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Center for Advanced Non-Ferrous Structural Alloys
An Industry/University Cooperative Research Center

Postdoc-L: Electron Microscopy Studies of Phase Transformation and Microstructural Evolution in TRIP/TWIP β-Ti and Multi-Principal Element Alloys

Spring 2019 Semi-Annual Meeting
Iowa State University, Ames, IA
April 3-5, 2019

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Faculty: Amy Clarke (Mines)

Other participants: Francisco Coury (UFSCar)

NSF

COLORADO SCHOOL OF MINES

IOWA STATE UNIVERSITY

Progress

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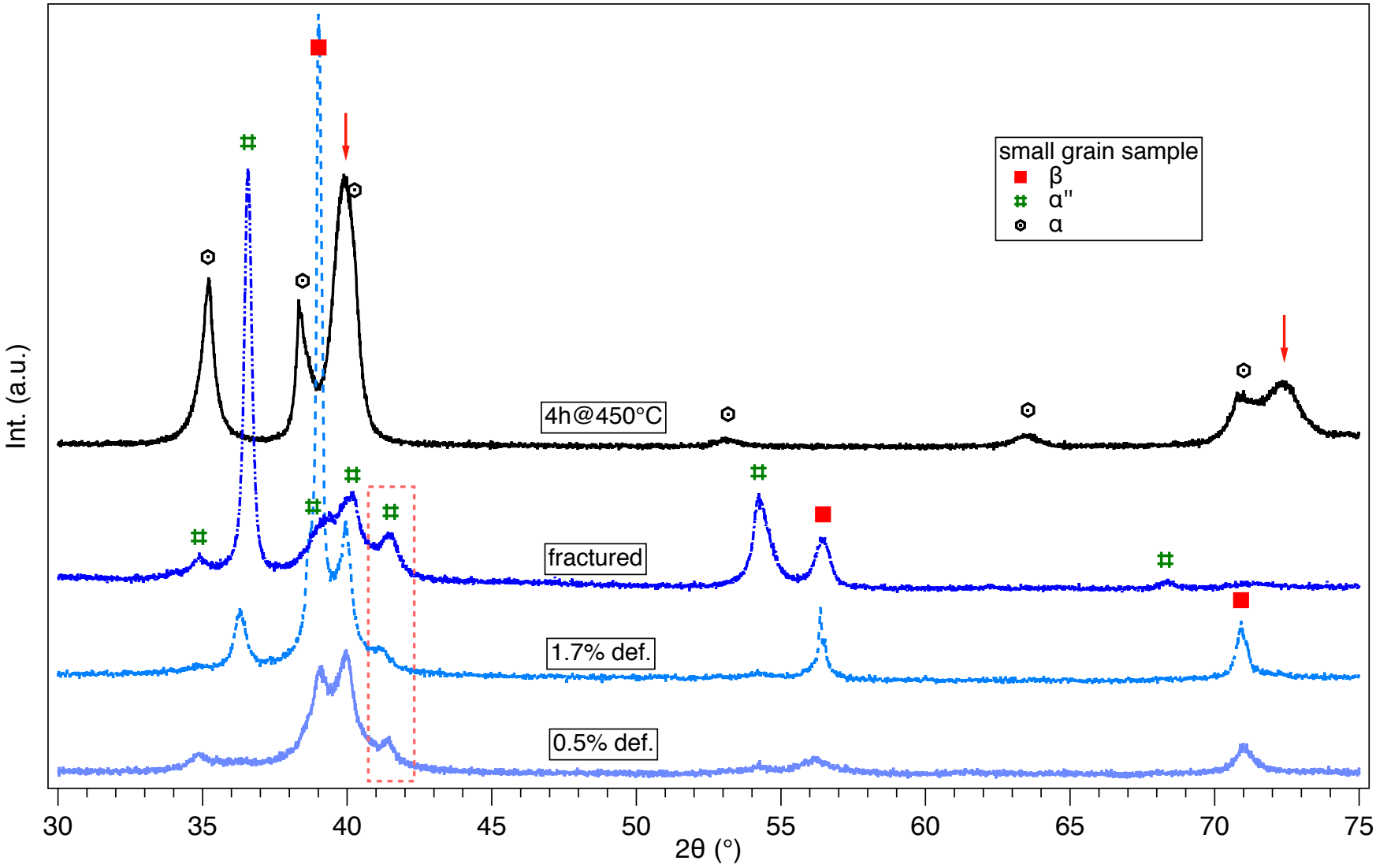
1. β-Ti Alloy
   - TRIP in Ti-10V-2Fe-3Al

2. Multi-Principal Element Alloy (MPEA)
   - TRIP in Co-Cr-Ni
   - New metastable phase

1: TRIP in Ti-10V-2Fe-3Al

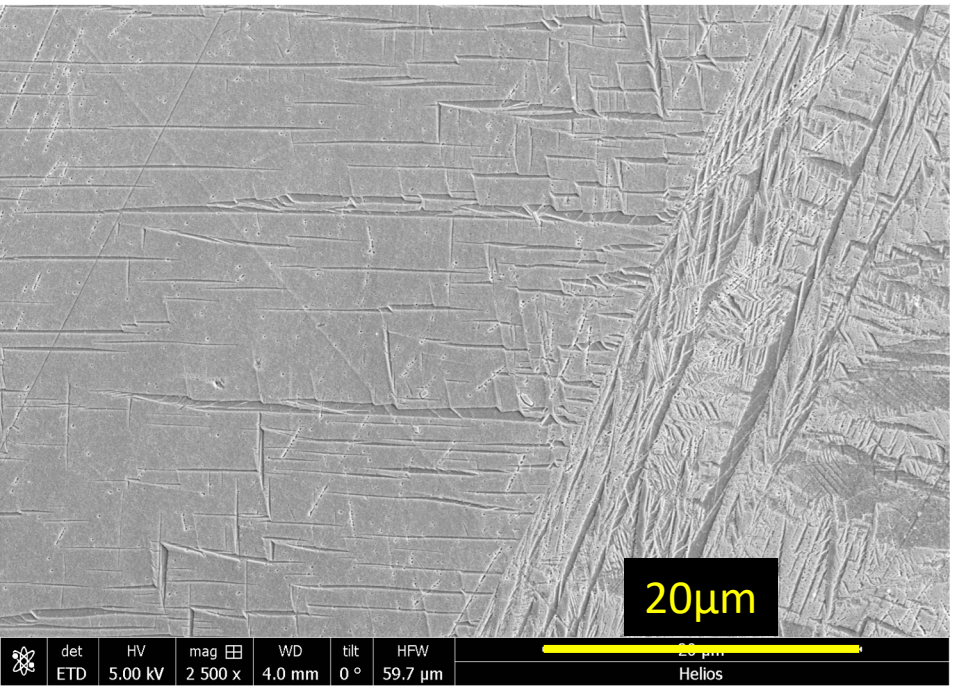
XRD Pattern of Ti-1023



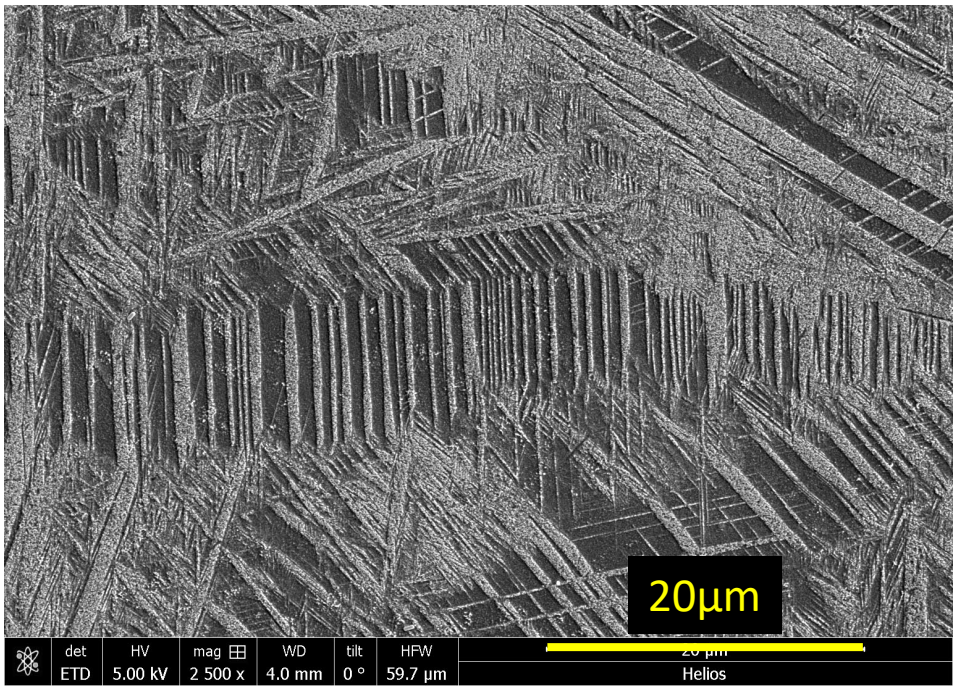
Deformed Ti-1023

- 1hr @ 850°C, small grain (~ 150 µm)
- Tension

0.5%

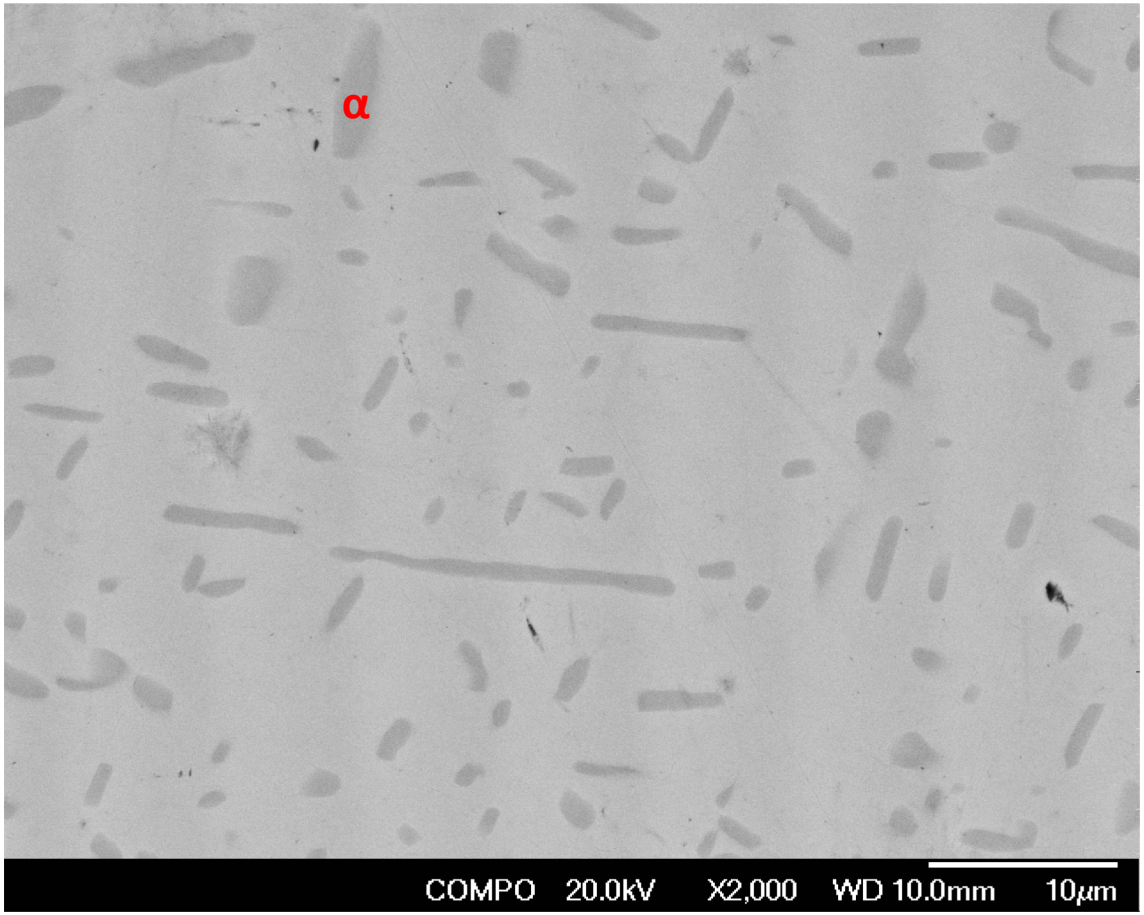


1.7%



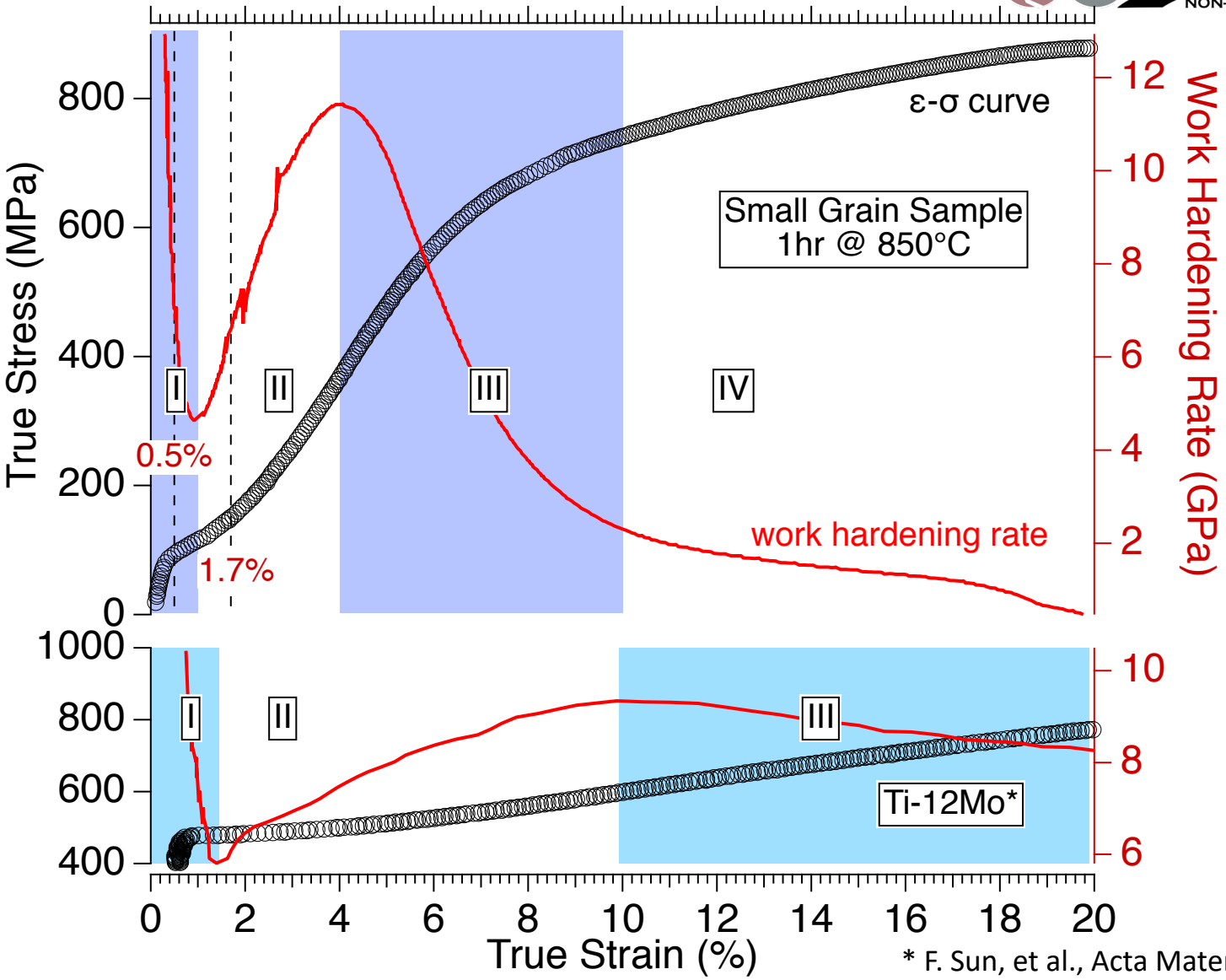
Annealed Ti-1023

- 4hr @ 450°C



- EDAX results show that α phase is lean in β-stabilizers (V and Fe) and richer in α-stabilizer (Al) than β matrix.
- Elemental segregation leads to lattice parameter change in β phase (XRD).

Work Hardening in Ti-1023



* F. Sun, et al., Acta Mater. 61 (2013) 6406–6417.

α” in 0.5% Deformed Ti-1023

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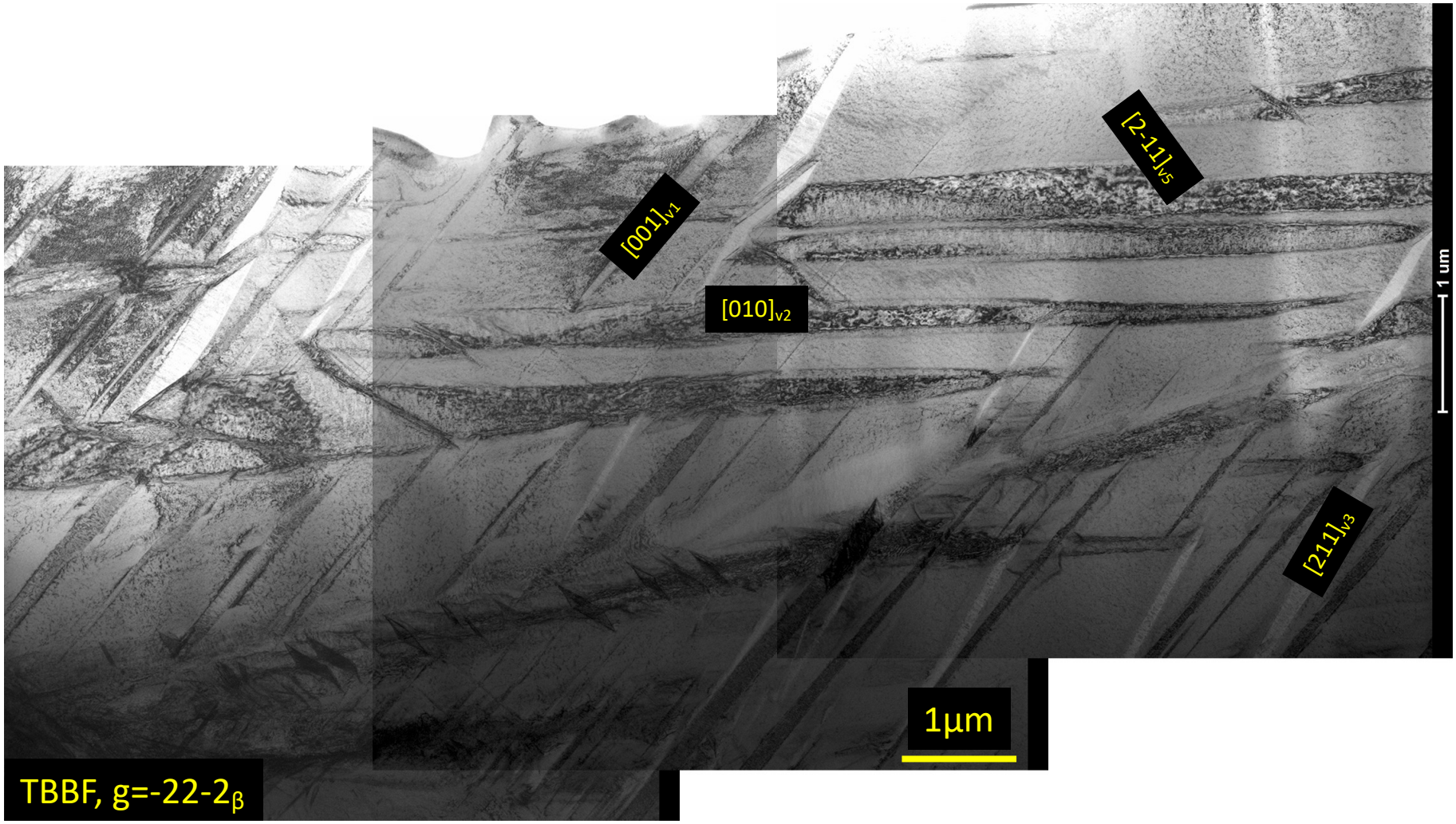

α” Martensites

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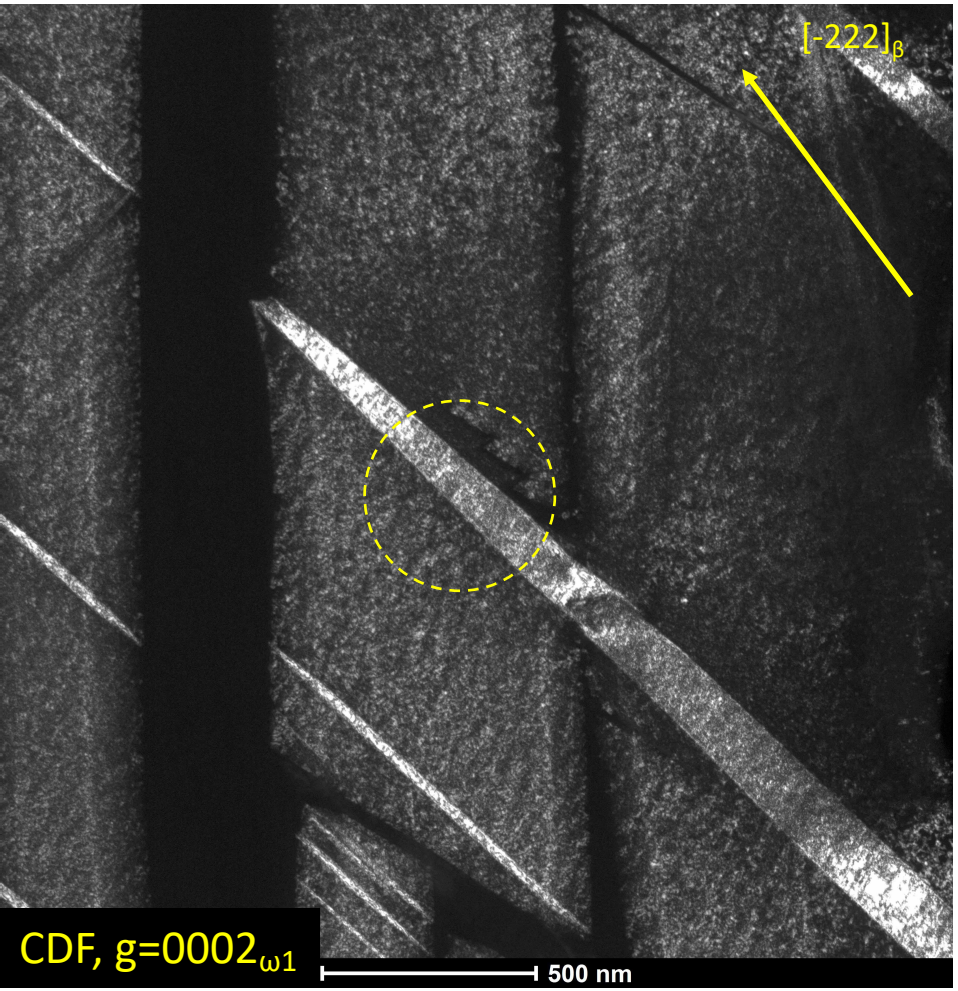
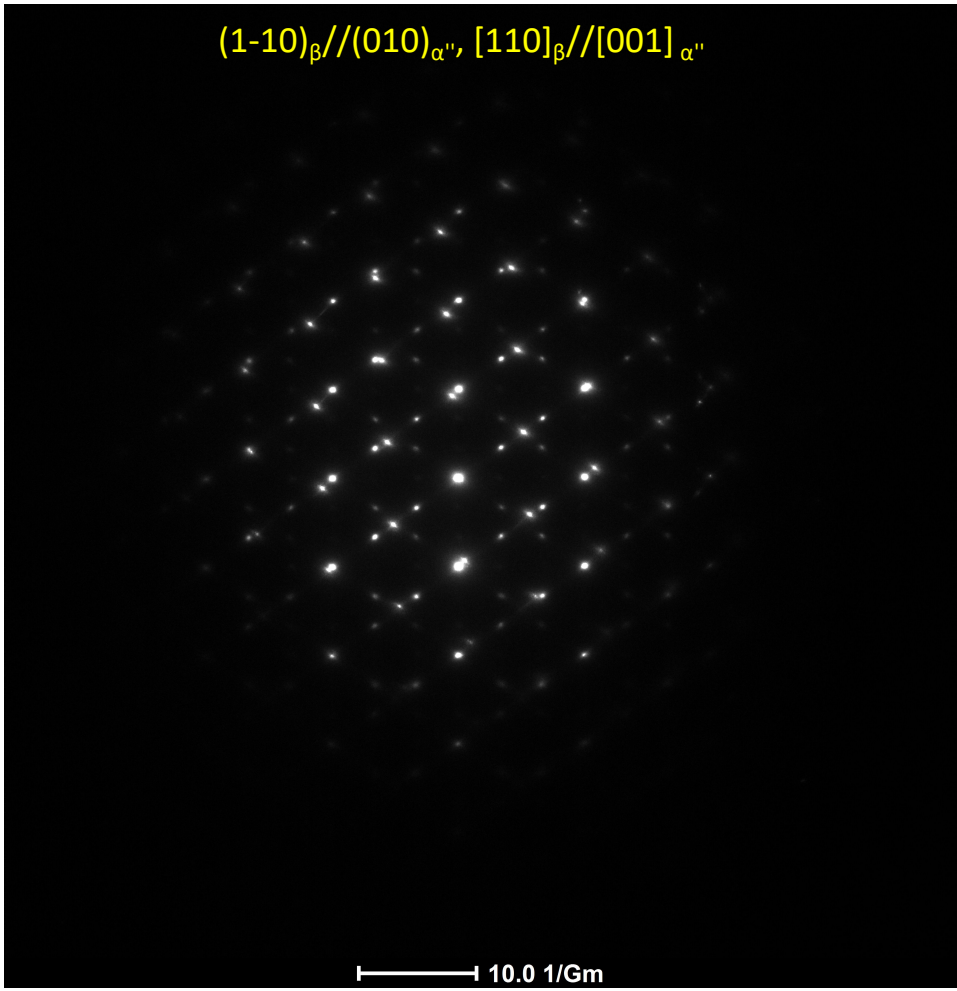
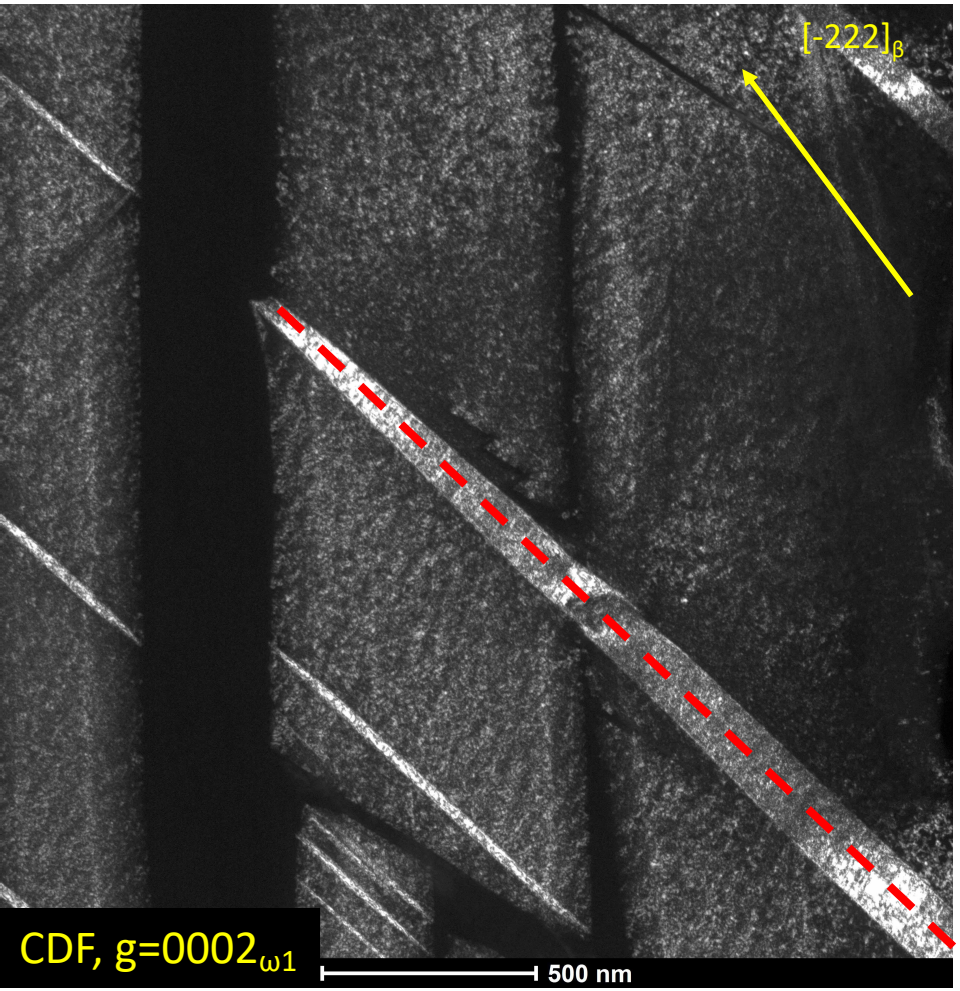
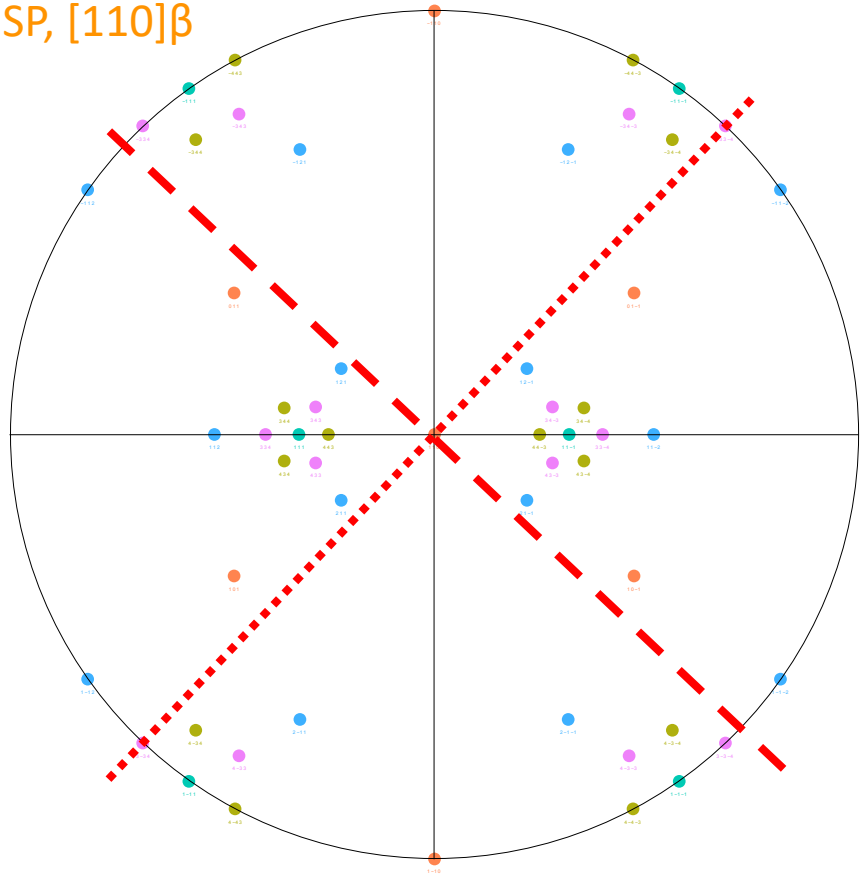




Habit Plane of α" Martensites





{112}, {110}, {111}, {334}, {344}

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2.1: TRIP in Co-Cr-Ni MPEA

Designing of $Co_{55}Cr_{40}Ni_5$

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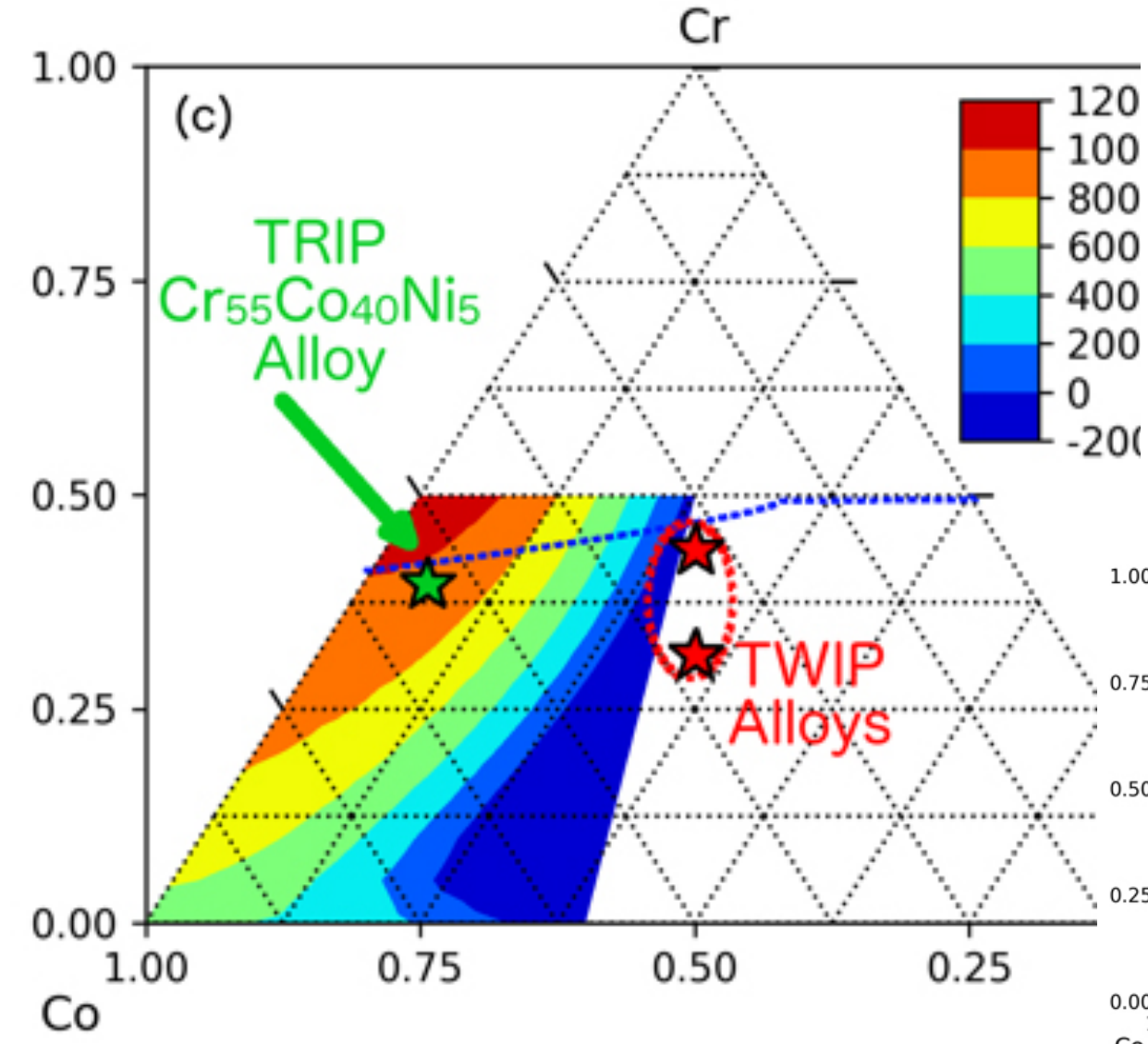

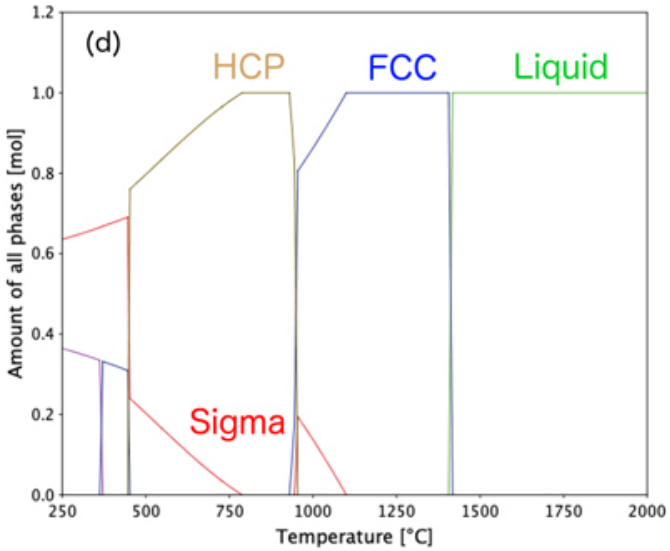

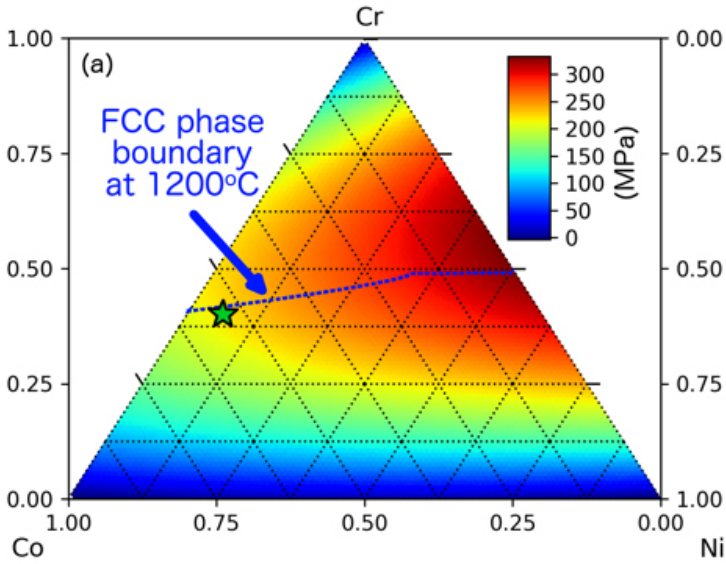

Courtesy of F. Coury

In situ Observation of the TRIP Behavior during Tension

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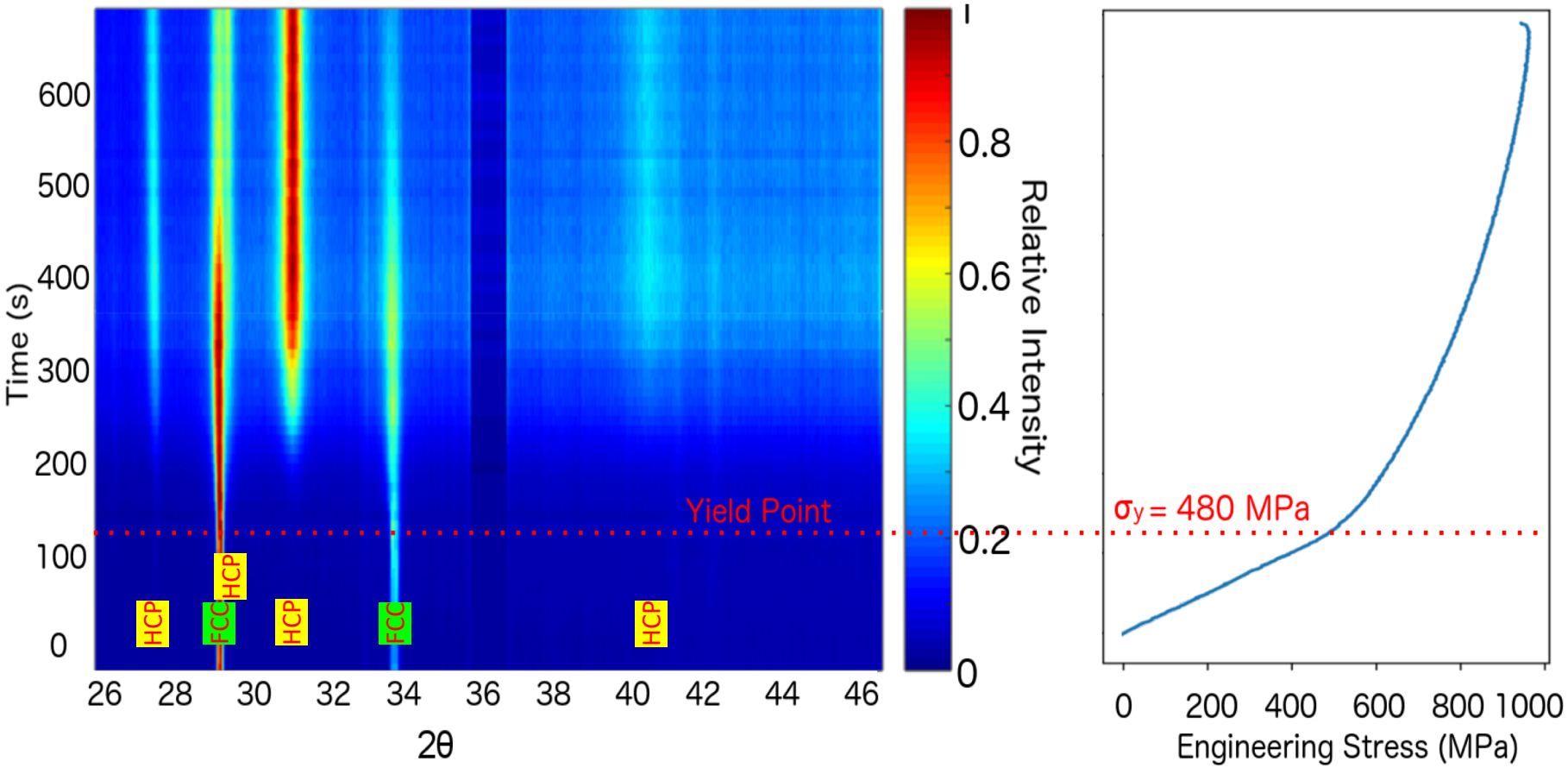
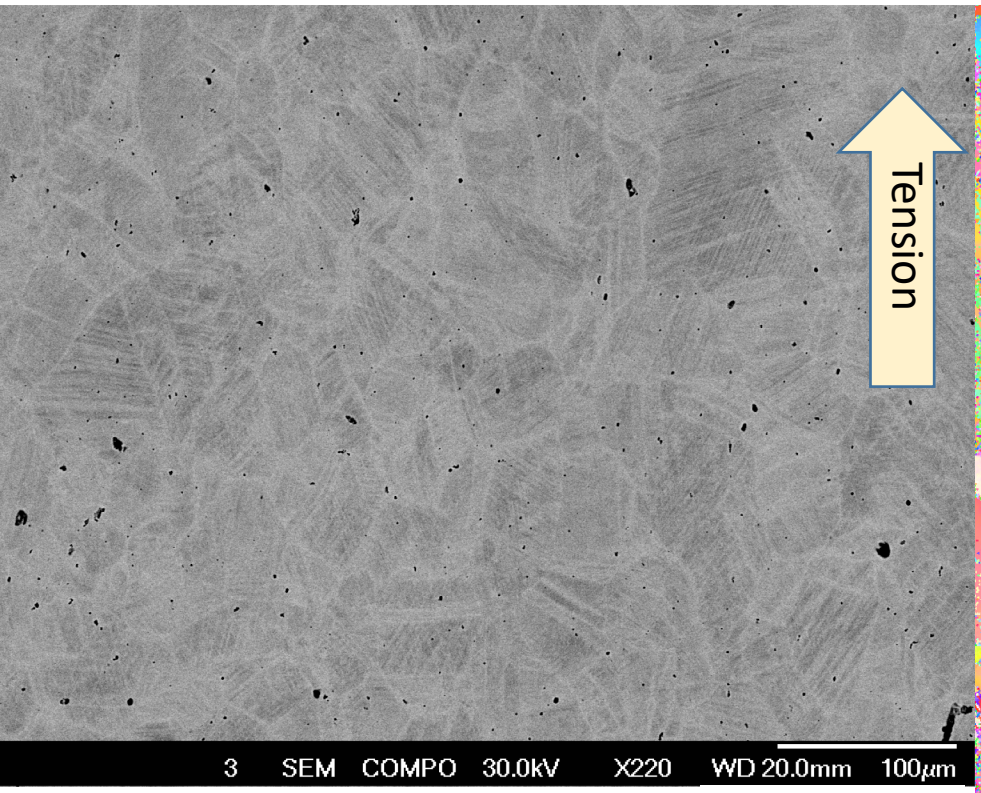


Courtesy of F. Coury

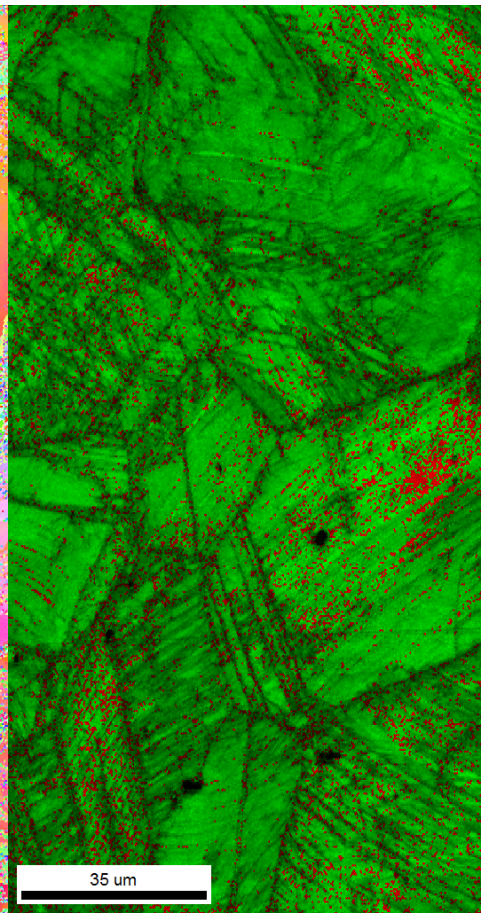
Post-Mortem Characterization

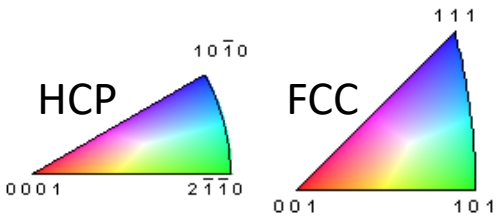
- >50% deformation



IPF

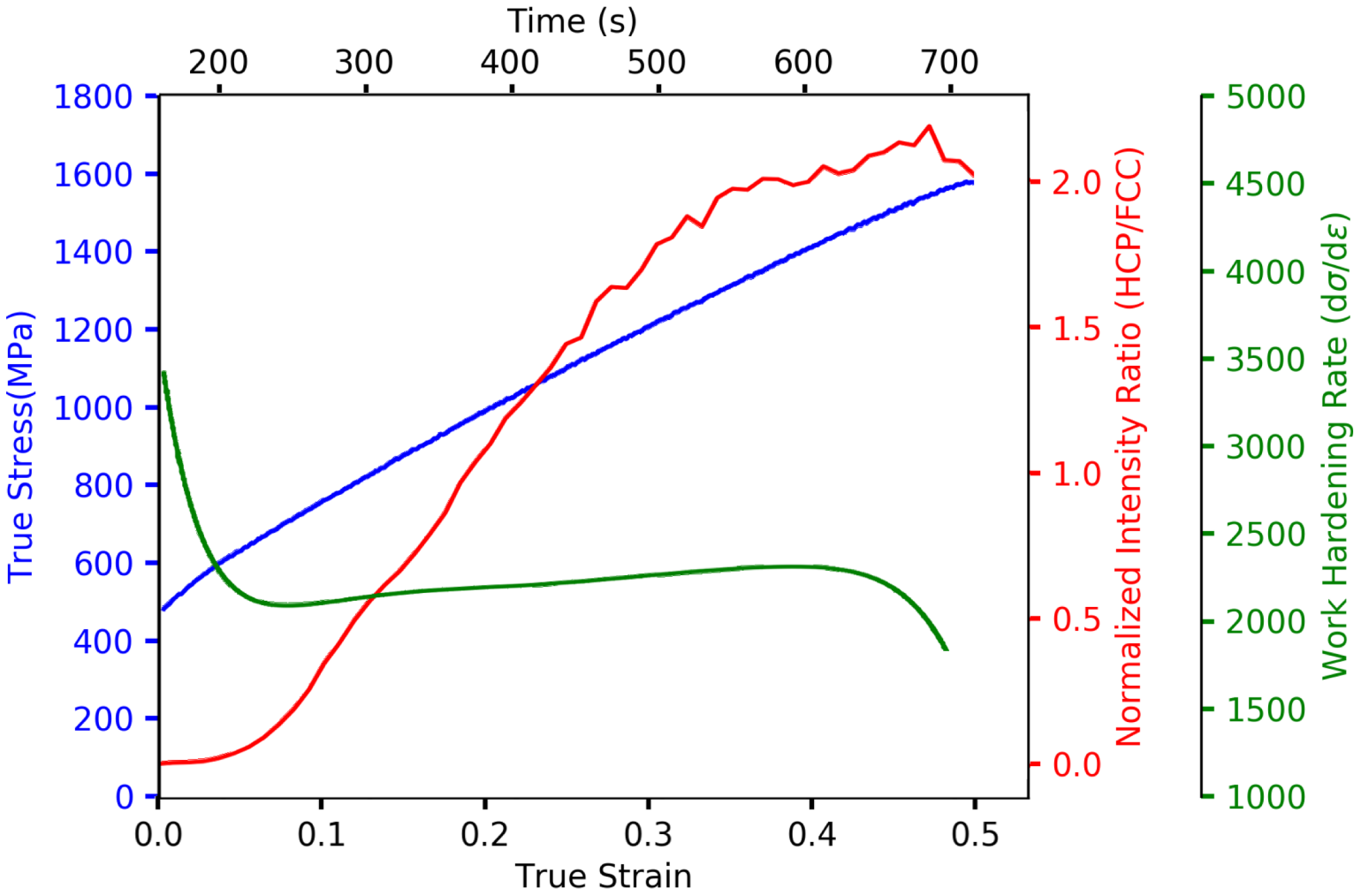
Phase+IQ





HCP, FCC

Mechanical Properties

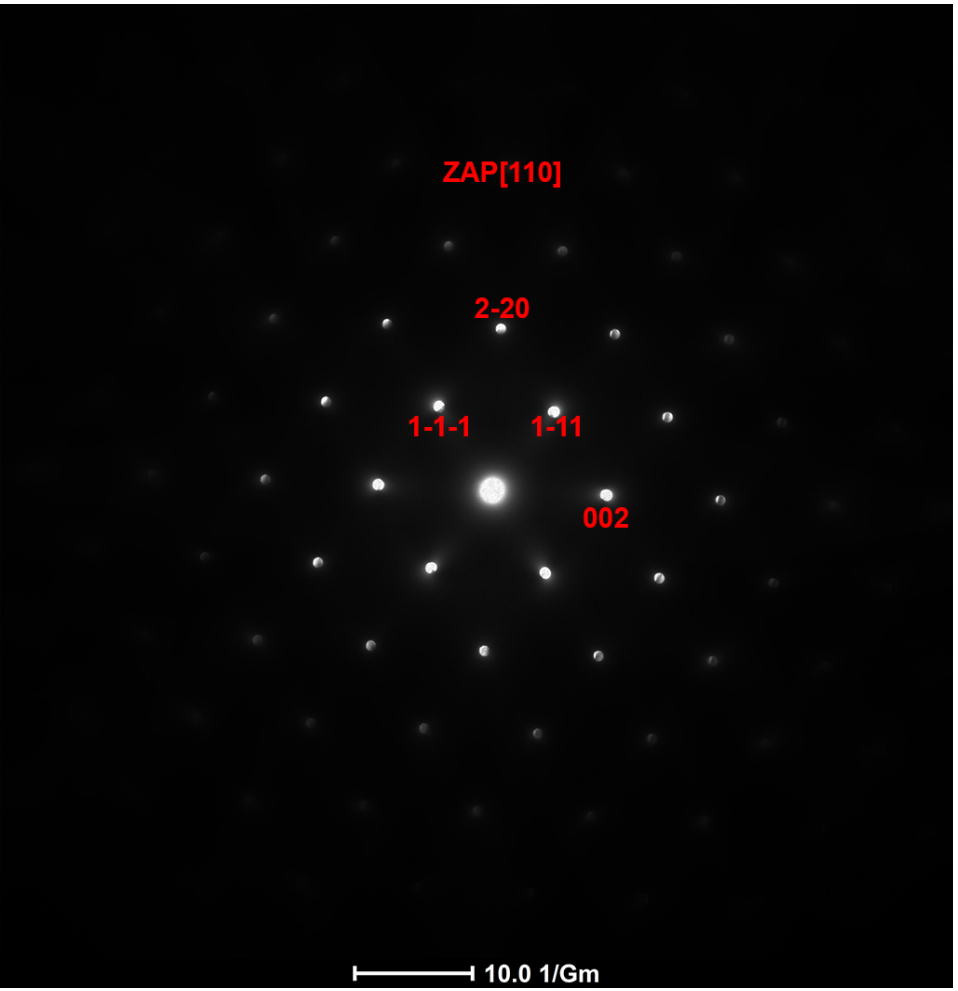


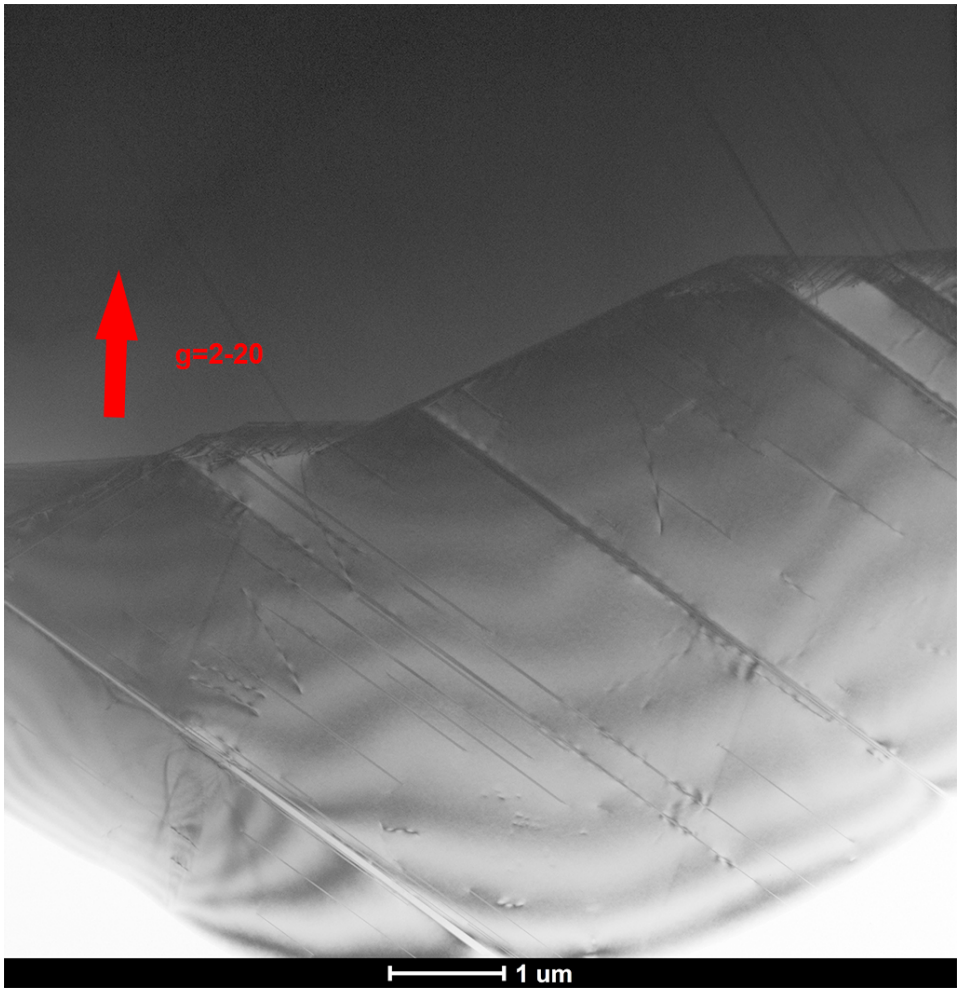
The **TRIP** behavior could be related to the **low stacking fault energy** (SFE, γ).

Courtesy of F. Coury

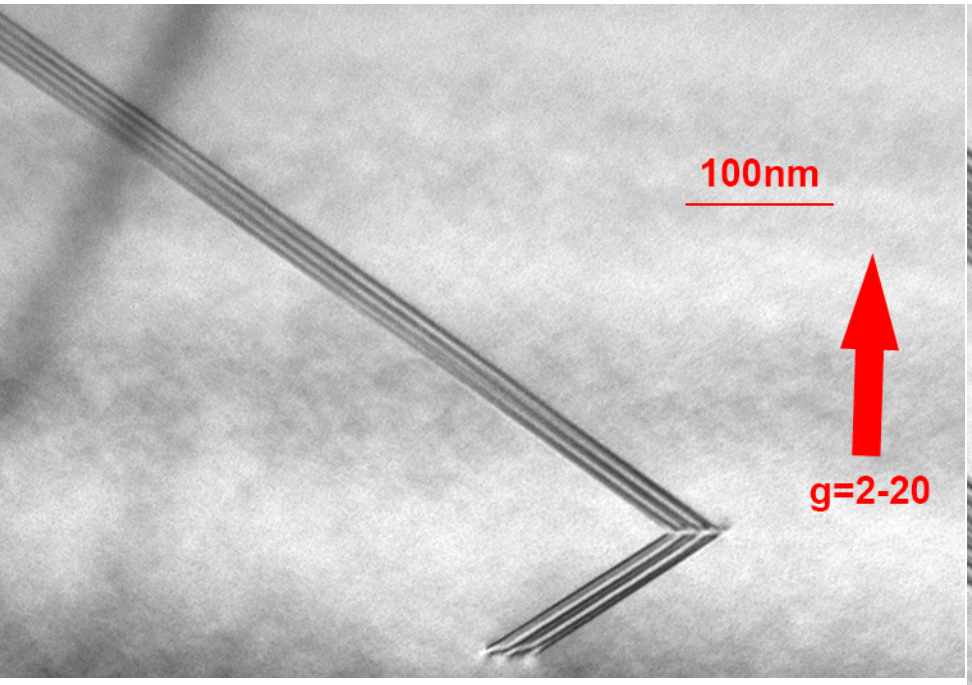
Single FCC $Co_{55}Cr_{40}Ni_5$

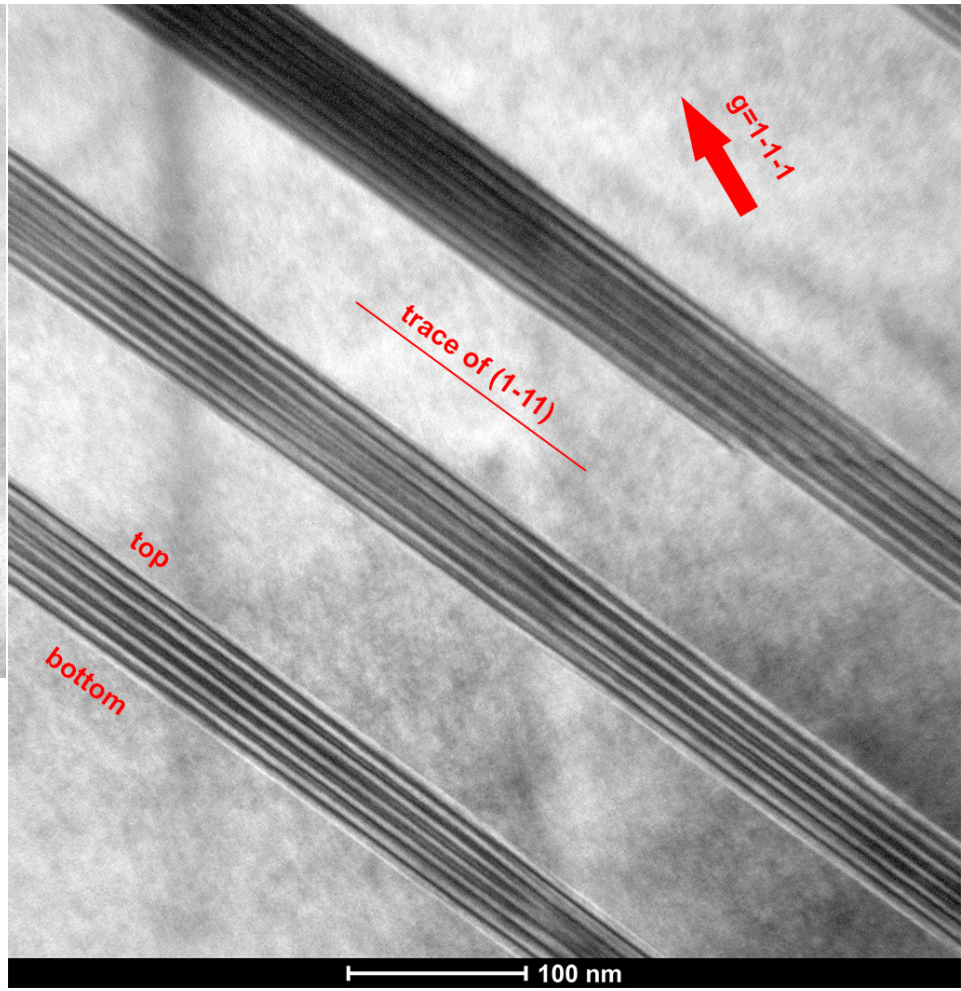
- as-Spray-Formed





Morphology of Stacking Faults





- **extrinsic SFs**

Calculating SFE

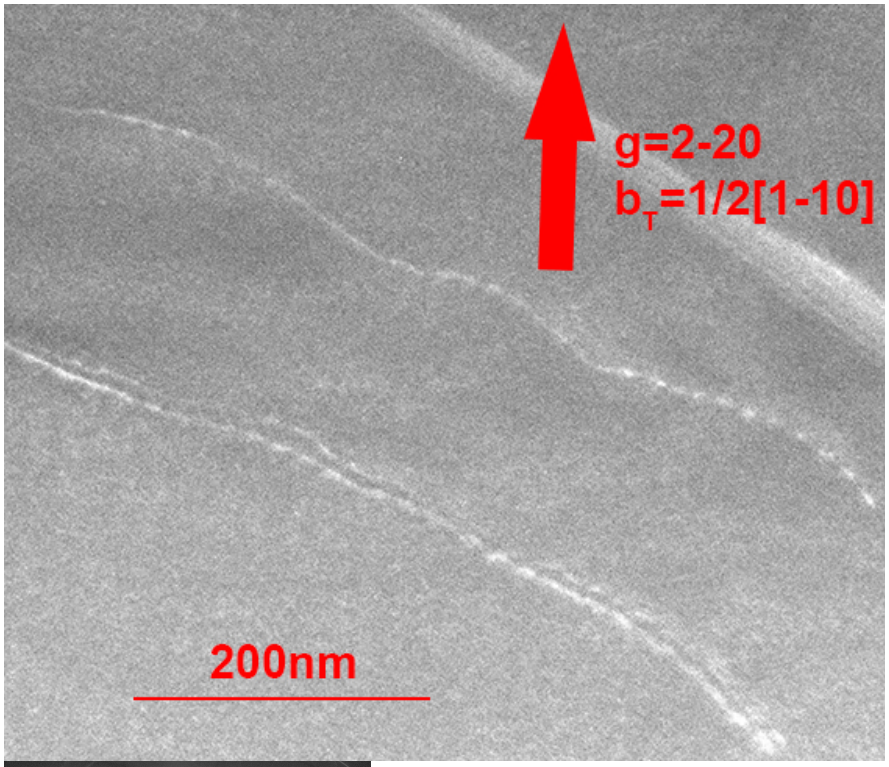
If sample is in **equilibrium***:

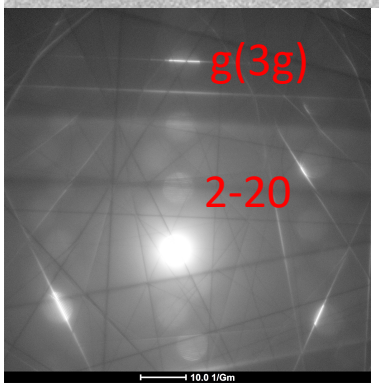
$$\gamma = \frac{\mu_{eff} b_p^2}{8\pi\,\Delta} \frac{2-\nu_{eff}}{1-\nu_{eff}} \left(1 - \frac{2\nu_{eff}\, Cos[2\beta]}{2-\nu_{eff}}\right)$$

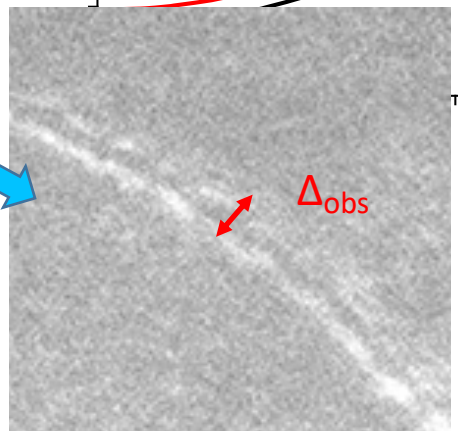
- γ: stacking fault energy
- b_p: Burgers vector of partial dislocations
- μ_{eff}: shear modulus
- ν_{eff}: Poisson's ratio
- **Δ**: actual separation distance between partials
- **β**: total dislocation character angle

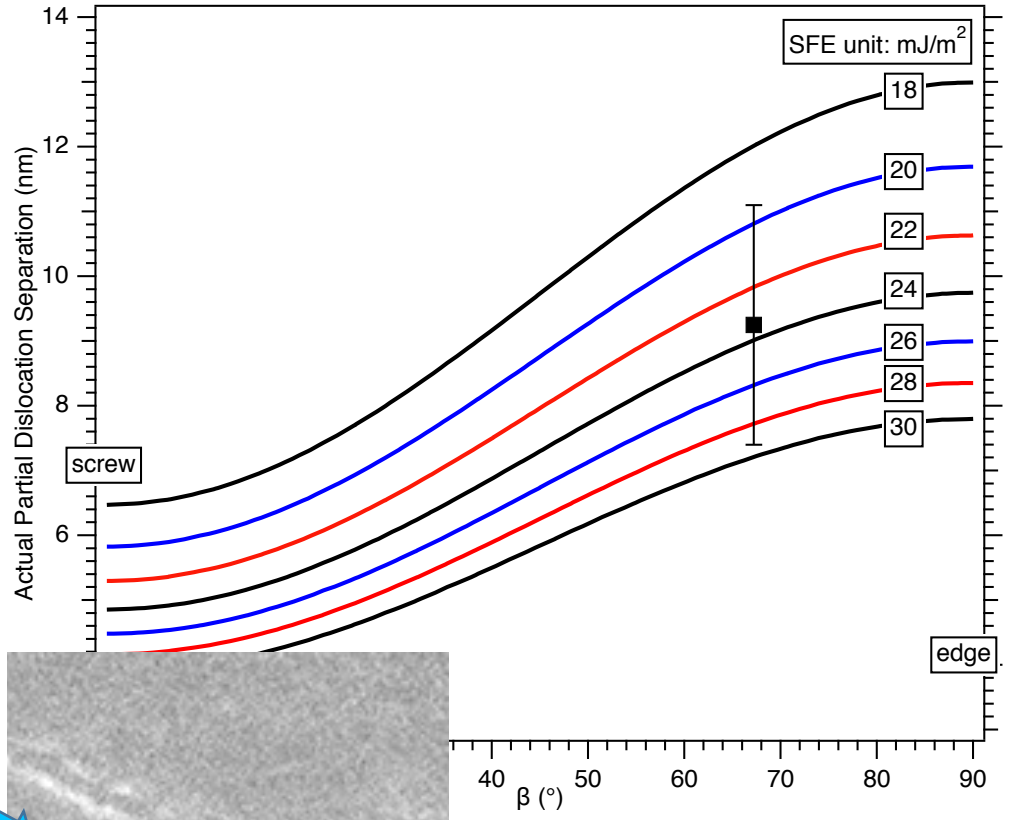
[*] D.T. Pierce et al. / Acta Materialia 68 (2014) 238–253

Preliminary Estimation of SFE









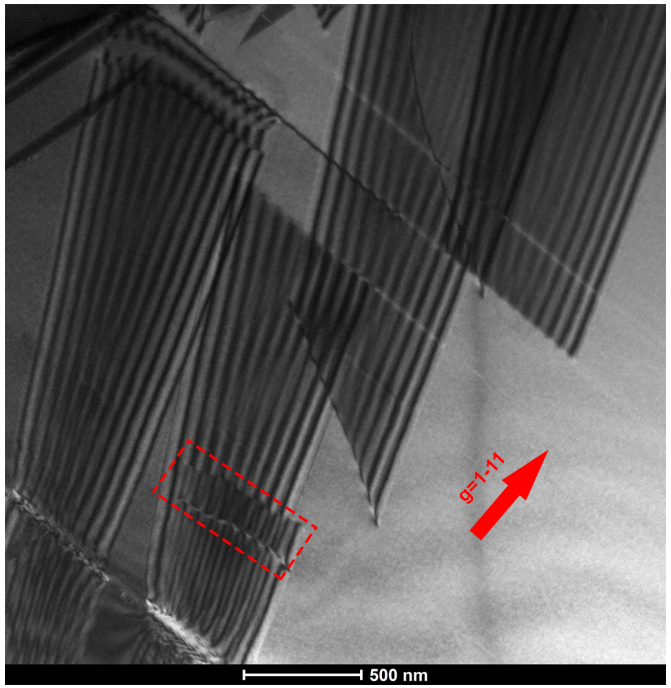
s_g: 0.16 nm^{-1}
β: 67.2°
Δ_{obs}: 9.80 ± 1.76 nm
Δ: 9.25 ± 1.85 nm

$$|g \cdot b_T| = 2$$
$$|g \cdot b_p| = 1$$

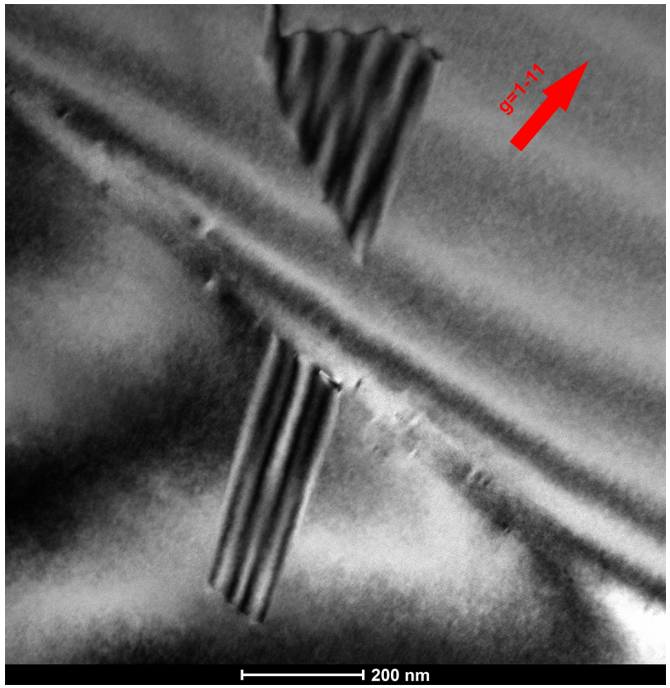
Caveats

- Equilibrium: isolated, uniform spacing, long, straight partial dislocation pairs
- Away from SFs
- Image force
- μ_{eff} and ν_{eff}: μ=89.75GPa, ν=0.287

wide SFs



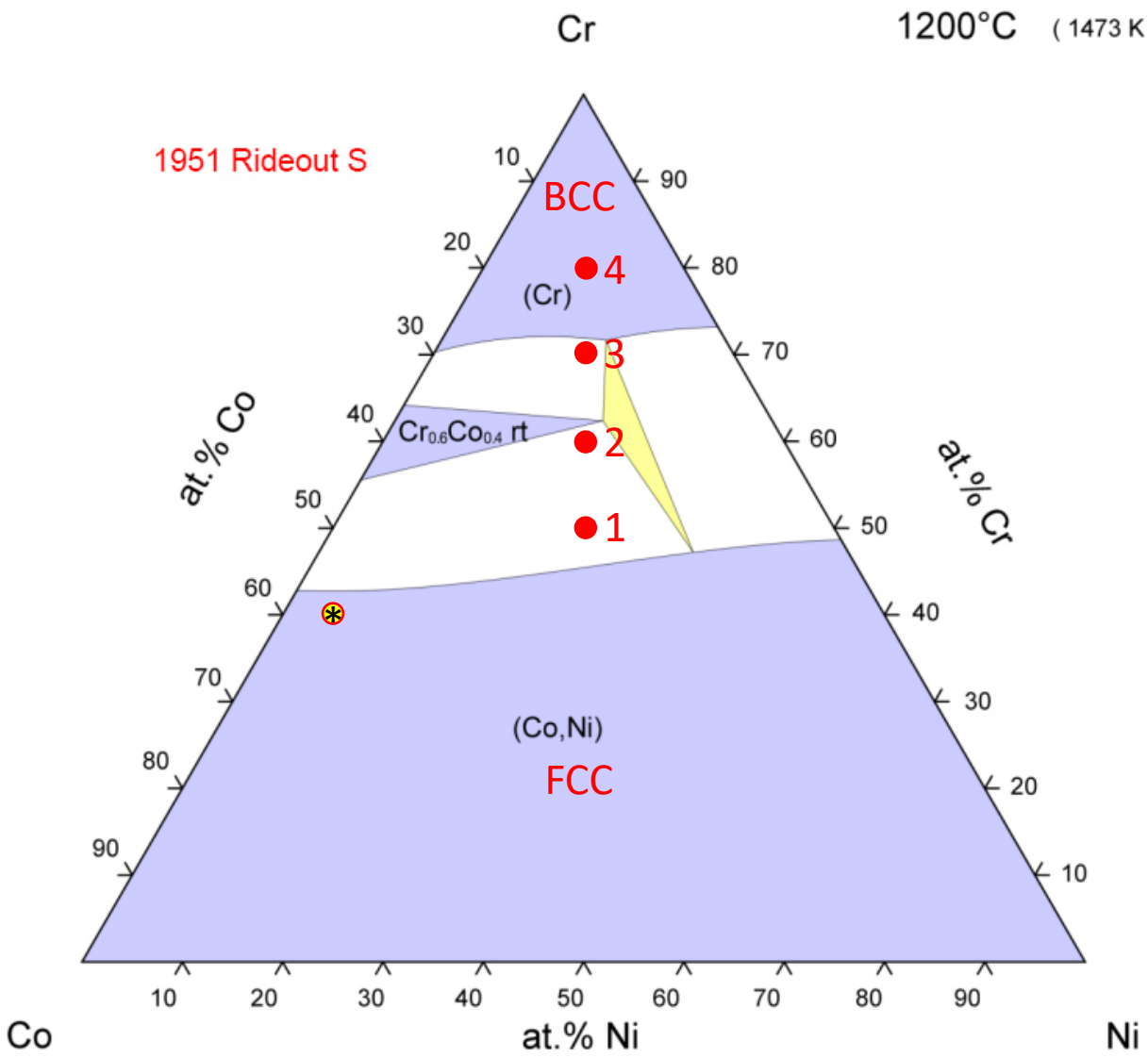
inclined



n	s_g (nm^{-1})
3	0.16
3.5	0.2
4	0.25

2.2: New metastable phase in Co-Cr-Ni

Can BCC Alloy TRIP?



#	Alloy
*	$Co_{55}Cr_{40}Ni_5$
1	$Co_{25}Cr_{50}Ni_{25}$
2	$Co_{20}Cr_{60}Ni_{20}$
3	$Co_{15}Cr_{70}Ni_{15}$
4	$Co_{10}Cr_{80}Ni_{10}$

Furnaced Cooled Alloys

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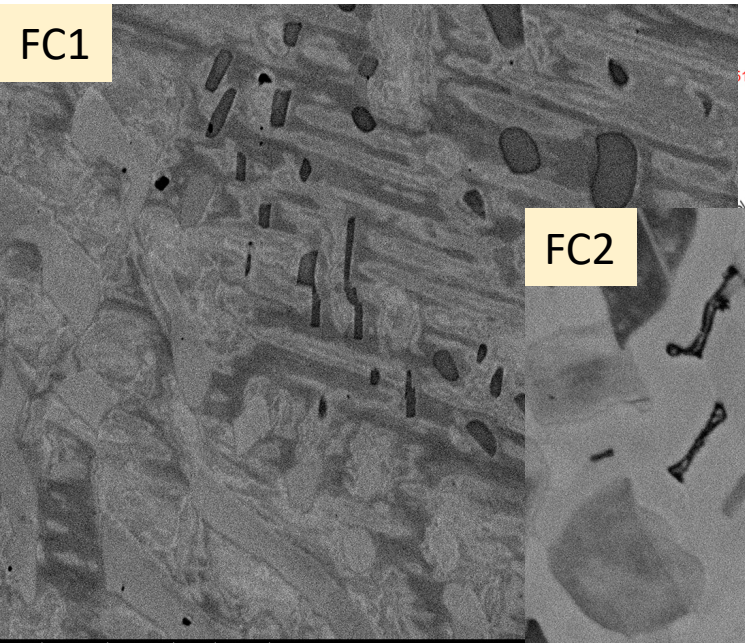
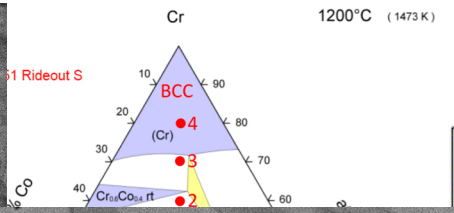
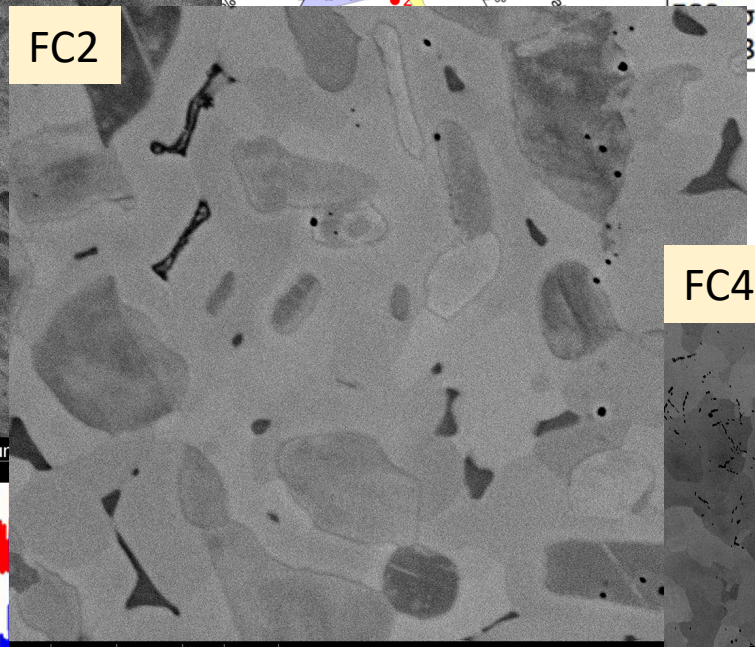
FC1

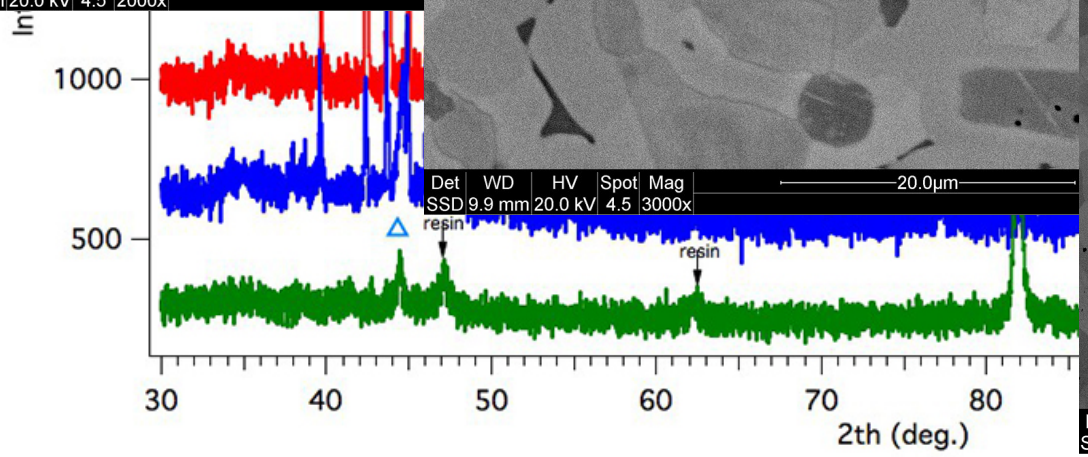




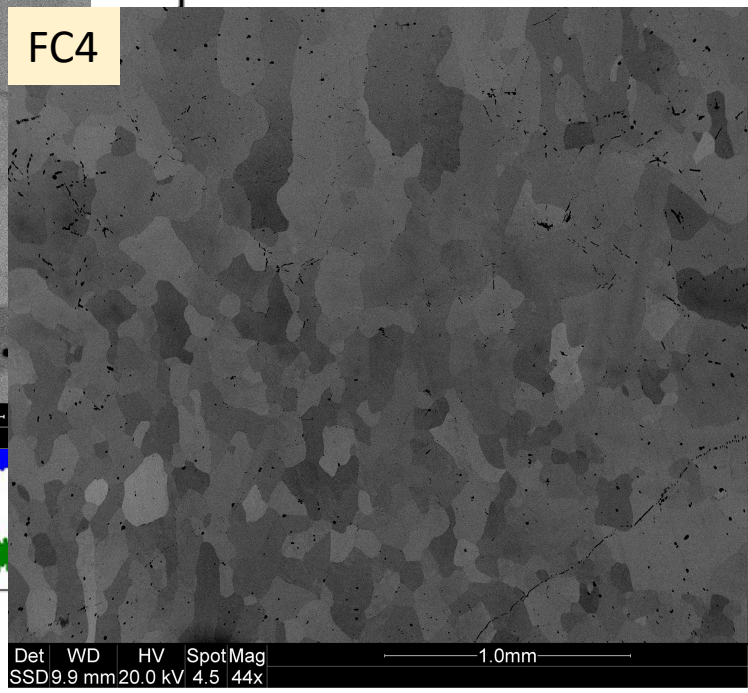
FC1: FCC (Fm-3m) + σ (P42/mnm)
FC2: FCC (Fm-3m) + σ (P42/mnm)
σ (P42/mnm)
BCC (Im-3m)

FC2





FC4



Microstructure of FC3 Alloy

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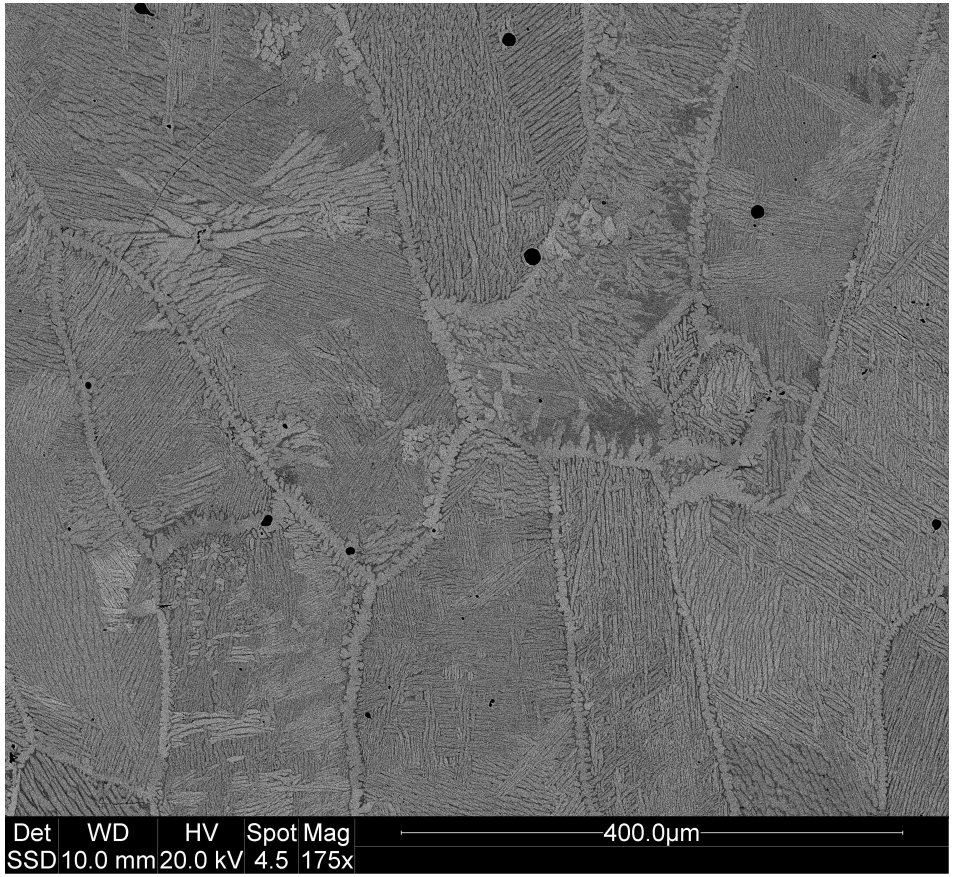
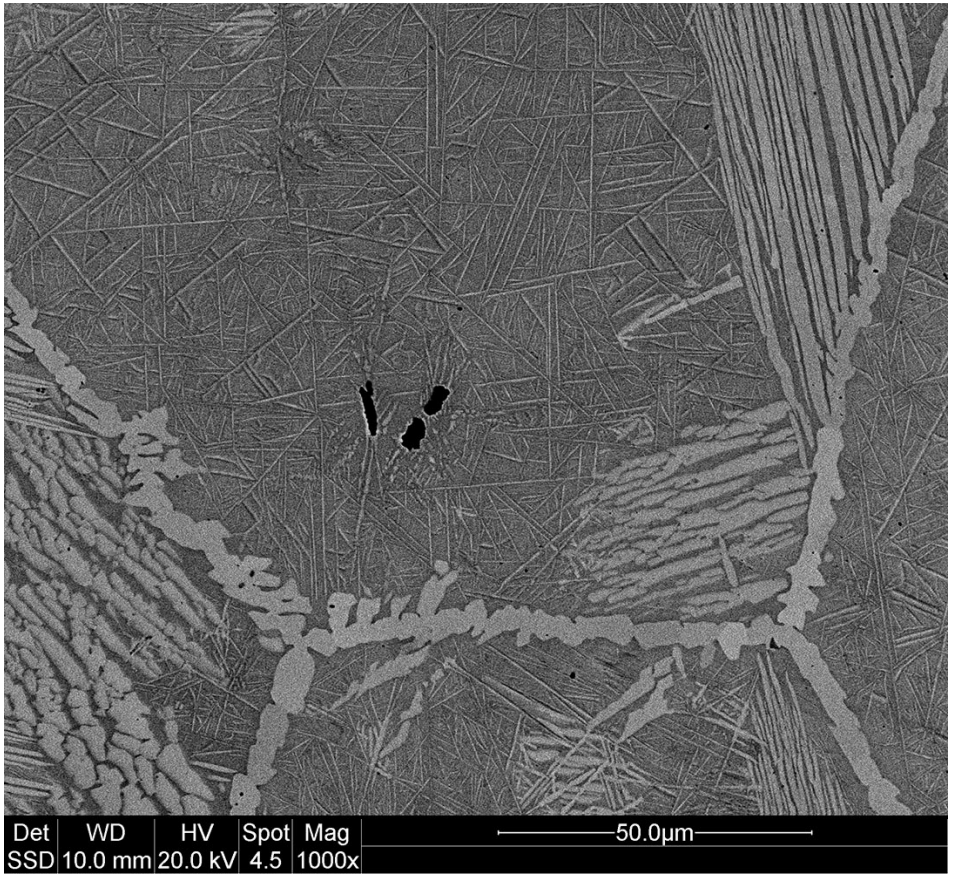
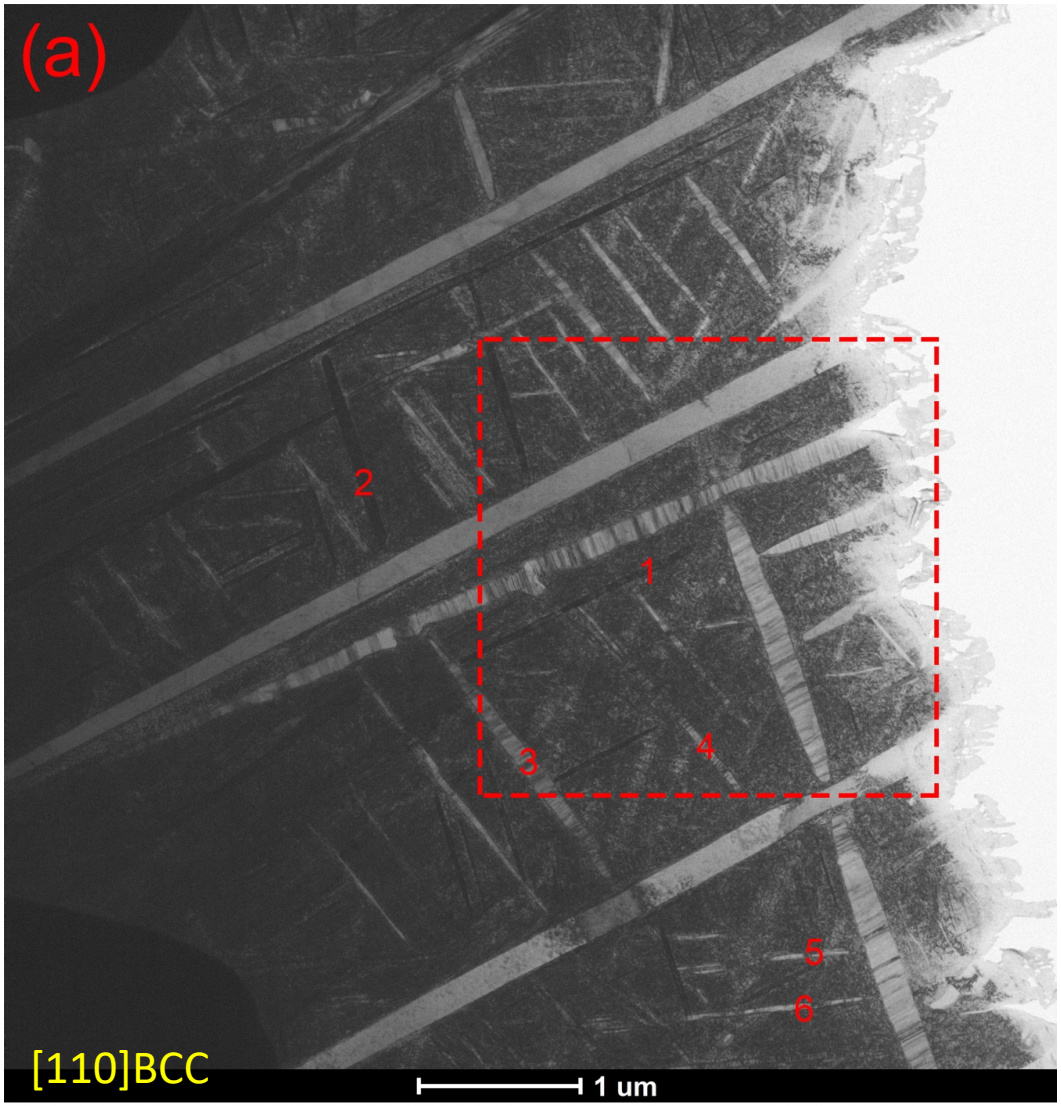
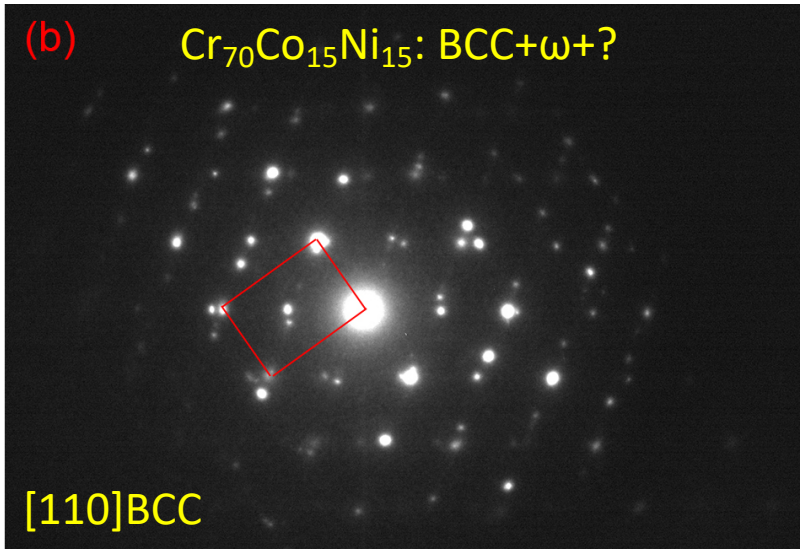
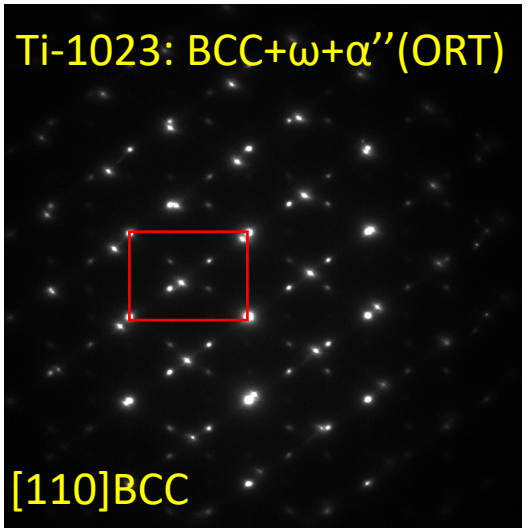




New Phase







Non-Martensitic Nature

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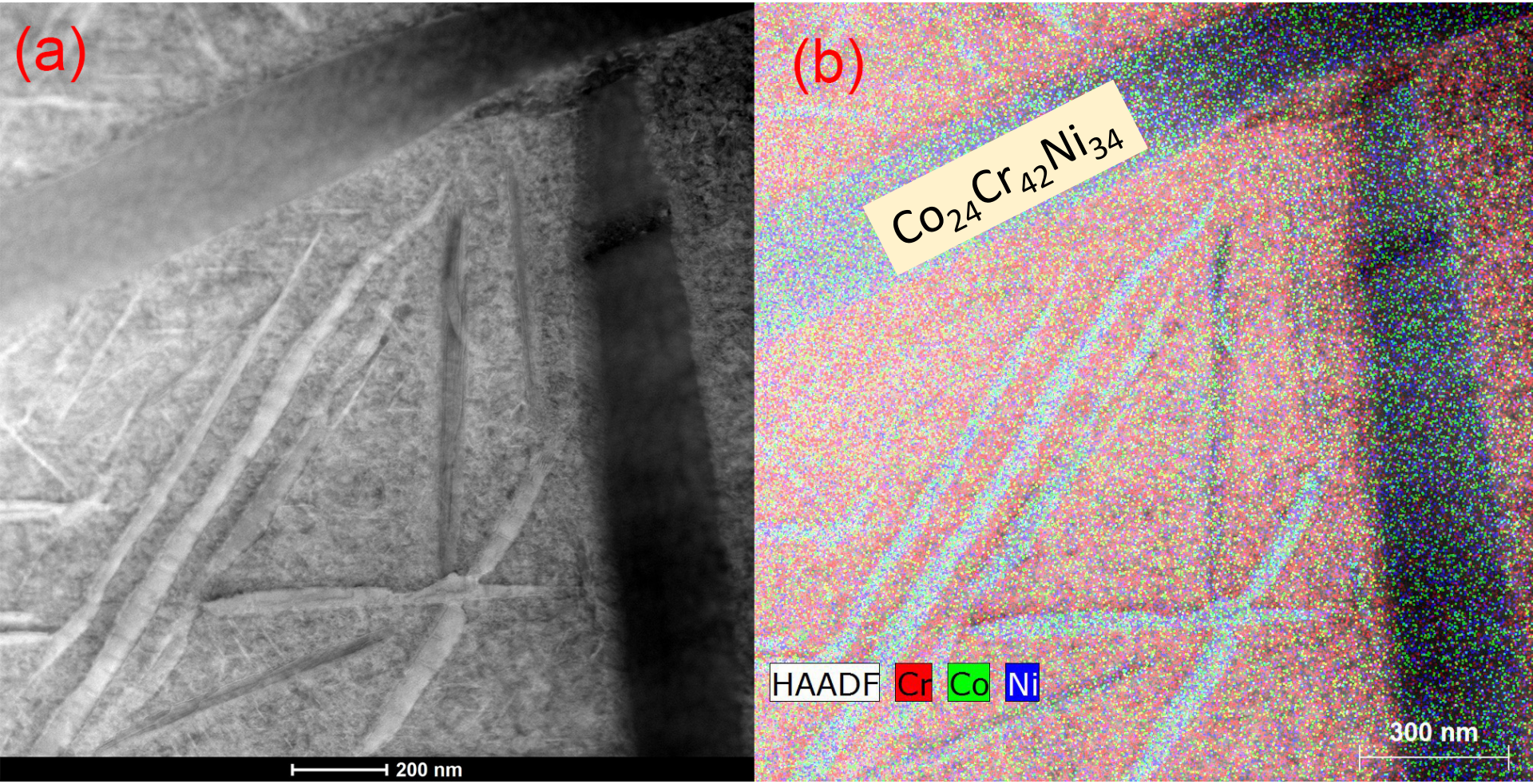
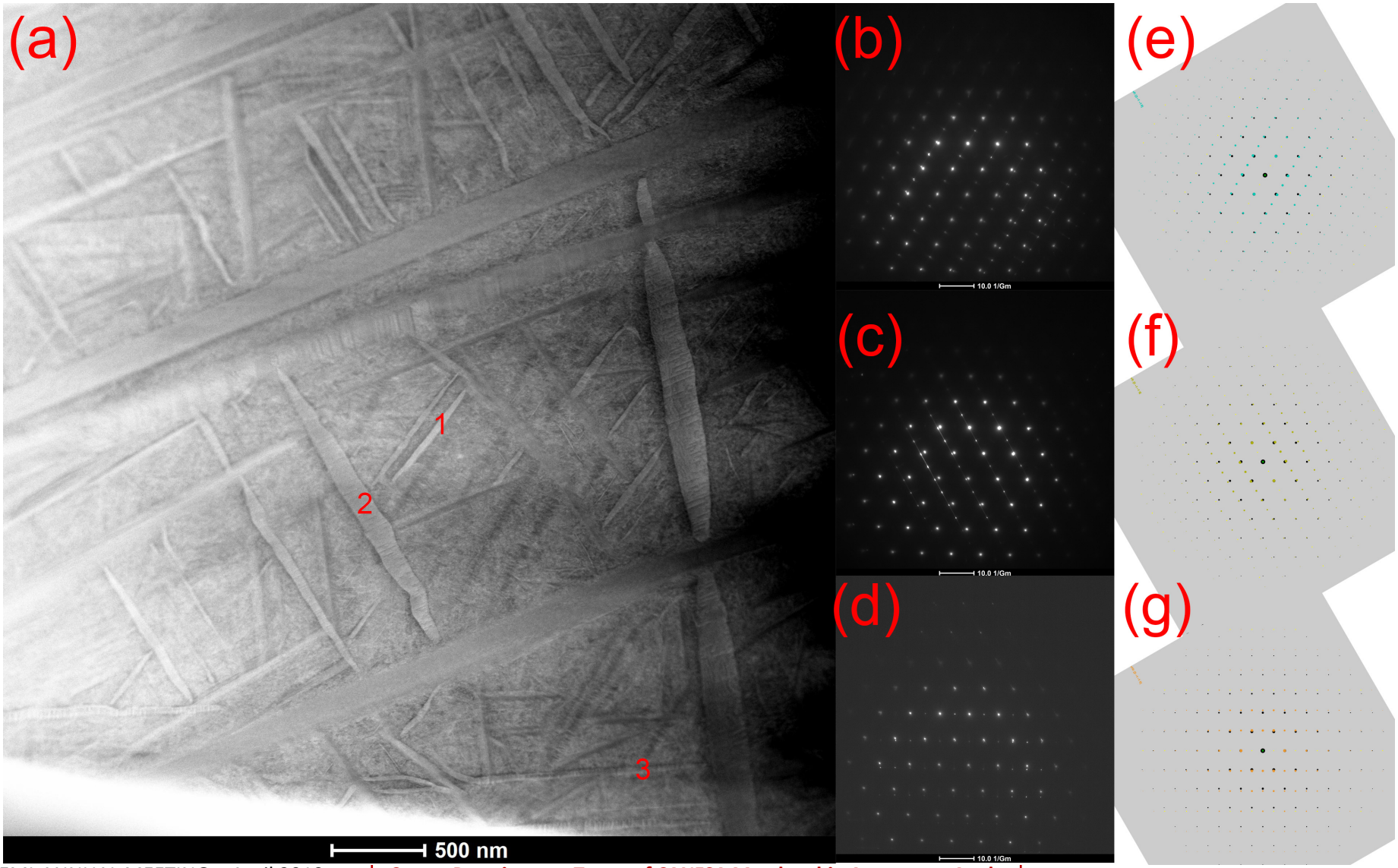
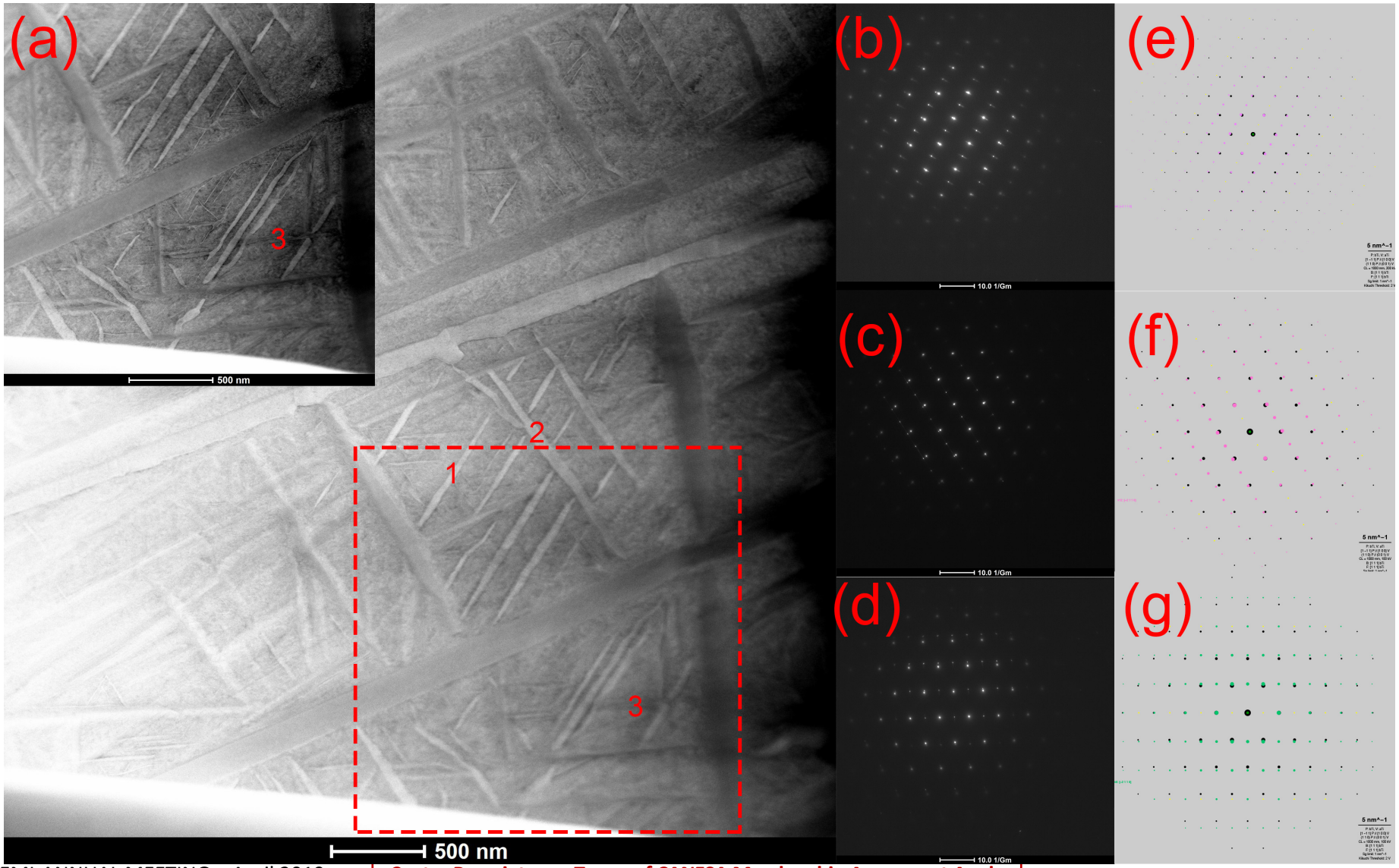


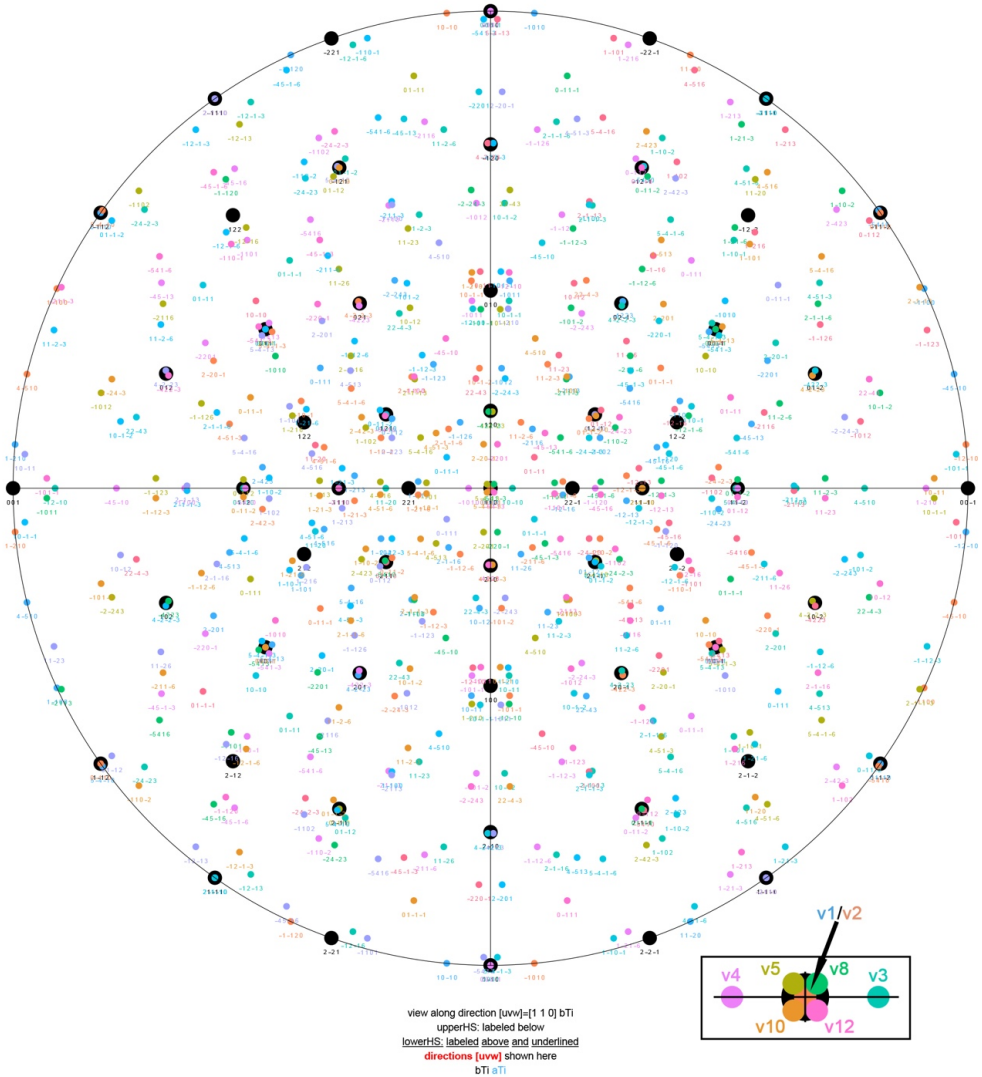
OR Determination: $[11\text{-}1]_{BCC}$



OR Determination: $[111]_{BCC}$



Hexagonal Structure



- Burgers OR
  $\{110\}_{BCC}//\{0001\}_{hex}$,
  $<1\text{-}11>_{BCC}//<2\text{-}1\text{-}10>_{hex}$
- 12 Variants

Habit Plane Determination

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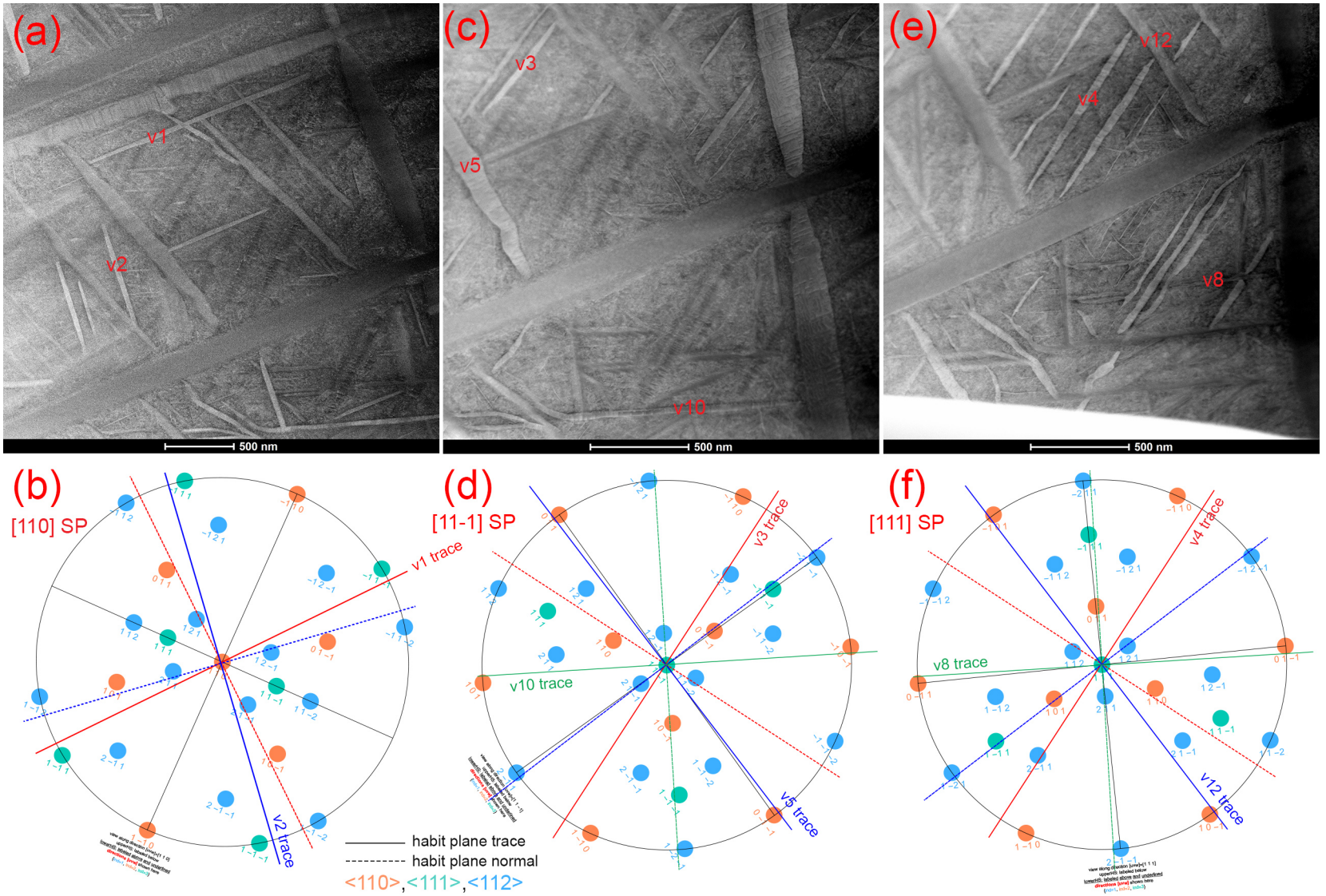
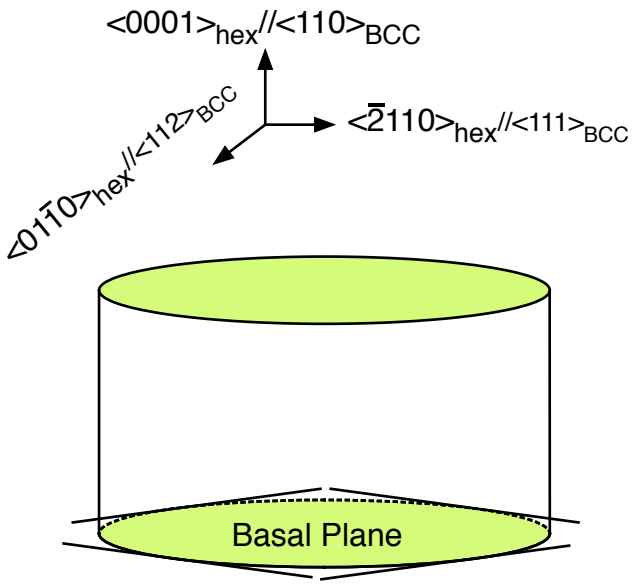
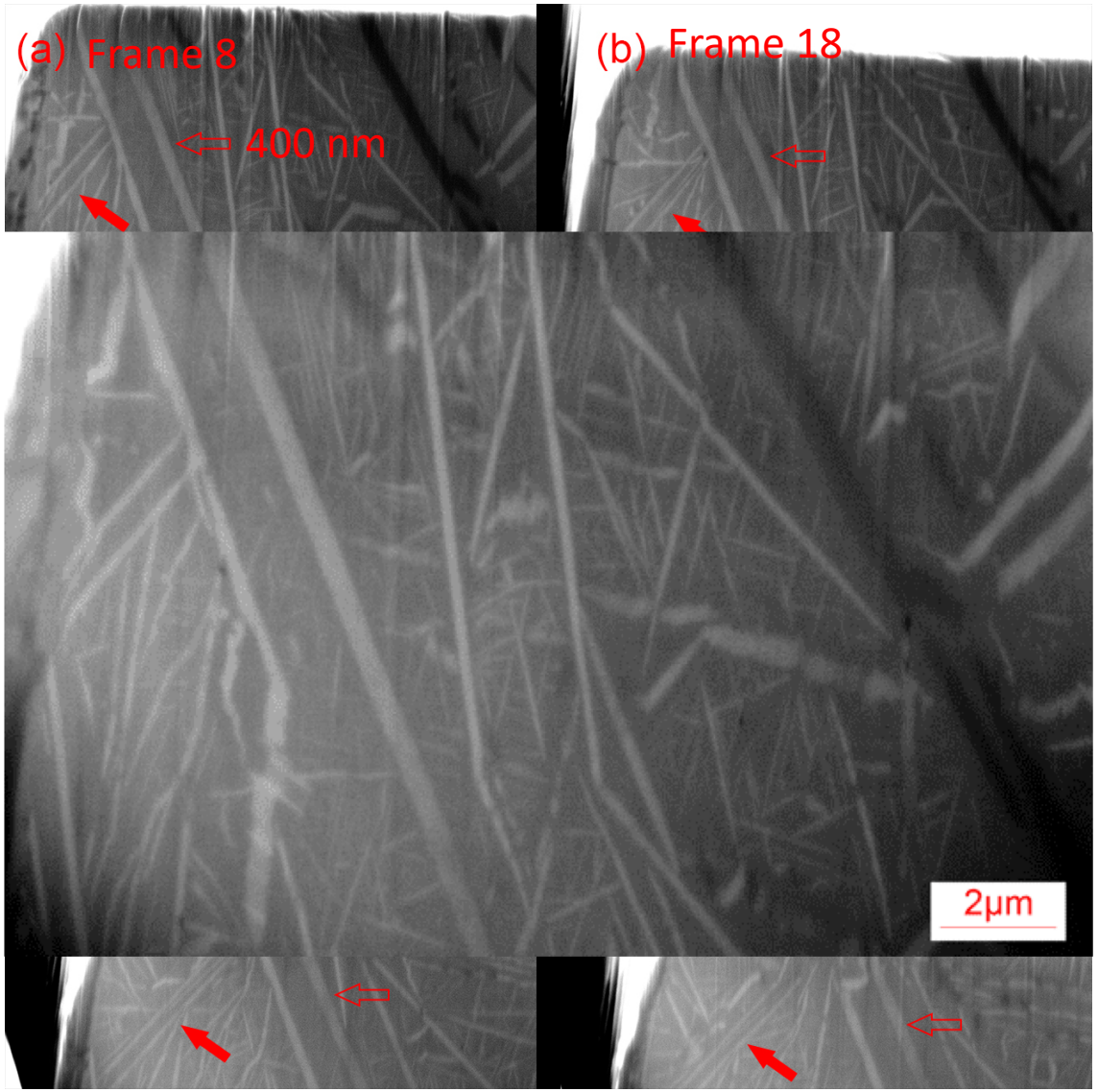


Crystal Shape





- Burgers OR with BCC matrix
- Thin plate, not needle!

forward distance: 50 nm/frame

Thank you!

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