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Practical Use of Scanning Low Energy Electron Microscope (SLEEM)

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The high negative bias of a sample in a scanning electron microscope constitutes the cathode lens (CL), with a strong electric field just above the sample surface [1] offers a tool for controlling the landing energy of electrons down to units or even fractions of electronvolts. Moreover, the field accelerates and collimates the signal electrons to earthed detectors above and below the sample, thereby assuring high collection efficiency and high amplification of the image signal. One important feature is the ability to acquire the complete emission of the backscattered electrons, including those emitted at high angles with respect to the surface normal. The cathode lens aberrations are proportional to the landing energy of electrons, so the spot size becomes nearly constant throughout the full energy scale.

At low energies and with their complete angular distribution acquired, the backscattered electron images offer enhanced information about crystalline structures thanks to contrast mechanisms that are otherwise unavailable. The example is shown in Figure 1.

The most straightforward expectation connected with decreasing the landing energy of primary electrons on the sample is their reduced penetration into the sample. Shortened information depth, along with reduced lateral diffusion, produces enhanced surface sensitivity, i.e. improved visibility of topographic details such as tiny dips, protrusions, and ridges, and also the sudden appearance of very thin surface coverage that is fully transparent and invisible at conventional energies. When comparing the two frames in Figure 2, we can identify examples of both of these types of differences. Here, the penetration depth of primary electrons is the main factor; however, as shown above, the contribution of signal electrons from a broad range of polar angles of emission also plays a role.

Even when the sample is ideally flat and smooth and not covered with any thin layer, we may be confronted with imaging issues in cases in which very small objects are immersed just below the surface with the object tops lying on the same level as the neighboring surface. The examples are precipitates in alloys prepared with an overall flat and smooth surface [2] as shown in Figure 3. The CL mode frame, thanks to much smaller interaction volume, not only shows quite sharp edges of the precipitates but also reveals their internal structure with a bright frame and a dark core. The explanation of the internal structure obviously also has to incorporate the crystal structure of the precipitates, providing a specific contrast contribution when a sufficiently broad angular range of BSE is acquired. [3].

References:

[1] I Müllerová and L Frank, Advances in Imaging and Electron Physics **128** (2003), p. 309.
[2] K Matsuda *et al*, Journal of Materials Science **41** (2006), p 2605.
[3] The authors acknowledge funding from the Technology Agency of the Czech Republic (Competence center Electron microscopy, no: TE01020118) and from the MEYS of the Czech Republic (LO1212) together with the European Commission (ALISI, no. CZ.1.05/2.1.00/01.0017).

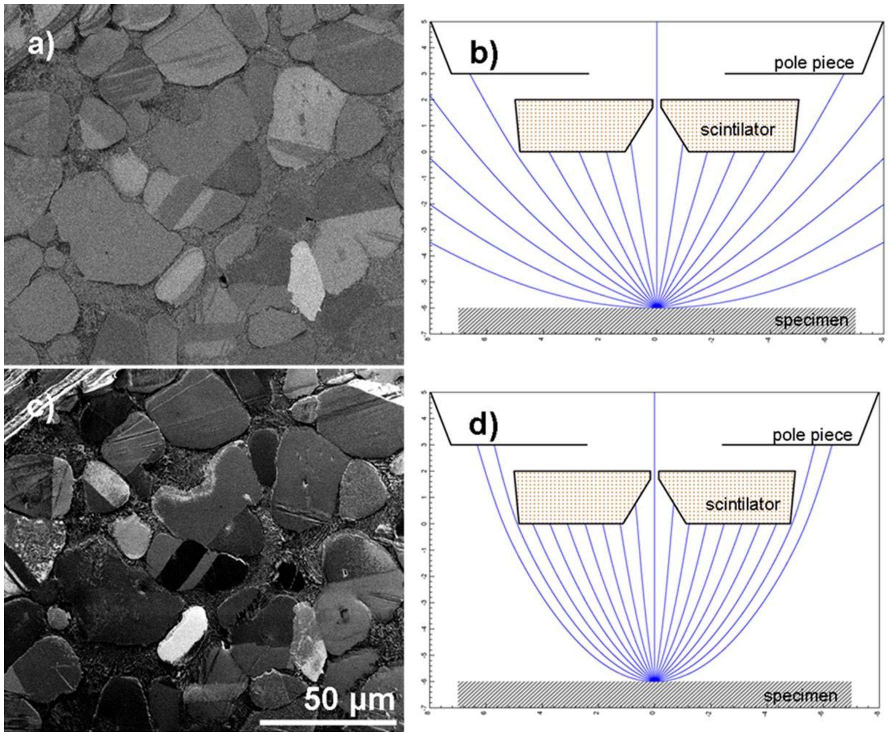

Figure 1. Ultra-high vacuum SLEEM images of X210Cr12 steel obtained at energy 4 keV (a) and 1 keV (c), together with corresponding simulations of the BSE trajectories (b and d).

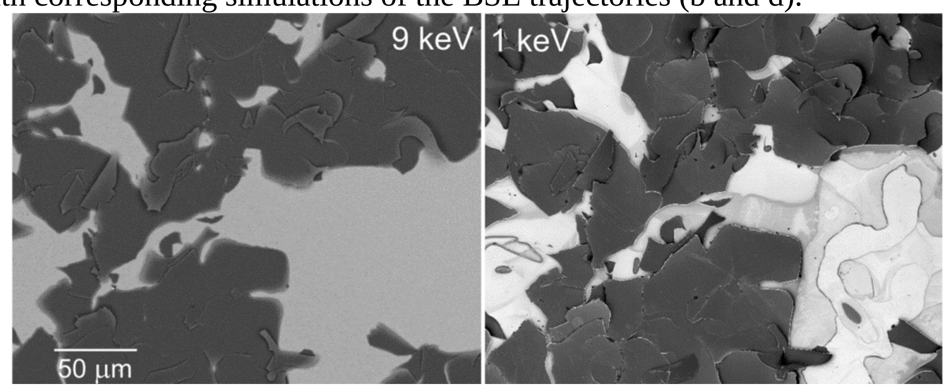

Figure 2. Carbon nitride film 200 nm in thickness deposited on a silicon substrate covered by around 5-nm-thick native SiO_x, delaminated due to compressive stress, CL mode, primary energy 9 keV.

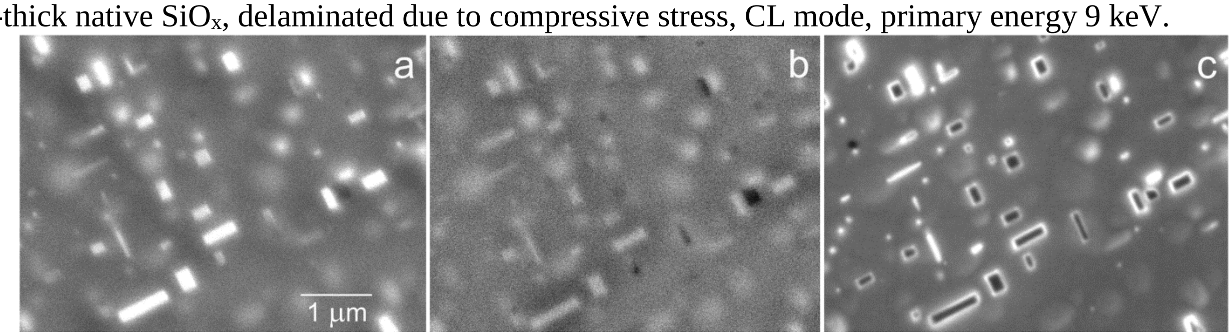

Figure 3. Precipitates in Al-1.0 mass% Mg_2Si with 0.4% excess Mg alloy, annealed, quenched, and age hardened: standard BSE image at 10 keV taken with a coaxial detector (a), SE image at 10 keV taken with a side-attached Everhart-Thornley detector (b), and the cathode lens image at 1,500 eV for 10 keV primary energy (c).

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