

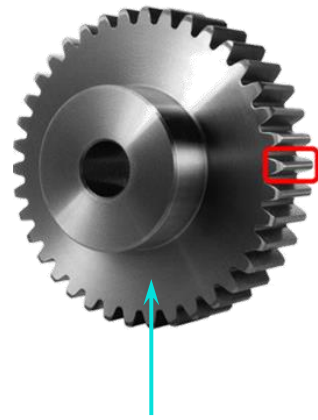


Kinetics and Mechanism of Austenite Isothermal Decomposition in Carbonitrided Low-alloy Steel

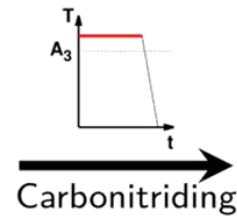
Hugo P. Van Landeghem

S.D. Catteau, J. Teixeira, J. Dulcy, M. Dehmas, M. Véron, A. Redjaïmia and S. Denis

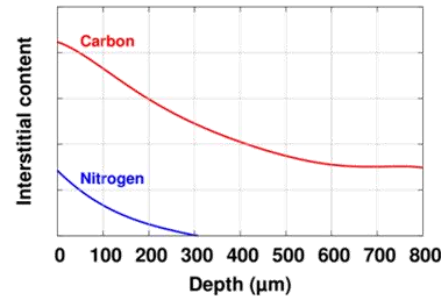
Understanding carbonitriding



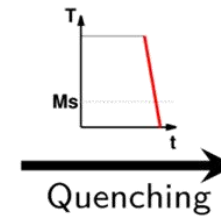
low-alloy steel
23MnCrMo5
Gear and bearing applications



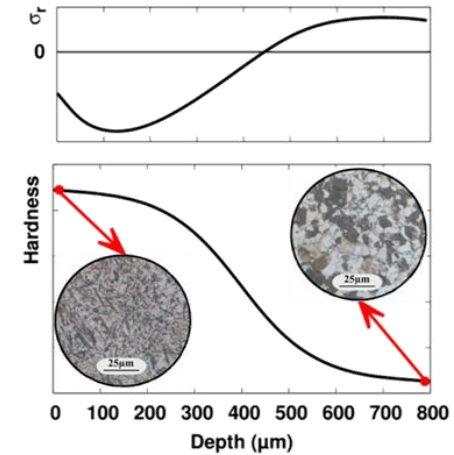
Carbonitriding



Surface enrichment in both C and N



Quenching



- High surface compressive residual stress
- High surface hardness

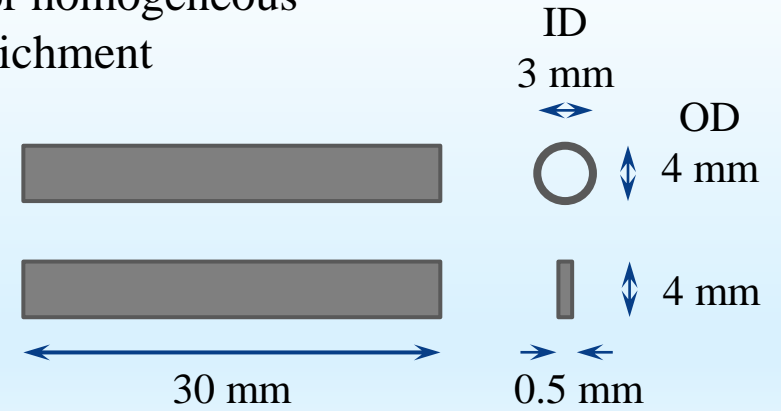
- What are the phase transformations happening during the treatment sequence?
- What is the influence of the added carbon and nitrogen?
- What is the influence of the transformation temperature?

Materials & HT

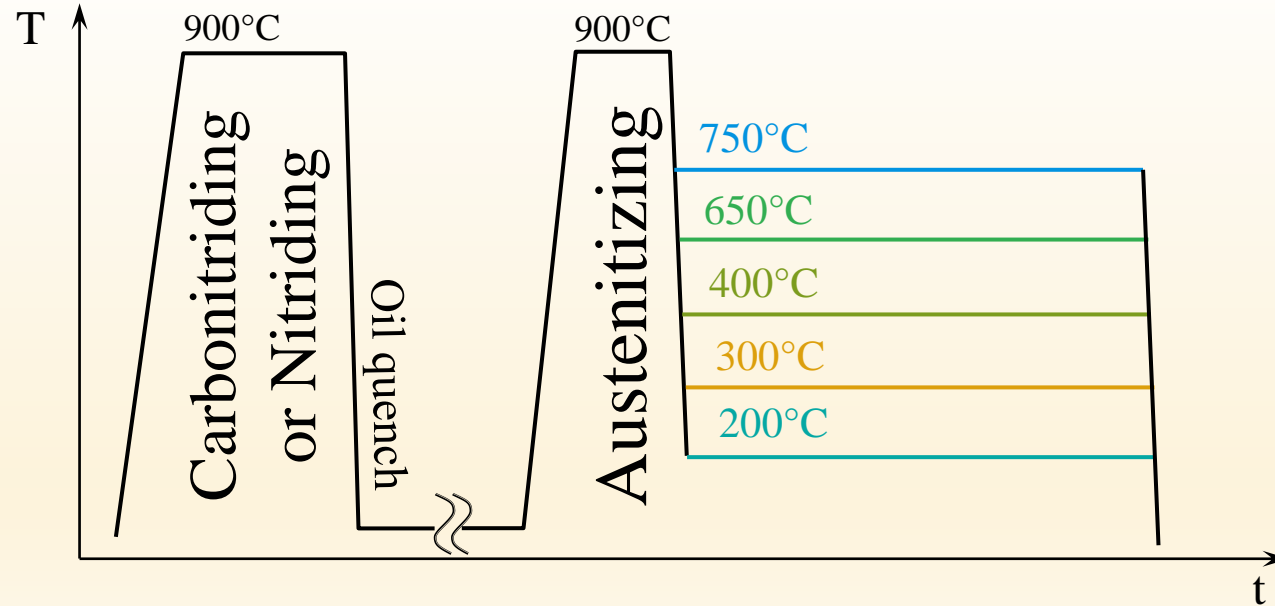
23MnCrMo5 base alloy (wt. %)

C	Mn	Cr	Mo	Si	Ni
0.246	1.21	1.31	0.1	0.237	0.184

Geometries for homogeneous interstitial enrichment



Treatment sequence



Enriched samples

Gas / solid reactions at 900°C:

- $\text{CH}_{4(g)} \rightarrow \text{C}_{[\text{Fe}]} + 2 \text{H}_{2(g)}$
- $\text{NH}_{3(g)} \rightarrow \text{N}_{[\text{Fe}]} + 3/2 \text{H}_{2(g)}$

List of samples:

Alloy		wt. % C (± 0.04 %)	wt. % N (± 0.07 %)	B _s (°C)	M _s (°C)
I	Base alloy	0.23	-	550 ± 25	385
C	Carburized	0.57	-	500 ± 25	260
N	Nitrided	0.12	0.26	400 < B _s < 500	-
CN	Carbonitrided	0.65	0.25		205

*Thermobalance
Institut Jean Lamour, Nancy*

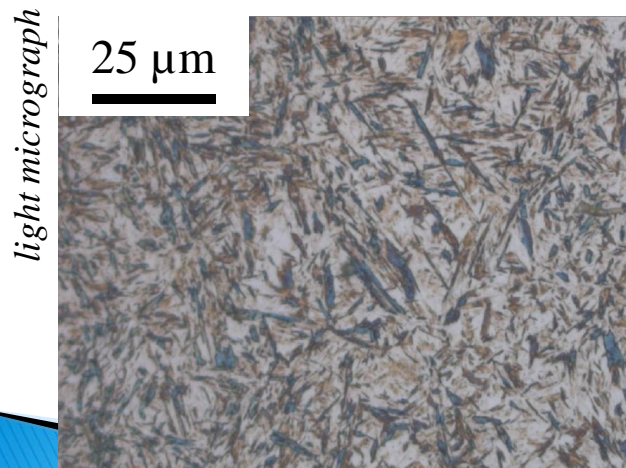


As-quenched

Carburized

- Martensite + RA
- No secondary phases

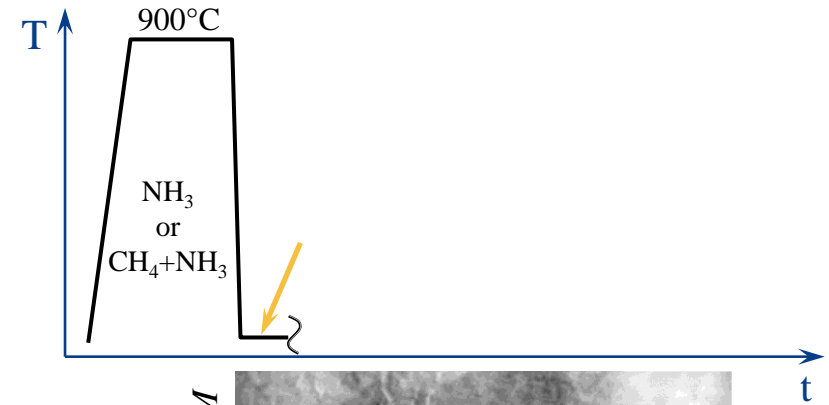
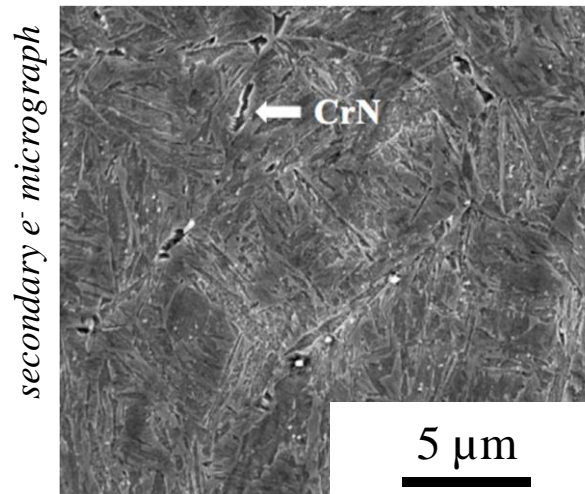
Martensite + 8 wt. % RA



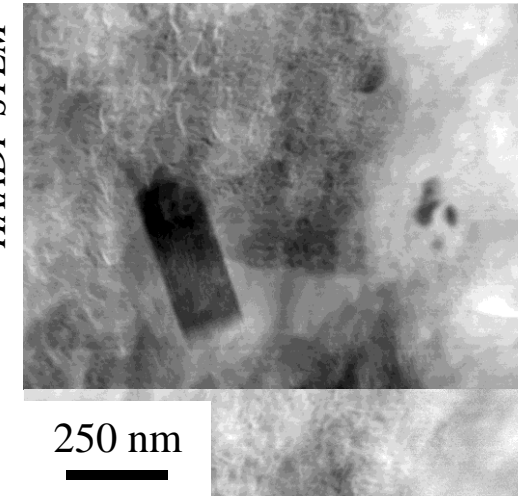
Carbonitrided

- Martensite + RA
- Microscale CrN
- Nanoscale CrN & AlN

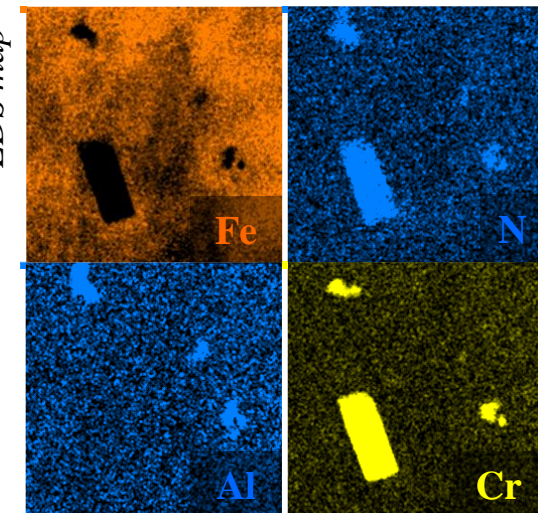
Martensite + RA + CrN



HAADF STEM

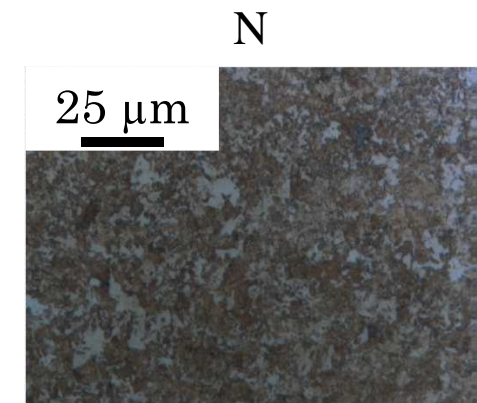
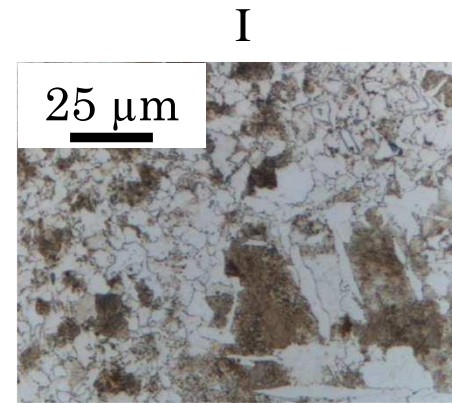
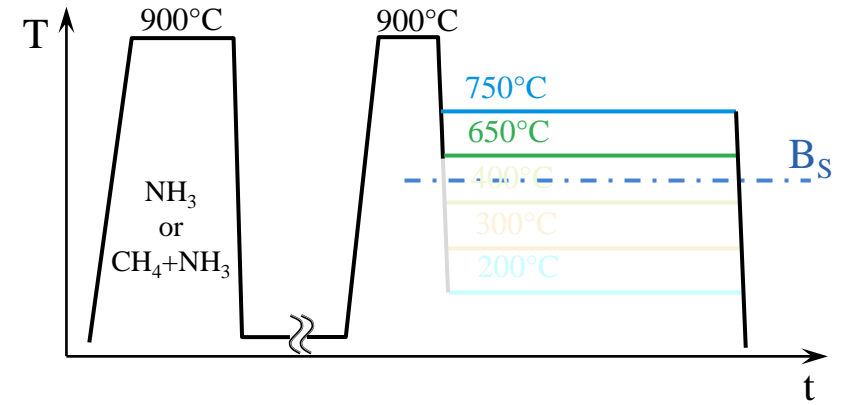
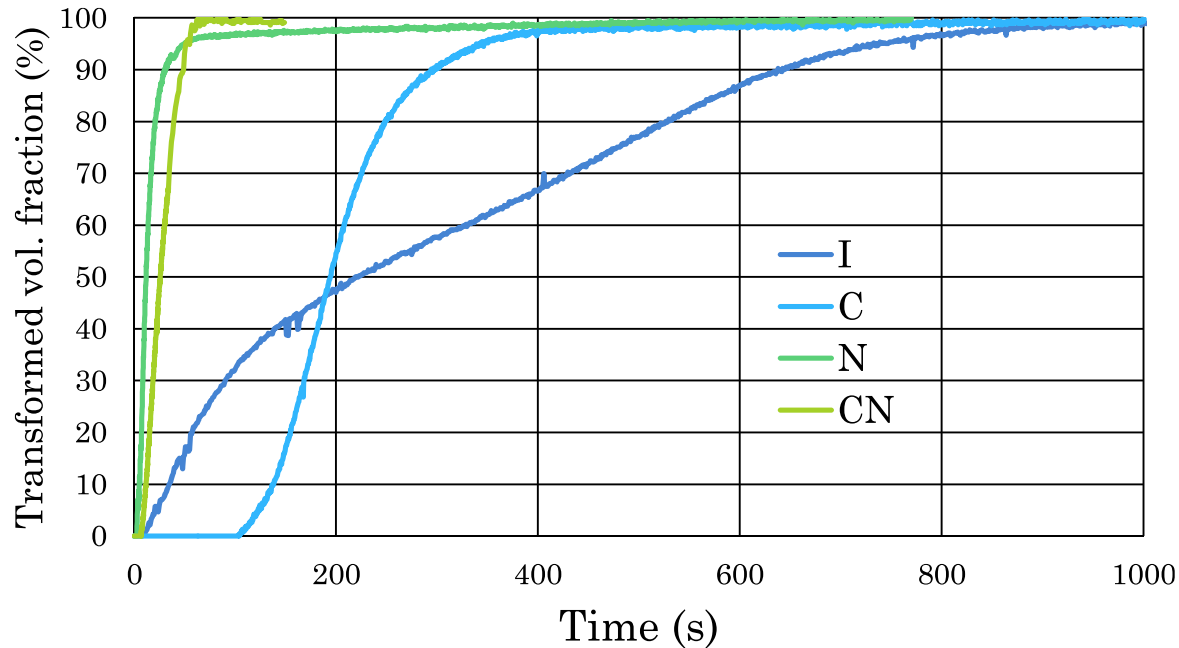


EDS map



Isothermal Kinetics @ $T > B_S$

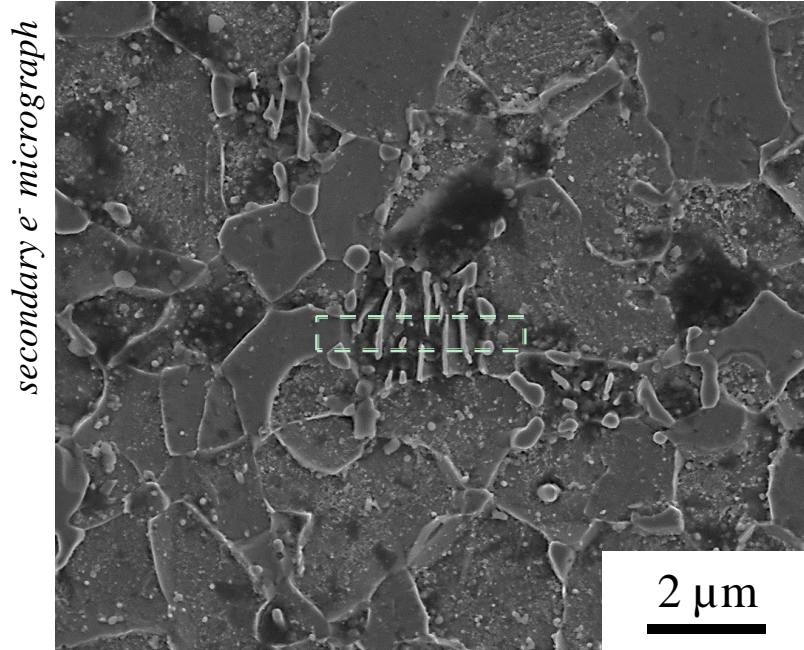
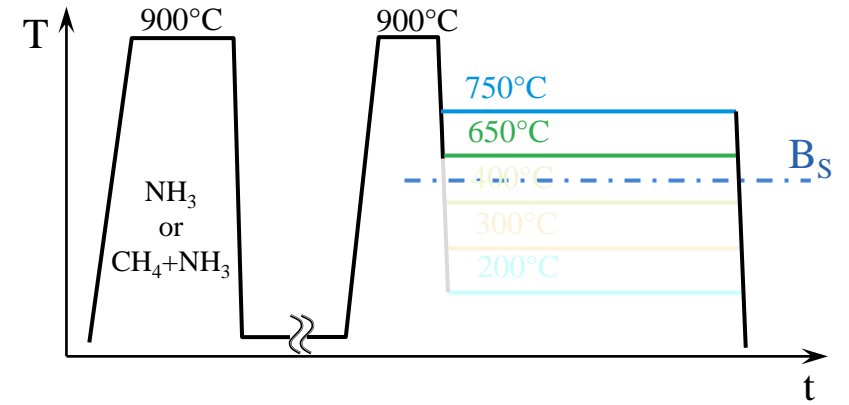
Dilatometry, 600°C



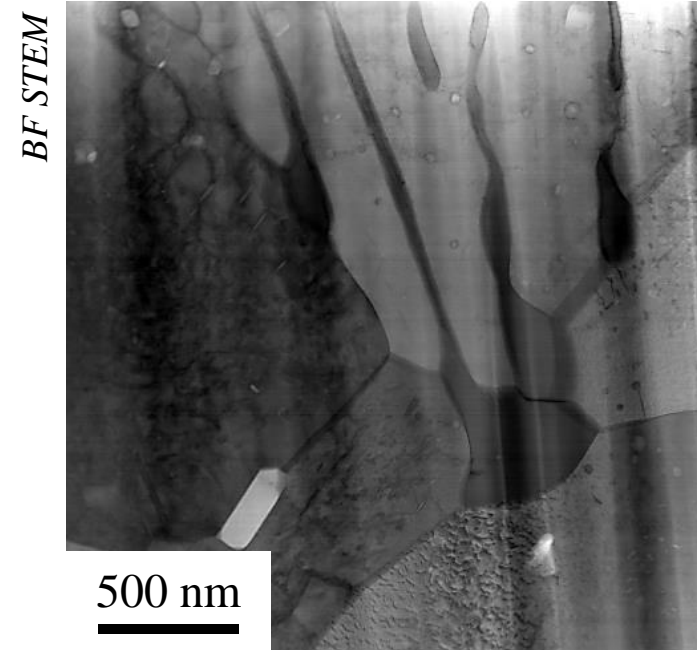
Base alloy (I)	Carburized (C)	Nitrided (N)	Carbonitrided (CN)
<ul style="list-style-type: none"> 2-stage kinetics Proeutectoid ferrite Pearlite 	<ul style="list-style-type: none"> Increased incubation ~100 % pearlite 	<ul style="list-style-type: none"> Decreased incubation Finer microstructure <ul style="list-style-type: none"> Nitride stimulated nucleation? Enhanced transformation rate 	

Nitrided Transformed @ $T > B_s$

N , 650 °C, 3 h
 $HV_{300g} \approx 250$



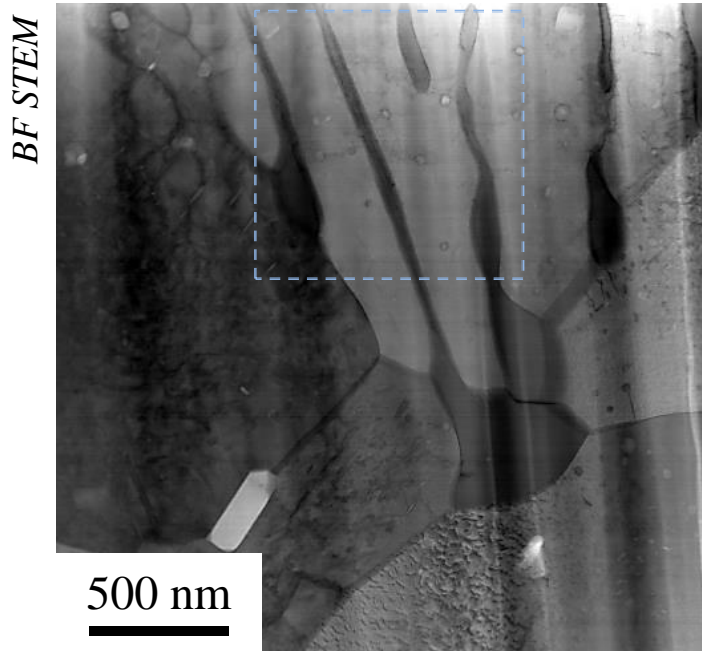
N , 650°C, 3 h
 $HV_{300g} \approx 250$



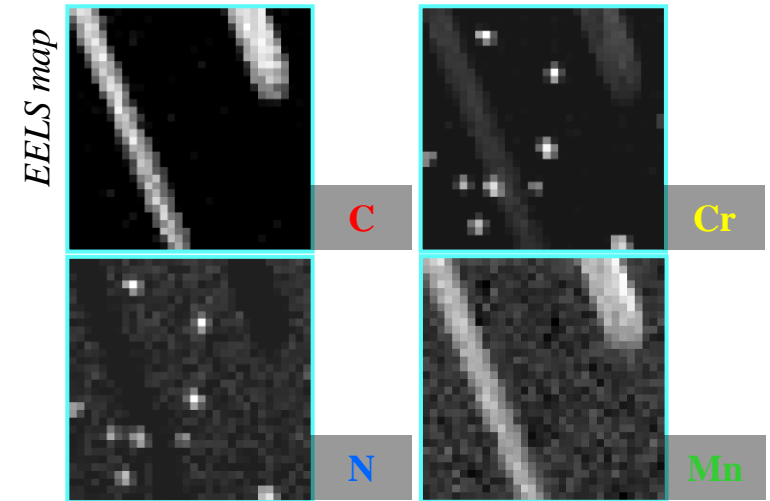
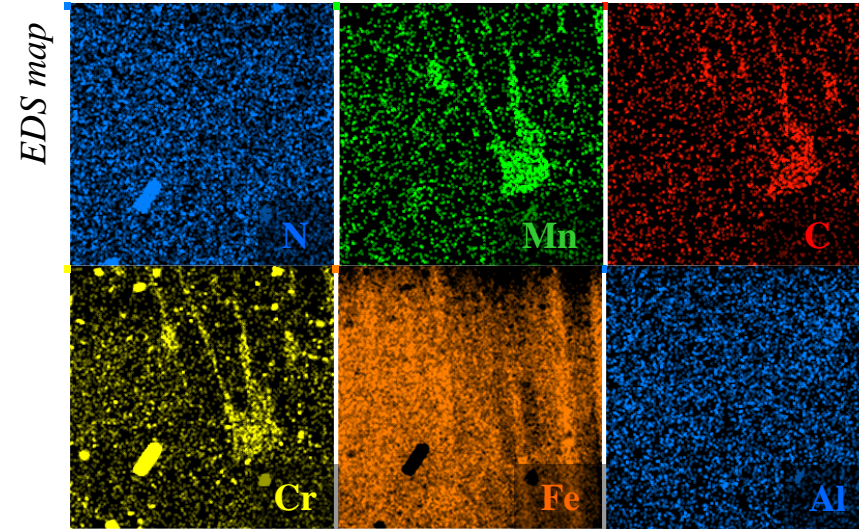
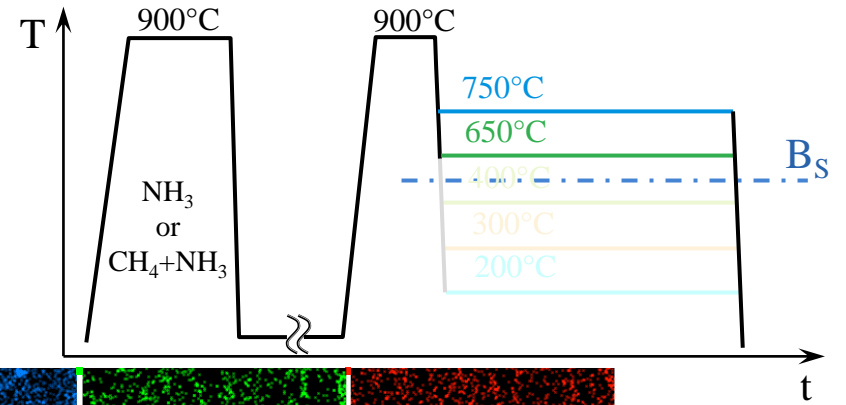
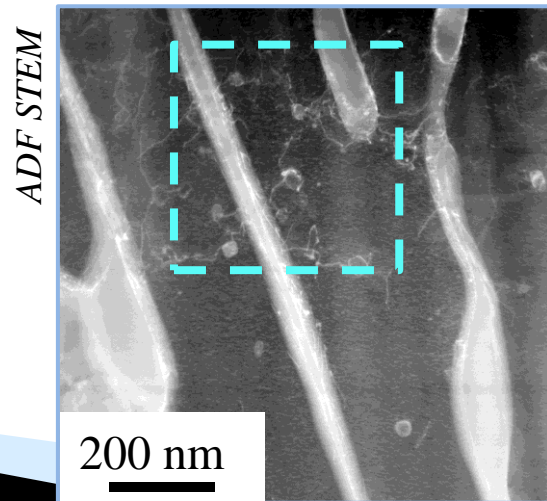
Pearlite

Nitrided Transformed @ $T > B_s$

N , 650 °C, 3 h
 $HV_{300g} \approx 250$

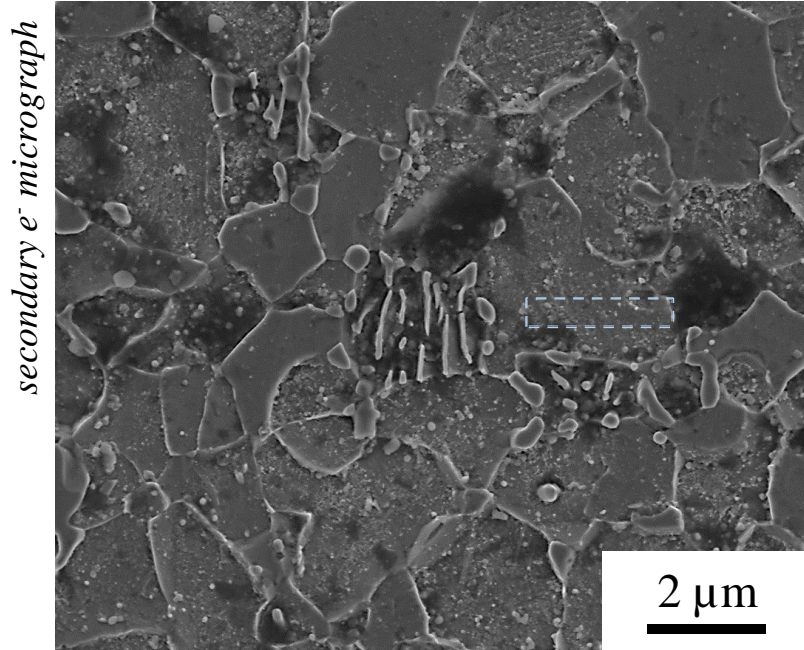
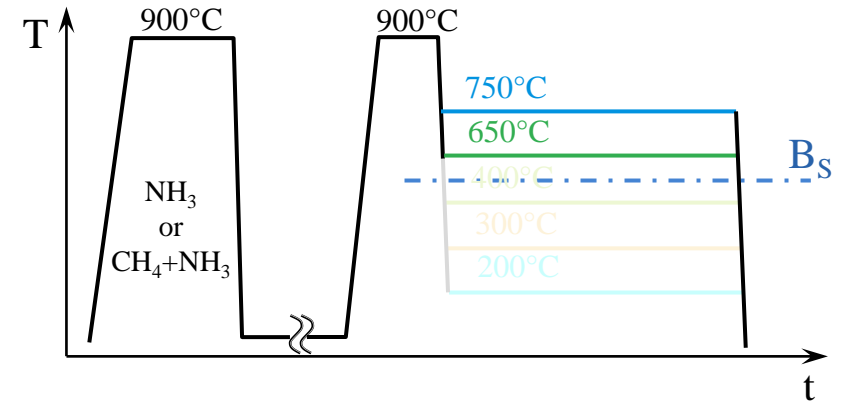


Pearlite

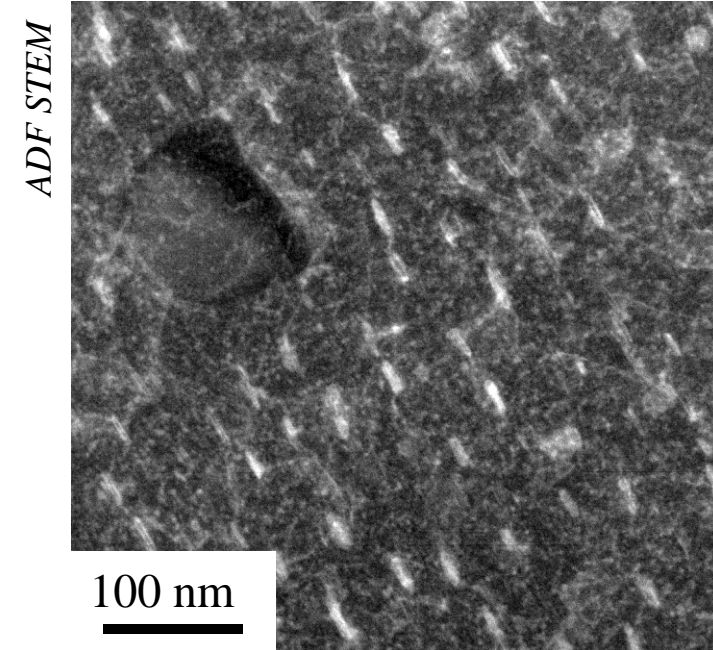


Nitrided Transformed @ $T > B_s$

N , 650 °C, 3 h
 $HV_{300g} \approx 250$



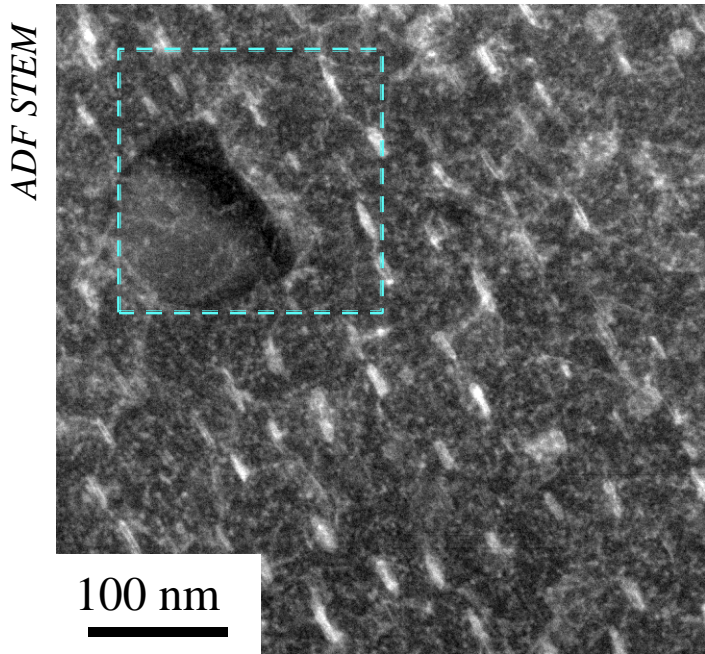
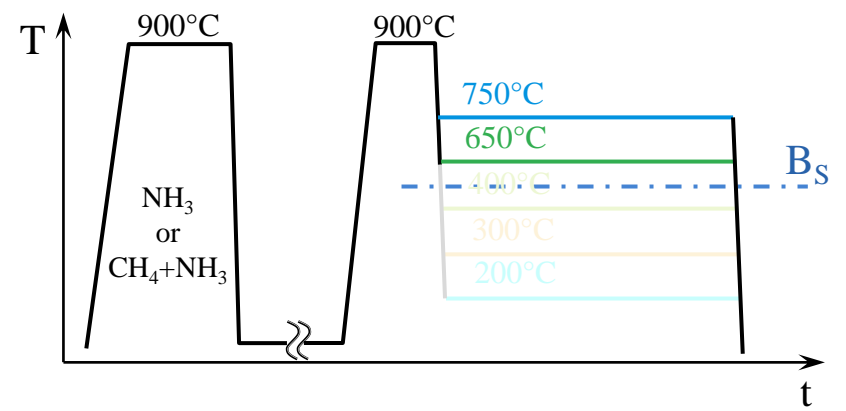
N , 650°C, 3 h



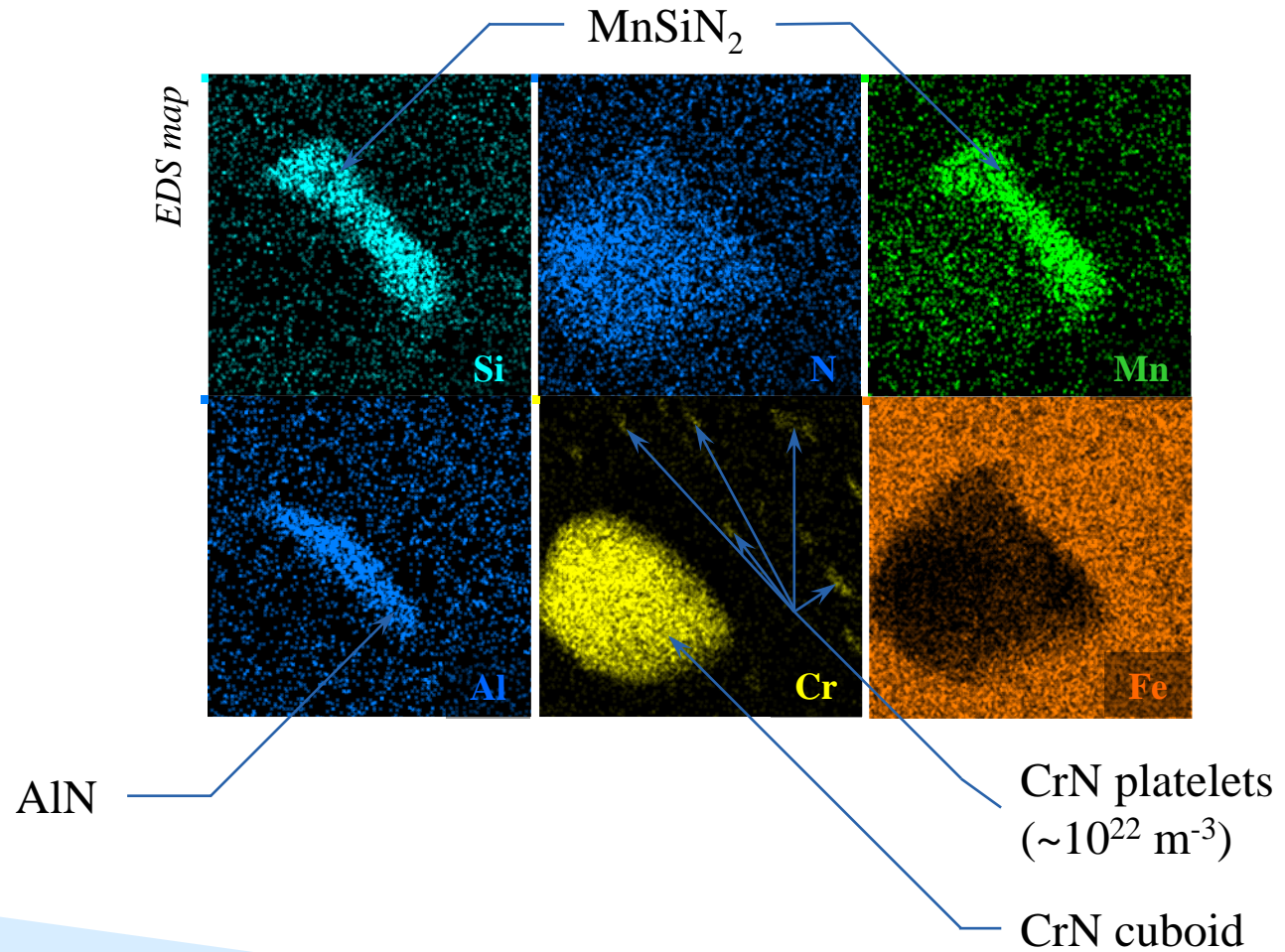
In a ferrite grain

Nitrided Transformed @ $T > B_s$

N , 650 °C, 3 h
 $HV_{300g} \approx 250$

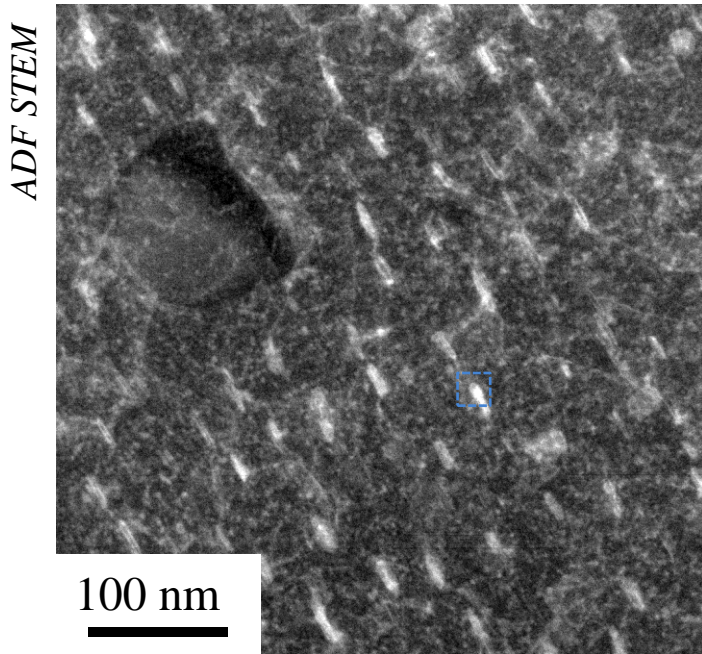


In a ferrite grain

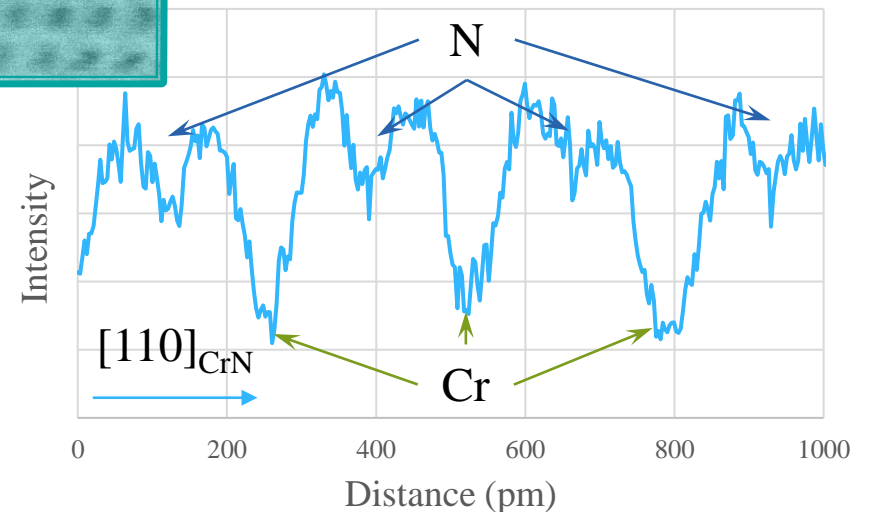
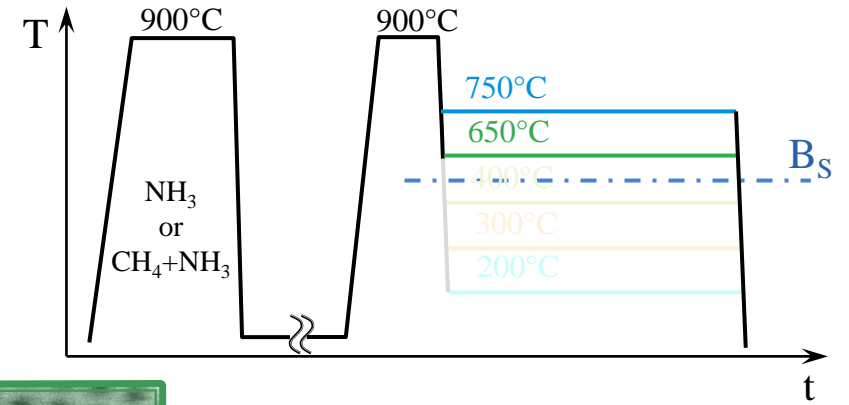
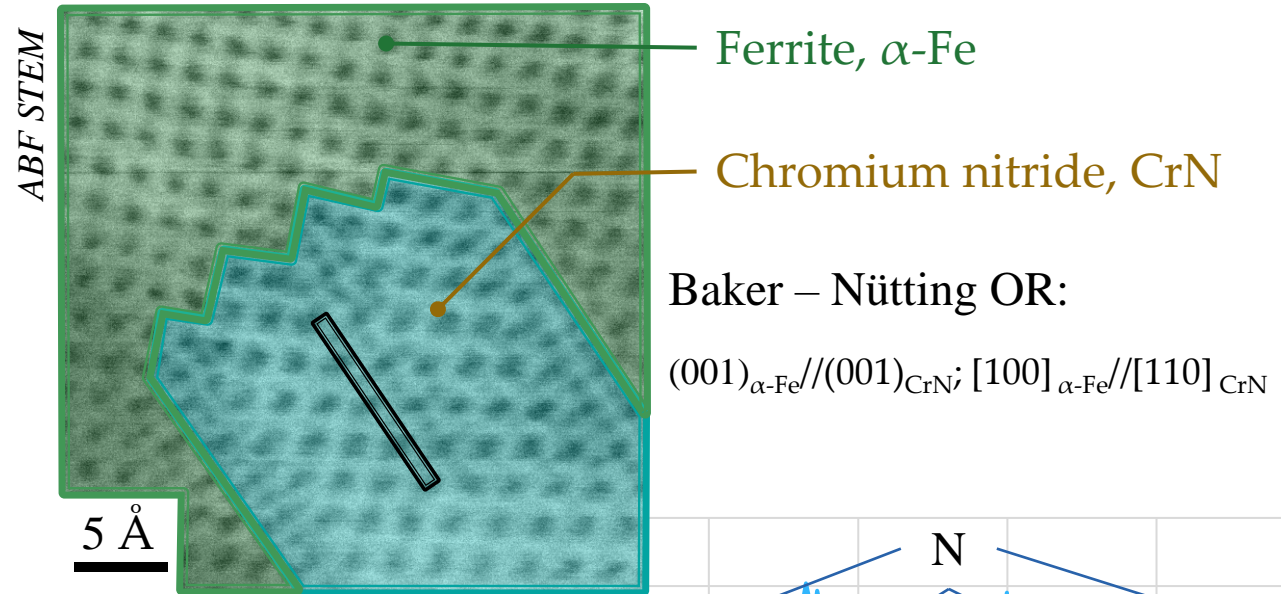


Nitrided Transformed @ $T > B_s$

N , 650 °C, 3 h
 $HV_{300g} \approx 250$

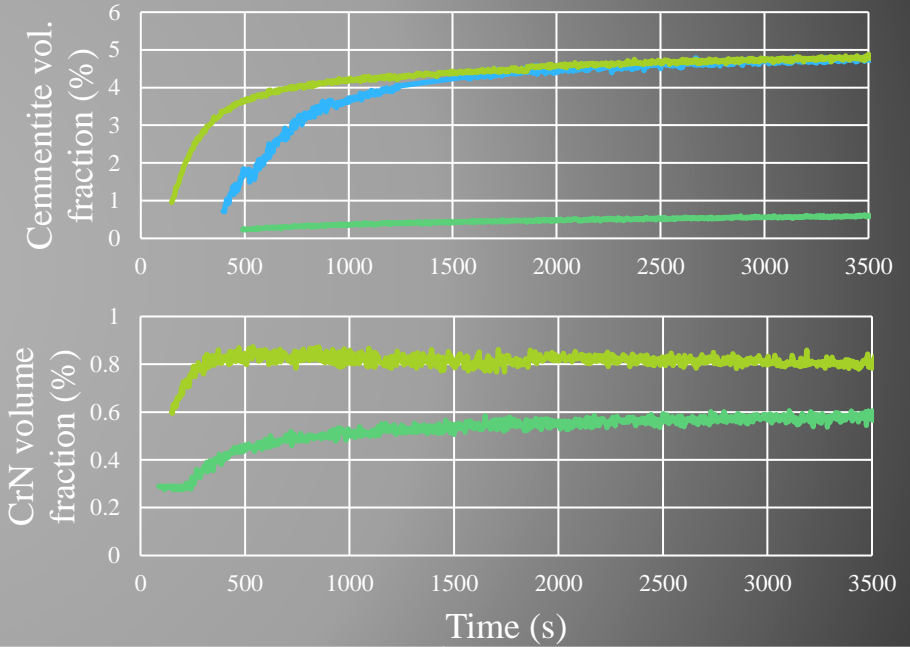
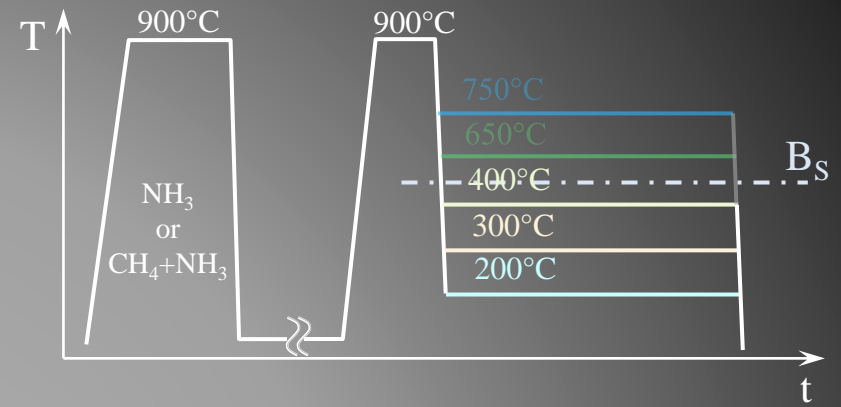
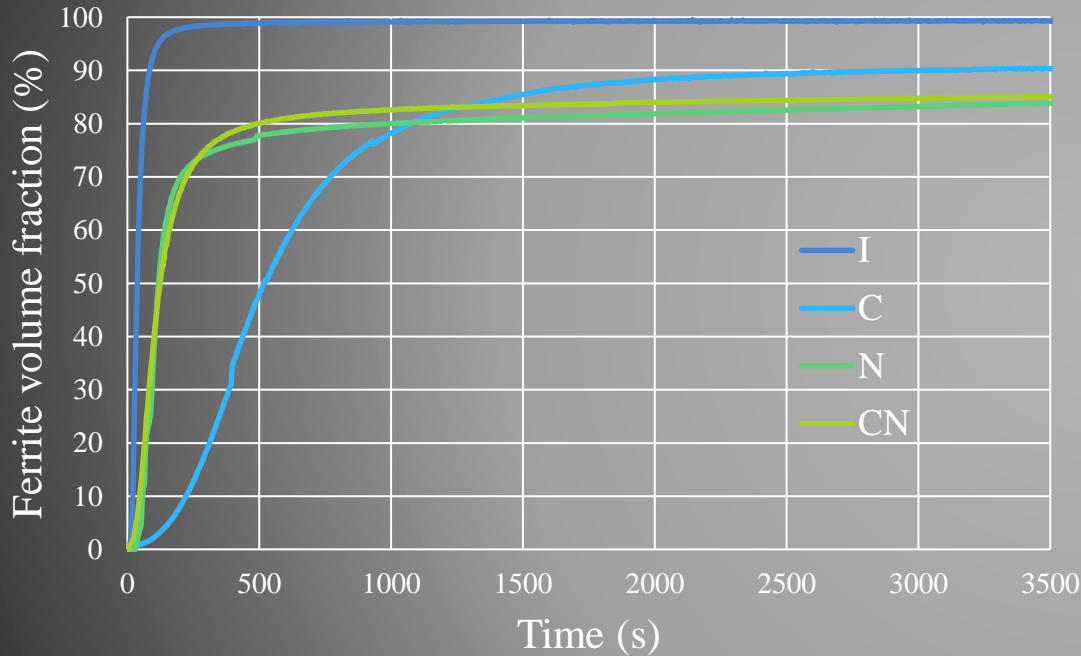


In a ferrite grain



Isothermal Kinetcs @ $T < B_S$

In-situ synchrotron HEXRD, 400°C



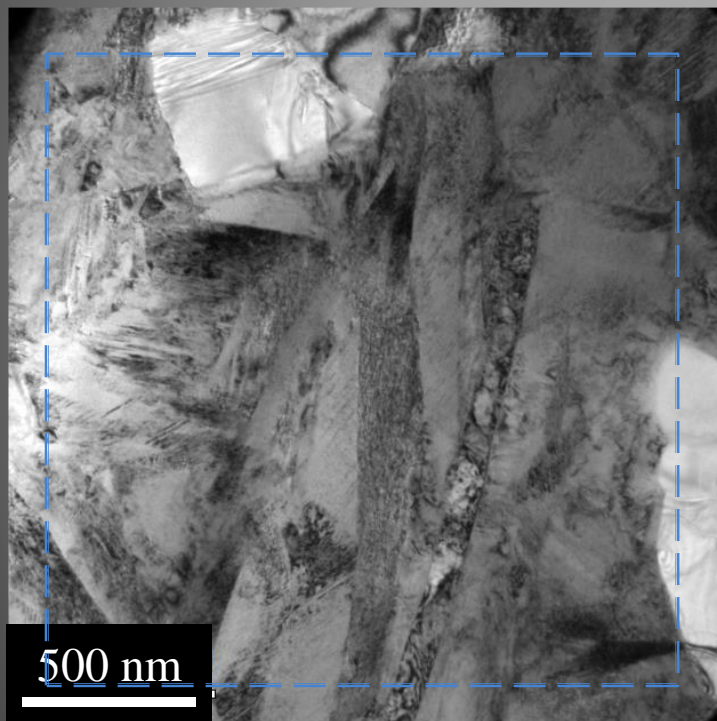
Base alloy (I)	Carburized (C)	Nitrided (N)	Carbonitrided (CN)
<ul style="list-style-type: none"> Fast nucleation of bainitic ferrite Complete trans. 	<ul style="list-style-type: none"> Increased incubation Slower rate 	<ul style="list-style-type: none"> Intermediate rate <ul style="list-style-type: none"> Nucl. and growth of ferrite Growth of CrN Nucl. and growth of cementite 	

Carbonitrided Transformed @ $T < B_s$

CN, 200 °C, 3 h
 $HV_{300g} \approx 700$

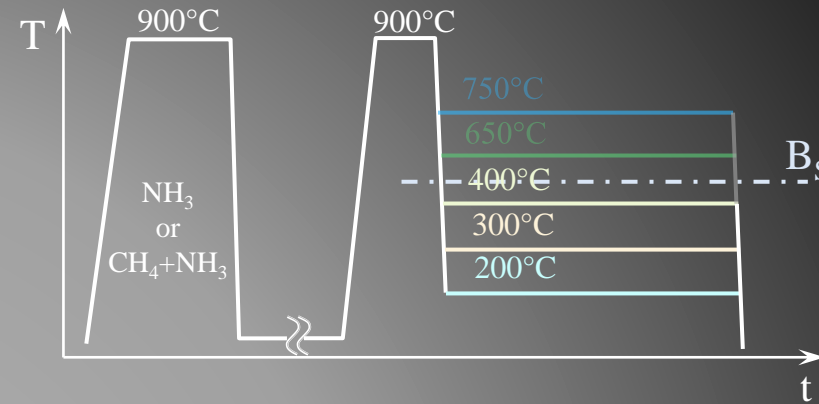
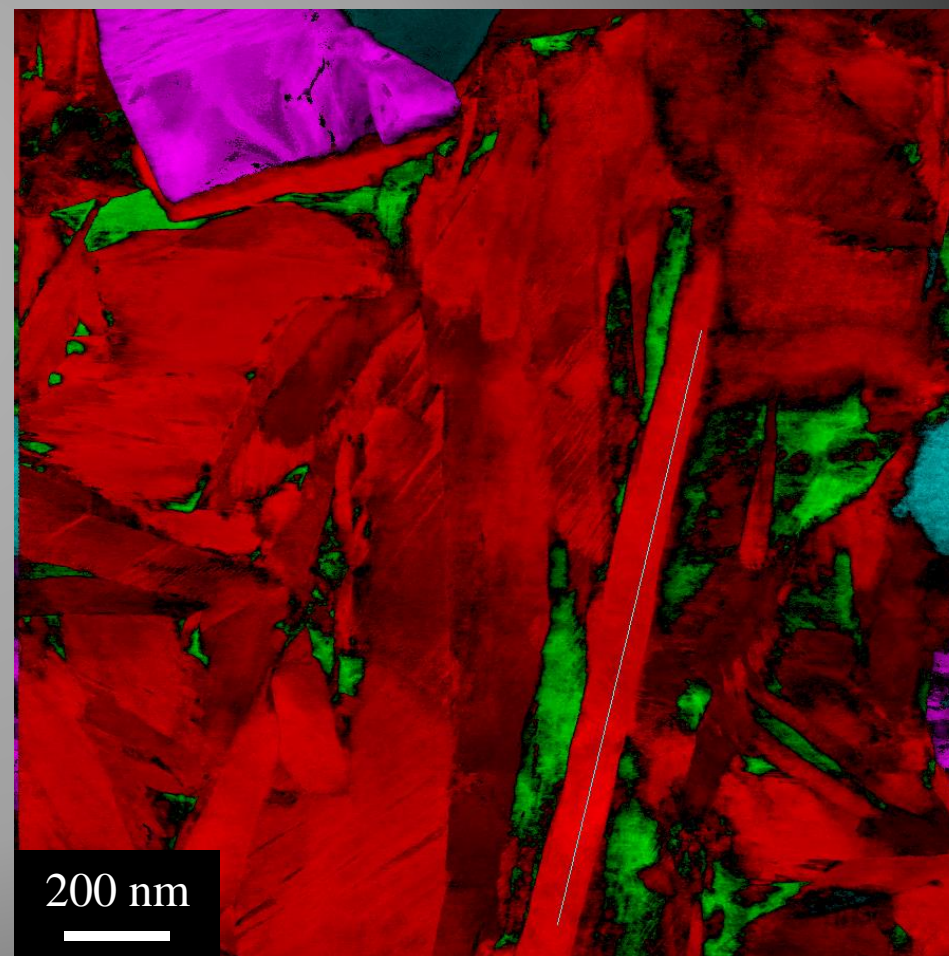


BF TEM



- Ferrite
- Austenite
- MnSiN₂
- CrN

Phase map

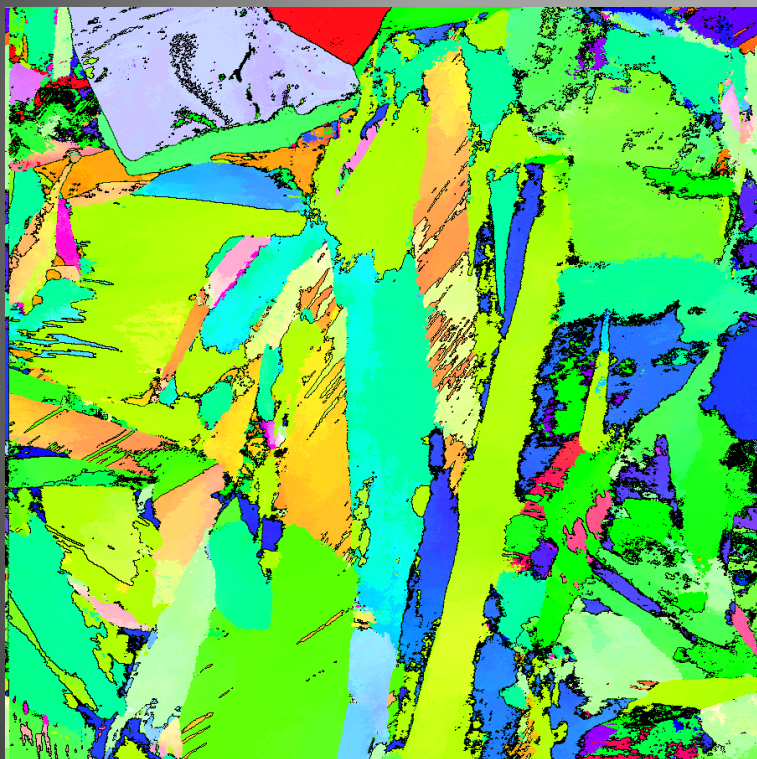


Carbonitrided Transformed @ $T < B_s$

CN, 200 °C, 3 h
 $HV_{300g} \approx 700$

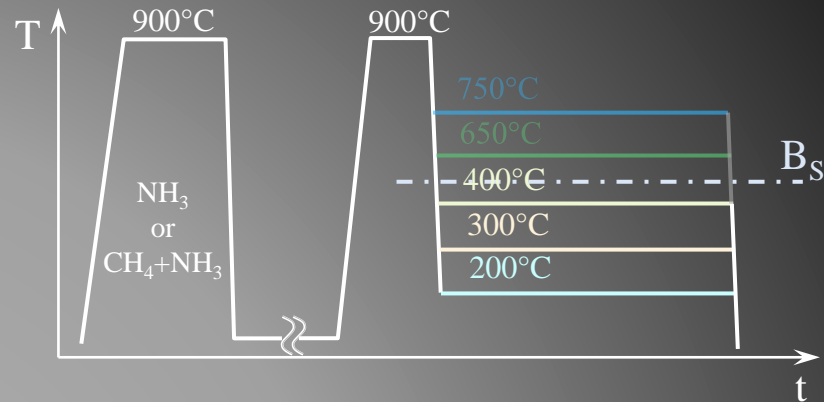
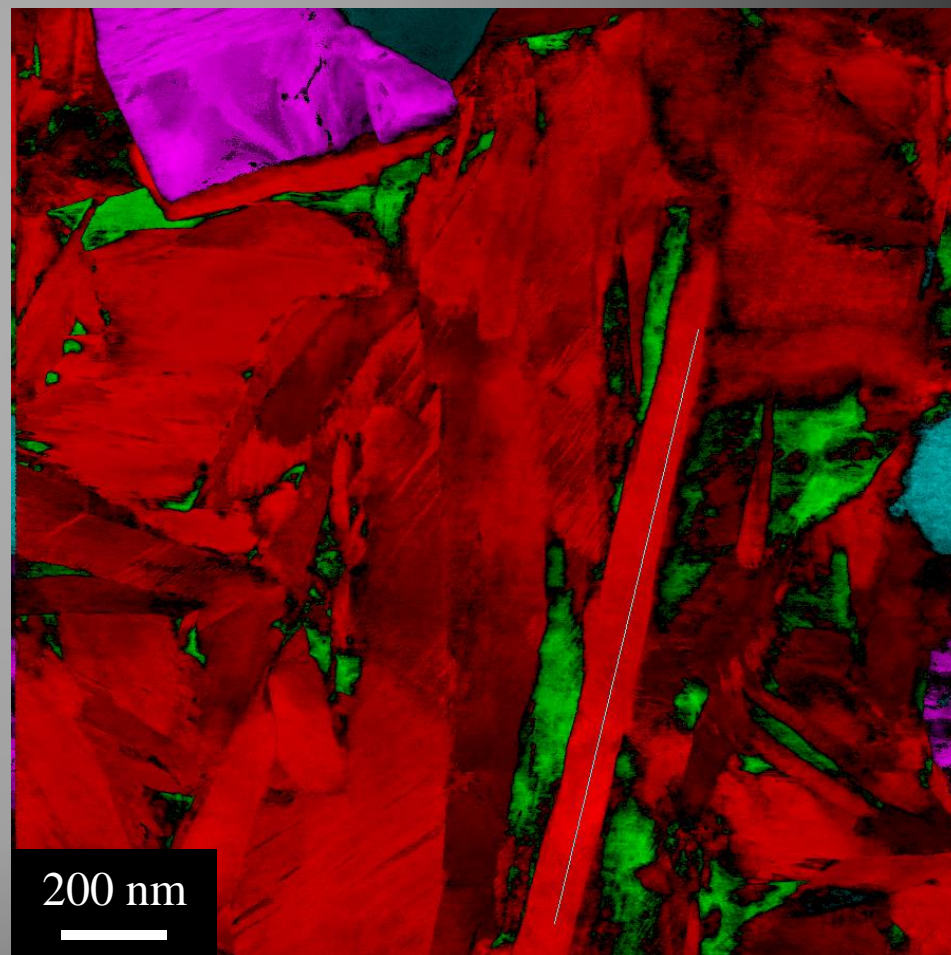


Orientation map



- Ferrite
- Austenite
- $MnSiN_2$
- CrN

Phase map



Carbonitrided Transformed @ $T < B_S$

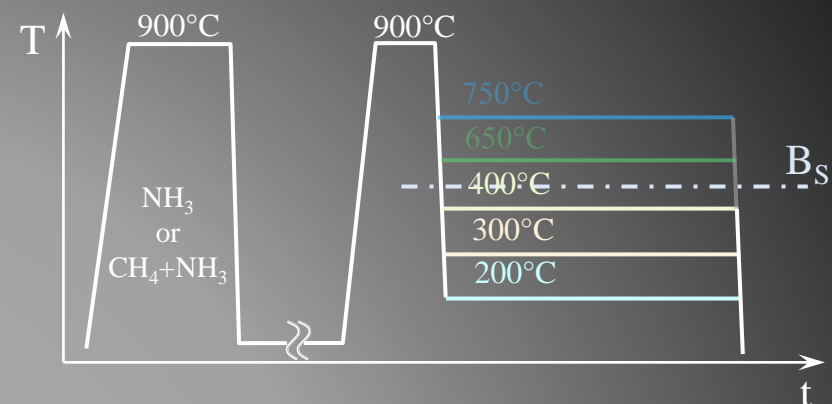
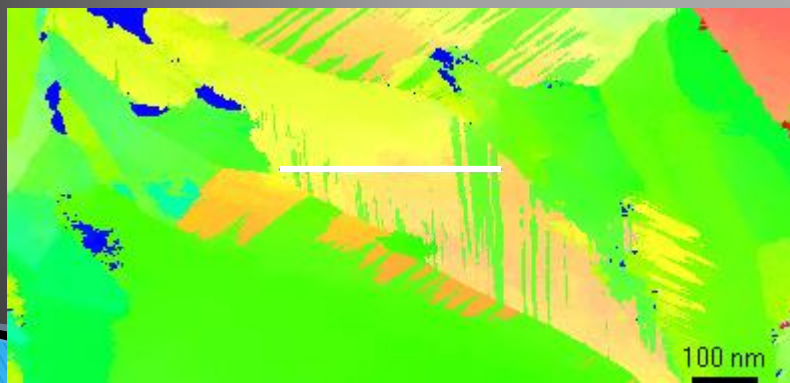
CN, 200 °C, 3 h
 $HV_{300g} \approx 700$



ACOM virtual BF



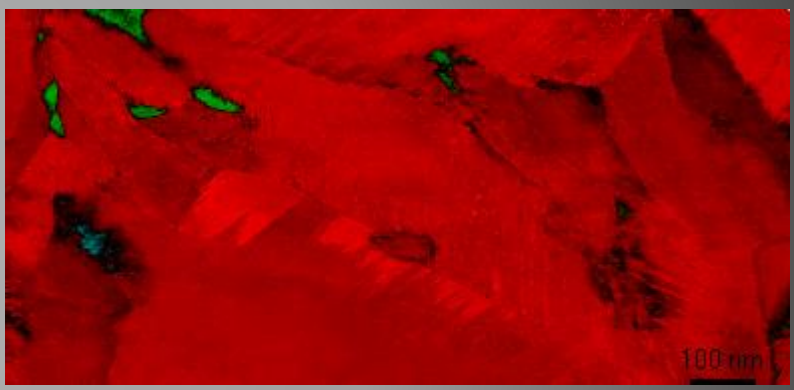
Orientation map (z)



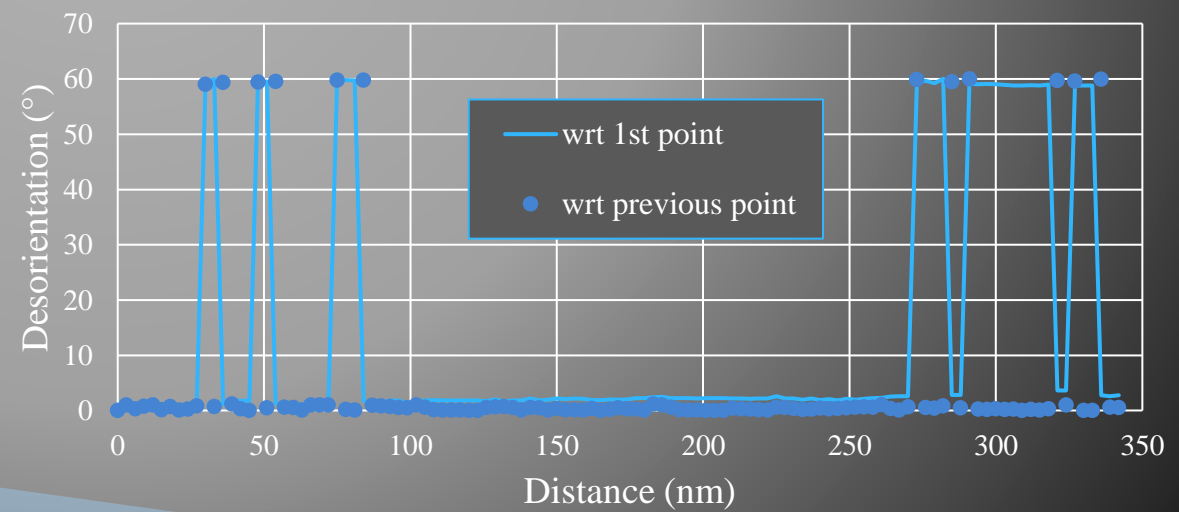
Pixel size
 3 x 3 nm²

200 nm

Phase map

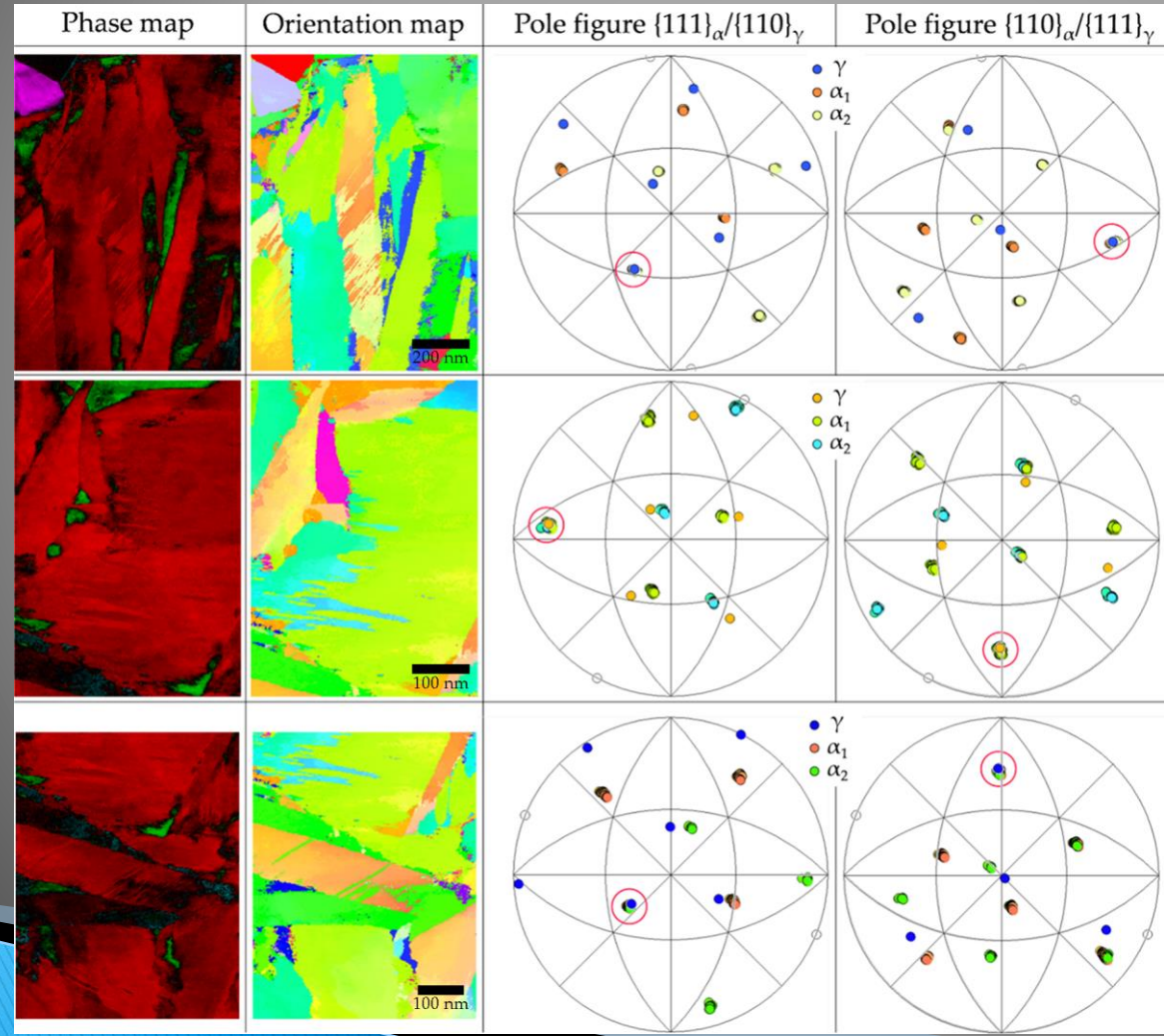
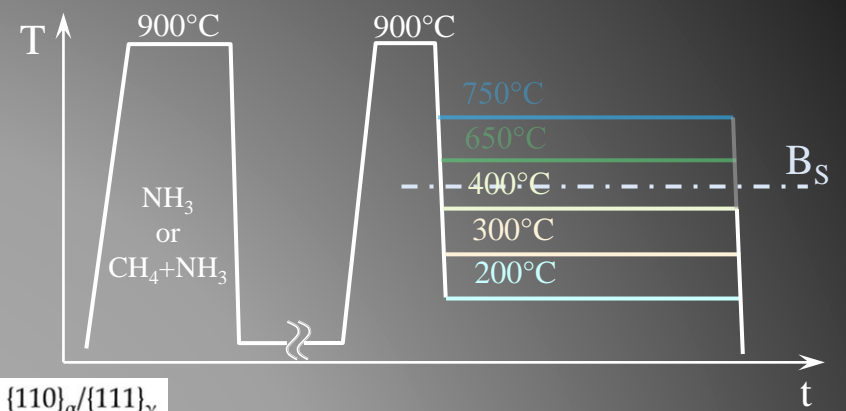


■ Ferrite ■ CrN ■ Austenite



Carbonitrided Transformed @ $T < B_S$

CN, 200 °C, 3 h
 $HV_{300g} \approx 700$

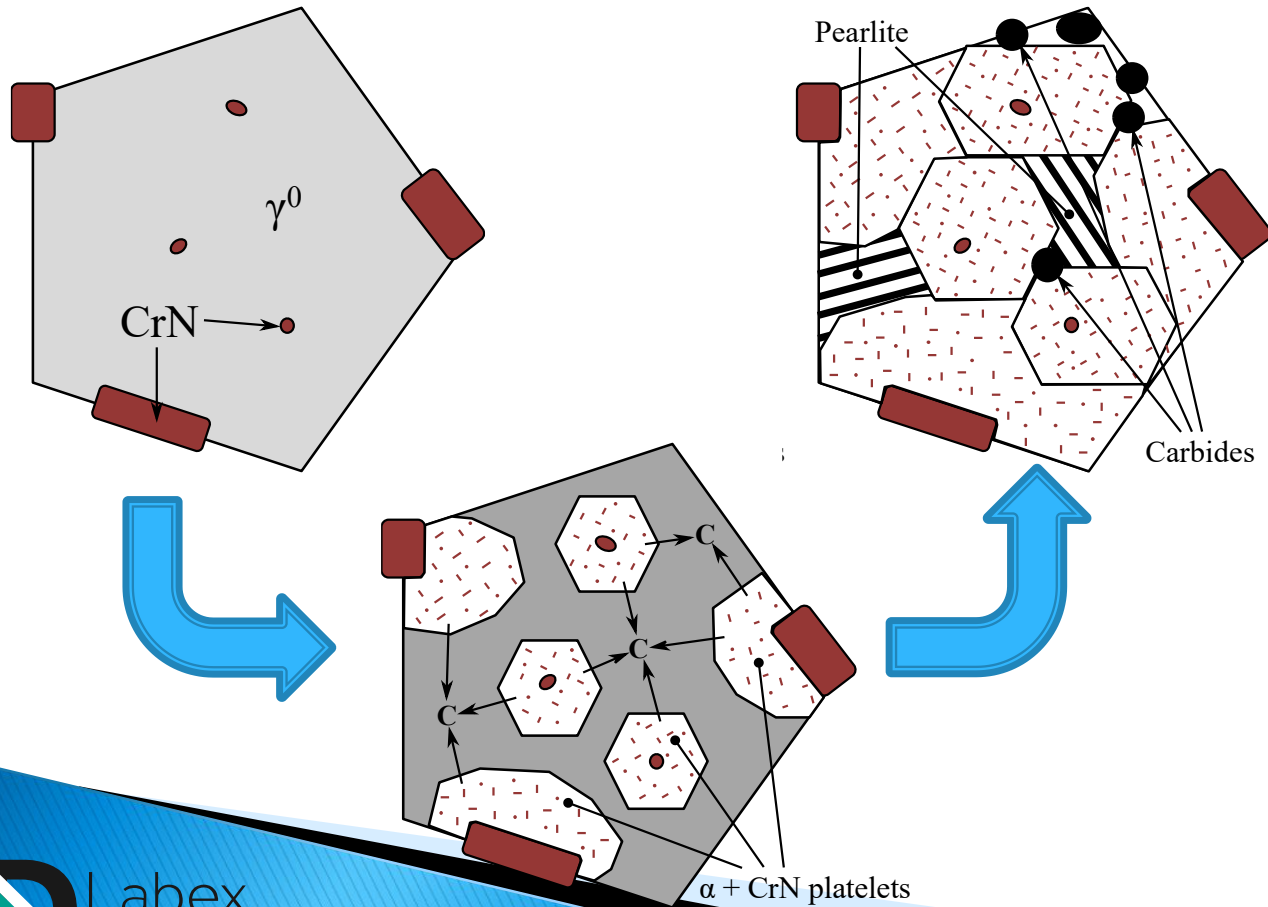


Both twins always have
 KS OR with parent austenite

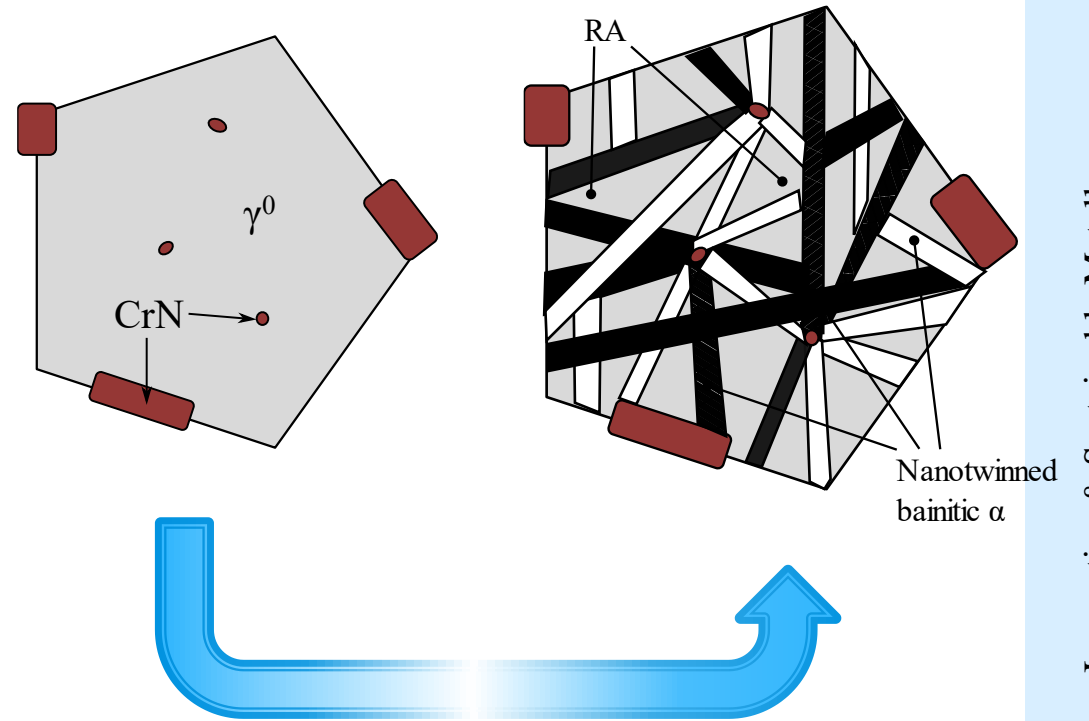


Conclusion

$T > B_S$



$T < B_S$



References

- ▶ J. Teixeira, S.D. Catteau, H.P. Van Landeghem, J. Dulcy, M. Dehmas, A. Redjaïmia, S. Denis, M. Courteaux, Bainite Formation in Carbon and Nitrogen enriched Low Alloyed Steels: Kinetics and Microstructures, *HTM Journal of Heat Treatment and Materials* 73 (2018) 144–156.
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- ▶ H.P. Van Landeghem, M. Véron, S.D. Catteau, J. Teixeira, J. Dulcy, A. Redjaïmia, S. Denis, Nitrogen-induced nanotwinning of bainitic ferrite in low-alloy steel, *Scripta Materialia* 155 (2018) 63–67.
<https://doi.org/10.1016/j.scriptamat.2018.06.021>.
- ▶ H.P. Van Landeghem, S.D. Catteau, J. Teixeira, J. Dulcy, M. Dehmas, M. Courteaux, A. Redjaïmia, S. Denis, Isothermal decomposition of carbon and nitrogen-enriched austenite in 23MnCrMo5 low-alloy steel, *Acta Materialia* 148 (2018) 363–373. <https://doi.org/10.1016/j.actamat.2018.02.008>.
- ▶ S.D. Catteau, H.P. Van Landeghem, J. Teixeira, J. Dulcy, M. Dehmas, S. Denis, A. Redjaïmia, M. Courteaux, Carbon and nitrogen effects on microstructure and kinetics associated with bainitic transformation in a low-alloyed steel, *Journal of Alloys and Compounds* 658 (2016) 832–838.
<https://doi.org/10.1016/j.jallcom.2015.11.007>.