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Challenges in EBSD investigations of microstructures formed during plastic deformation

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In many metals and alloys dislocations introduced during plastic deformation collect into rotation boundaries, such that crystallographic texture evolution during deformation is accompanied by a process of microstructural subdivision over several length scales. Because the misorientation across each boundary is an important microstructural parameter, investigation of deformation microstructures requires crystal orientation measurements. There is much interest therefore in orientation mapping using electron back-scatter diffraction (EBSD), as this technique allows more than 10^5 orientations per hour to be measured in a fully automated manner. Deformation microstructures present challenges, however, with regard to both the spatial and angular resolution of the EBSD technique. The angular resolution limitation is particularly important as low angle (<2°) dislocation boundaries are introduced continually during deformation, and the number and distribution of these low angle boundaries is important for such properties as mechanical strength, ductility, and the annealing behavior.

The angular resolution limitation manifests itself in so-called "orientation noise": a large number of measurements within a region of orientation **g** results in a distribution of orientations P(**g**) with mean **g**. A good quantitative knowledge of the function P(**g**) is important for developing and testing ways of dealing with the orientation noise. In undeformed single crystals the function can be measured directly. The distribution of misorientation angles between adjacent measurements in a grid ($\theta_{i,j}$) takes a characteristic shape, such that the noise can be described by a single value (e.g. the mean value, $<\theta_{i,j}>_N$). For deformed metals it is not possible to measure the noise directly, though indirect methods for estimating the noise level can be developed.

Several post-processing methods exist for dealing with orientation noise. One approach is to use filtering in orientation space. A variant of the edge-preserving Kuwahara filter has been developed that allows a considerable reduction in the orientation noise without the introduction of artifacts (Fig. 1). Filtering can also be applied in image space on misorientation map. The grain reconstruction algorithm is particularly sensitive to the presence of orientation noise, and methods based on gap-repair algorithms are also being investigated. Simulated EBSD orientation maps are useful for investigating the effect of post-processing methods on the data quality as a function of the orientation noise level, and for deciding on an experimental strategy. Figure 2 shows example simulated EBSD maps, constructed for a region of a deformed bicrystal where orientations were measured in the transmission electron microscope. The maps show the effect of both step-size and orientation noise level on the data quality. Such simulations rely on a good description of the orientation noise. Research is therefore also being carried out to determine the extent to which orientation noise deteriorates near boundaries (where patterns from more than crystallite are encountered). The most direct method for evaluating EBSD data quality is to examine the same area in both the TEM and using EBSD. The results of such experiments highlight the fact that the EBSD-determined average boundary spacing is strongly influenced by artifacts remaining after the application of orientation filtering methods.

References
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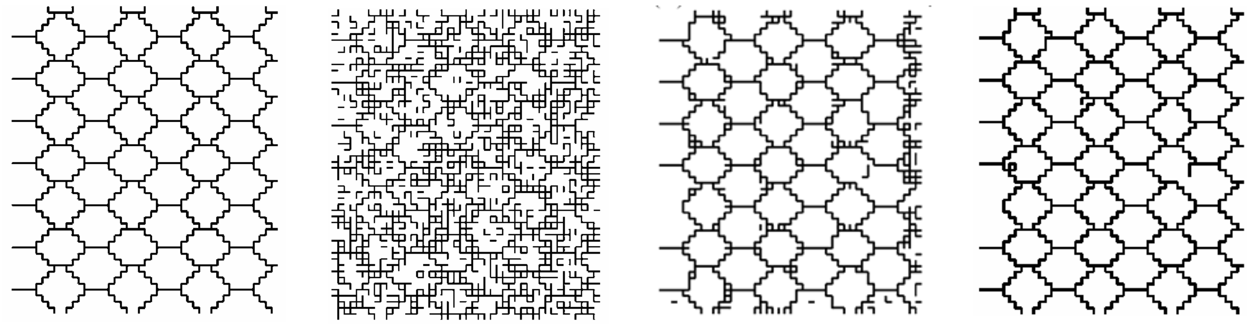

(a) (b) (c) (d)

FIG. 1. Simulated EBSD misorientation maps: (a) idealized dislocation cell structure; (b) after addition of orientation noise; (c) after application of a 7x7 Kuwahara filter; (d) after application of a 7x7 MSMV-Kuwahara filter. Maps (b-d) show misorientations of > 0.5°.

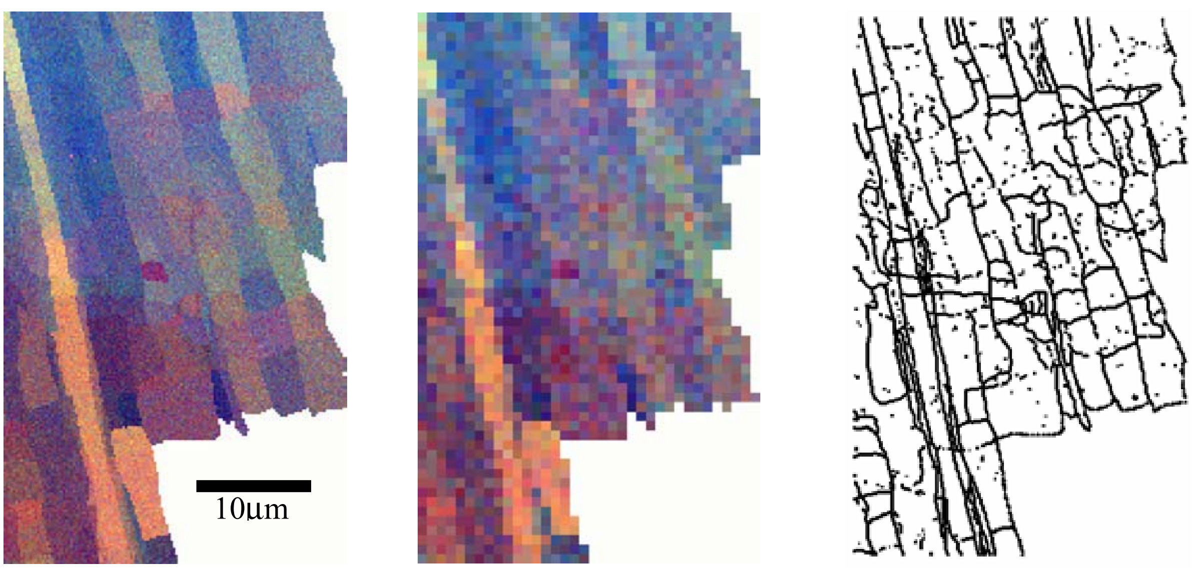

FIG. 2. Simulated EBSP orientation maps for a region where orientations were determined in the transmission electron microscope: (a) step-size = 0.2μm, $<\theta_{i,j}>_N = 0.8°$, raw data, Euler angle map; (b) step-size = 0.8μm, $<\theta_{i,j}>_N = 0.8°$, raw data, Euler angle map; (c) step-size = 0.100μm, $<\theta_{i,j}>_N = 0.8°$, after 2 applications of a 5 x 5 MSMV-Kuwahara filter, misorientations > 0.5°.

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