

SEM Lab

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1 Depth of field

Theoretical depth of field was calculated from

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

using $d_p = 8 \text{ nm}$, $M = 50$ and $\delta = 0.1 \text{ mm}$. 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.

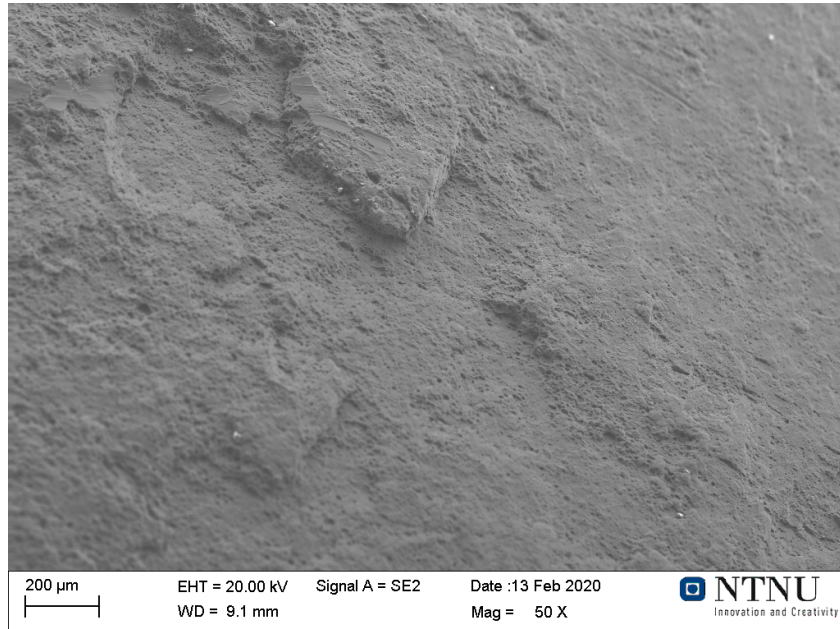


Figure 2: 30 µm aperture, 10 mm working distance, high current off. Theoretical depth of field: 0.473 mm

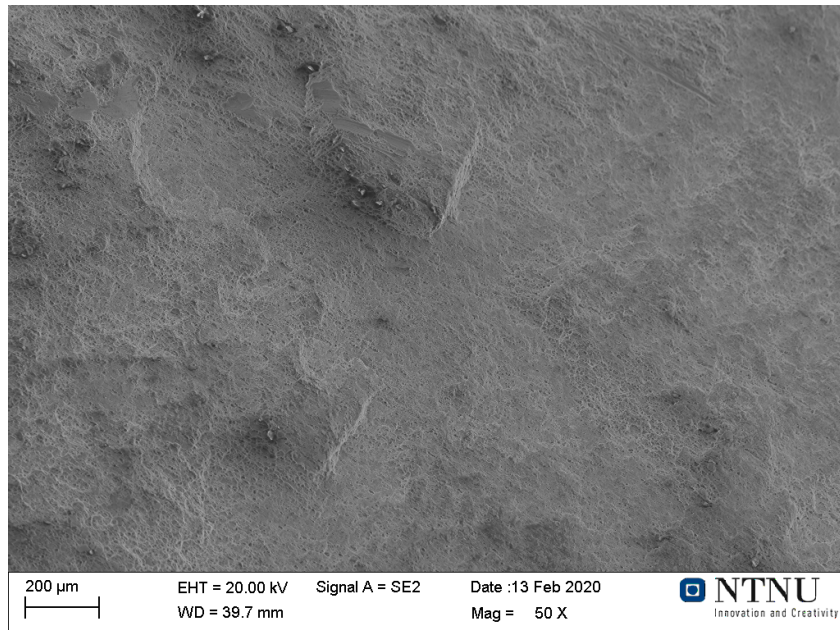


Figure 3: 120 μ m aperture, 40 mm working distance, high current on. Theoretical depth of field: 1.0375 mm

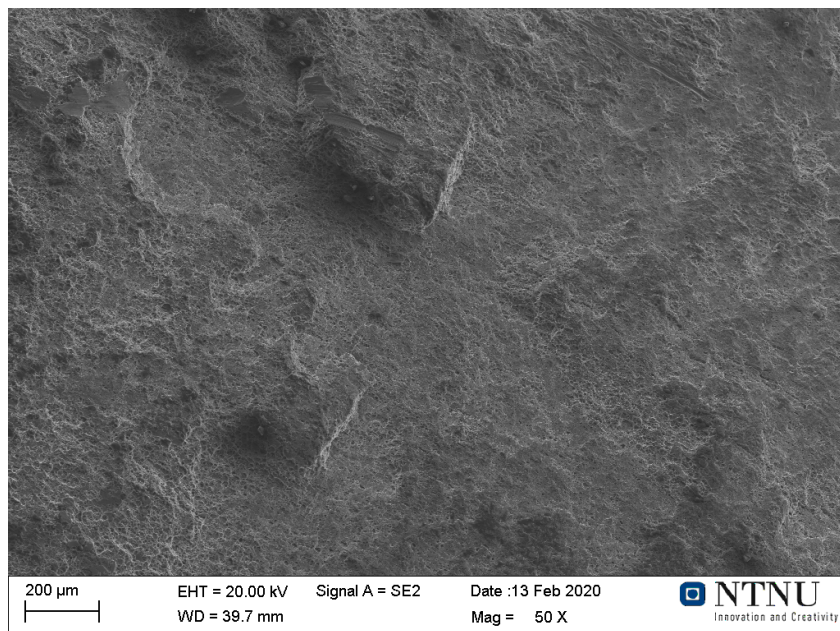


Figure 1: 30 μ m aperture, 40 mm working distance, high current on. Theoretical depth of field: 4.15 mm



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

2 Resolution

Resolution (excluding aberrations) can be calculated from

$$d = K \sqrt{\frac{i_p}{E_0}} \alpha^{-1} = K \sqrt{\frac{i_p}{E_0}} \frac{a}{r} \quad (2)$$

where E_0 is acceleration voltage, $\alpha = \frac{r}{a}$ is beam divergence, r is aperture opening, a is working distance, i_p is primary current and K is a konstant. Consequently, resolution can be improved by increasing the acceleration voltage, and α . The latter can be achieved by reducing aperture opening and increasing working distance. Equation 2 can be rewritten to so that K can be calculated from measured values: Calculating K from given values yields

$$K = \frac{dr}{a} \sqrt{\frac{E_0}{i_p}} \quad (3)$$

$$K = 734.8 \text{ nm} \sqrt{\frac{\text{kV}}{\text{pA}}}$$

The primary current is equal to the sum of currents leaving the sample:

$$i_p = i_{BSE} + i_{SE} + i_{AE} \quad (4)$$

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 $i_{BSE} \approx 0.1i_p$ from figure in the lecture notes. This gives

$$\begin{aligned} i_p &= 0.1i_p + 0.1i_p + i_{AE} \\ i_p &= \frac{i_{AE}}{0.8} \end{aligned} \quad (5)$$

which in turn gives

$$d = K \sqrt{\frac{i_{AE}}{0.8E_0}} \alpha^{-1} \quad (6)$$

for the images shown in Figures 5 and 6, α is 1.92 and 4.21 respectively, this is reflected in the images, as the image in Figure 6 clearly has better resolution (lower d). Using the i_{AE} values shown in the captions, and α -values obtained from the task description yields the calculated resolutions shown in the captions of Figures 5 and 6.

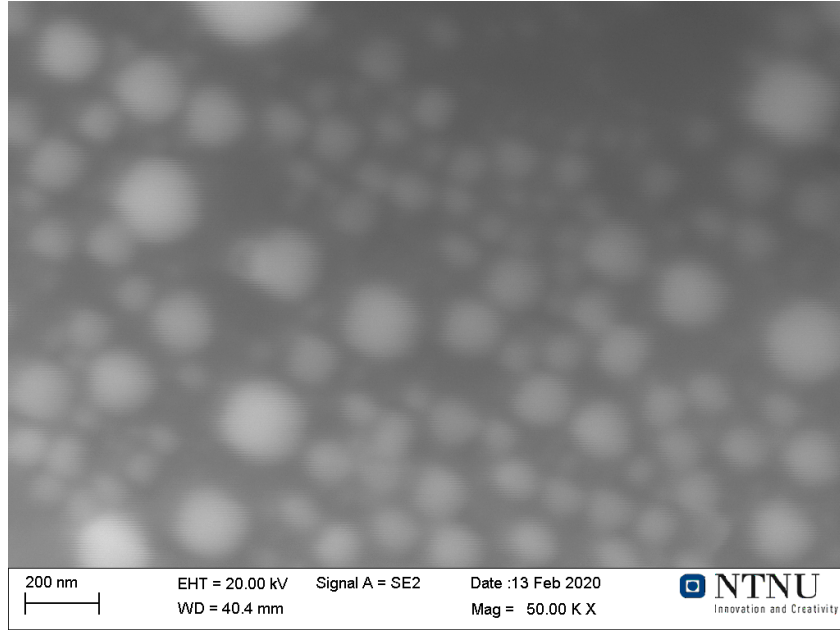


Figure 5: 120 μm aperture, 40 mm working distance. $i_{AE} = 12\,962\text{ pA}$. Calculated resolution: 48.5 nm

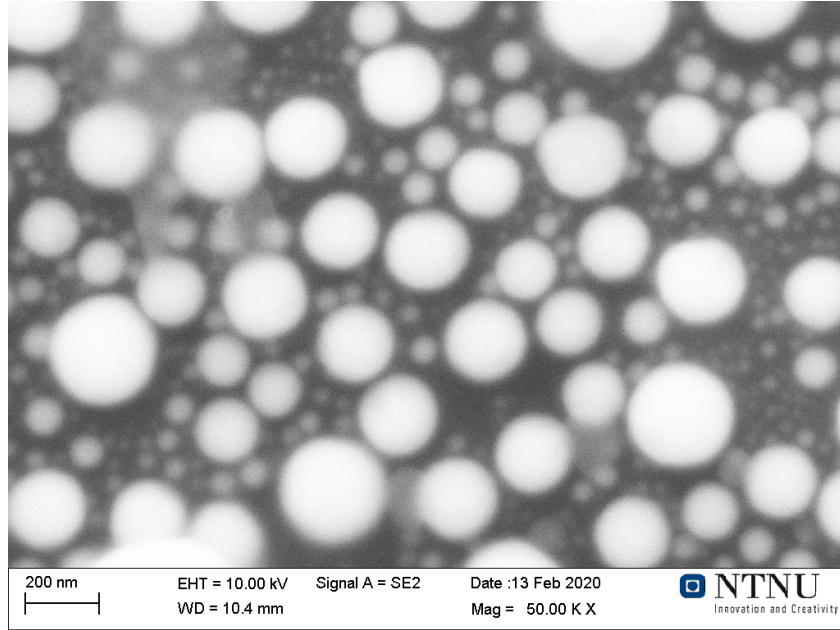


Figure 6: 30 μm aperture, 10 mm working distance. $i_{AE} = 354 \text{ pA}$. Calculated resolution: 22.7 nm

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 respectively 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 incapable of exciting an atom so much that it will generate K_β radiation upon relaxation. The analysis reveals that the species present in the sample are Carbon, Iron, Nickel, Copper and Oxygen. 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 oxygen 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 oxygen as in the light gray phase. Following the same argument as with

the two previous phases, this is as expected.

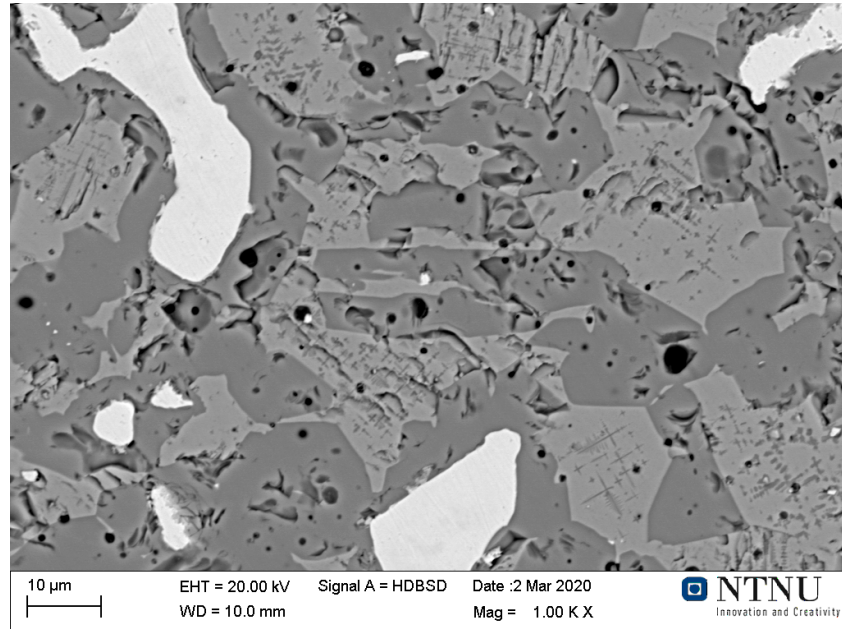


Figure 7: Backscatter-imaging of multiphase metallic specimen

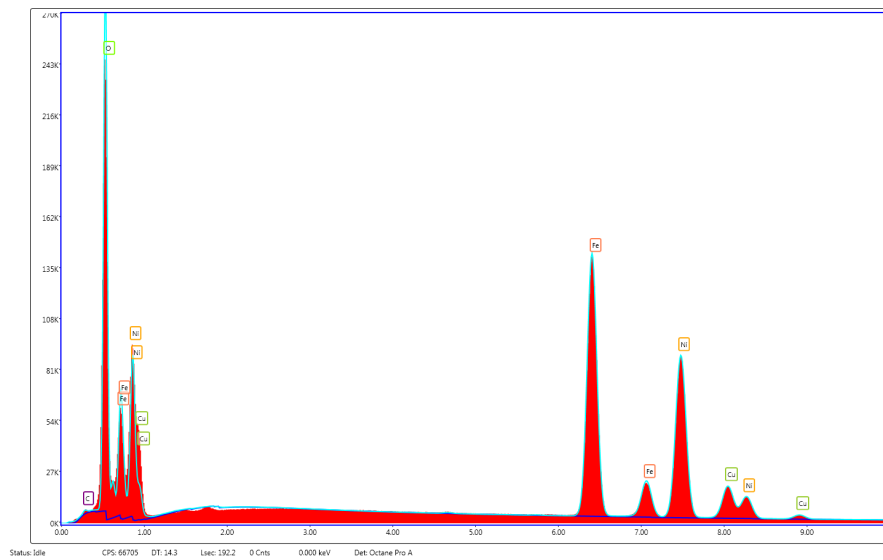


Figure 8: EDS, whole sample, high voltage



Figure 9: EDS, whole sample, low voltage

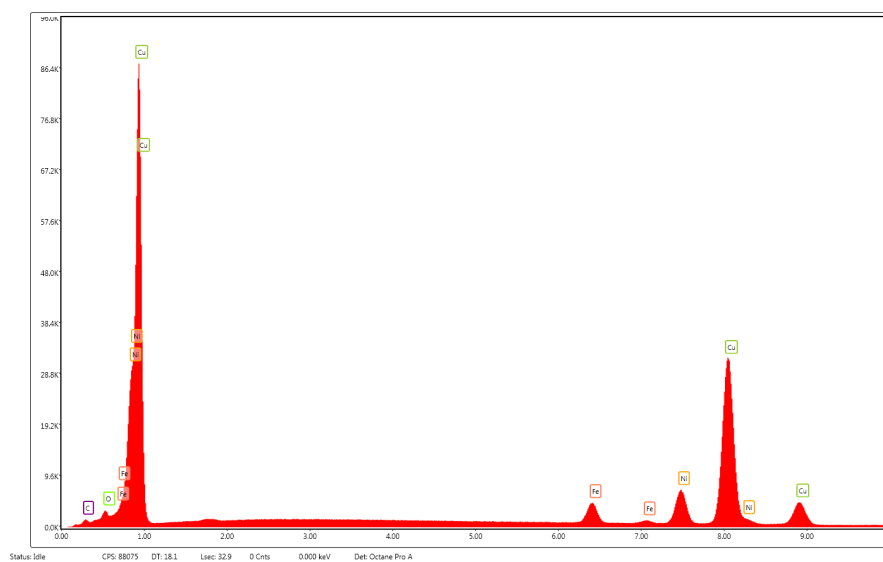


Figure 10: EDS, bright phase

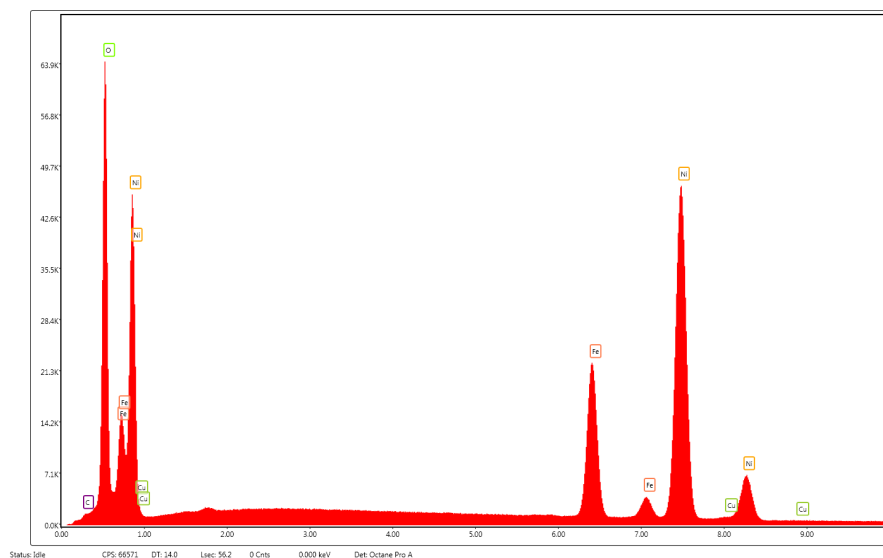


Figure 11: EDS, bright gray phase

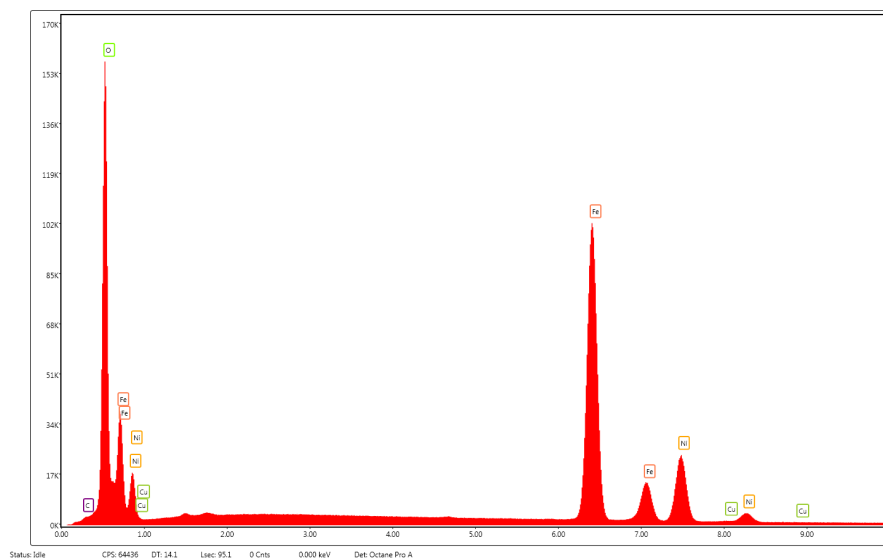


Figure 12: EDS, dark phase