Machine learning–enabled SEM-driven surface morphometrics

Vineet Kumar[1*], Yogesh Paul[2], Himanshu Mishra[1], Saurabh Sudan[3]

[1]Dept. of Surface and Plasma Science, Faculty of Mathematics and Physics, Charles University in Prague, Czech Republic

[2]Institute for Neuromodulation and Neurotechnology, University Hospital and University of Tuebingen, Tuebingen, Germany

[3]Independent Researcher, London, UK

Abstract

Surface morphology reflects microstructural detail linked to mechanical performance, and SEM provides non-contact, high-resolution imaging to support this understanding visually. Recently, a classical computer-vision approach for quantitative SEM analysis, defining microcracks as a feature class and estimating crack count, length distribution, and area within the field of view (FOV), are applied [1]. To enhance analysis, the framework was extended with neural-network (NN) segmentation and thus enabling additional crack detection alongside classical one. For this purpose, plasma-treated cobalt-sputtered samples were imaged at multiple FOVs to demonstrate the implementation.

Methodology:

Cobalt films display strong ferromagnetic behaviour influenced by their hcp and fcc crystal structures. To examine these structure–dependence behaviour, cobalt was deposited onto silicon wafers substrates, followed by SEM analysis. Figure 1 shows the setup (for detail see Ref. [2]) and sample prepared over 15 min via magnetron sputtering for these studies.

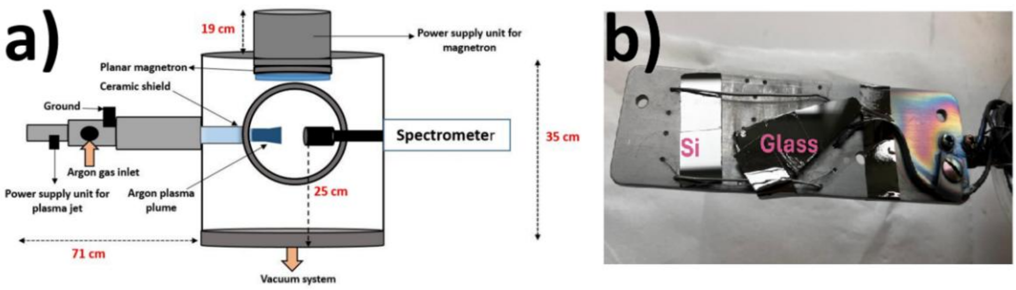

Figure 1: (a) Schematic of the hollow-cathode setup, showing chamber insight; and (b) photograph of the Co-sputtered sample holder.

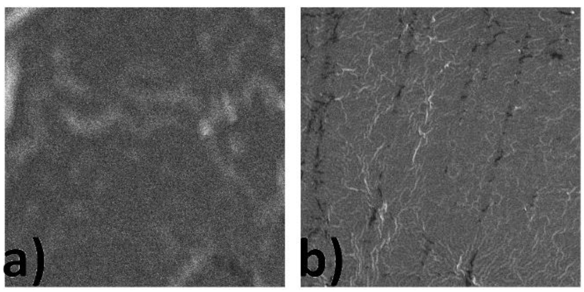

Figure 2: SEM image at same setting over different FOV. a) For $\sim 10\ \mu m$ with $2\ \mu m$ scale bar, and b) for $\sim 100\ \mu m$ with $20\ \mu m$ scale. Both data were captured using the MIRA TESCAN.

Figure 2 shows the SEM images acquired at a 15 kV voltage, providing topographical contrast across the surface. The working distance was 16.25 mm, magnification 1.70 kx.

Figure 3 summarizes the classical crack-pattern based on edge detection. At $10\ \mu m$ FOV, 351 microcracks detected, with a crack length of $53893\ px\ (956\ \mu m)$ and a cracked area of $71927\ px\ (23\ \mu m^2)$. The crack density reached $1.1 \times 10^{-3}\ px^{-1}$ and $3.5\ \mu m^{-2}$. At a $100\ \mu m$ FOV, 227 microcracks identified, with crack length $41429\ px\ (7372\ \mu m)$ and cracked area of $58763\ px\ (1861\ \mu m^2)$. The density measured $7.1 \times 10^{-4}\ px^{-1}$ and $2.3 \times 10^{-2}\ \mu m^{-2}$.

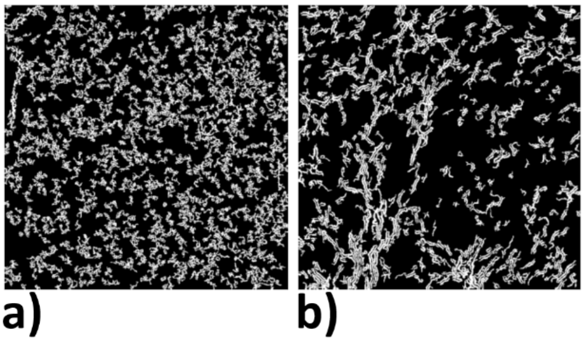

Figure 3: Classical crack-pattern mapping corresponding to the SEM images in Figure 2, showing segmented crack structures at FOVs: a) $\sim 10\ \mu m$, and b) $\sim 100\ \mu m$.

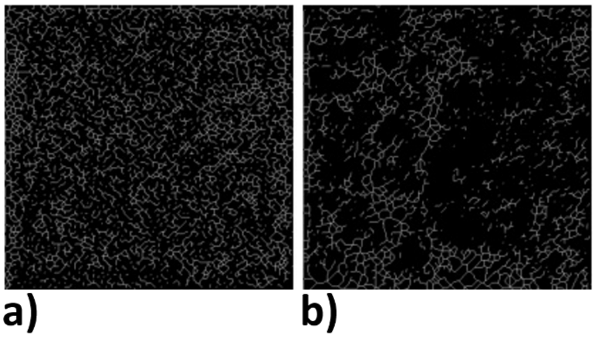

Figure 4: Machine learning based cack pattern detection compared to corresponding classical-based detection shown in Figure 3.

Figure 4 summarizes the NN-based crack detection. At $10\ \mu m$ FOV, 526 microcracks detected, with a crack length of $28000\ px\ (496\ \mu m)$ and an area of $26598\ px\ (8.4\ \mu m^2)$. The crack density reached $1.7 \times 10^{-3}\ px^{-1}$ and $5.3\ \mu m^{-2}$. At a $100\ \mu m$ FOV, 385 microcracks identified, with a crack length $18027\ px\ (3207\ \mu m)$ and an area of $17217\ px\ (545\ \mu m^2)$. The density is $1.2 \times 10^{-3}\ px^{-1}$ and $3.9 \times 10^{-2}\ \mu m^{-2}$. The code is available on GitHub [3].
NN-based detects more microcracks than the classical based at both FOVs, indicating greater sensitivity to fine structural detail. While the classical method produces longer crack length and larger area, primarily due to edge-based tracing, which thickens crack paths and may overestimate surface coverage. In contrast, the NN segmentation isolates crack regions more precisely, resulting in higher density and a more realistic representation of crack distribution.

References:

[1] Kumar, Vineet, et al. "Verification and experimental validation of neutral atom beam source produced by L-PBF." *arXiv preprint arXiv:2512.11364* (2025).
[2] Mishra, Himanshu, Milan Tichý, and Pavel Kudrna. "Optical emission spectroscopy study of plasma parameters in low-pressure hollow cathode plasma jet and planar magnetron powered by DC and pulsed DC supply." *Vacuum* 205 (2022): 111413.
[3] https://github.com/PaulYogesh/Mic-hackathon-2025