Microsc. Microanal. 8 (Suppl. 2), 2002
DOI 10.1017.S1431927602106167

Ultra-Low-Voltage Scanning Electron Microscopy In The FEG-SEM

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The use of a high-brightness field-emission gun (FEG), new lens designs, and novel secondary electron (SE) detection systems in the SEM makes it possible to routinely examine surface features of bulk samples at a nanometer resolution. The development of high-resolution FEG-SEM has significantly enhanced our ability to solve challenging materials problems. By forming images with both the SE and the backscattered electron (BE) signals we can extract useful information about the dispersion of the active species in supported catalysts [1]. By further decreasing the Cs and Cc values (e.g., with Cs- and Cc-correctors), we can again improve the image resolution and increase the probe current and thus significantly enhance the XEDS spectroscopy for high spatial resolution chemical microanalysis of bulk materials[2].

Another advantage of FEG-SEM is the flexibility of varying the primary electron energy to probe surface or sub-surface features of bulk samples or to reduce electron-beam-induced artifacts. The use of low beam voltages, for example, provides opportunity for directly observing non-conducting materials with high spatial resolution and reduced beam damage. Low voltage FEG-SEM is now the preferred mode of operation for examining non-conducting or delicate materials. Since electrons with an energy < 200 eV strongly interact with most of the solid materials, we expect that highly surface-sensitive signals can be generated with the use of extremely low-energy electrons. Because of the effect of lens aberrations, however, reduction in primary electron energies to below 200 eV rapidly deteriorates the image resolution. To extend the applications of the FEG-SEM instrument to solving challenging industrial problems, we tried to manipulate the contrast or the surface sensitivity of FEG-SEM images by applying a bias potential to the sample of interest [3].

A recent development is the use of a retarding field to modulate the landing energy of the primary electrons [4]. By simply applying a negative potential (V_b) to the specimen, a retarding field can be generated between the specimen and a grounded electrode above the specimen (the cold finger or the objective lens in a semi-in-lens type FEG-SEM instrument). In this simple configuration, the specimen itself is part of a "cathode lens" system. The landing energy (E_L) of the incident electrons can be varied by changing the applied potential: $E_L = E_0 - eV_b$, where E_0 is the energy of the primary electron beam. The nature of the electron-specimen interactions is determined by the electron landing-energy E_L. When eV_b is equal to or larger than E_0, the incident electrons will not enter the specimen at all; in this particular configuration a mirror image may be formed. Therefore, by varying the potential applied to the sample, we can conveniently extract useful surface information of the sample. The ultimate resolution of ultra-low-voltage (ULV) SEM images is determined by the combined properties of the probe-forming lens and the cathode lens. For electron landing-energies > 40 eV, surprisingly good image resolution can be achieved as demonstrated in figure 1 (conducting material), figure 2 (semiconducting material), and figure 3 (low-conducting material). With electron landing energies < 20 eV, significant contrast variations can occur and the collected signal is highly sensitive to surface modulations as demonstrated in figure 4. The contrast of ULV images is also strongly influenced by the specific SE detection configuration and the electrical field

distribution on the sample surface. The contrast mechanisms, the image resolution, and the applications of ULV imaging technique will be discussed.

References

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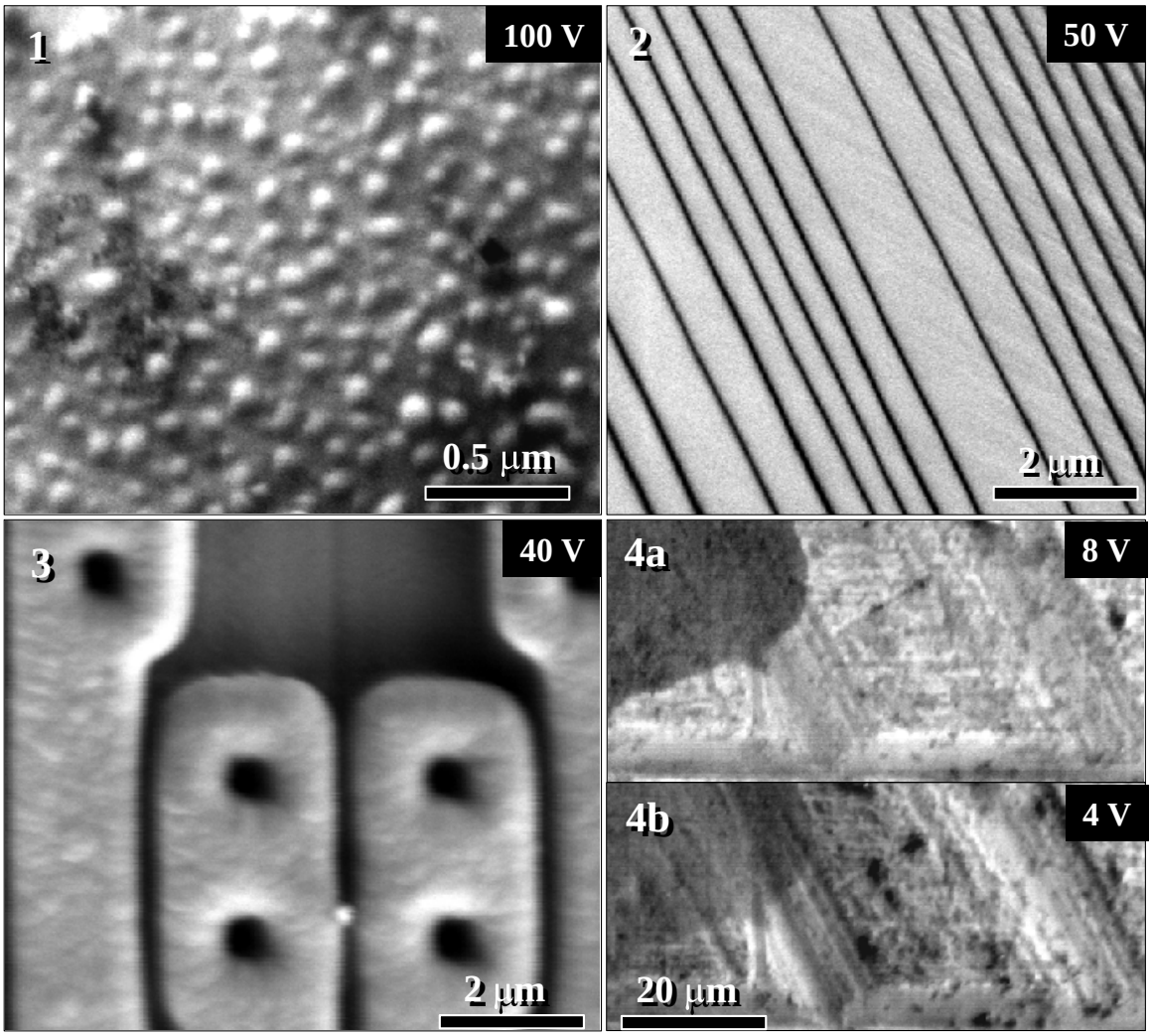

Fig. 1 ULV SEM image of activated carbon powders shows fine surface features with high image contrast and resolution. E_0 = 1000 eV and E_L = 100 eV.

Fig. 2 ULV SEM image of an in situ cleaved silicon crystal shows surface steps and modulations. E_0 = 500 eV and E_L = 50 eV.

Fig. 3 ULV SEM image of a semiconductor device shows details of the surface morphology and the grain structure of the aluminum/aluminum oxide.

Fig. 4 ULV SEM images show variations of image contrast with change of electron landingenergy. The sample is a copper coupon used in a corrosion test. E_0 = 500 eV.

https://doi.org/10.1017/S1431927602106167 Published online by Cambridge University Press