Nonlinear material contrast in low voltage backscatter electron images.

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The strong increase in nano- particle and nano- layer research necessitates image acquisition with very low electron energies (<1 keV) in scanning electron microscopy. The high landing energy in classical scanning electron imaging avoids these investigations because of the relatively large scattering volume and the diffusion of the signal.
The combination of the Zeiss Gemini lens system with the on axis inlens energy selective backscatter detector (EsB) in the Zeiss Ultra 55 allows the detection of backscattered electrons (BSE) at very low primary electron energies (>50 eV) [1]. There is no need for a retarding field inside the specimen chamber and secondary electron (SE) and BSE images can be detected simultaneously at very low energies which reduce charging artifacts and radiation damages of insulating and radiation sensitive samples.
But the backscatter coefficient becomes nonlinear with decreasing electron energy [2] and misinterpretations of low voltage BSE images are possible. For these electron energies (<1 keV) new material contrasts appear and the Rutherford scattering model is no longer valid because it neglects the spin-orbit coupling. Only the Mott cross section can describe the elastic scattering of electrons [3,4] properly.
Material contrast inversion was demonstrated by Frank et. al. [5] for gold and aluminum in a cathode lens system with a negatively biased specimen. These investigations were performed in ultra high vacuum to minimize oxidation and contamination of the sample. Especially oxide layers can complicate image interpretation in low voltage electron microscopy. The whole interaction of the primary beam electrons take place inside an oxide layer which leads to charging of the sample surface and new contrast formation.
To avoid oxidation of the sample and to simplify the interpretation, a gold- carbon system was investigated. The high purity 500 nm thick layers guarantee pure material contrast for electron energies between 100 and 1000 eV.
For the correct interpretation of low voltage BSE images comparison with calculations (Mott cross section [3]) and Monte Carlo simulations (CASINO v2.42 [6]) are unavoidable. The backscatter coefficients of gold and carbon in figure 1a predict contrast inversion at about 300 eV primary electron energy. The interaction volume at 300 eV in figure 1b clarifies this condition. The electrons interact up to a depth of about 2.4 nm in gold and carbon comparably.
The low voltage BSE images in figure 2 and figure 3 agree very well with these simulations. Above 300 eV the material contrast is as expected linear with the atomic number. But at 300 eV electron energy the material contrast disappears and below this intersection energy the contrast inverts and the carbon layer appears brighter than the gold layer.

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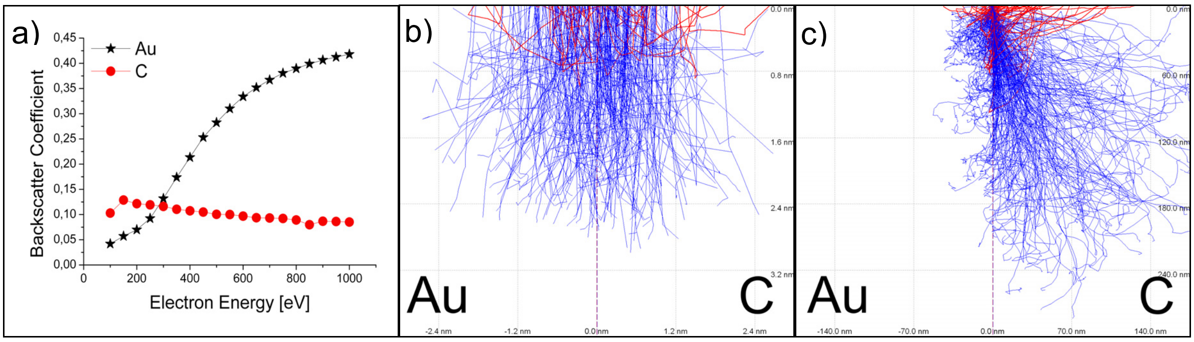

Figure 1. a) Backscatter coefficient vs. primary beam energy [eV] for carbon and gold b) simulated interaction volume of 300 eV electrons in gold and carbon (CASINO v2.42) (image width 6 nm) c) simulated interaction volume of 1000 eV electrons in gold and carbon (CASINO v2.42) (image width 350 nm)

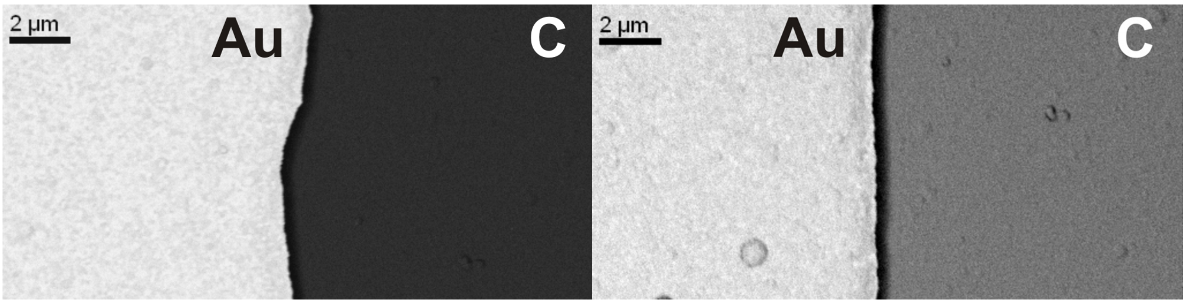

Figure 2. Backscatter images of gold and carbon (left image: primary beam energy: 1000 eV; right image: primary beam energy: 400 eV)

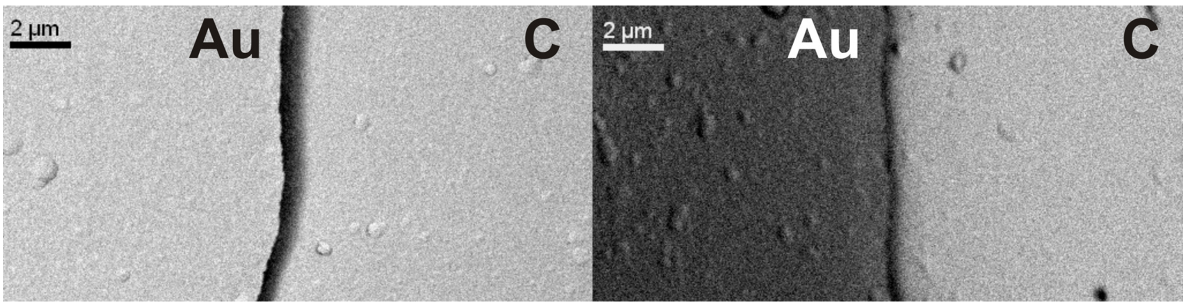

Figure 3. Backscatter images of gold and carbon (left image: primary beam energy: 300 eV; right image: primary beam energy: 100 eV)

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