Live Quantitative BSE Acquisition with Standard-less Calibration

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Whilst successive new generations of electronics are being deployed in Scanning Electron Microscopy (SEM) for faster and lower noise imaging, most of electron signals acquired today still remain purely qualitative. Conventional SEM is indeed based purely on contrast, e.g. distances or angles, however knowledge of absolute intensity provides a deeper level of analysis, e.g. concentration or gradients. Quantitative analysis has become the norm for a few techniques, such as Energy Dispersive X-ray Spectroscopy (EDS) and Electron Beam Induced Current (EBIC), however Backscattered Electron (BSE) imaging is rarely quantitative (qBSE) because it still requires calibration samples [1]. This work formulates an automated calibration method for standard-less BSE quantification.

There are five overall aspects of signal acquisition that need to be considered for calibration: signal digitization, signal amplification, detector response, geometrical alignment and sample topography.

Calibration of digitization is straightforward, as it describes relationship between analogue-to-digital units and input voltage, which is obtained by applying a range of voltages at the input of the imaging system. Calibration of amplification is similarly obtained by applying a range of input voltages and recording the resulting gains. Calibration of detector response describes amplification as a function of acceleration voltage, and requires either a pre-recorded look-up table, or preferably a detector model where the parameters are measured experimentally. Required parameters are energy loss without induced signal and leakage current. Geometrical alignment calibration requires knowledge of the SEM, including angles and positions of the sample, the electron beam, and the BSE detector in relation to the pole piece, as well as positions and shapes of sensitive areas within the BSE detector. Sample position and angles, as well as those of the electron beam, are readily obtained from the SEM and rely on the standard calibration for magnification, scan rotation and working distance. Detector coordinates can be calibrated through alignment with samples of known geometry, e.g. flat and horizontal sample surface, by means of equalising live simultaneous signals from the segmented BSE detector. Spherical aberration must be taken into account at low magnifications, which again can be calibrated with a flat sample and segmented BSE detector. These calibration steps are already sufficient for polished samples.

For samples that present topography, the established live shape-from-shadow algorithm already uses the annular dependency of backscattered electrons to calculate sample surface orientation at each scan point, and thus again relies on simultaneous acquisition from segmented detectors [2]. This algorithm is now extended to calculate an integrated BSE signal in addition to surface orientation, as illustrated in Figure 1. Further, if the intensity of the beam is known, then the backscattered yield may also be determined.

In conclusion, it is found that whilst the quantitative model required for standard-less calibration has many parameters to fully describe the acquisition, each of these parameters is relatively simple and thus can be measured and applied during the acquisition to provide live quantitative analysis of the sample. Application to a range of samples of varying densities will also be shown for illustration.

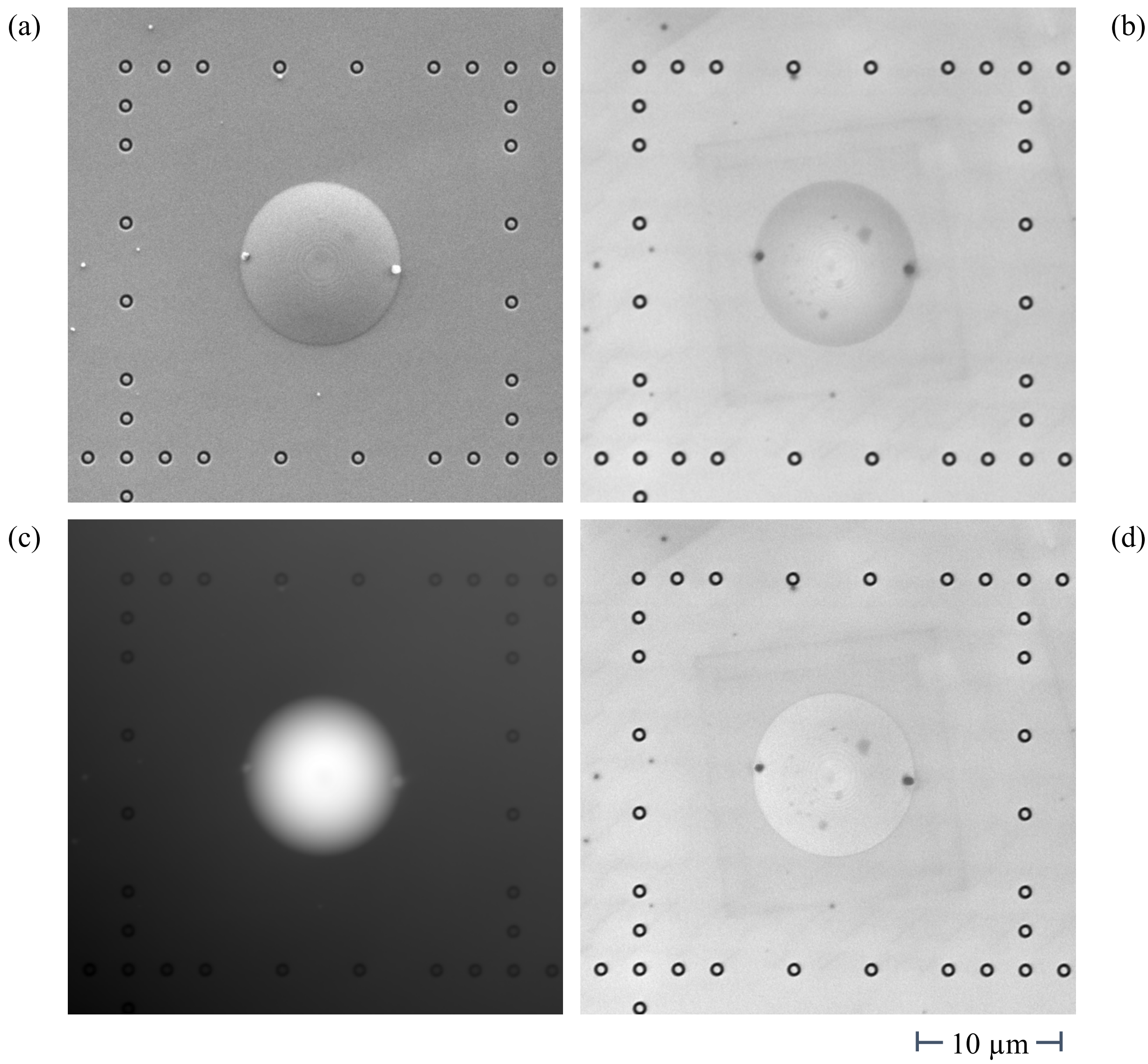

Figure 1. Table of experimental (a-b) and calculated (c-d) signals illustrating simultaneous extraction of surface topography and backscatter intensity from a FIB manufactured test object of uniform composition. SE image (a) is included here to present the dome-shaped structure surrounded by automatic alignment marks. The conventional "compositional" sum of all BSE quadrants (b) shows radial intensity artefacts from the centre of the dome structure to the edges, as expected from the annular distribution of backscatter electrons. The shape-from-shadow algorithm is able to use the quadrant BSE information (not shown here) to calculate topographic (c) and backscatter intensity (d) values at image pixel. Whilst artefacts remain at sharp interfaces in the calculated backscatter intensity image (d), as seen here at the edge of the dome and the alignment marks, the calculated values over the dome structure are now free of radial intensity artefacts and thus represent pure compositional information.

References:

[1] E. Sánchez *et al.*, Microscopy and Microanalysis (2012), 1355-1261
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