SEM Lab

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1 Depth of field

Theoretical depth of field was calculated from

$$D = \left(\frac{\delta}{M} - d_p \right) \alpha^{-1}, \tag{1}$$

using $d_p = 8\,\mathrm{nm}$, $M = 50$ and $\delta = 0.1\,\mathrm{mm}$. α was obtained from tabulated values given in the task description. Calculated values are given in the caption of the corresponding images. Theoretical depth of field was calculated for images shown in Figures 1 through 4.

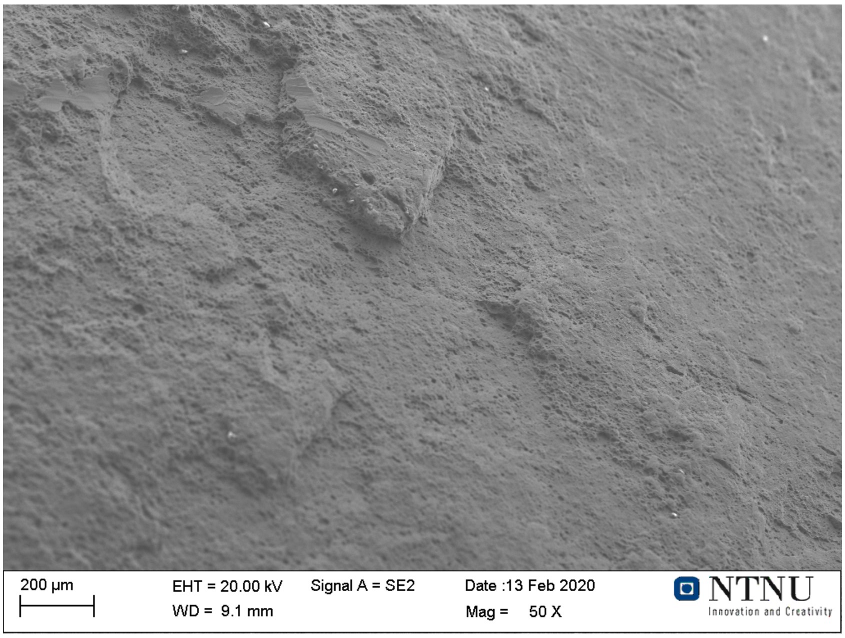

Figure 2: 30 µm aperture, 10 mm working distance, high current off. Theoretical depth of field: 0.473 µm

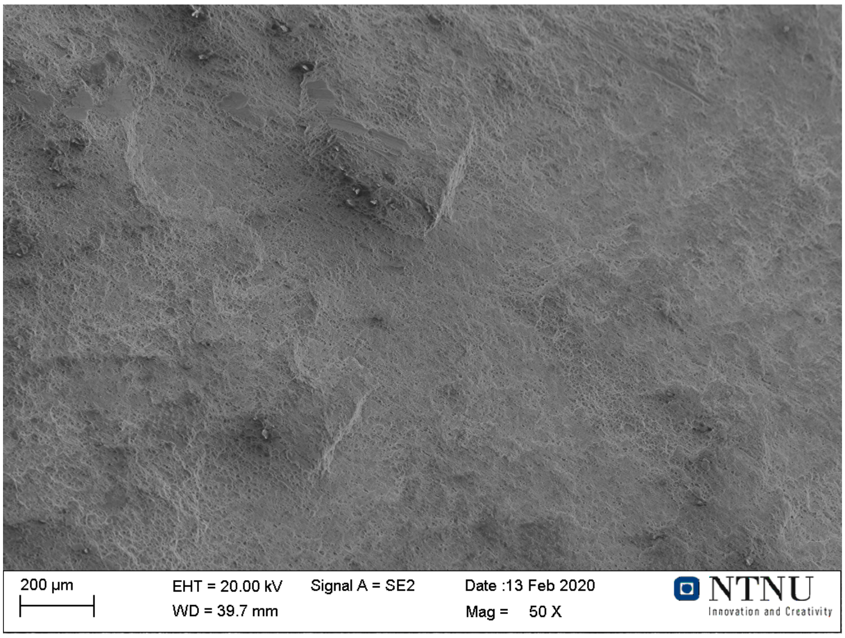

Figure 3: 120 µm aperture, 40 mm working distance, high current on. Theoretical depth of field: 1.0375 µm

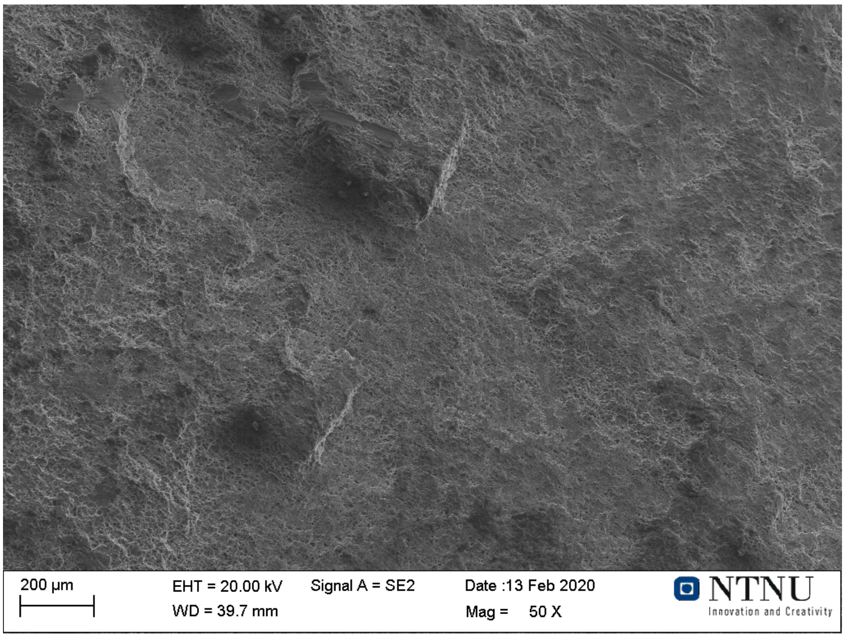

Figure 1: 30 µm aperture, 40 mm working distance, high current on. Theoretical depth of field: 4.15 µm

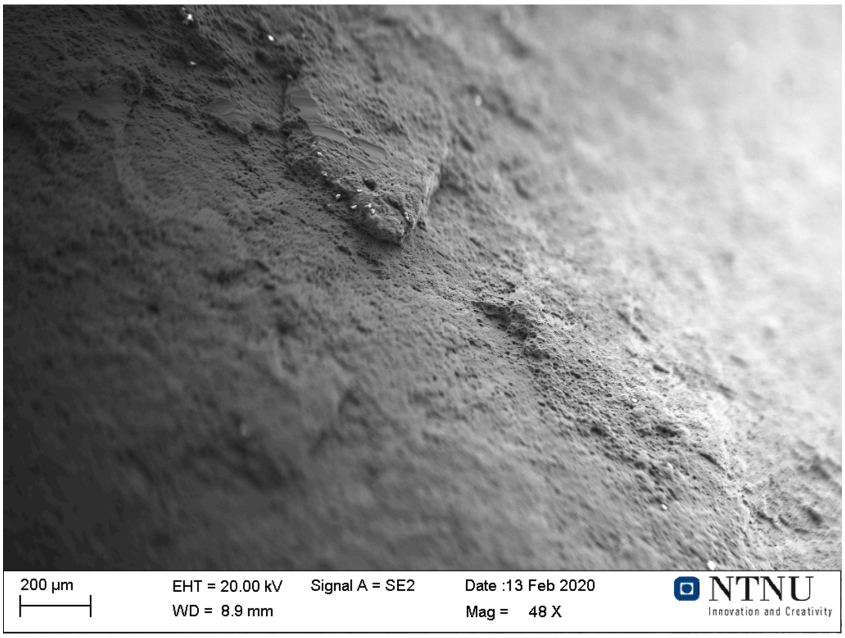

Figure 4: 120 µm aperture, 10 mm working distance, high current off. Theoretical depth of field: 0.079 µm

2 Resolution

Resolution (excluding aberrations) can be calculated from

$$d = K\sqrt{\frac{i_p}{E_0}}\alpha^{-1} \tag{2}$$

where E_0 is acceleration voltage, α is beam divergence, i_p is primary current and $K \approx 4 \cdot 10^6 \mathrm{V}^{0.5}\mathrm{pA}^{-0.5}\mathrm{nm}$ is a konstant. The primary current is equal to the sum of currents leaving the sample:

$$i_p = i_{BSE} + i_{SE} + i_{AE} \tag{3}$$

where i_{BSE}, the current of backscattered electrons is dependent on surface angle and mean atomic number. i_{SE}, the current of secondary electrons is roughly equal to 10% of the primary current, and i_{AE} is the current measured leaving the sample to ground. $Z = 13$ gives $i_{BSE} \approx 0.1 i_p$ from figure in the lecture notes. This gives

$$\begin{aligned} i_p &= 0.1 i_p + 0.1 i_p + i_{AE} \\ i_p &= \frac{i_{AE}}{0.8} \end{aligned} \tag{4}$$

which in turn gives

$$d = K\sqrt{\frac{i_{AE}}{0.8E_0}}\alpha^{-1} \tag{5}$$

for the images shown in Figures 5 and 6, α is 1.92 and 4.21 respectivly, this is reflected in the images, as the image in Figure 6 clearly has better resolution (lower d).

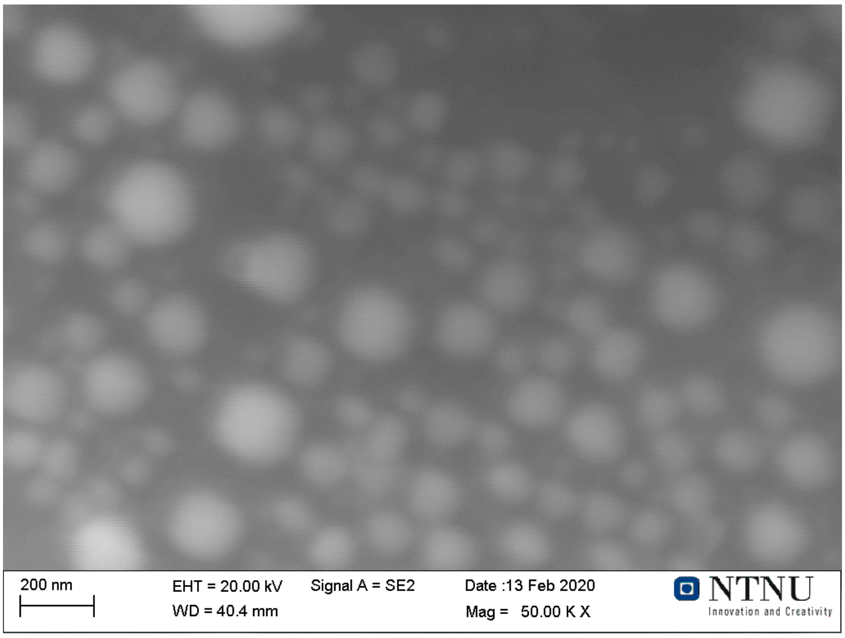

Figure 5: 120 µm aperture, 40 mm working distance. High current on.

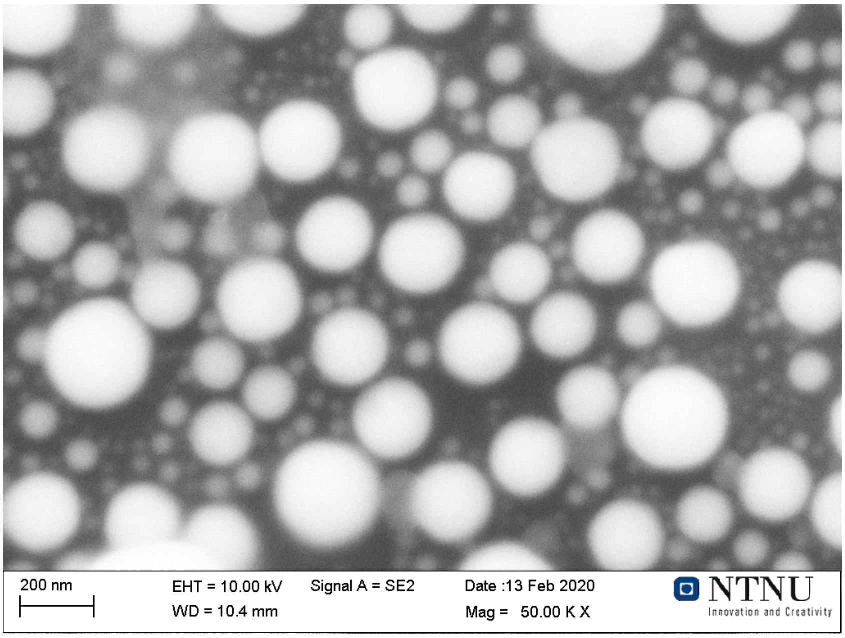

Figure 6: 30 µm aperture, 10 mm working distance. High current off.

3 Z-contrast and EDS

Figure 7 shows a multiphase sample imaged with backscatter electron imaging. The image shows clear Z-contrast from three phases with different mean atomic number. Figures 8 and 9 show EDS-analysis of the whole sample with respectivly 20 kV and 5 kV acceleration-voltage. It can be observed that K_α radiation is visible in both tests, while K_β is only visible to the far right in the high-voltage spectrum. This is because electrons with only 5 keV of energy are uncapable of exciting an atom so much that it will generate K_β radiaton upon relaxation. The analysis reveals that the species present in the sample are Carbon, Iron, Nickel, Copper and Okysgen. Figure 10 shows that copper is the dominating species in the bright phase, this is as expected because copper has the highest atomic number of all the elements in the sample, and therefore gives highest fraction of backscattering. Figure 11 shows large relative amounts of nickel, and considerable amounts of oksygen in the light gray phase, which again is as expected because nickel has the second highest atomic number in the sample, and is therefore likely to find in the second brightest phase. Figure 12 shows a larger concentration of iron in the darkest phase than in the other phases, and approximately the same concentration of oksygen as in the light gray phase. Following the same argument as with the two previous phases, this is as expected.

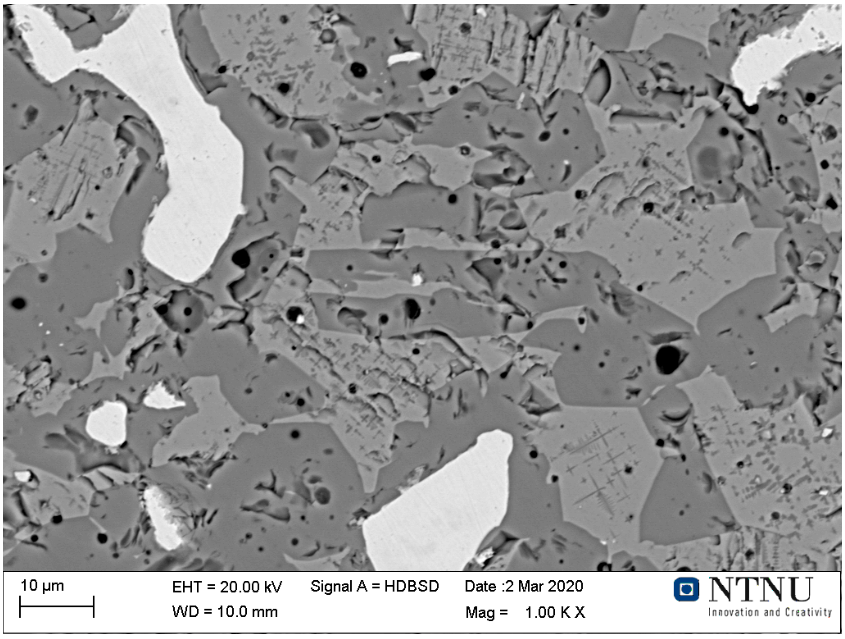

Figure 7: Backscatter-imaging of multiphase metallic specimen

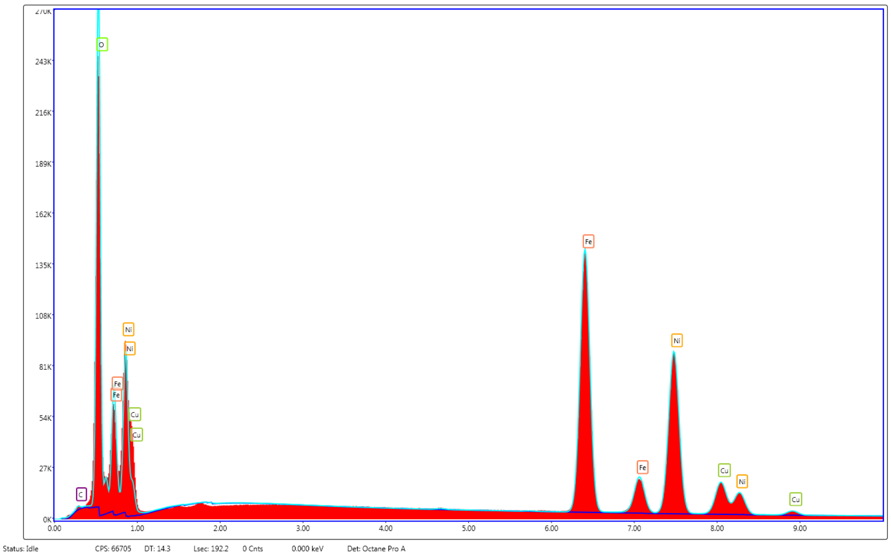

Figure 8: EDS, whole sample, high voltage

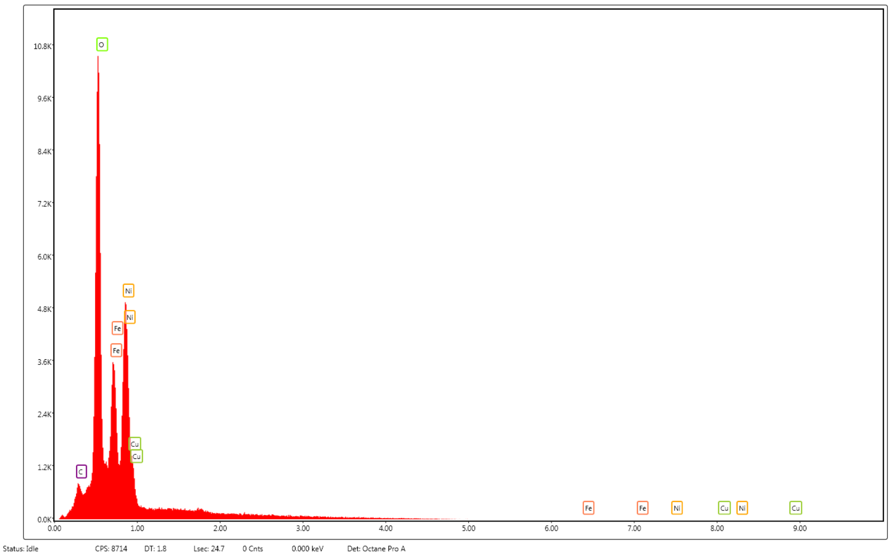

Figure 9: EDS, whole sample, low voltage

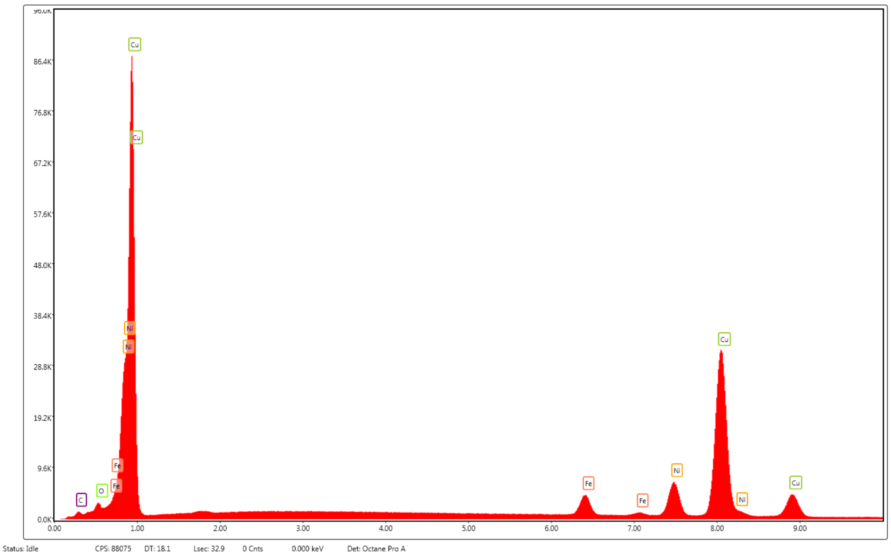

Figure 10: EDS, bright phase

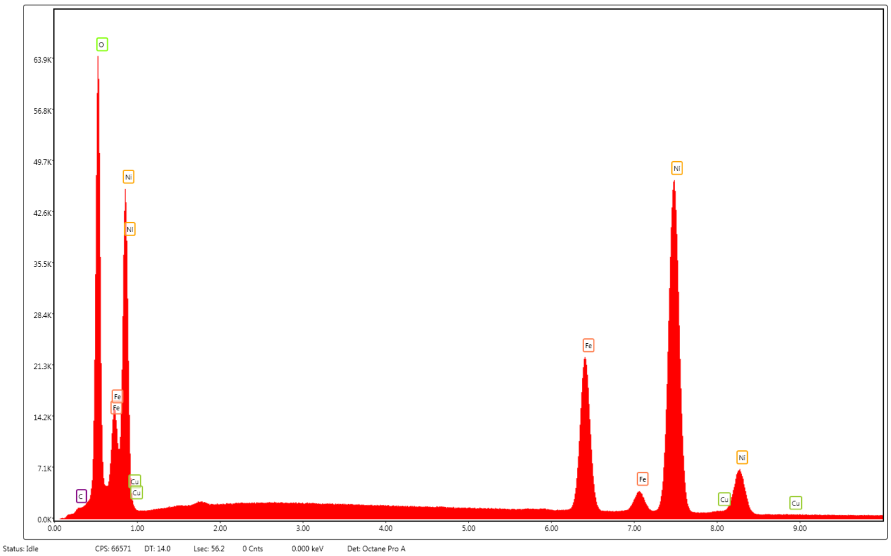

Figure 11: EDS, bright gray phase

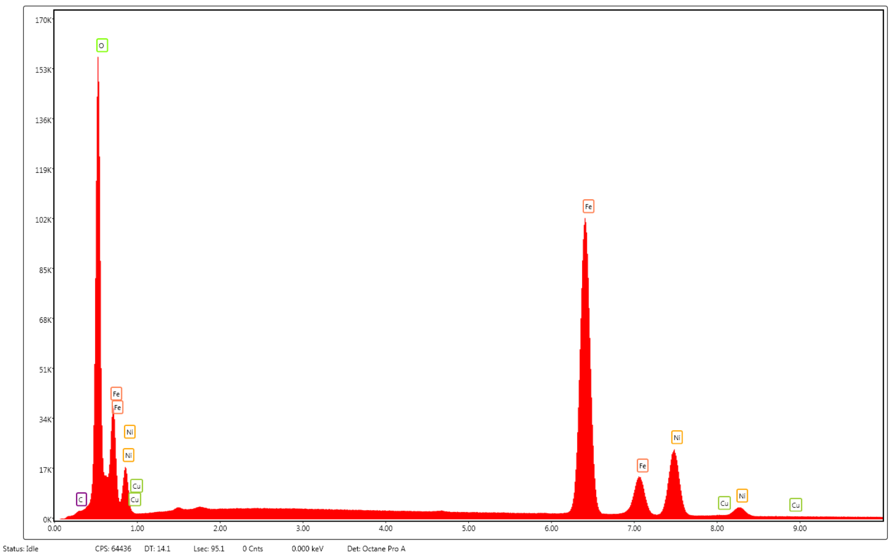

Figure 12: EDS, dark phase