

Proceedings

Measurement of Surface Roughness with SEM

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Roughness is a most important and very frequent measurement for surface quality control. Roughness is often decisive for correct function of a workpiece and thus roughness is measured not only in development and prototype stages but also measured routinely in production. Stylus profilometry has allowed reliable, traceable data for more than 30 years, however, profilometry is long known to have reached its limits. Firstly, the lateral resolution is limited by the tip radius, which is typically not smaller than 2 μm , and secondly, the speed is too slow for imaging. Optical surface measurement techniques, such as CLSM, WLI and focus variation do provide image data but still lack sufficient lateral resolution. AFM does provide excellent resolution but it's still relatively slow and with a limited field-of-view. The work presented here shows that SEM does provide an effective and reliable method for roughness measurements, enabling characterization of samples with micro to nanometer roughness. This is a major advantage for roughness measurements, especially if additional characterization with complementary analytical methods (e.g., EDS) is required.

With the growing variety of techniques for roughness measurements, the equipment and its calibration play an increasingly important role in the validation and equivalence of resulting roughness parameters. Whilst calibration of 3D measurement axes is usually accomplished by traceable lateral and depth-setting standards, characterization of roughness measurement limits must be done separately. Apart from the measurement mode and particular sensor specifications, hardware parameters such as optical specifications, image formation and data processing have a complex impact on roughness measurements [1]. With regards to 3D SEM, BSE directional dependence is used to calculate surface gradients and respective height differences for each surface element – therefore live measurement and display of the complete sample topography as height maps is easily achieved, without sample tilting [2]. 3D calibration in SEM is readily achieved with an adequate calibration sample and does account for the geometry of the 4Q-BSE detector and the SEM settings during acquisition, including parameters such as working distance, acceleration voltage or rotation angle. Still, correct roughness measurements cannot be assumed from this 3D calibration, and independent testing is required with a known roughness testing sample.

A commercial roughness standard ARS c3 [3] was used to compare SEM measured values with nominal values. These samples are formed by a lapping process on Silicon, are uniform and independent of the direction at the surface and therefore suitable as isotropic areal roughness standards [4]. The typical roughness is stated with $S_a = 290 \text{ nm}$, measured with a confocal microscope at 50x magnification without filtering. An upgraded LEO 1500 SEM was used, equipped with a point electronic GmbH BSE-Topography measurement system including a retractable 4Q-BSE detector with calibrated amplification and automated signal adjustment [5]. SEM was calibrated with a 3D standard MMC-80 to ensure correct lateral and height scales [6]. Surface topography was measured at 15 kV HV at different positions and varying magnifications, as shown in Figure 1. Because of the higher SEM resolution, even the smallest grooves are visible in the SEM topography data, which are likely invisible with optical methods.

MountainsMap 10.3 (Digital Surf) was used for calculation of the surface roughness parameter [7] conform to ISO 25178. For this comparison, only arithmetic mean height (S_a) was analyzed, because this value was stated with the roughness sample. Given the higher SEM resolution, results are stated with two varying Gaussian filters (λ_s 2,5 μm and 5 μm) and without filtering. This Gaussian filtering was applied and has a significant influence on S_a , as shown in Figure 2. Results presented here show a good comparison with the stated roughness ($S_a = 0.290$, measured with a confocal microscope without filtering). In general S_a is slightly higher for lower magnification, which possibly depends on the chosen sample positions, which naturally leads to more differing results at higher magnifications. As clearly seen, the choice of an adequate Gauss filter is important for comparison with roughness measurements with optical instruments.

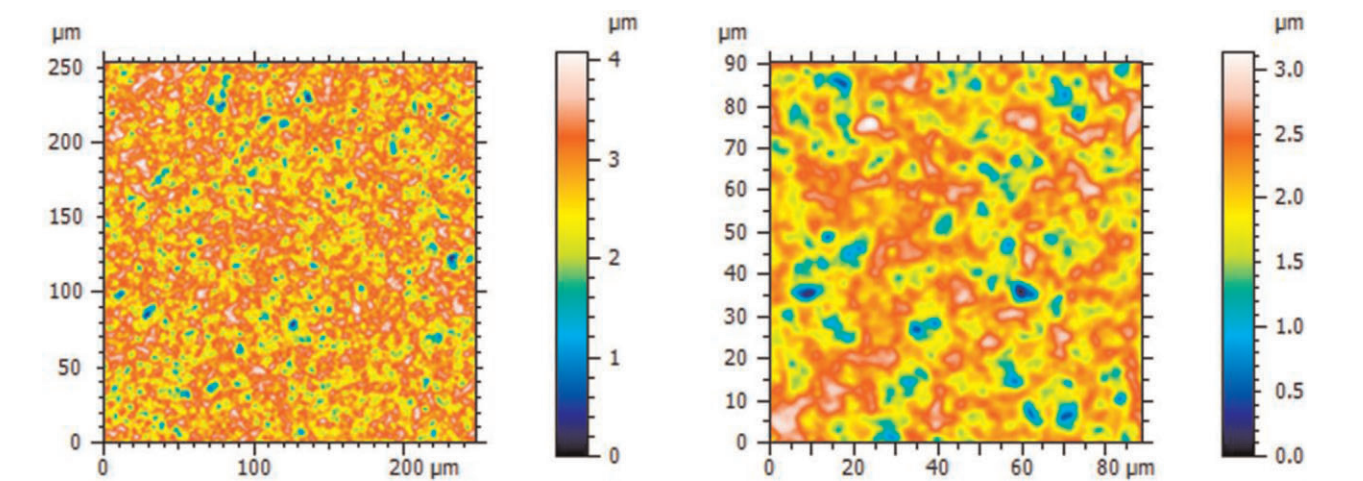


Fig. 1. Height map of surface detail from roughness sample ARS c3, measured with BSE topography at 15 kV HV, magnification 500x (left), 1400x (right)

Position	Magnification	Sa (μm)		
		Unfiltered	Gauss 2,5 μm	Gauss 5 μm
1	1400x	0.335	0.328	0.303
2		0.314	0.304	0.276
3		0.313	0.301	0.275
Mean		0.321±0.012	0.311±0.015	0.285±0.016
4	500x	0.331	0.317	0.289
5		0.350	0.337	0.308
6		0.345	0.332	0.304
Mean		0.342±0.010	0.328±0.010	0.300±0.010

Fig. 2. Roughness values (Sa) measured with SEM for different positions, magnifications and filter settings. Mean roughness values and their mean errors are stated for each magnification, filtered and unfiltered.

References

1. T. Dziomba *et al.*, How reliable are optical measurements of surface roughness? Ilmenau Scientific Colloquium, 2023, DOI: [10.22032/dbt.58670](https://doi.org/10.22032/dbt.58670)

2. M. Hemmleb *et al.*, 3D surface reconstruction with segmented BSE detector: New improvements and application for fracture analysis in SEM, EMC, 2016, DOI: [10.1002/9783527808465.EMC2016.6175](https://doi.org/10.1002/9783527808465.EMC2016.6175)

3. <https://www.simetrics.de/downloads/RnS.pdf> (accessed February 12, 2026)

4. J. Frühauf *et al.*, Development of Si-chips with anisotropic rough surface, *Surf. Topogr.: Metrol. Prop.* 8 045001, 2020, DOI [10.1088/2051-672X/abb528](https://doi.org/10.1088/2051-672X/abb528)

5. <https://www.pointelectronic.de/en/systems/topographic-analysis/> (accessed February 12, 2026)

6. M. Xu *et al.*, Validation and reliability of the 3D calibration evaluation algorithm for SPM, *Meas. Sci. Technol.* 35 095020, 2024, DOI: [10.1088/1361-6501/ad56b4](https://doi.org/10.1088/1361-6501/ad56b4)

7. <https://guide.digitalsurf.com/en/guide-surface-texture.html> (accessed February 12, 2026)