HTC Project 2a

New corrosion resistant materials for challenging process environments – low oxygen activities and very high temperatures

Presented by LG. Johansson, T. Sand and M. Sattari

- *Project leader:* LG Johansson, Chalmers
- *Companies:* SANDVIK, KANTHAL® Part of Sandvik Group, Entech
- *Researchers in HTC :* LG Johansson, JE Svensson, C Geers, S. Bigdeli, M Halvarsson, M. Sattari, N Mortazavi (all Chalmers)
- *PhD student:* T. Sand (Chalmers)

Background

- Materials that can withstand process environments at very high temperatures without corroding are necessary in, e.g., steel production, in the thermal treatment of metals and ceramics, and in the manufacture of batteries and electronics
- New better materials that can withstand higher temperatures and more corrosive environments can lead to large gains in energy efficiency and also enable development of novel, energy efficient and environmentally friendly, processes and technologies

Goals

- Investigate the nitridation of high temperature alloys and the RE effect with the aim to formulate new strategies for developing alloys with superior ability to resist challenging environments and extreme temperatures
- **Materials:**
  - Alumina-forming alloys
  - Chromia-forming alloys

Exposures at 800-1100 °C in
95 % N_2, 5 % H_2, ppm-levels of O_2

Alloys tested

Grade	**253MA**	**7RE10 (310H)**	**SANICRO 31HT**	**353MA**	**SANICRO 70**
ELEM	V.VÄRDE	V.VÄRDE	V.VÄRDE	V.VÄRDE	V.VÄRDE
C	0.073	0.045	0.064	0.069	0.013
NI	10.80	20.16	30.31	34.91	Bal.
CR	20.95	24.31	20.26	25.65	16.73
SI	1.52	0.34	0.44	1.39	0.31
MN	0.67	1.24	0.50	1.68	0.19
N	0.156	0.038	0.012	0.172	0.006
CE	0.04			0.04	
AL			0.46		0.14
TI			0.51		0.33
FE	Bal.	Bal.	Bal.	Bal.	9.76

Nitridation resistance increases with increasing Ni and decreasing Cr

Expected increasing nitridation resistance

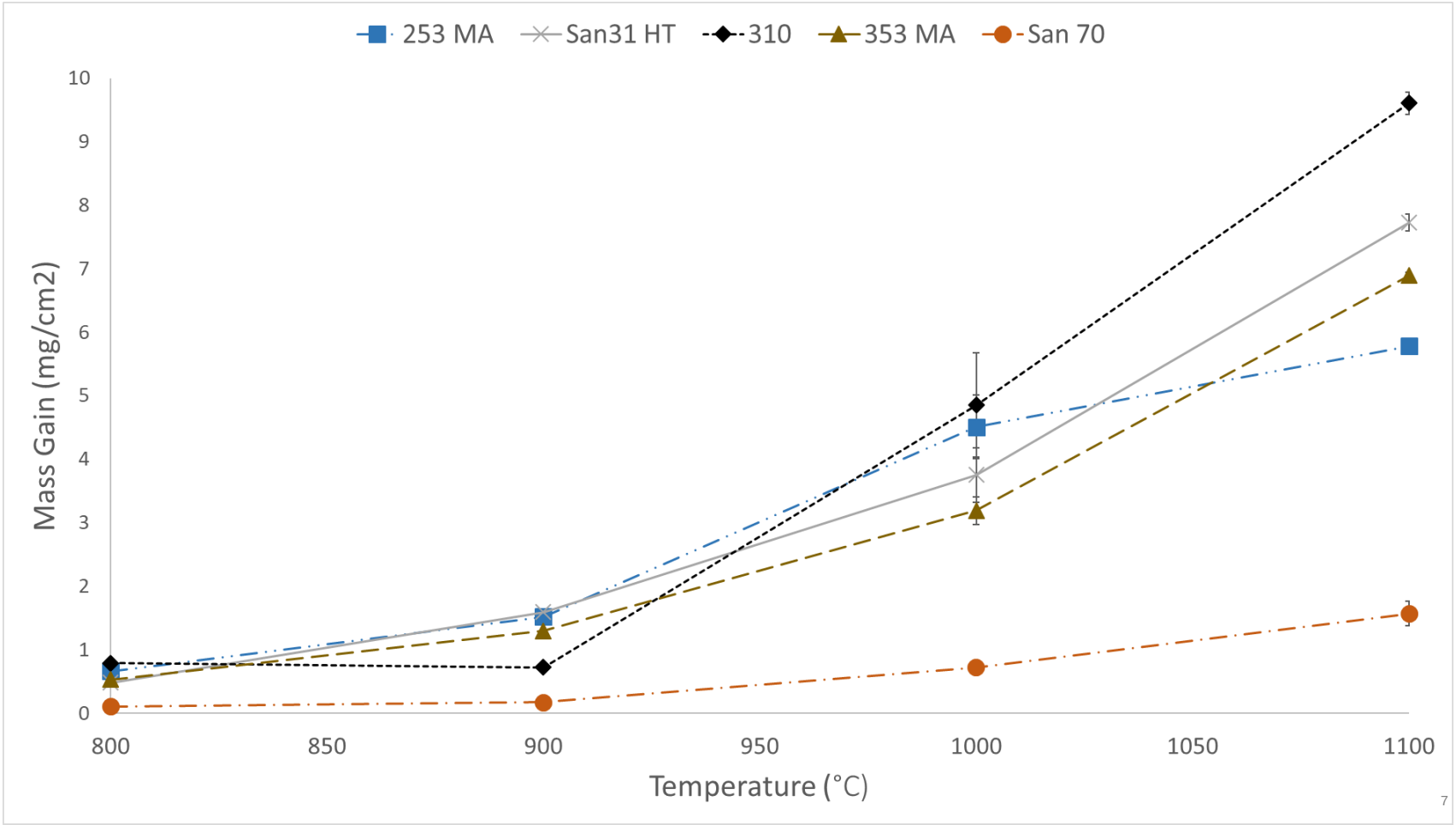
253MA

310H

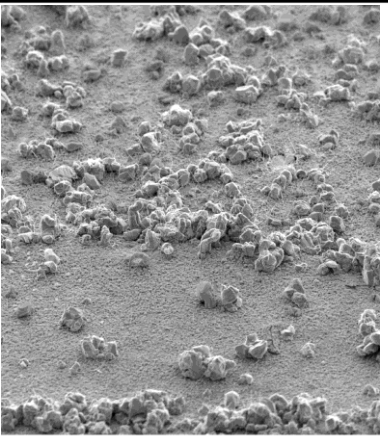
353MA

Sanicro 31HT

Sanicro 70


253 MA
San31 HT
310
353 MA
San 70
Mass Gain (mg/cm2)
0
1
2
3
4
5
6
7
8
9
10
800
850
900
950
1000
1050
1100
Temperature (°C)

800 °C



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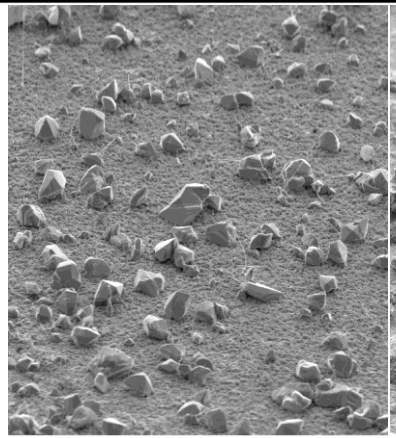
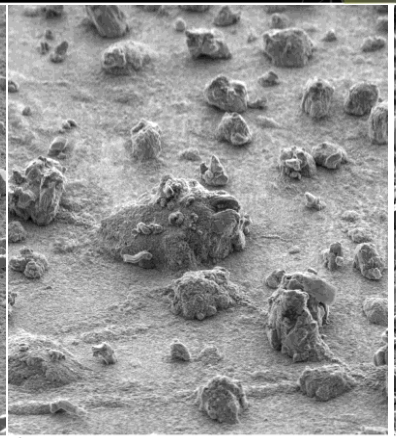


310H



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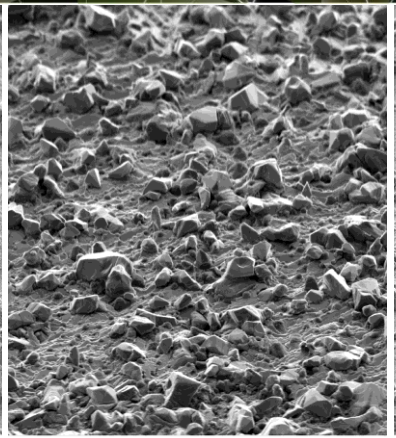

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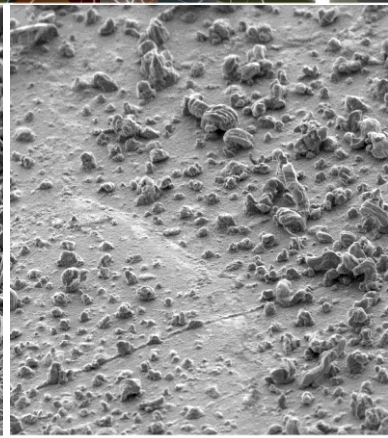

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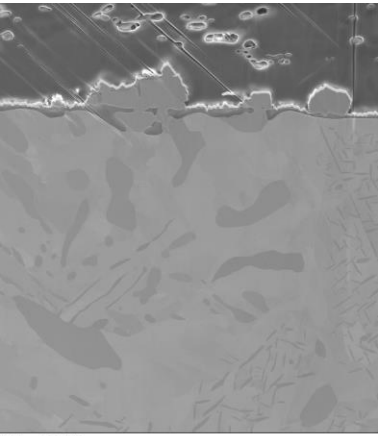

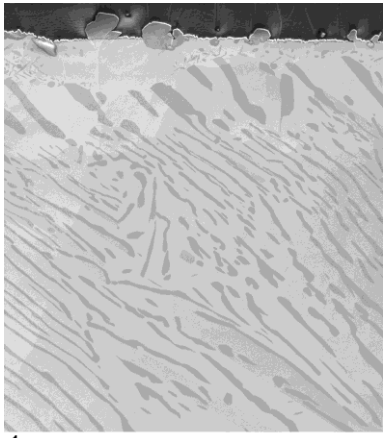

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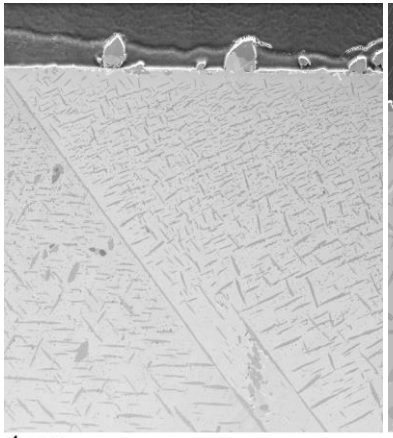

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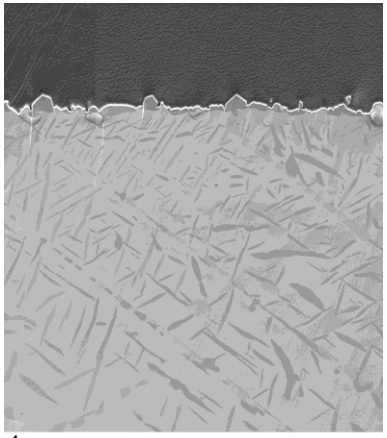

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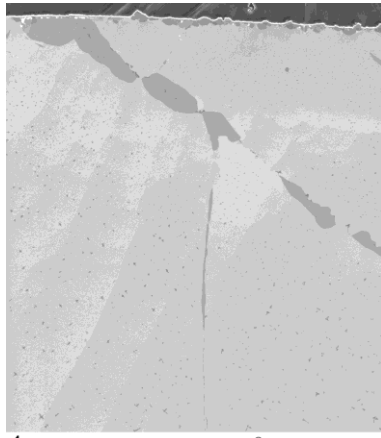
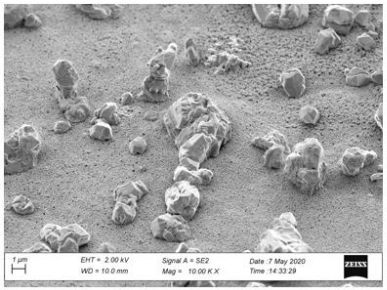


San70

900 °C



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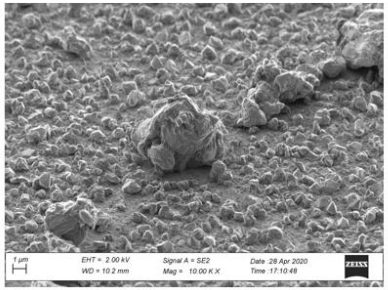

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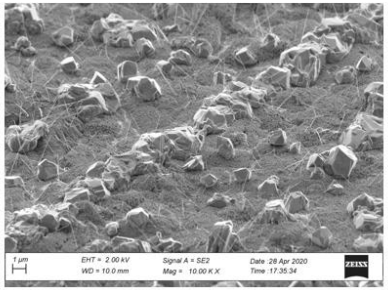

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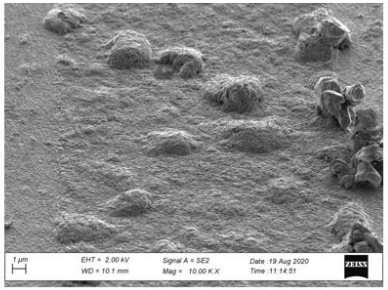

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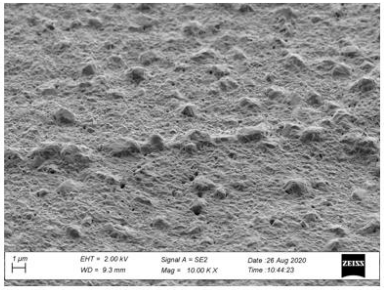

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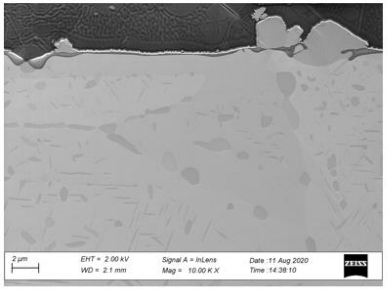
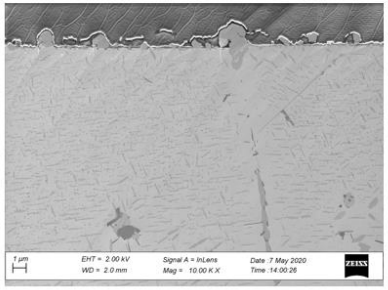
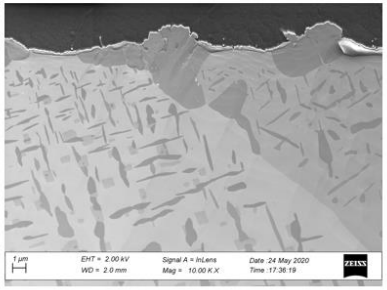
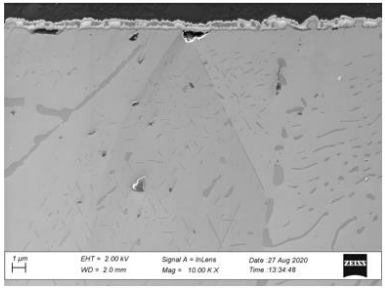
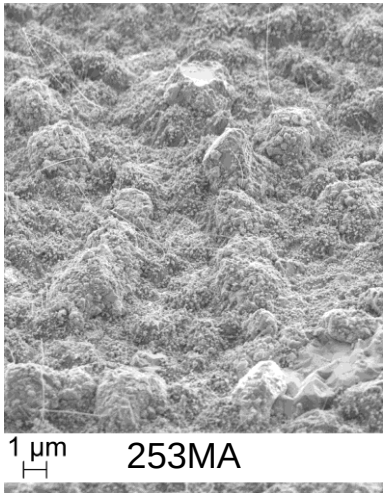








1000 °C



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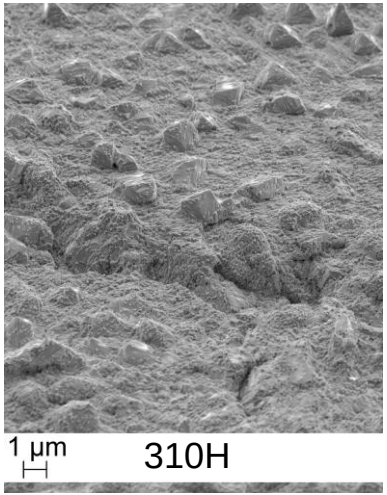

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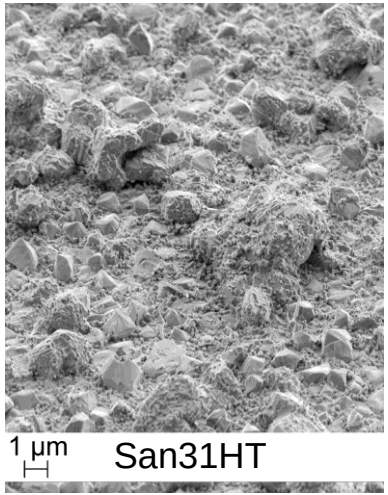

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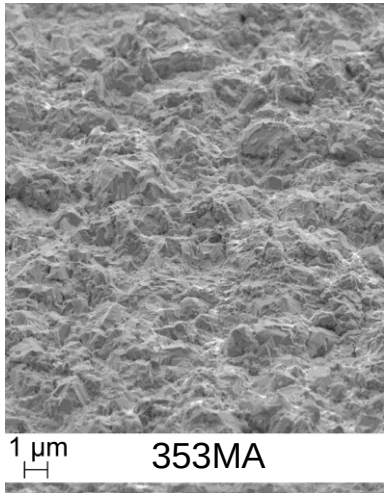

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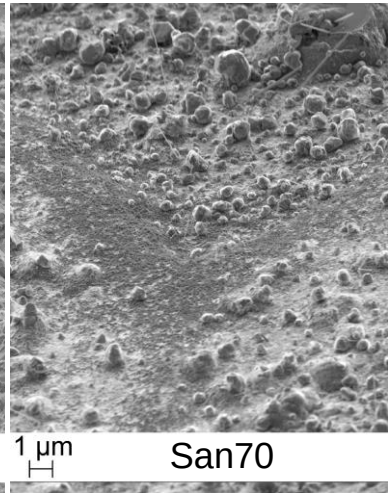

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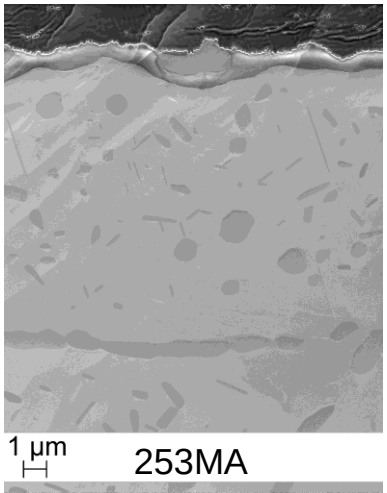
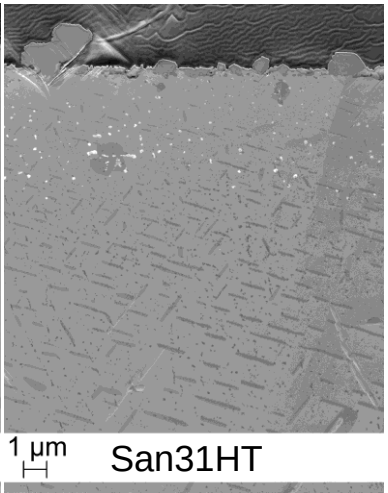


253MA

310H



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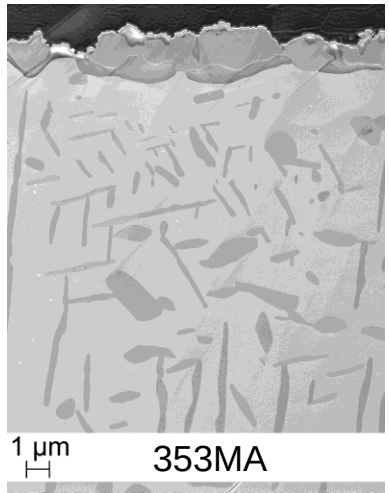

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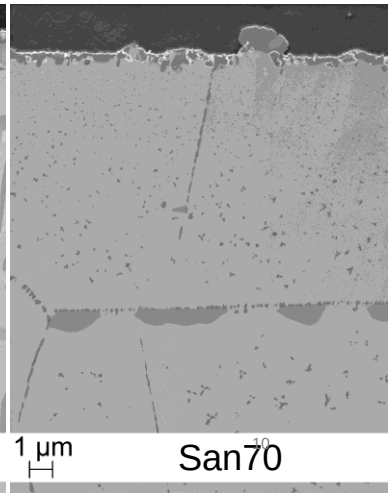

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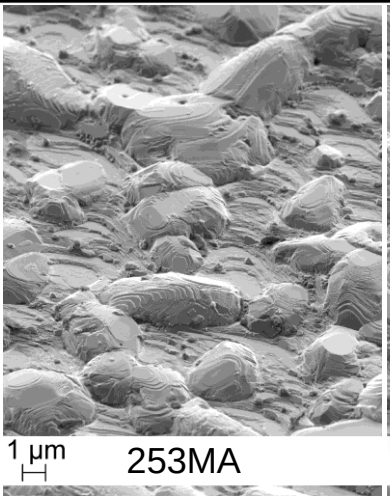
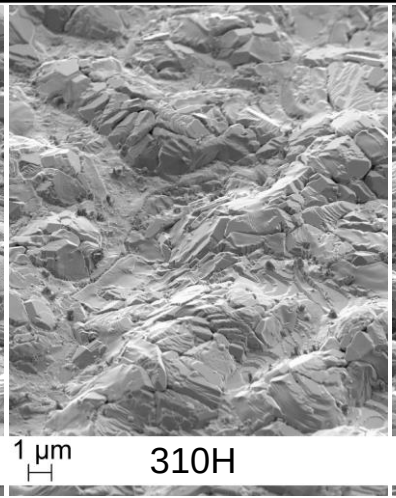
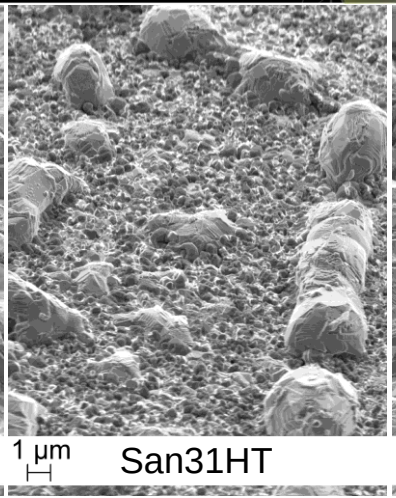
1100 °C


1 µm
253MA


1 µm
310H


1 µm
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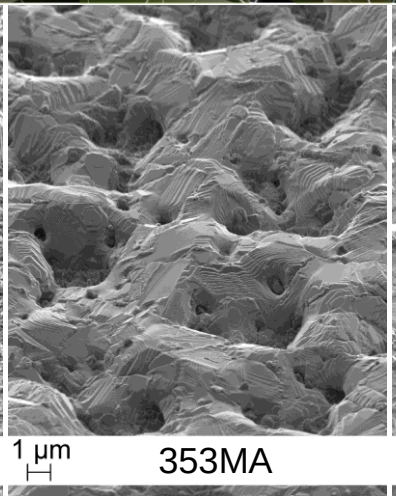
1 µm
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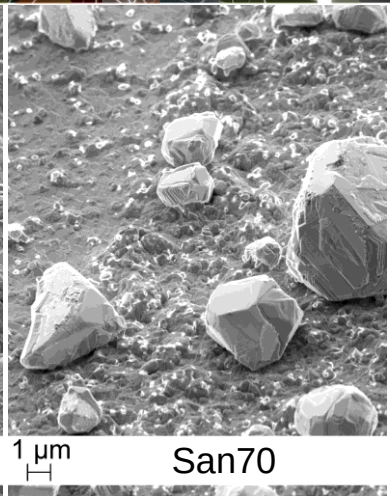
1 µm
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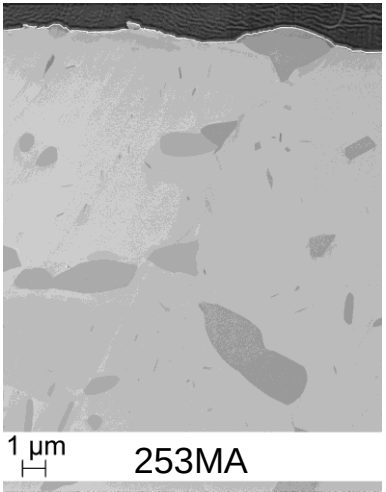
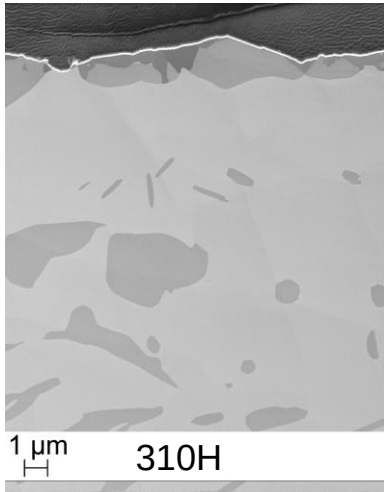

1 µm
253MA


1 µm
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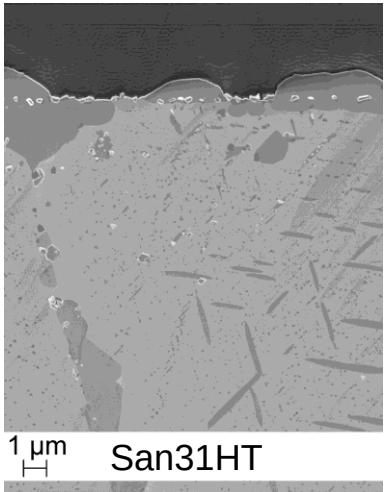
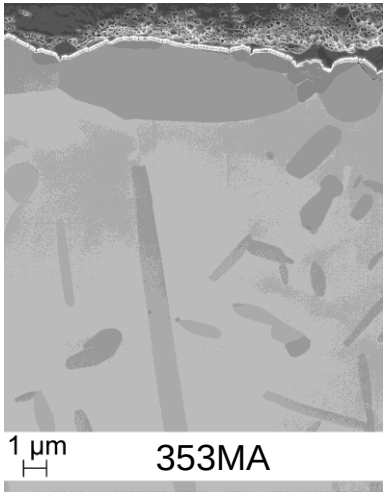

1 µm
San31HT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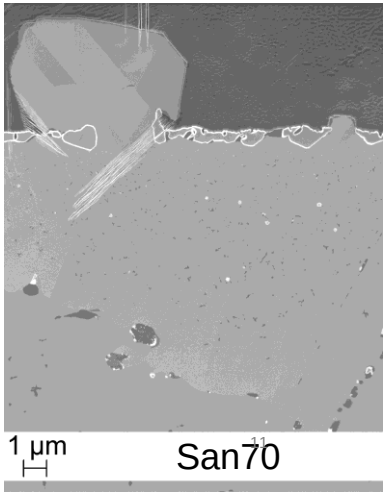
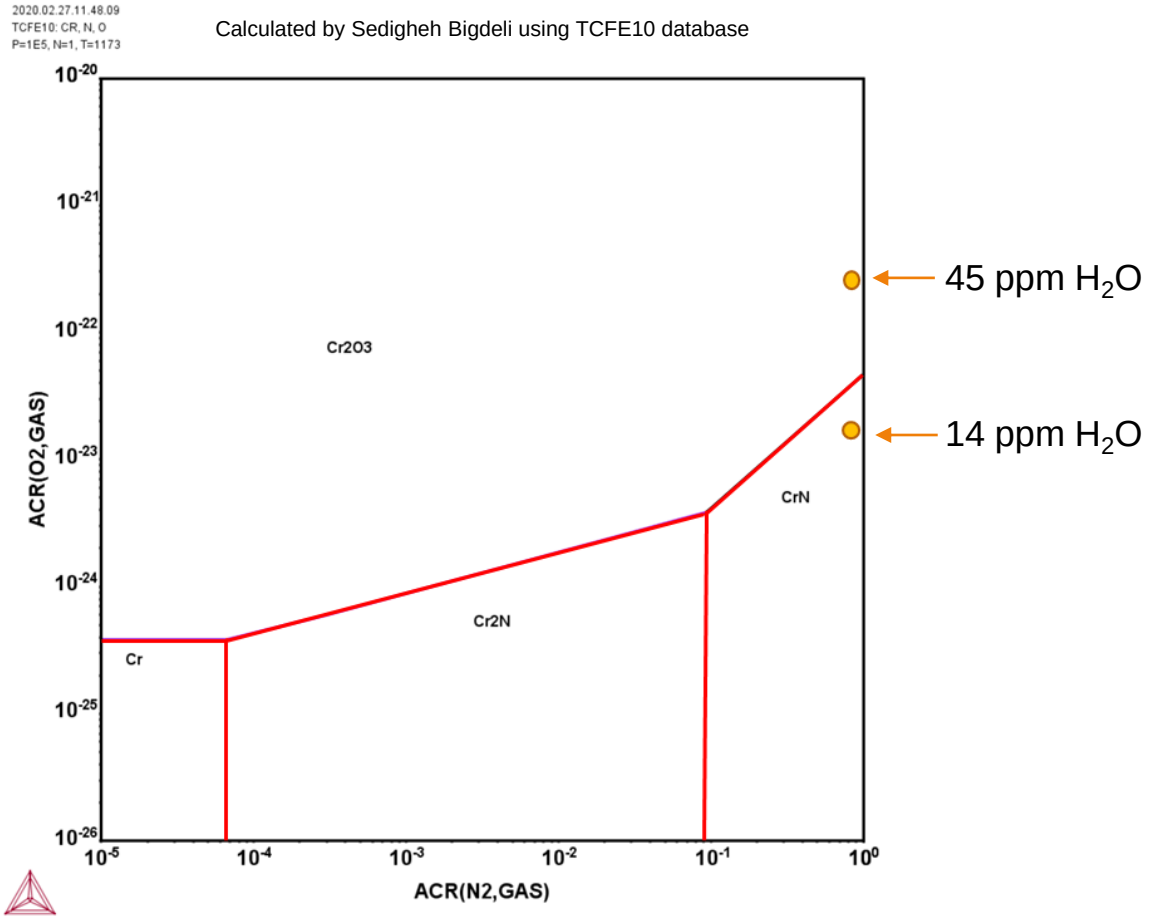
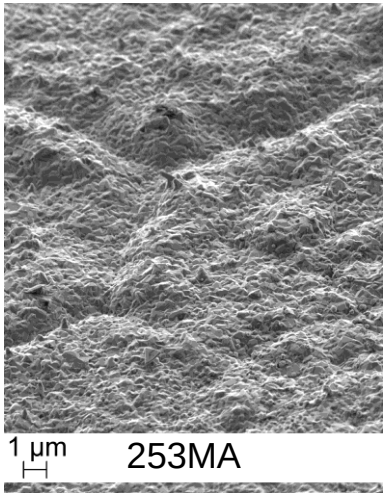
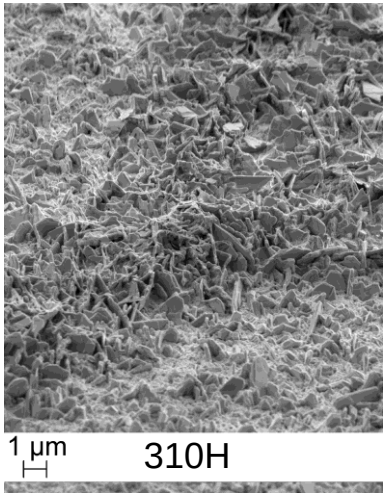

1 µm
San70

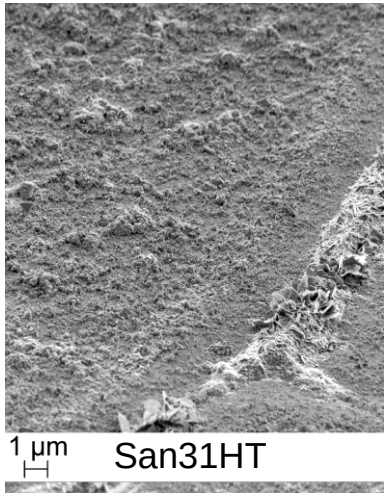
900 °C

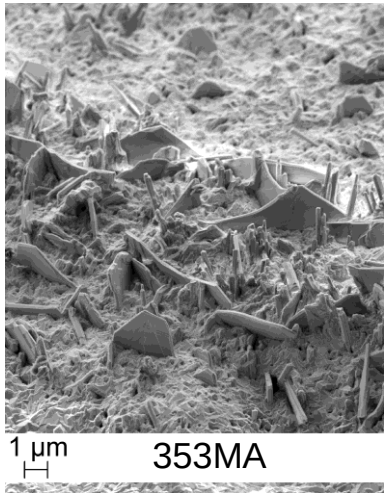

2020.02.27.11.48.09
TCFE10: CR, N, O
P=1E5, N=1, T=1173
Calculated by Sedigheh Bigdeli using TCFE10 database
ACR(O2,GAS)
ACR(N2,GAS)
Cr2O3
CrN
Cr2N
Cr
45 ppm H2O
14 ppm H2O

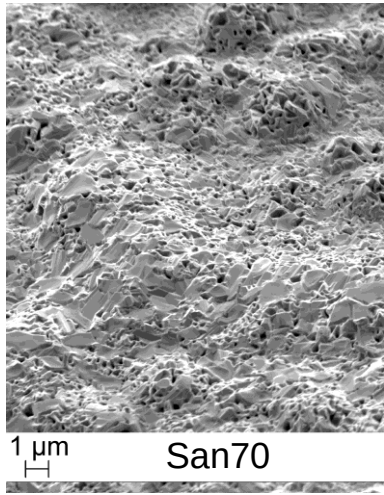
900 °C 45 ppm H_2O

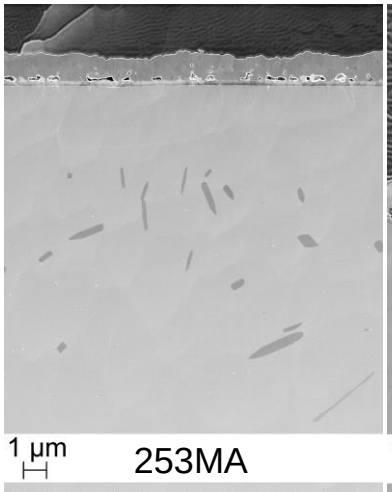


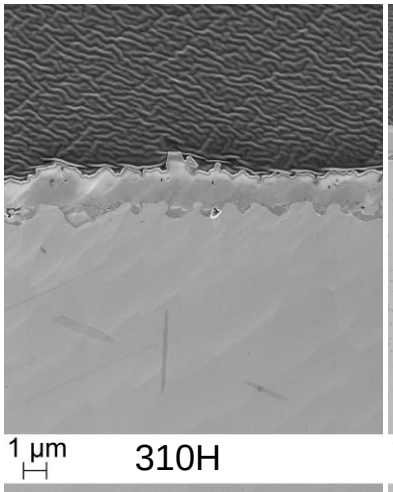


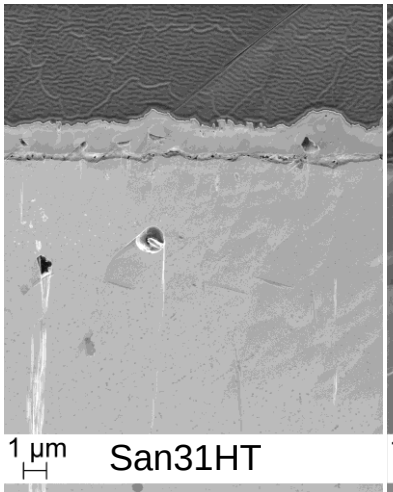


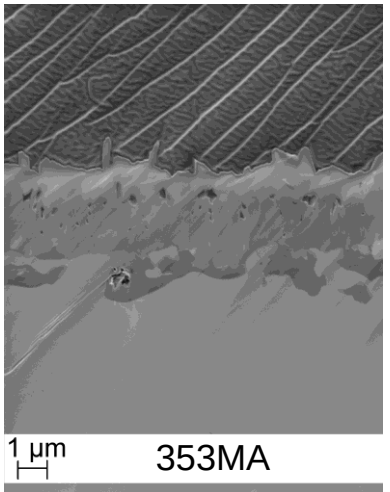


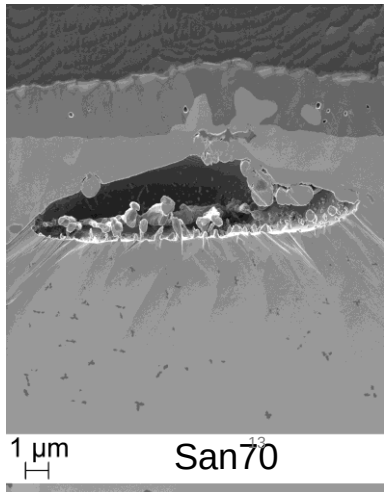




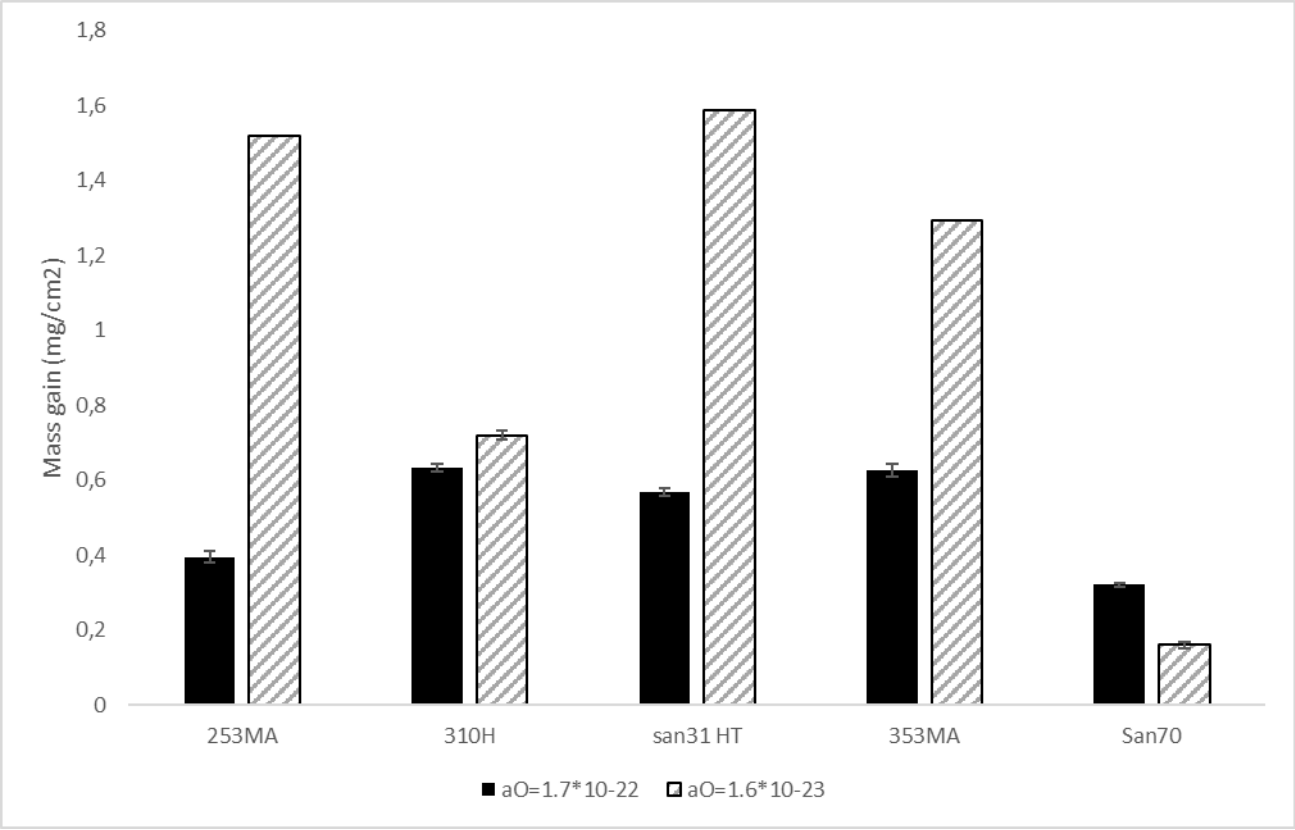






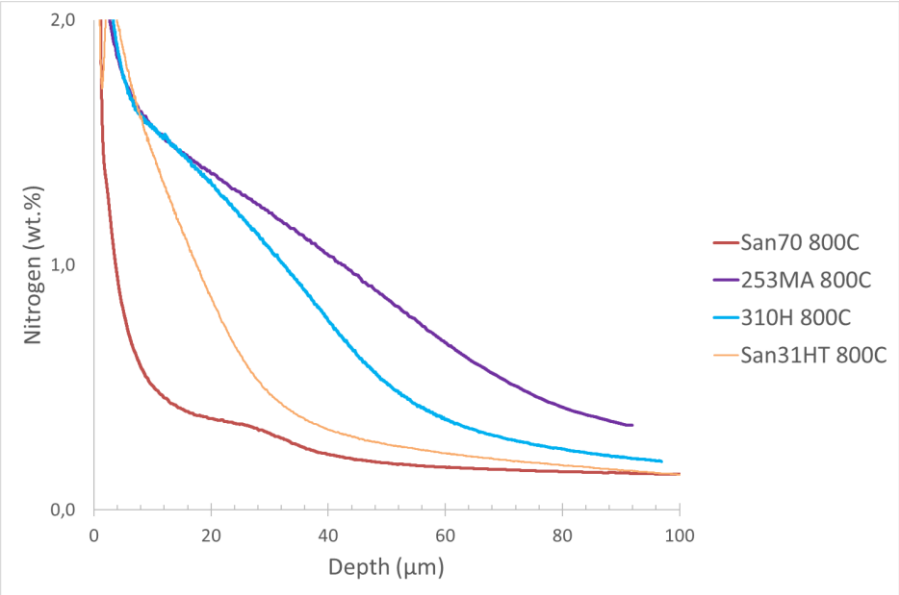


Mass gains after 168 h at 900 °C

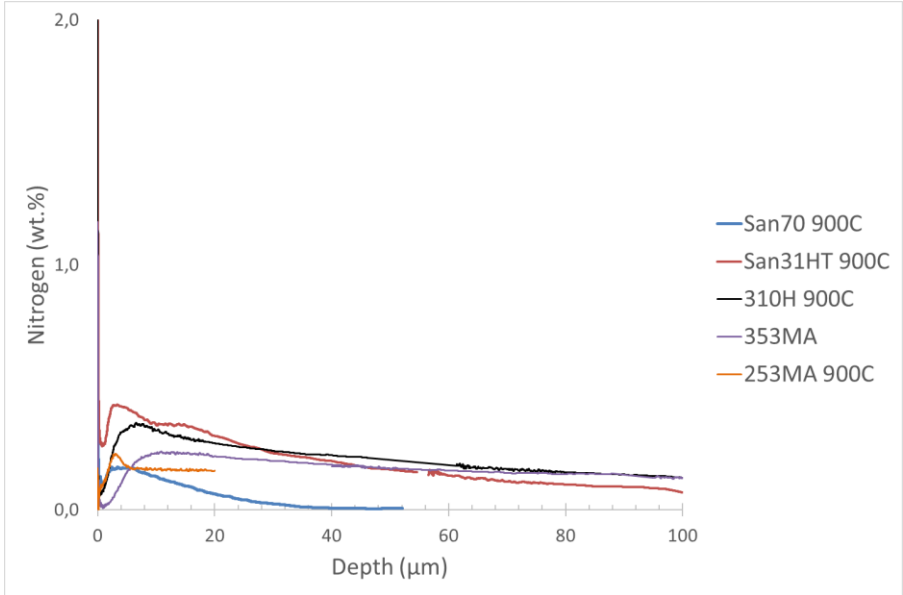


Nitrogen depth profiles by GD-OES

800 °C H_2O = 14 ppm



900 °C H_2O =45 ppm

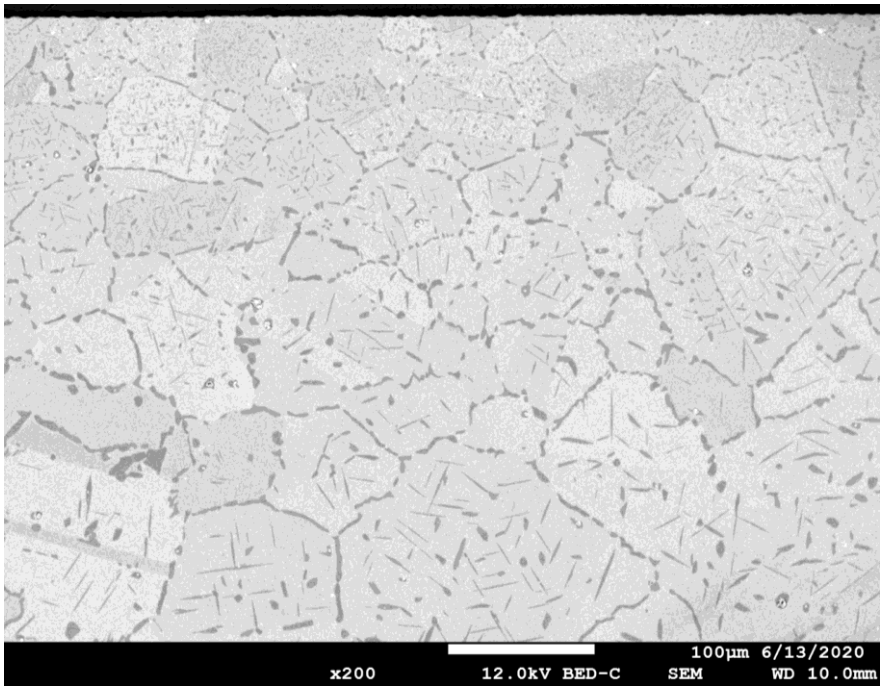


253 MA, 1100° C – outline

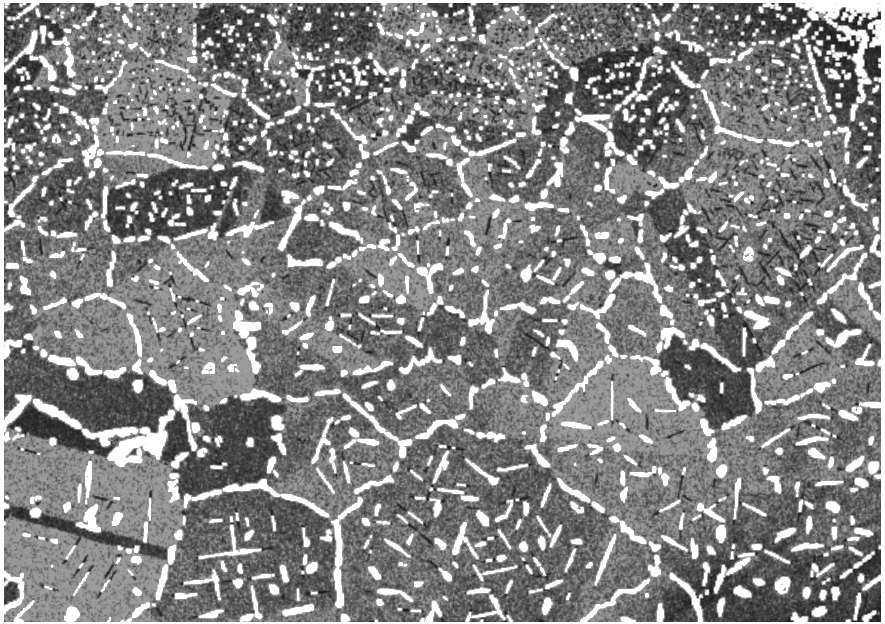
- SEM/EDX on BIB cross section
- FIB/SEM lift out from BIB cross section
- TKD on TEM foil
- STEM/EDX on TEM foil
- SEM/EDX on TEM foil

Exposure in 95% N_2, 5% H_2, ppm levels of O_2 for 168h

Cross-section SEM analysis



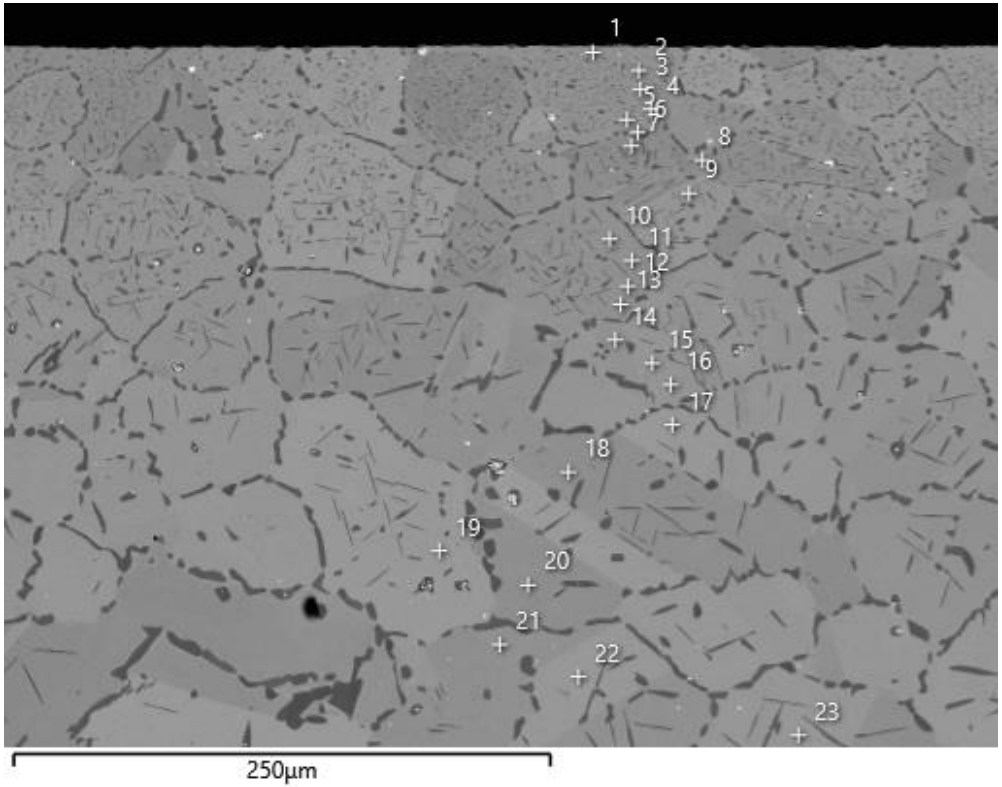
BSE image

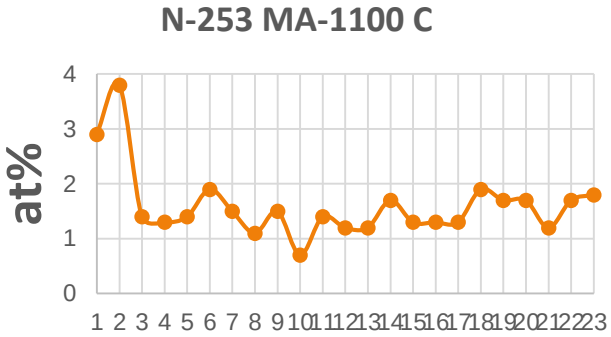


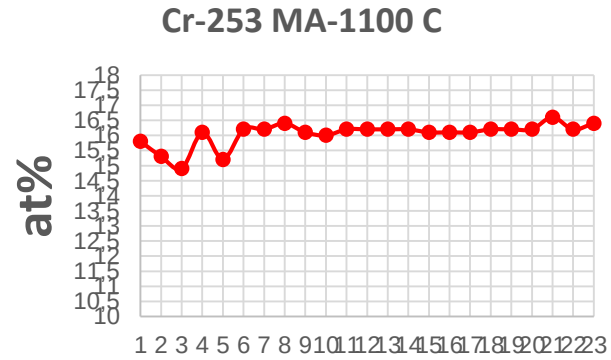
16 area-% nitrides

SEM/EDX 12 kV

Cross-section SEM/EDX analysis

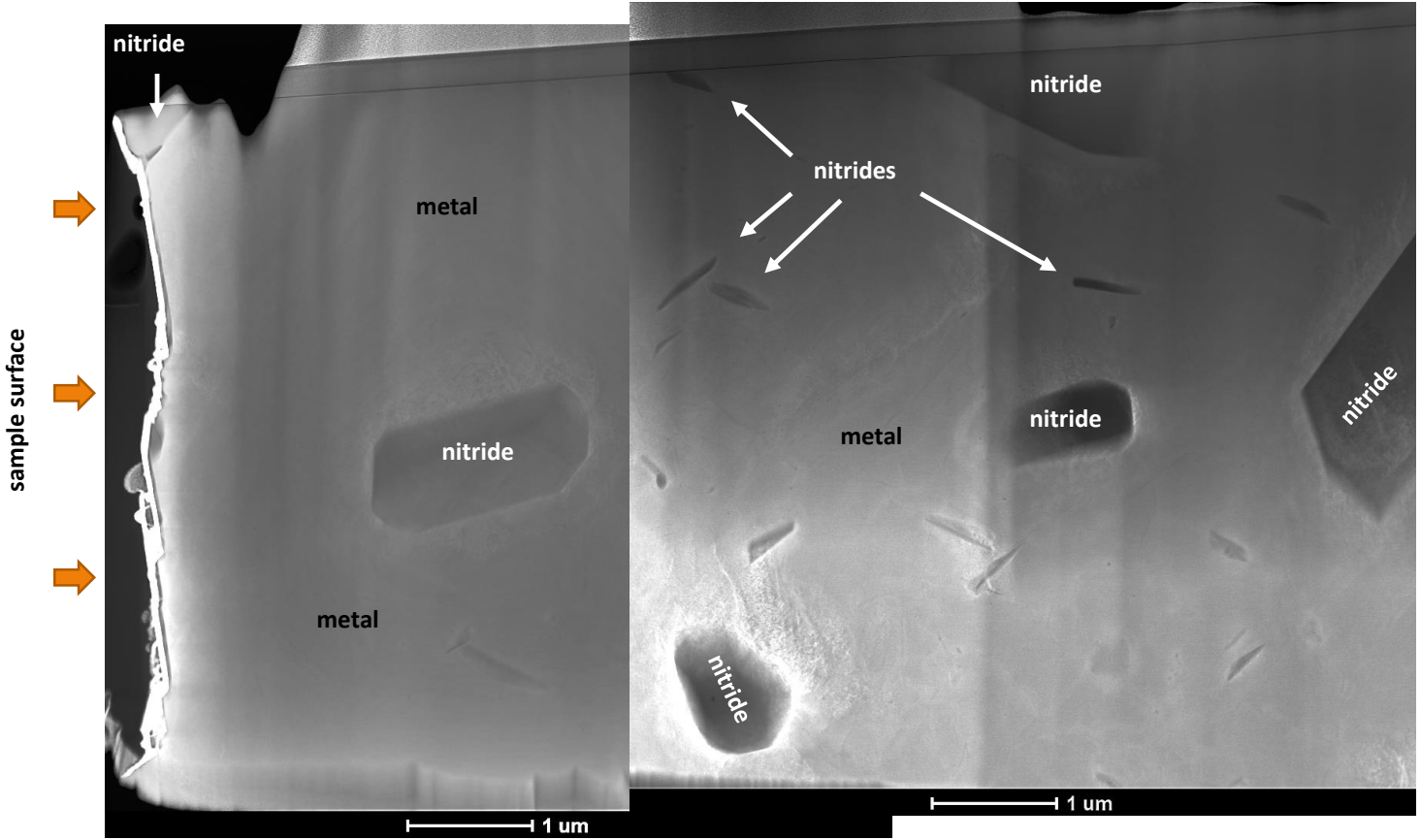




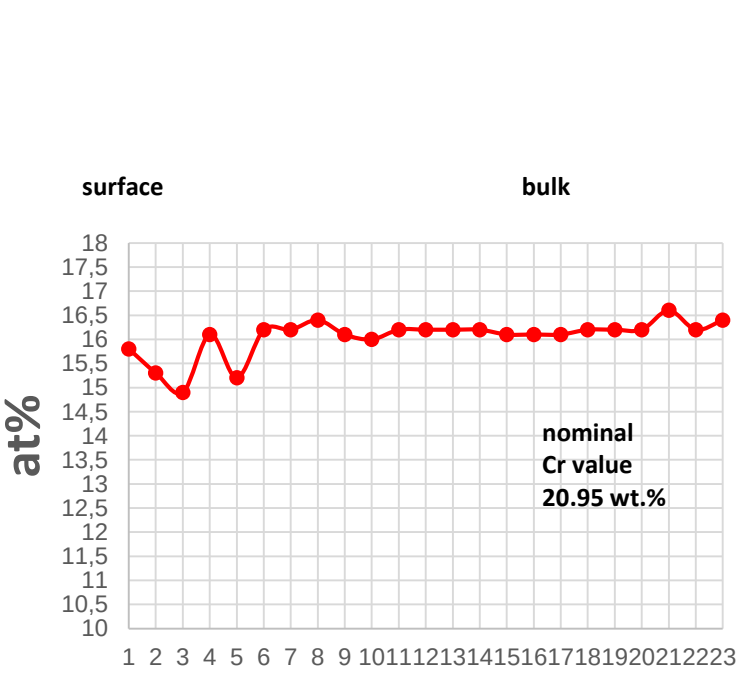


nominal Cr value 20.95 wt.%

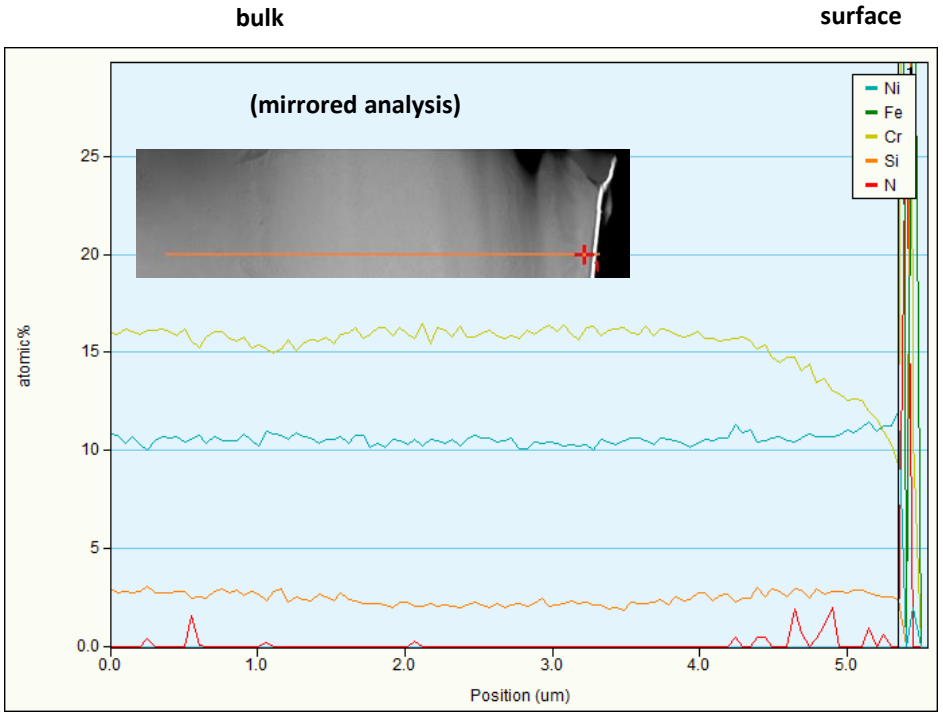
STEM HAADF from BIB cross-section



Depth profile



SEM/EDX

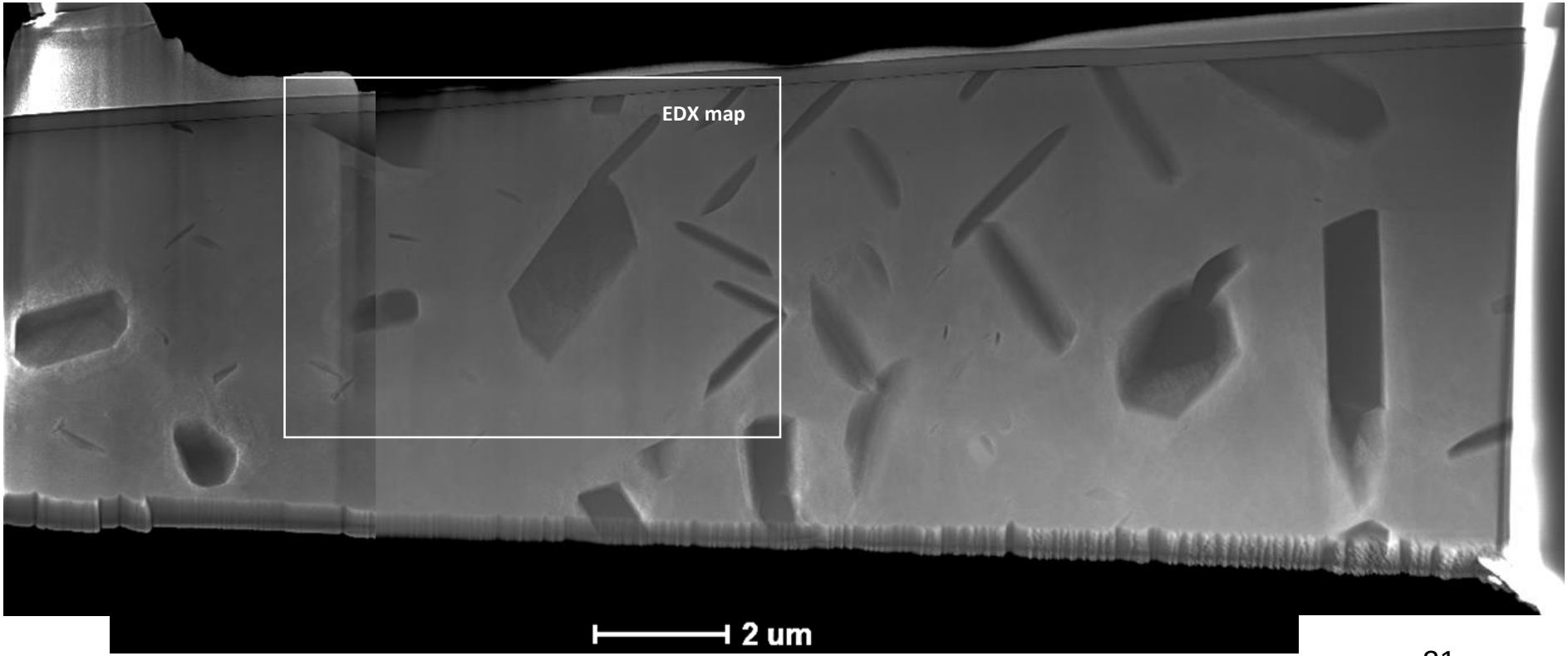


STEM/EDX

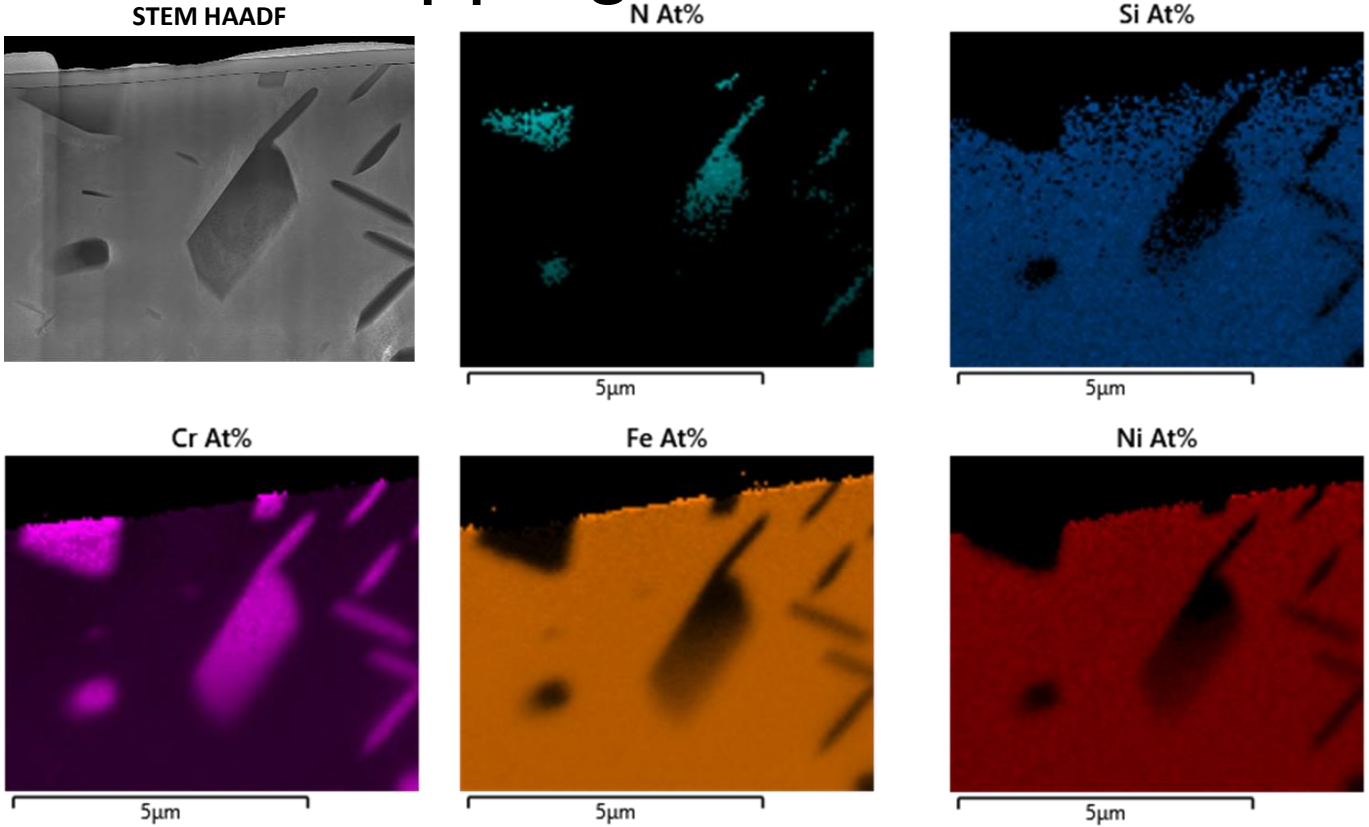
surface outside this micrograph

STEM HAADF overview

into the bulk

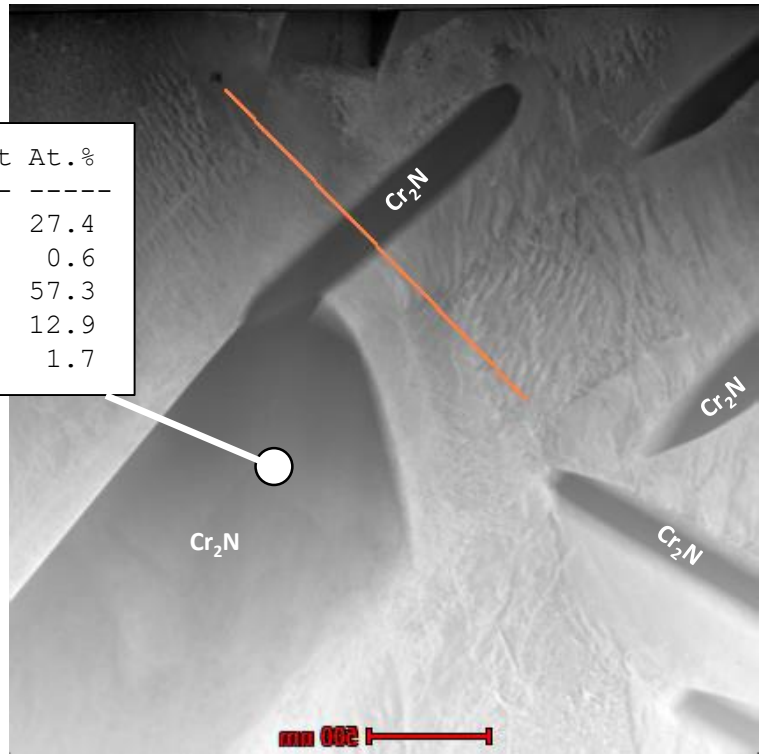


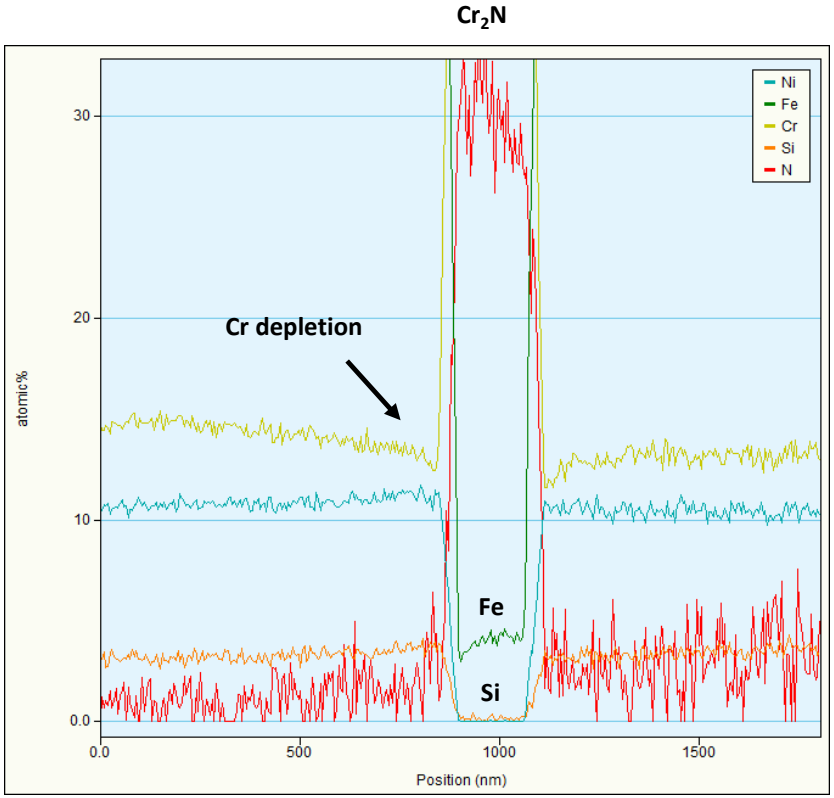
SEM/EDX mapping



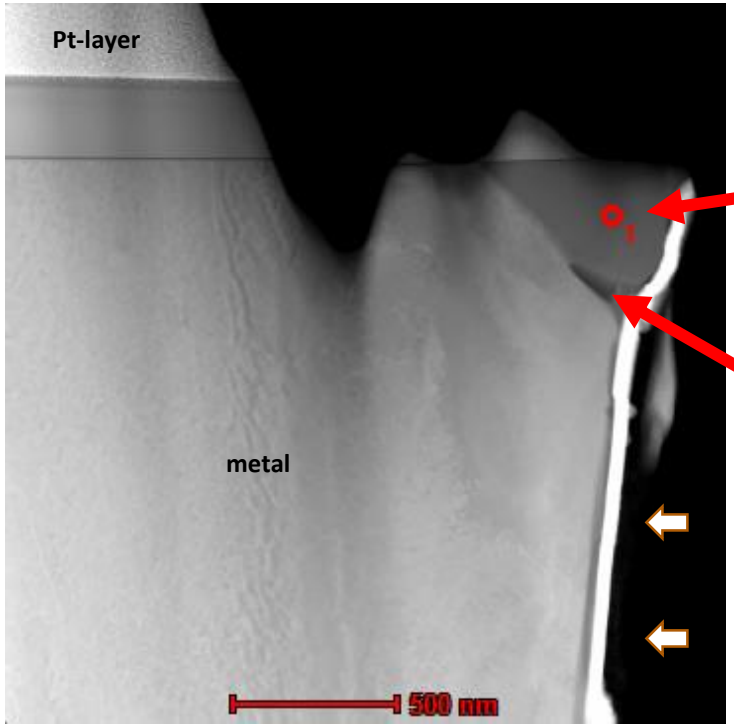
EDX linescan profile

Element	At.%
N(K)	27.4
Si(K)	0.6
Cr(K)	57.3
Fe(K)	12.9
Ni(K)	1.7





Surface features



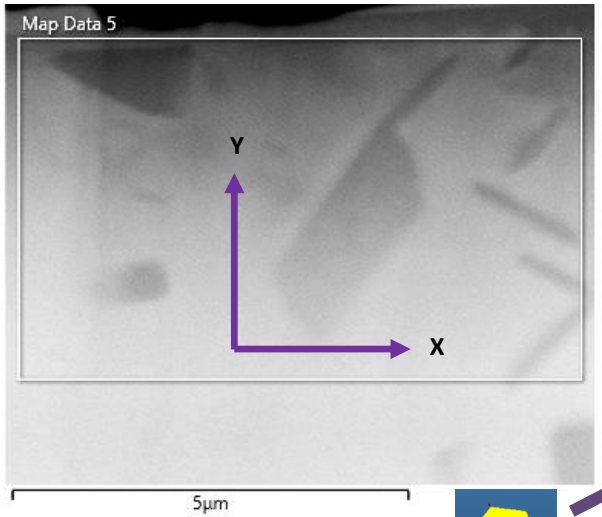
CrN

Element	Weight %	Atomic %
N(K)	18.34	45.58
Cr(K)	76.23	51.03
Fe(K)	5.42	3.37

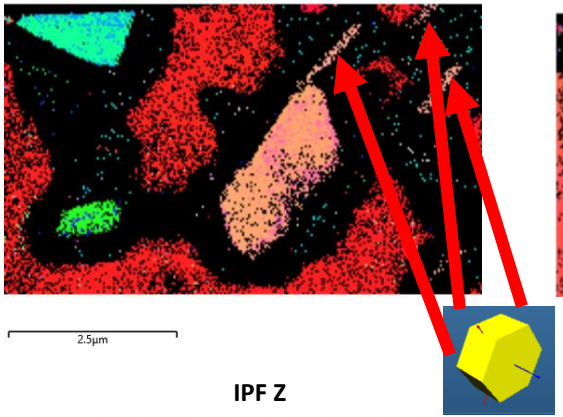
SiO_2

Element	Weight %	Atomic %
N(K)	8.40	16.40
O(K)	23.16	39.56
Si(K)	18.22	17.73
Cr(K)	47.60	25.01
Fe(K)	2.60	1.27

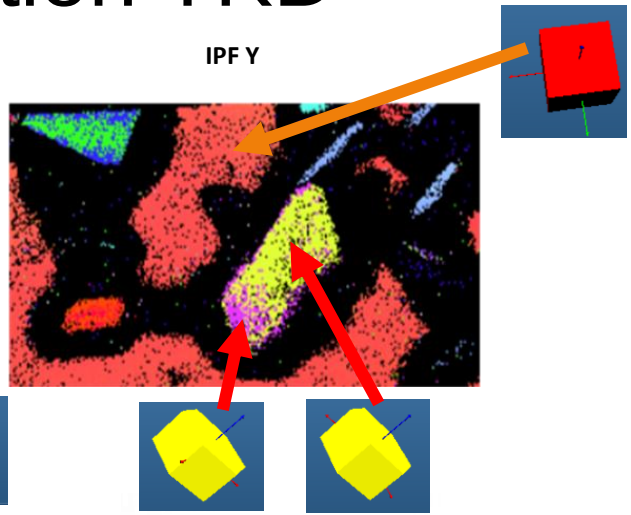
Transmission Kikuchi Diffraction TKD



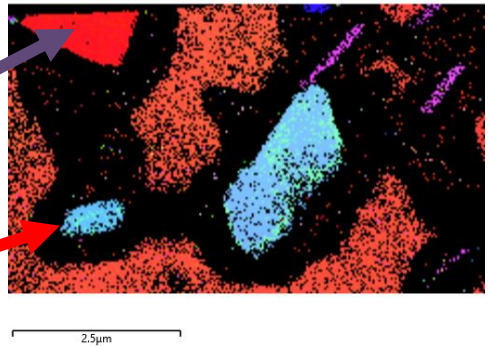
IPF X

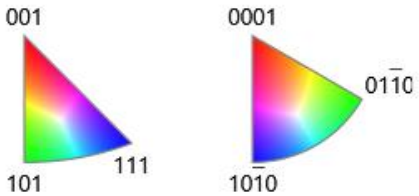


IPF Y



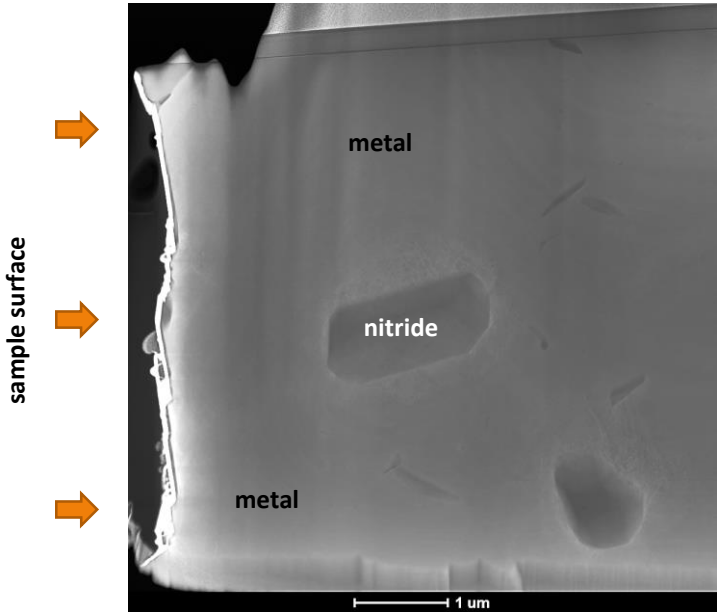
IPF Z



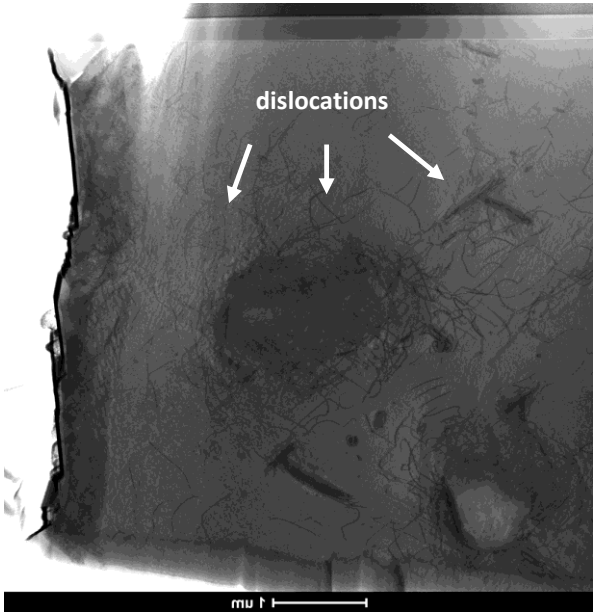


FCC metal Cr_2N

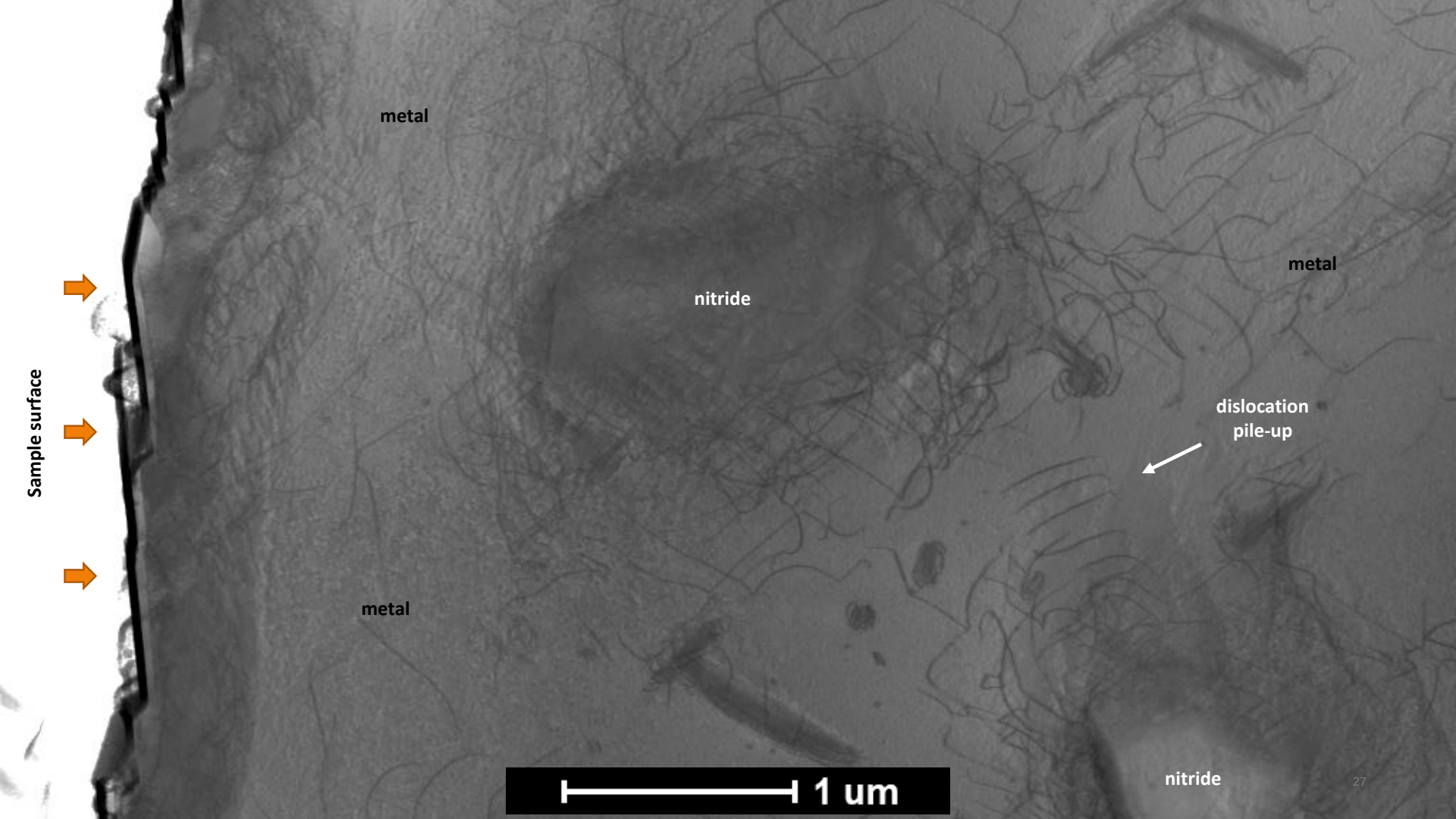
Defect formation



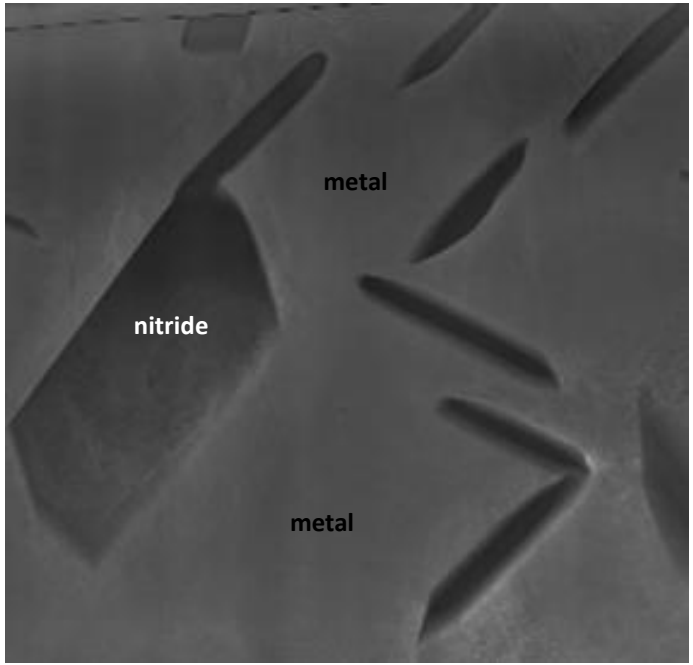
STEM HAADF



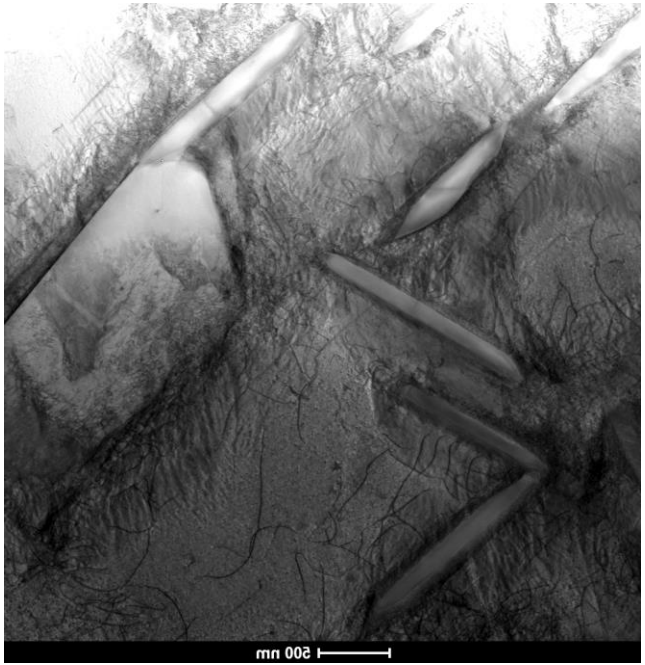
STEM BF


metal
nitride
metal
dislocation
pile-up
Sample surface
metal
1 um
nitride

Dislocation networks



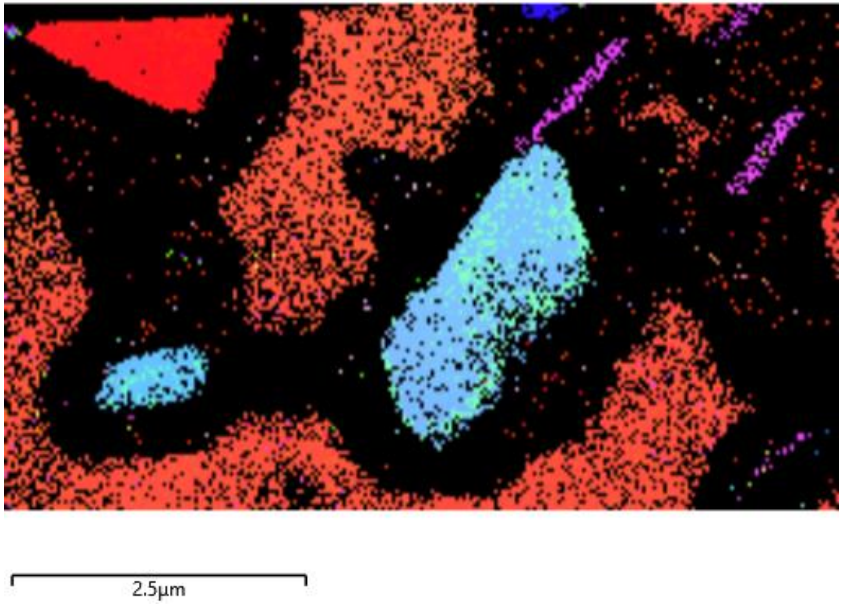
STEM HAADF



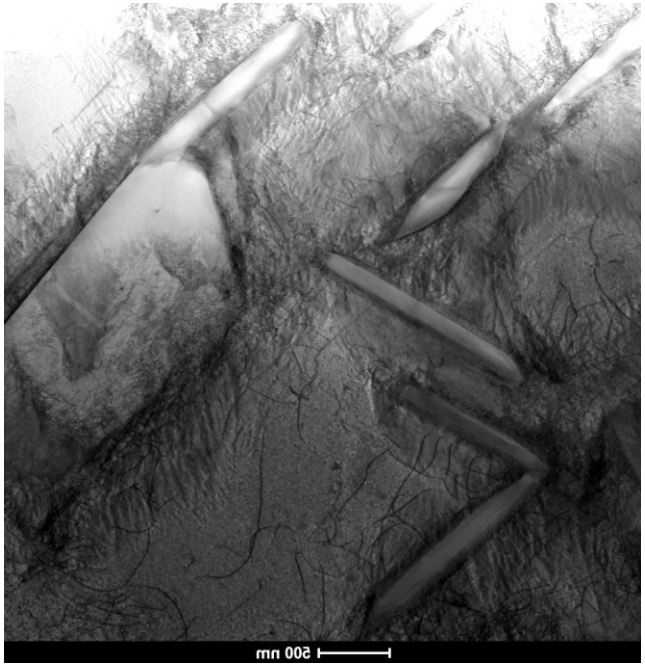
STEM BF

Camera length: 410 cm

Defect strain – lower TKD indexing level



TKD map



STEM BF

Camera length: 410 cm

Dislocation networks