3D in SEM, (S)TEM, Ion Imaging, incl. FIB-SEM and SBF-SEM

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Automated geometric SEM calibration

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Several SEM applications (e.g. layer thickness in solar cells or dielectric optical layers, pore and grain sizes) require well calibrated measurements of distances. For some applications (e.g. wave guides) the precise determination of angles is needed in addition. Usually, reference samples with line features are used to calibrate the scale of SEM images in x- and y-direction. Due to the more or less manual measurements and the reduction of the geometrical calibration parameters to a single distance, this procedure is not very accurate and a time consuming process. Moreover, it might not provide information of the shear factors between x and y and cannot be used to calibrate angles.

Although SEM is mostly applied for 2D imaging and analysis, it is more and more used for 3D applications. Hence, 3D calibration standards are required. A sophisticated solution for 3D calibration are samples with pyramidal structures and circular reference marks, already applied for SPM and SEM detector calibration [1,2]. In this paper, the application of such calibration structures for automated geometrical SEM calibration with high accuracy is presented.

The calibration structures (Figure1) consist of three pyramidal structures. The spherical element necessary for the calibration of BSE detectors [2] is not used here. Following the principle of marker-based calibration, the pyramidal structures contain circular nanomarkers at specific three-dimensional coordinates, which serve as reference for the scale and shear calibration in all three spatial directions. The necessary reference measurement of the calibration structure is performed at the PTB with the Met.LR-SPM, (Metrological Large-Range SPM) based on a NanoMeasuringMachine (SIOS GmbH). The position of all three translation axes of the Met.LR-SPM are monitored by laser interferometers and thereby direct traceability to the SI unit meter is guaranteed [3].

For a successful calibration, the operator has to select appropriate SEM parameters (detector type, magnification, beam voltage, working distance). After acquisition of the calibration sample image, the calibration is performed by the calibration software in an easy way. The software automatically detects and measures all markers on the base plane with sub-pixel accuracy by image processing methods. This includes the detection of the sample orientation and the allocation of special reference marks by using coded targets. The calibration results in the calculation of all linear geometrical parameters: scale in x- and y-direction, shearing between x and y, as well as the sample orientation (rotation and translation). The approach applied here is based on LSM (least-squares methods) and allows the statistical analysis of the results, including data snooping for outlier detection and analysis of non-linearities. All results can be saved as reports and the calibration data are stored in external files. These calibration files enable an automated SEM image correction (rectification) when using the image correction software included in the calibration software package. Alternatively, the calibration parameters can be transferred manually to your SEM software in order to obtain calibrated images.

Figure 1 shows the 2D calibration of the SEM Hitachi S520 with the calibration structure MMC-40. The size of MMC-40 is about 40 x 40 x 1.5 µm³, the base edge length of every pyramid is 10 µm, allowing fields of view (FOV) of 15 to 50 µm for the SEM calibration. Table 1 shows calibration results using various geometric parameters. Compared to non-calibrated image data, the maximum remaining deviations between the coordinates of the reference and the calibrated image are reduced from 268 to 27 nm in x-direction and from 534 to 56 nm in y-direction when applying shear corrections (2D affine). This result shows, that the application of a single scale (2D similar) or even the application of two scales (2D nonisotrop) is not sufficient to get the highest accuracy.

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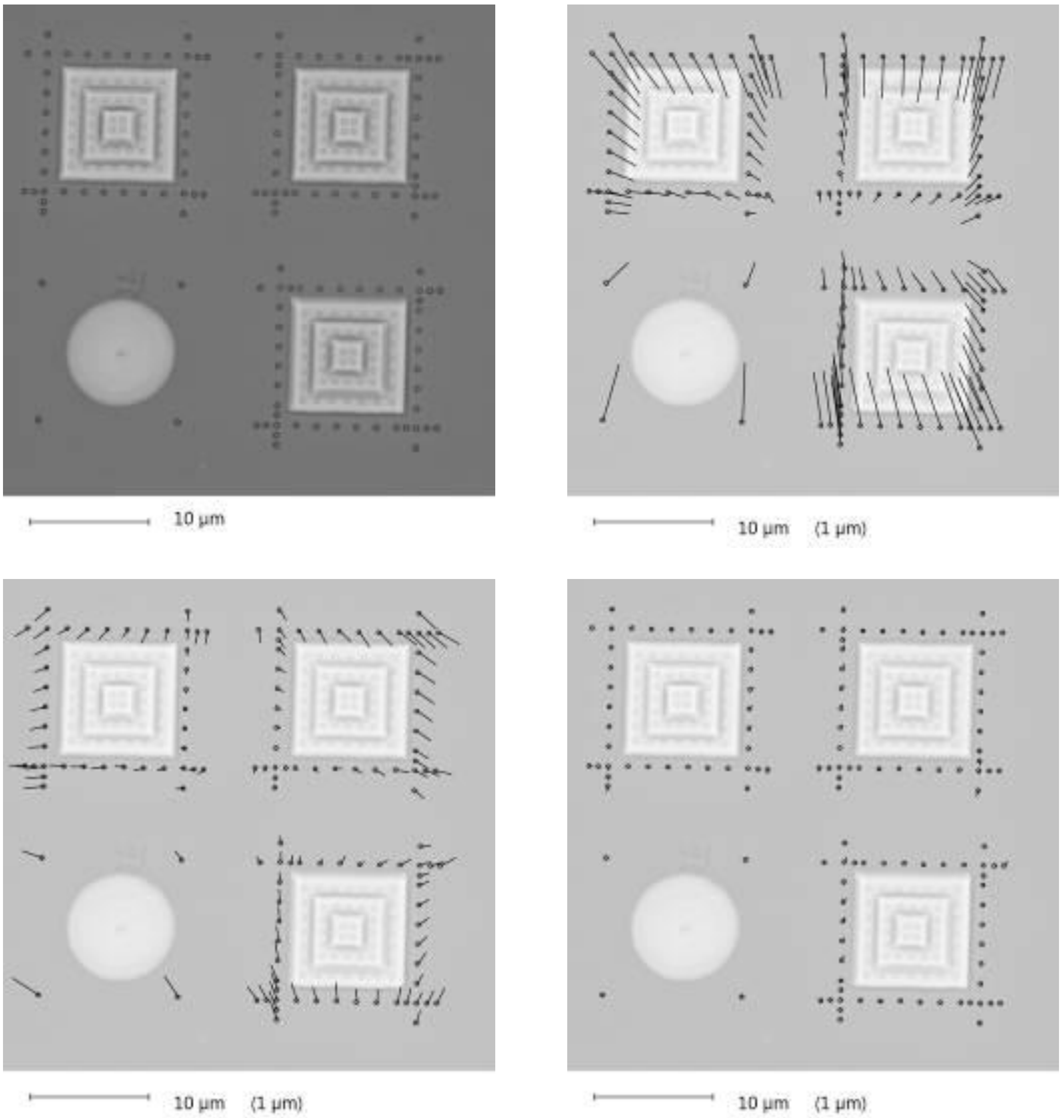

Figure 1. Original SEM image of MMC-40 (upper left), with deviations against reference data (upper right, deviation vectors 10x enlarged), with remaining deviations after scale calibration (2D similar, lower left) and with full 2D calibration (2D affine, lower right).

calibration approach	maximal deviation in x (nm)	maximal deviation in y (nm)	scale correction in x	scale correction in y	shear correction
2D rigid	268	534	-	-	-
2D similar	229	177	1,019	1,019	-
2D nonisotrop	36	66	1,011	1,027	-
2D affine	27	56	1,010	1,026	-0,002

Table 1. Results of different 2D calibration approaches with the marker-based calibration method (first line: comparison with reference data, second and third line: scale calibration, fourth line: complete calibration with scales in x- and y-direction and shearing).