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Expanding the Depth of Field for Imaging with Low keV Electrons: High Resolution Surface Observations of Nanostructured LaB_6 Using Low keV Secondary and Backscattered Electrons

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The observation of nanomaterials at low voltages via STEM (≤ 30 kV) and ultra-low voltages (≤ 1 kV) via SEM/BSE enables the characterization of the constituent nano-objects with respect to both surface and volume, while simultaneously providing elemental analysis (EDS) and band-structure/nearest-neighbor bonding (EELS/ELNES) information [1]. Furthermore, this broad range of data can be collected using a single microscope [1]. These combined features make low voltage electron microscopy a growing topic of interest for studying both hard and soft material systems.

With the resolution of immersion lenses for SEM/STEM type microscopes reaching ≤ 0.4 nm at 30kV, the ultra-low voltage imaging quality (lateral resolution) has improved, meaning the convergence angle of the electron beam has increased. Unfortunately, this increased convergence angle greatly reduces the depth-of-field (DOF), i.e., the distance along the optical axis in which the sample appears in focus [2,4]. Therefore, improvement of the DOF with increasing lateral resolution is a critical feature for the further improvement of low voltage electron microscopy. In the following example, we illustrate a successful approach to this problem.

The nanostructured lanthanum hexaboride (LaB_6) crystals shown in Figure 1 [5] were imaged with 300V electrons (wavelength of 0.7 Å), and the limits of the DOF are quite visible. Due to the use of a cold FEG immersion lens and deceleration techniques, details much less than 10 nm can be seen in the areas that appear in-focus; however, the sample has a strong 3D component and the depth of the sample easily exceeds 100 nm. As a result, many areas appear out of focus. As discussed in [3,4], several possibilities to improve the DOF exist. All of them rely on the acquisition of a series of images at different foci. An example of such a focus series is shown in Figure 2. We then used the information-passing capacity (IPC) method introduced in [4] to merge only image elements of the focus-series that are in-focus. The result of this fully-automated procedure is shown in Figure 3. The BSE image (left panel) provides only one surface in focus. In comparison, after IPC processing (right panel) the sample now appears fully in focus throughout the 3D volume while maintaining lateral resolution. We plan to use these results as a first step to combine surface imaging with data sets obtained in transmission mode for the purpose of obtaining full 3D data sets on challenging nanomaterials [5].

References:

[1] T Sunaoshi *et al,* Microsc. Microanal. **22(S3)** (2016), p. 604.
[2] M Born and E Wolf in “Principles of Optics: Electromagnetic Theory”, (Cambridge Univ. Press).

[3] R Hovden, HL Xin, DA Muller, Microscopy and Microanalysis **17(1)** (2011), p. 75.

[4] M Sato *et al,* Nuclear Instruments and Methods in Physics Research A **519** (2004), p. 280.

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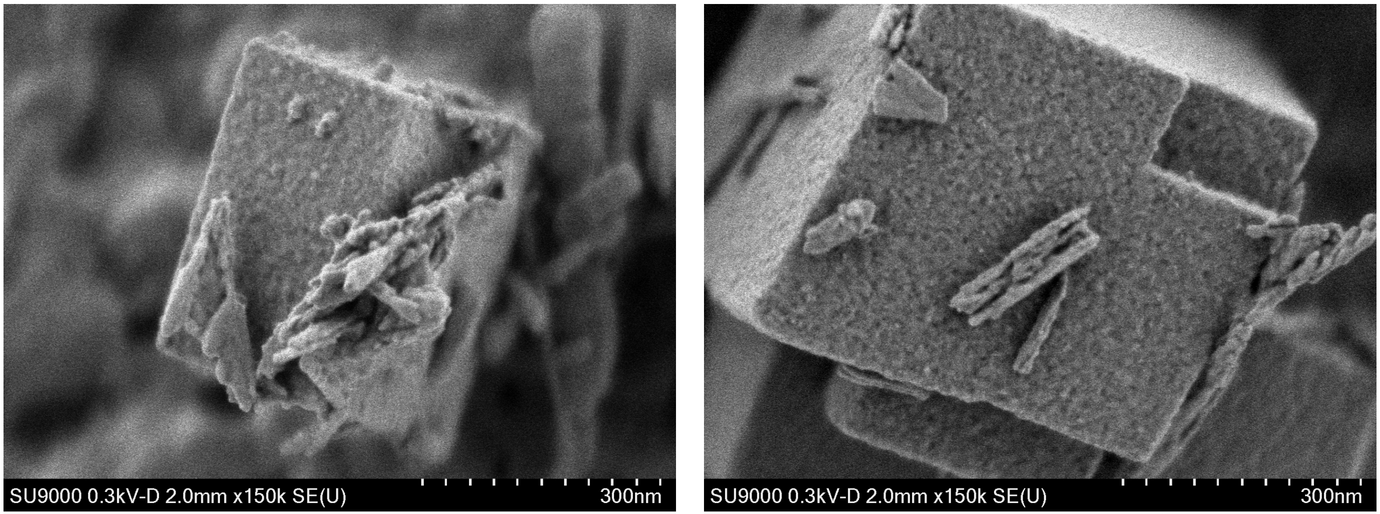

Figure 1. Surfaces of nanostructured LaB_6 crystals imaged with a wavelength of 0.7 Å (300V). The signal is a mix between SE and BSE electrons. Although central surfaces show excellent lateral resolution, depth of field suffers significantly.

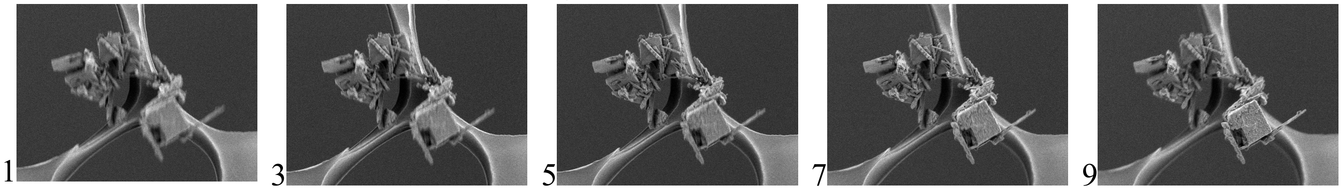

Figure 2. A through-focus series of 10 (only 5 shown) consecutive images (mix of SE and BSE) is sufficient to allow a significant extension of the DOF range after processing (see details in Figure 3).

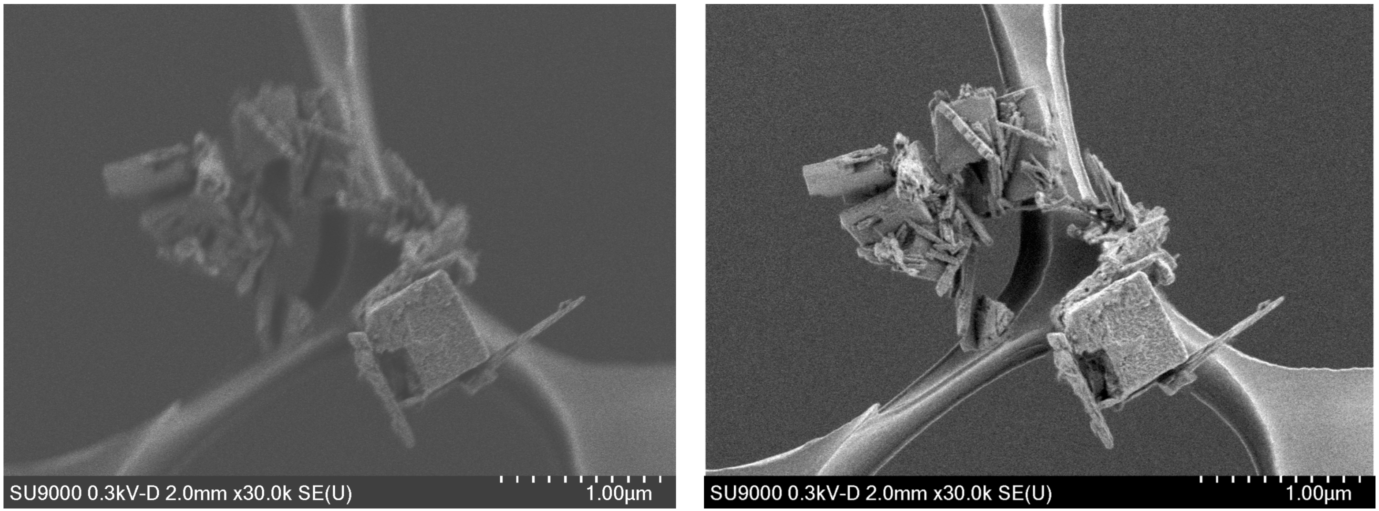

Figure 3. Left: At a wavelength of 0.7 Å, the DOF is strongly reduced. Right: Using the data set in Figure 2, automated data processing based on the IPC method provides a significant improvement in DOF with little to no loss of lateral resolution.