

High Throughput Imaging with ZEISS Crossbeam 550

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Introduction

Since more than 13 years ZEISS has been known as a manufacturer of two-beam FIB-SEM systems – Crossbeam instruments. During these years Crossbeam performance in terms of image resolution and contrast, ease of use, workflow automation and throughput has improved continuously. This development culminates in today's ZEISS Crossbeam 550.

In this technology note, a simple experiment is presented to illustrate the superb SEM imaging resolution of Crossbeam 550 when imaging simultaneously at low voltages and high probe currents. Implications for different FIB-SEM applications are discussed, especially with regard to throughput.

Experiment

The sample used for this experiment consists – from top to bottom – of a silver layer on a 1.5 μm -thick nickel seed layer on a copper substrate [1]. A standard FIB cross-section of the sample was produced (see top left image in figure 1). Prior to FIB milling of the cross-section the sample surface was protected with a platinum deposition layer by ion beam induced deposition (IBID) using standard trimethyl (methylcyclopentadienyl) platinum (IV) as a precursor gas.

The subject of study of this note is the cross-sectioned platinum deposit. The platinum deposit was imaged with the SEM at high magnification at two different accelerating voltages, 1.5 kV and 3 kV, to reveal its internal structure.

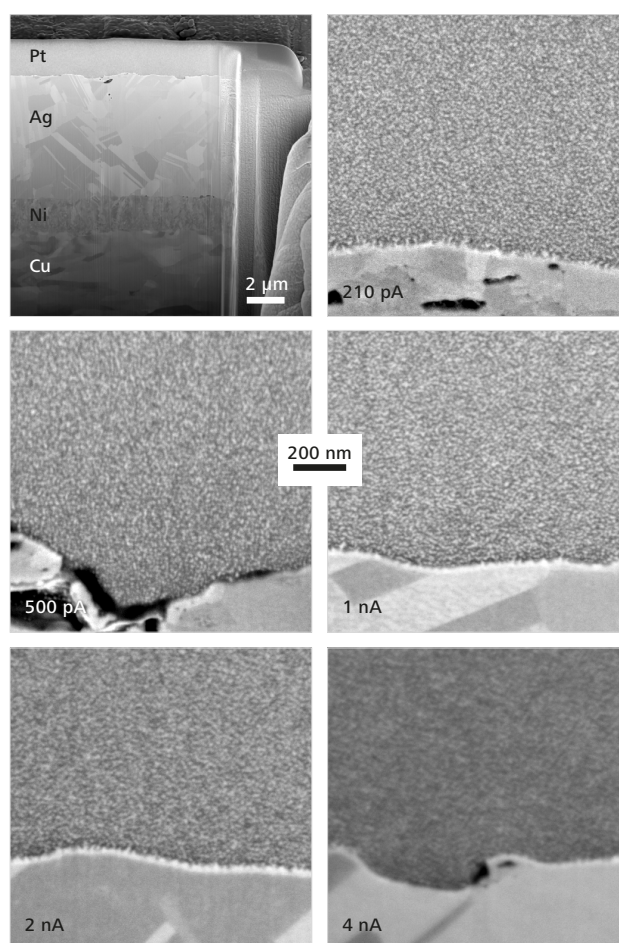


Figure 1 Images of a platinum deposition for different SEM probe currents in the range of 210 pA to 4 nA at 3 kV. (top left) Overview image of the cross-section used for the experiment.

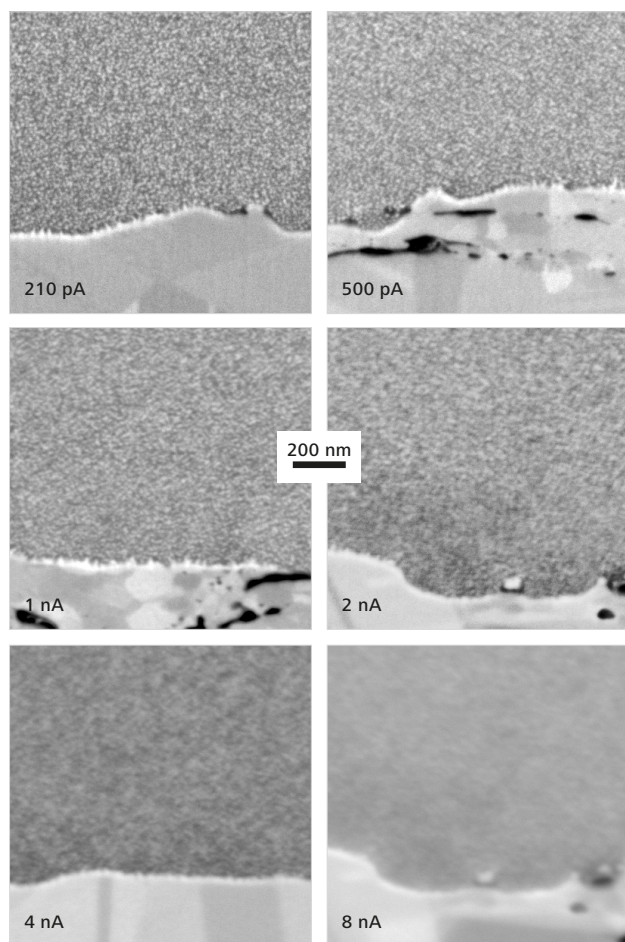


Figure 2 Images of a platinum deposition for different SEM probe currents in the range of 210 pA to 8 nA at 1.5 kV (current increases from top left to bottom right image).

For each voltage the SEM probe current was varied in a range from 210 pA to 8 nA. The images were acquired in the coincident point of SEM and FIB beams, i.e. at a working distance of 5 mm.

To exclude any contamination artifacts, every image shown in this note was acquired from an area of the platinum deposition, which had not been imaged or exposed to the electron beam previously.

Results

Figures 1 and 2 show the results for 3 kV and 1.5 kV, respectively. For both imaging voltages, a granular structure in the deposition is observed. This structure is well known for FIB-SEM users. It consists of platinum nanoparticles surrounded by a matrix of an amorphous carbon and gallium mix. In the context of this note, it is used as a visual measure for the instrument's SEM resolution. The platinum grains in the images are well defined up to a SEM current of 2 nA. With increasing current, they start to wash out at 4 nA, but are still clearly resolved. For 1.5 kV and the highest current of 8 nA the particles cannot be discerned.

Note that for 3 kV and 1.5 kV the SEM imaging current can be increased from 210 pA to 4 nA roughly by a factor of 20 and – the platinum particles – the structure of interest – can still be resolved.

The acquisition time for all the deposition images shown in Figures 1 and 2 was either 5.4 s or 10.7 s.

Discussion

The results summarized in figures 1 and 2 demonstrate Crossbeam 550 ability to maintain a very high resolution even when imaging at very high SEM currents. This allows to boost throughput of the FIB-SEM instrument, as will be explained in the following for two common FIB-SEM applications:

A) Live imaging – For process control some applications rely on live SEM imaging during FIB milling. Often live imaging might not be strictly necessary, but it is still the preferred mode of operation for ZEISS FIB-SEM instruments, since it gives the operator the possibility to interact with the instrument at any time and it has no drawbacks^[2].

During live imaging a higher SEM probe current reduces the impact of interferences caused by secondary electrons produced by the scanning FIB beam. Thus, better SEM imaging results can be achieved, or alternatively, the milling process can be accelerated, because higher FIB currents can be afforded without compromising the SEM monitoring.

B) FIB-SEM tomography – As the need for 3D characterization of samples grows, FIB-SEM tomography is becoming increasingly important: A volume of interest in the sample is sliced by FIB and the resulting cross-sections imaged with the SEM. Typically, material removal and imaging are performed in a sequential manner. Experiments can run from several hours up to several days. Meanwhile, hundreds to thousands of SEM images are acquired.

In order to reduce the image acquisition time for a single frame, and with it, for the complete 3D image stack, it is important to choose the maximum possible SEM imaging current, which still does not compromise the resolution required to resolve the features of interest in the sample.

On the other hand, low voltages need to be employed to ensure that the SEM information depth is comparable – ideally less – than the thickness of the slices of material removed by FIB. The information depth probed by the SEM can be reduced to a few nanometers by detecting only low energy loss backscattered electrons ^[3].

Recently, with the introduction of the advanced FIB-SEM tomography solution Atlas 3D the sequential slicing and imaging approach is no longer needed. Instead, tomography data acquisition is done in live imaging mode (see above), which allows to increase FIB-SEM tomography throughput further. Researchers at NIH have reported 3 nm isotropic voxel resolution using this method ^[4].

Summary

Cross-sections of platinum depositions were imaged with ZEISS Crossbeam 550. The platinum nanoparticles present in the depositions were used as a model system to show the behavior of instrument resolution as a function of current at low voltages. A very high imaging resolution can be achieved for SEM beam currents up to several nA. This makes Crossbeam 550 the tool of choice for high throughput FIB-SEM work.

References:

^[1] Sample courtesy of D. Willer, MPA Stuttgart, Germany.

^[2] All ZEISS FIB-SEM instruments have a non-immersion type objective lens. Therefore, live imaging is performed in normal imaging mode as opposed to immersion type systems, where live imaging is only possible if the final lens is deactivated, which comes along with an important loss in SEM resolution.

^[3] E. Schröder-Reiter et al., *Journal of Structural Biology* 165 (2009), 97–106; M. Cantoni and L. Holzer, *Mrs Bulletin*, 39 (2014), 354–360

^[4] K. Narayan et al., *Journal of Structural Biology* 185 (2014), 278–284



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