Development of low noise quantitative EBAC imaging in FEG SEM

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Electron Beam Absorbed Current (EBAC) is a specimen current imaging technique that has been established in the earliest stages of Scanning Electron Microscopy (SEM), but which has been somewhat overlooked for last few decades [1], with the exception of nanoprobing for failure analysis [2]. Whilst the technique has been noted for its uncomplicated electron collection geometry, it has not found use in routine microscopy because of the slow and noisy electronics of the time. This work revisits the design and application of EBAC to general SEM and demonstrates that modern low-noise and high-speed amplification entirely overcome the traditional limitation of the technique, whilst adding full quantification and unprecedented imaging flexibility.

Traditional limitations of EBAC amplification were linked to the very low signal intensity, as only a fraction of the primary electron current was passed outside the SEM chamber. In contrast with Everhart-Thornley or solid-state detectors, no amplification could be provided inside the chamber as traditional amplifiers could not be placed in situ. This is no longer the case with modern electronics, and a miniature pre-amplifier was designed and placed on the sample stage. A further amplifier was placed ex situ to control the gain further, and the signal was recorded with full quantification alongside the conventional Secondary Electron (SE) and In-Lens (IL) signals. A Tungsten wire test sample was loaded on a custom electrical holder for EBAC, and is used here to compare SE, IL and EBAC signals recorded simultaneously on a PE upgraded ZEISS DSM982 FEG SEM. EBAC electronics have sufficient bandwith for live monitoring, alignment and focus, and was used as the main signal throughout this work.

As illustrated in Figure 1, it is first found that resolution of the EBAC signal far exceeds that of SE at all accelerating voltages and working distances. Since at all points on the sample the sum of all electron currents must be constant, it follows that the higher resolution of IL signal must be present in EBAC signal. Indeed, the IL images (not shown in this abstract) and EBIC images are highly correlated. As reported by [1], it is found that EBAC imaging is largely independent from working distance, whilst the IL signal is limited to very short working distances in order to maintain good solid angle collection efficiency (not shown in this abstract).

Further differences arise from the direct nature of absorbed signal, which is not convoluted with information arising from the trajectories of emitted electrons as they leave the surface. This is observable in Figure 1 and explained more clearly with low magnification data of the W wire (Figure 2). SE signal presents very pronounced shadowing as the low energy electrons are attracted towards the detector, and thus the opposing side of the cylindrical wire appears darker. Such effects are less visible in the IL signal because of the collection geometry, whereas the EBAC signal is completely free of such shadowing.

Contrast of sub-micron grains is readily found in both IL and EBAC signals, albeit of different relative intensities (not shown in this abstract) and is attributed to orientation contrast (OC). As illustrated in Figures 1 and 3, grains with strong OC are presents in all images, but with the highest noise in SE and lowest noise in EBAC. The uncomplicated geometry and calibrated property of EBAC signal, presents the opportunity to quantify values of OC independent from imaging conditions (Figure 3). Whilst physical origin of OC in both IL and EBAC signals is thought to be the same, it is proposed that differences in relative intensities arise from the different collection geometries.

Further new observations are enabled by quantitative imaging, including the discovery that the EBAC signal can change polarity. It is found that for a range of conditions, the total sum of emitted electrons can exceed the sum of absorbed electrons. Examples include protruding nanoscale features (Fig. 1), grains of strong orientation contrast (Fig. 3), or locations of high electron beam incidence angle, as observed at the edges of the W wire (Fig. 2).

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[2] K. Dickson, G. Lange, K. Erington and J. Ybarra, Proceedings from the 36th International Symposium for Testing and Failure Analysis, November 14–18, 2010, Addison, Texas, USA.

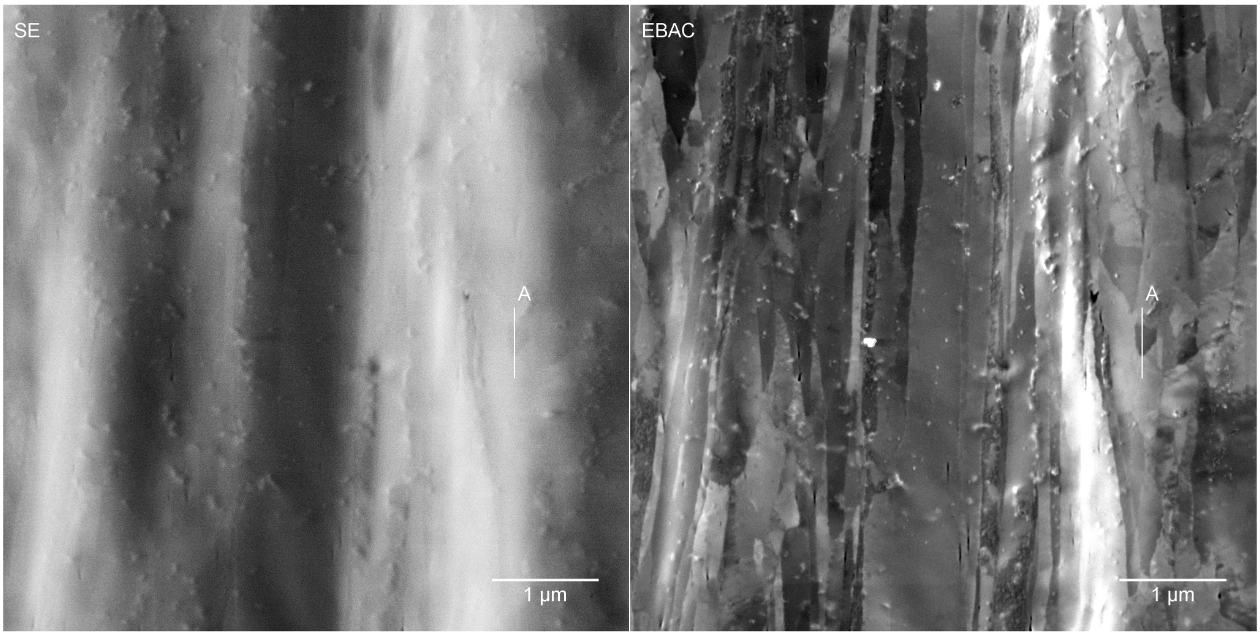

Figure 1: correlated secondary electron (SE) and electron beam absorbed (EBAC) micrographs of W at an accelerating voltage of 5kV and a working distance of 5mm. EBAC signal presents stronger orientation contrast and higher resolution than the corresponding SE signal, following closely the in-lens (IL) signal, not shown here.

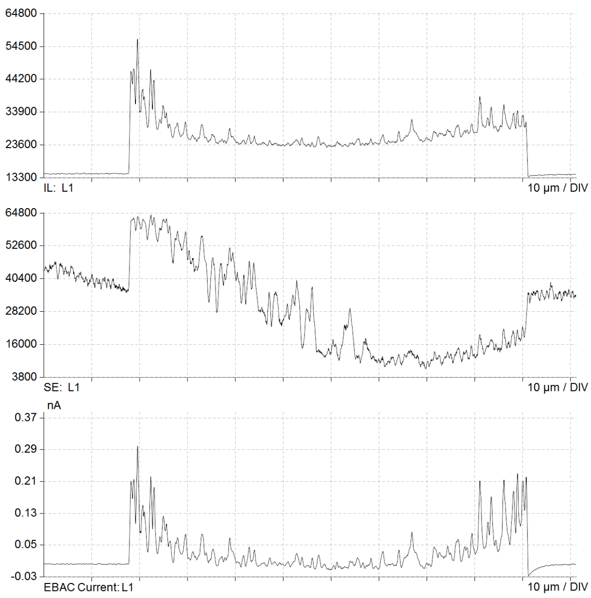

Figure 2: correlated SE, IL and EBAC line profiles across a W wire illustrating differences in perceived illumination. SE signal gives the impression of lateral illumination, IL and EBAC signals give the impression of top-down illumination.

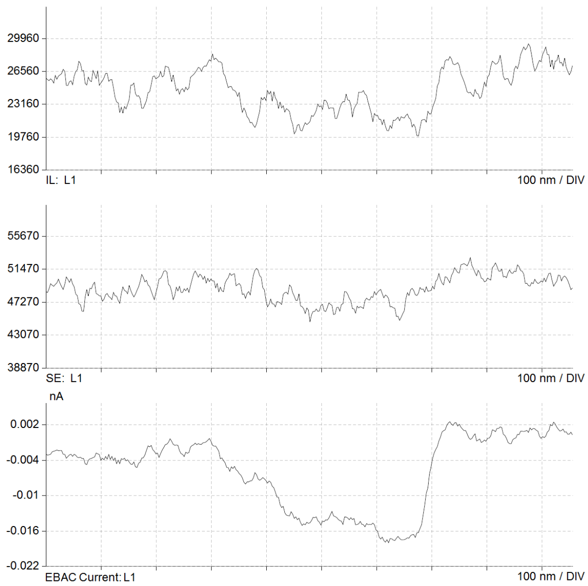

Figure 3: Correlated IL, SE and EBAC line profiles across a grain with orientation contrast from Figure 1. The much reduced noise of the EBAC signal is associated with the optimal collection efficiency. Note sign reversal in EBAC signal is possible, with these three grains showing averages signals of -3.1, -15.2 and 0.6pA with standard deviation of 2.3pA.