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Improving Data from Electron Backscatter Diffraction Experiments using Pattern Matching Techniques

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Since the first electron backscatter diffraction (EBSD) systems were developed in the early 1990s, automated indexing of Kikuchi diffraction patterns has been based on the detection of individual Kikuchi bands using the Hough image transform (or variants thereof), with subsequent evaluation of interplanar angles to determine the 3D crystallographic orientation [1]. This approach has been significantly refined in the subsequent 3 decades but still underpins all commercial EBSD systems due to its high speed and robust performance with noisy diffraction patterns. Although dynamical simulations of EBSD patterns have been available for ~15 years [2], it was only relatively recently that researchers implemented pattern correlation techniques as an alternative to Hough-based indexing, with the development of the "dictionary indexing" approach [e.g. 3]. Further recent developments have accelerated the application and speed of dictionary-based indexing, with benefits including improved indexing in highly deformed and nanocrystalline materials, where the EBSD pattern quality can be insufficient for reliable Hough-based indexing. However, despite these improvements, this "brute force" indexing approach is still relatively slow and, in the majority of EBSD application fields, provides little or no benefit over conventional Hough-based indexing.

In this paper we present new developments in the use of EBSD pattern correlation for improving the quality of EBSD datasets. Our focus is not to replace Hough-based indexing but instead to utilize the valuable orientation and phase information provided by real-time analyses. Although not a new strategy [e.g. 4], this approach significantly reduces the number of potential simulations that need to be considered for each analysis point, thus greatly increasing the speed of the pattern matching process. Our work, in the first instance, is focused on improving the orientation precision of each measurement, and on minimizing the non-indexed or incorrectly indexed points in EBSD datasets.

Improving the orientation precision of EBSD measurements is beneficial in applications where small orientation changes need to be resolved. Conventional Hough-based indexing has an orientation precision of 0.1 – 0.5°, which can be reduced below 0.05° using real-time solution refinement processes (such as "Refined Accuracy" in the AZtec software). However, such precision is insufficient for the study of orientation changes associated with individual dislocations. In this work the EBSD patterns are stored during the initial analysis and then, during offline reprocessing using the AZtecCrystal EBSD data processing software, simulated patterns covering orientations close to the originally measured orientation are used to refine each orientation. This process is fast, with speeds possible in excess of 1000 reprocessed patterns per second (for low pattern resolutions) and can give a final orientation precision better than 0.01°. The results shown in figure 1 are taken from an EBSD analysis of a GaN thin film, collected at 200 patterns per second with only 156 x 128 pixel pattern resolution. Live indexing using Refined Accuracy reveals some of the dislocation structure (figure 1a), but many of the threading dislocations visible in the forescatter electron image (figure 1b) are not well resolved.

Following offline refinement using pattern matching, all the dislocations are visible (figure 1c) and can be subsequently classed as screw <c> type or edge <a> type.

The second example shows how pattern matching can be used to effectively improve the indexing success rate in challenging samples. Here, a nanocrystalline Cu film has been analyzed using transmission Kikuchi diffraction (TKD). In the finer matrix regions, the pattern quality is very poor (figure 2a) and the Hough-based indexing approach fails (figure 2b). During the initial analysis, only the non-indexed patterns were stored and these were subsequently reprocessed using an intelligent, iterative pattern matching approach. The results (figure 2c) show that the dataset quality has been significantly improved, with far more information in the nanostructured matrix areas – crucially without interpolation from or duplication of existing data. Further examples of the use of pattern matching to improve EBSD data quality will be provided, and future developments discussed.

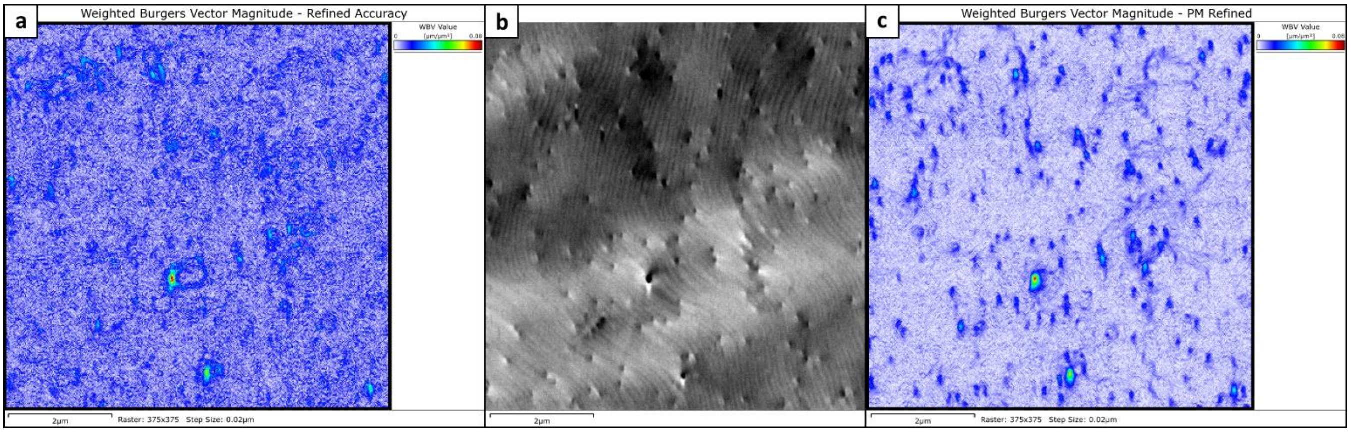

Figure 1. EBSD analysis of threading dislocations in a GaN thin film, using dislocation density maps. (a) Refined Accuracy indexing. (b) Forescatter electron image (c) Pattern matching refined data

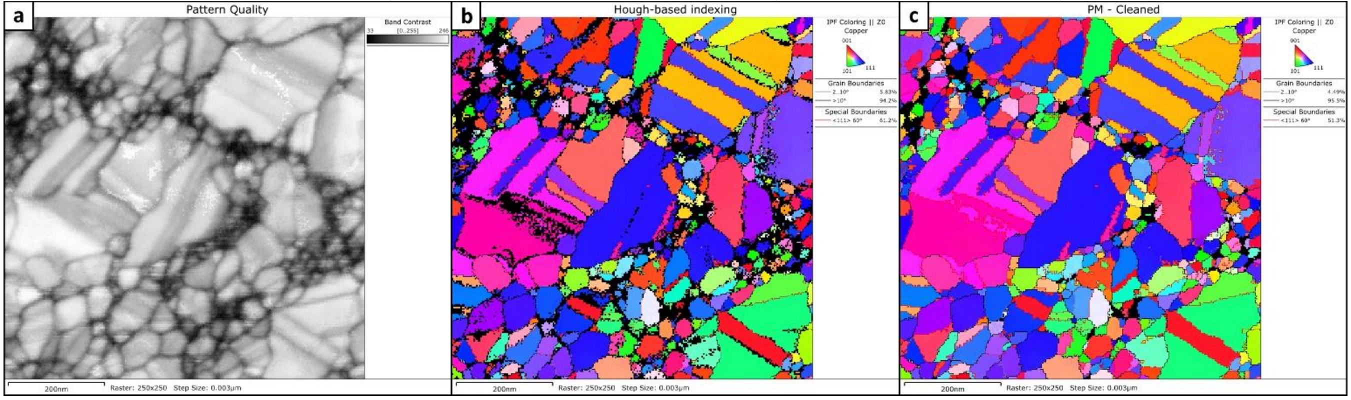

Figure 2. TKD results from a nano-Cu sample (field width: 750 nm). (a) Pattern quality map (b) Orientation map - Hough-based indexing (81% hit rate). (c) Pattern matching cleaned data (97% hit rate)

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