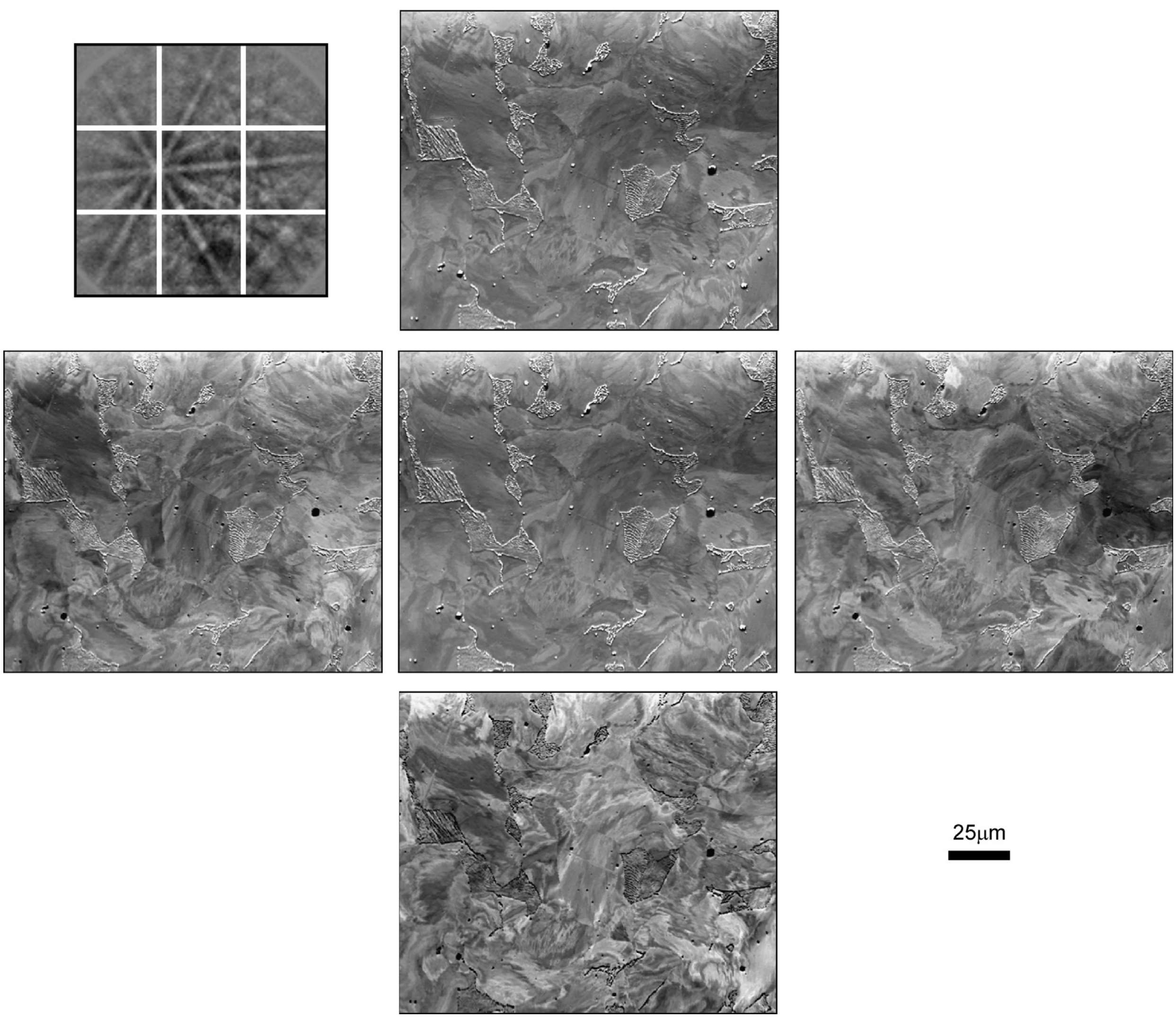

Fig. 1. VFSD images formed from five virtual apertures defined as squares on the EBSD pattern as shown in the inset.