Karlsruhe Institute of Technology

Segregation to creep-induced planar faults in Ni-base SX superalloys

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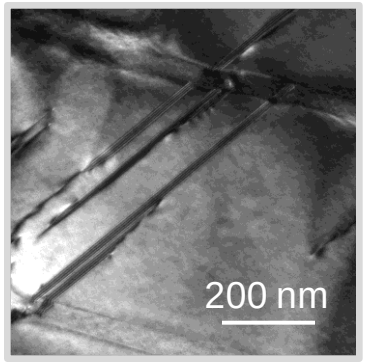
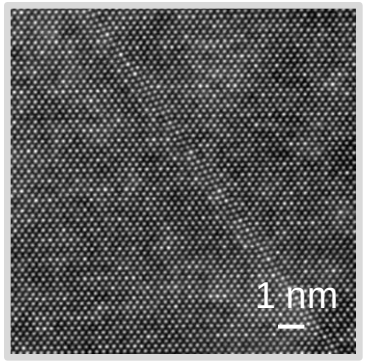
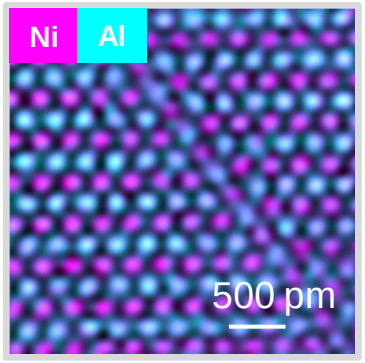
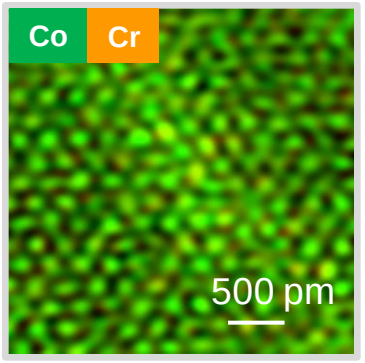








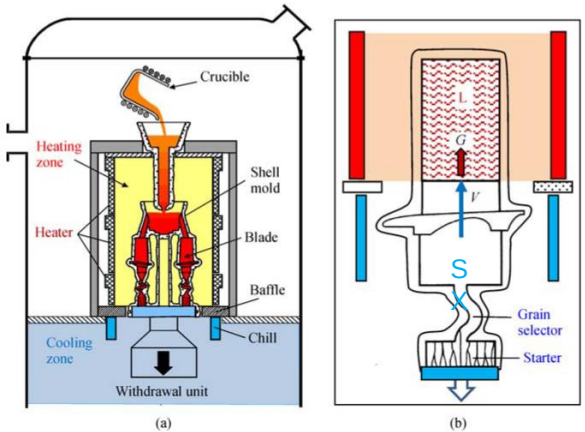
Introduction: Ni-base SX Superalloys

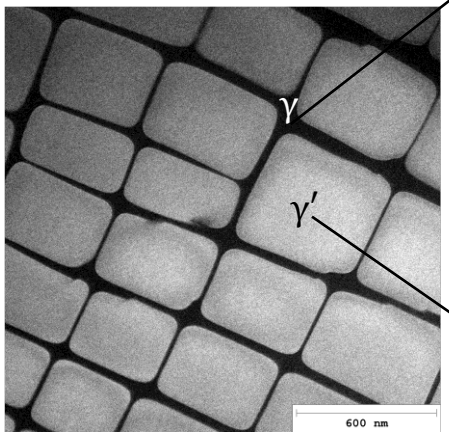
- Application
- Fabrication: Bridgman process
- γ / γ′ microstructure

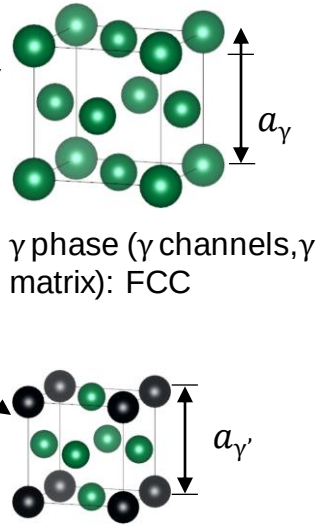
[1]

(a) Bridgman furnace (b) SX solidification

[2]







γ phase (γ channels,γ matrix): FCC

γ′ phase (γ′ precipitates) $L1_2$ structure (Ni_3Al)

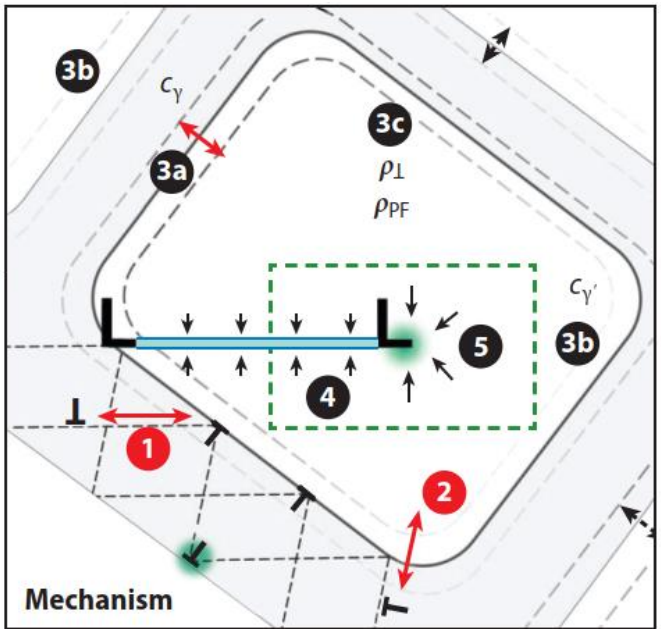
Table 1. Chemical composition of ERBO/1 in weight-%.

Element	Al	Co	Cr	Hf	Mo	Re	Ta	Ti	W	Ni
weight-%	5.5	9.7	6.4	0.1	0.6	2.9	6.5	1.0	6.4	Bal.

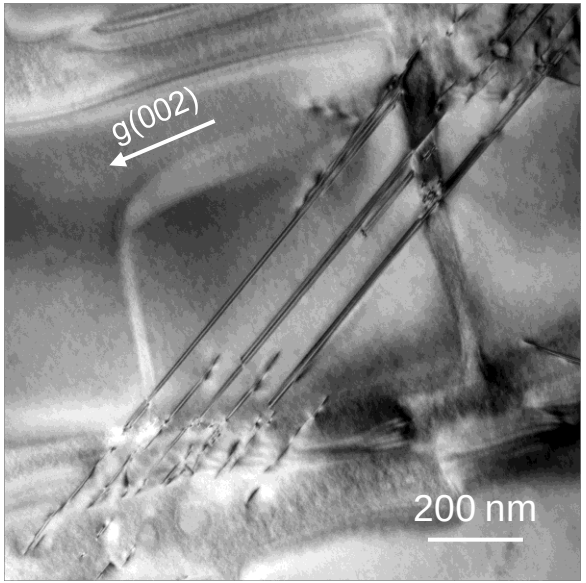
[1] https://www.theengineer.co.uk/
[2] Frontiers of Mechanical Engineering 13.1 (2018): 3-16.

Motivation

- If creep deformation behaviors and elemental segregation at 750 °C / 250 MPa are different with respect to different creep time (1% and 2%).



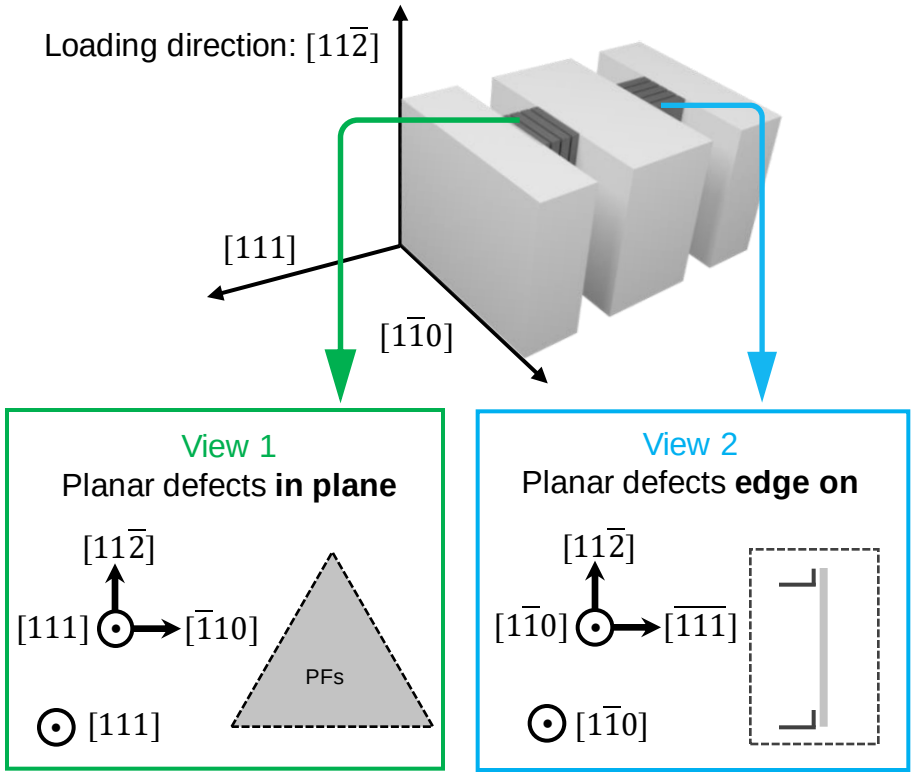
⊥ Dislocation
– – γ/γ′ interface
Planar defect
← Segregation to crystal defects
← Dislocation processes and microstructural evolution
--- {111} trace
L Partial dislocation
$\rho_\perp$ Dislocation density
ρ_{PF} Planar fault density
Cottrell atmosphere



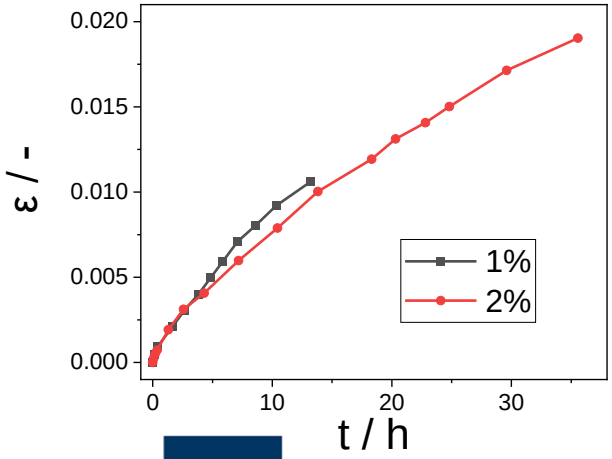
[3] *Annu. Rev. Mater. Res.* 51 (2021): 209-240.

Experimentals

- Objective



- Double shear creep test
  - Shear system: $[11\bar{2}](111)$
  - Creep regime: 750 °C / 250 MPa
  - Schmid factor: 1 with slip system $[11\bar{2}](111)$
  - Creep time of 1%: 13.2 h; 2%: 35.5 h.



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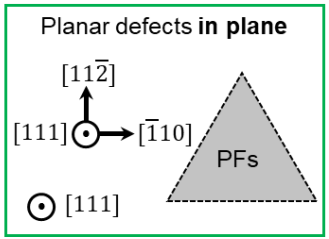
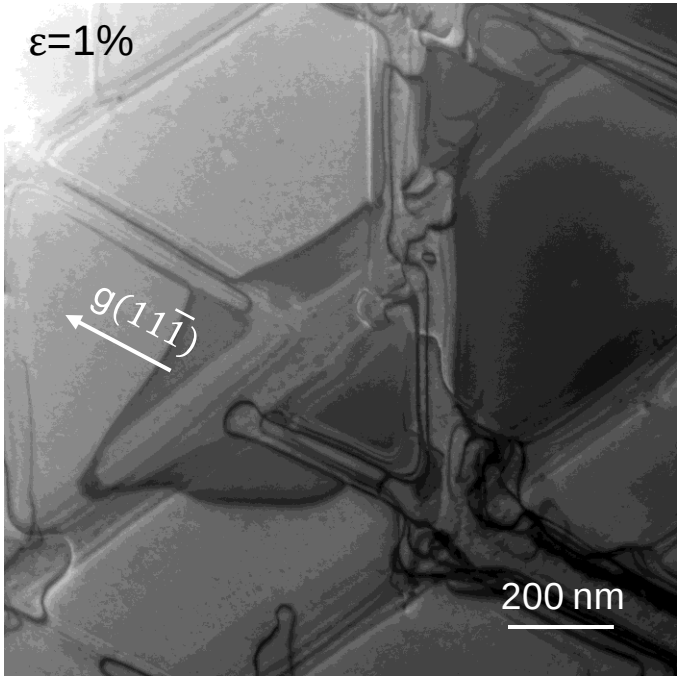
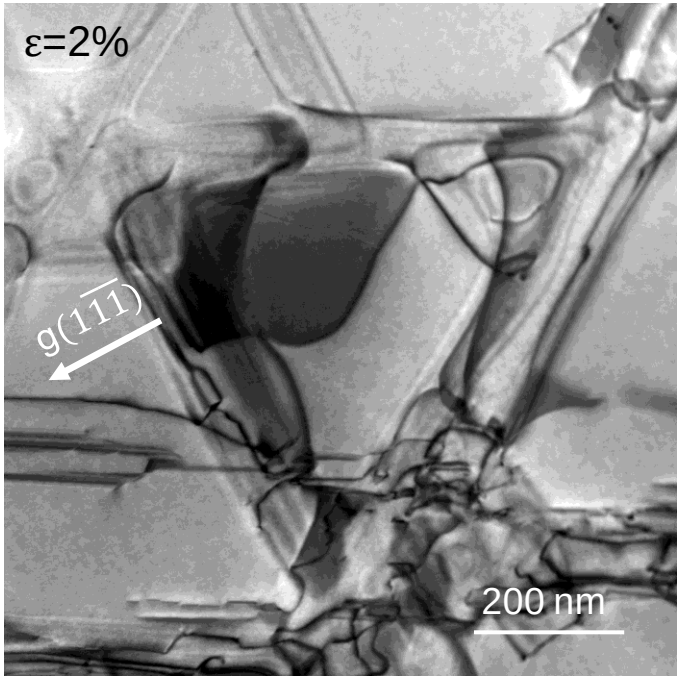
Dr. David Bürger

Creep induced planar faults in plane

- STEM-BF images

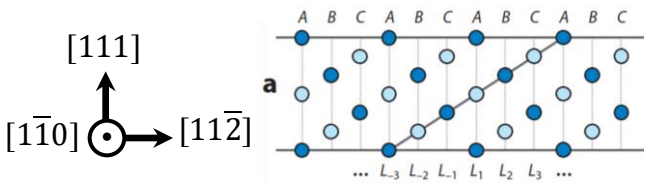




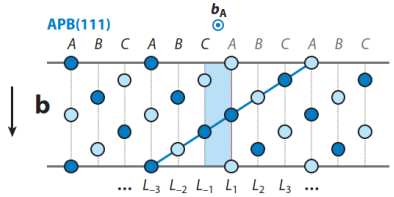


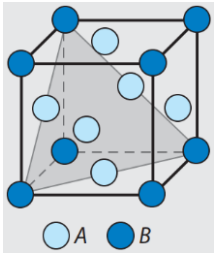
Creep induced planar faults edge on

- Perfect $L1_2$ structure

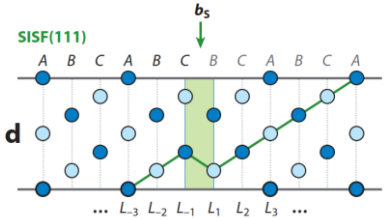


- Anti phase boundary (APB)

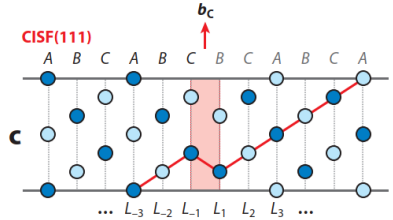


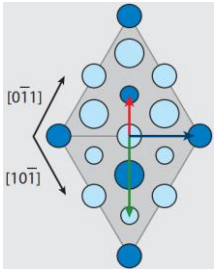


- Superlattice intrinsic stacking fault (SISF)

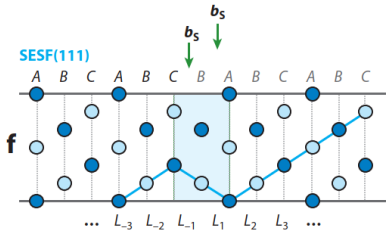


- Complex intrinsic stacking fault (CISF)

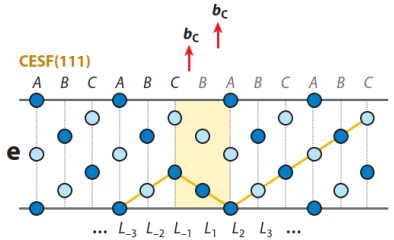


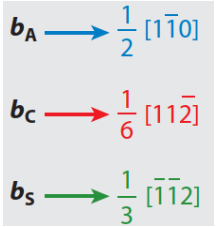


- Superlattice extrinsic stacking fault (SESF)



- Complex extrinsic stacking fault (CESF)

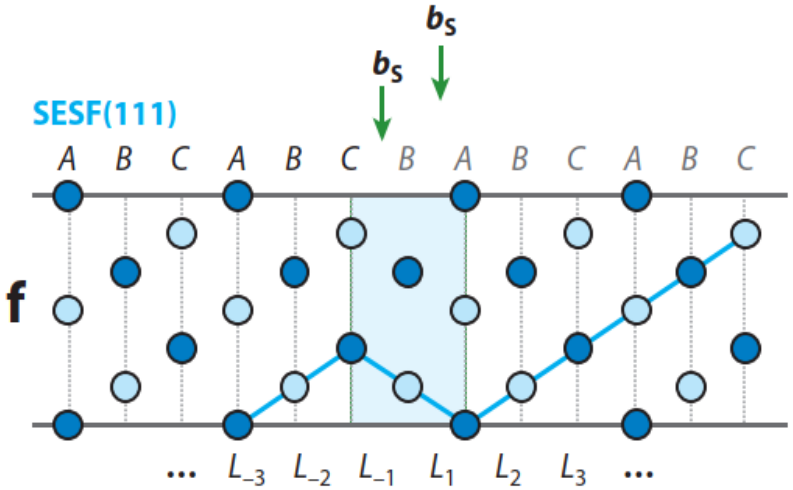


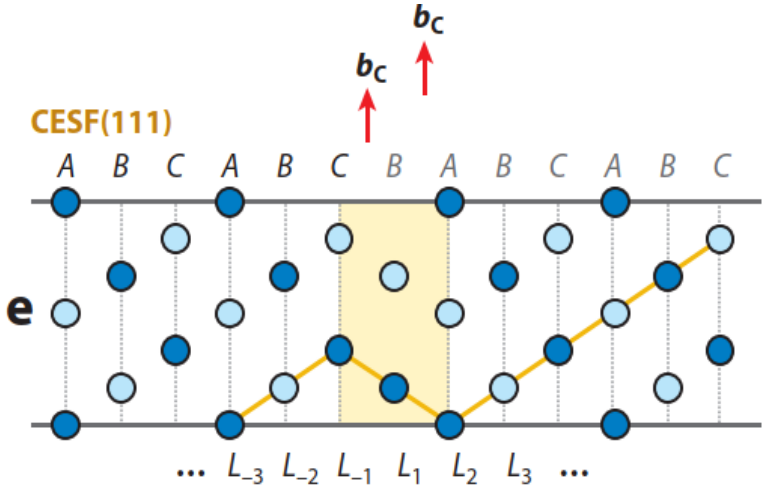


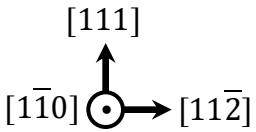
[3] *Annu. Rev. Mater. Res.* 51 (2021): 209-240.

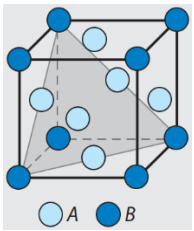
Creep induced planar faults edge on

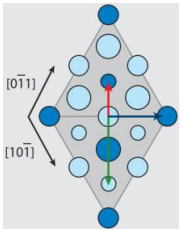
- Superlattice extrinsic stacking fault (SESF)
- Complex extrinsic stacking fault (CESF)











$b_A \rightarrow \frac{1}{2}[1\bar{1}0]$

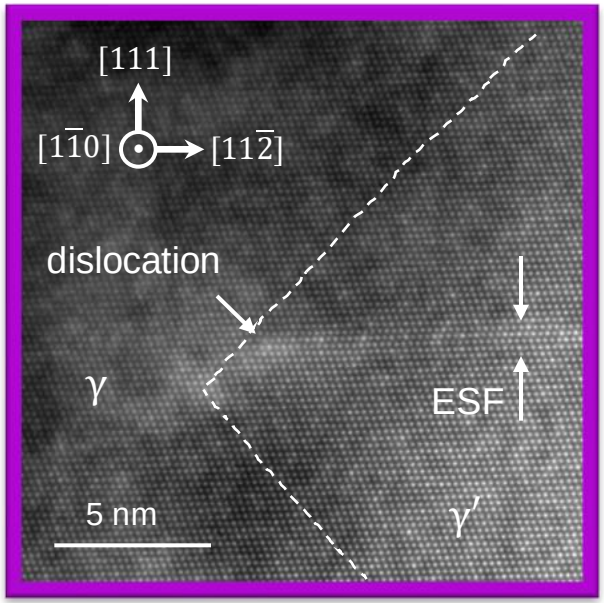
$b_C \rightarrow \frac{1}{6}[11\bar{2}]$

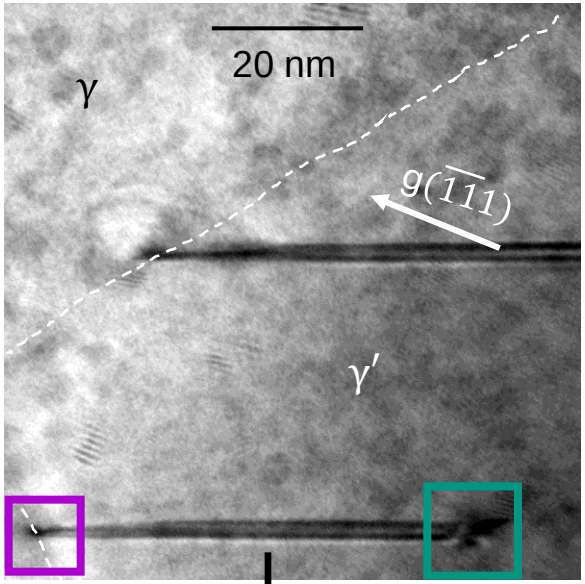
$b_S \rightarrow \frac{1}{3}[\bar{1}\bar{1}2]$

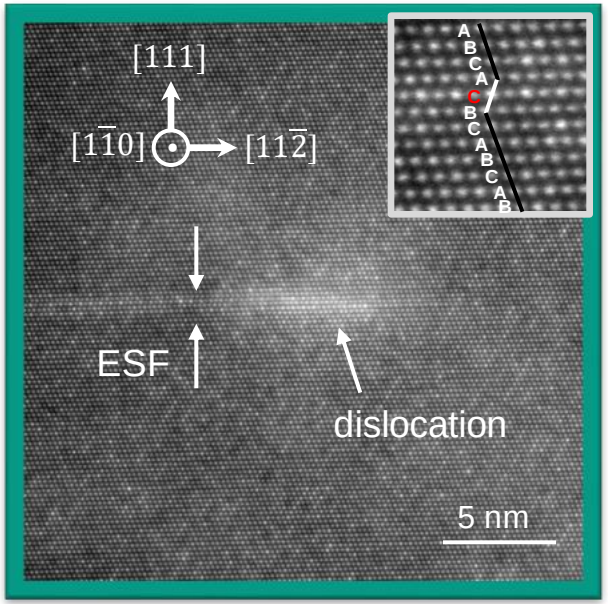
[3] *Annu. Rev. Mater. Res.* 51 (2021): 209-240.

Creep induced extrinsic SF of 2%

- Trailing dislocation
- Stacking faults
- Leading dislocation





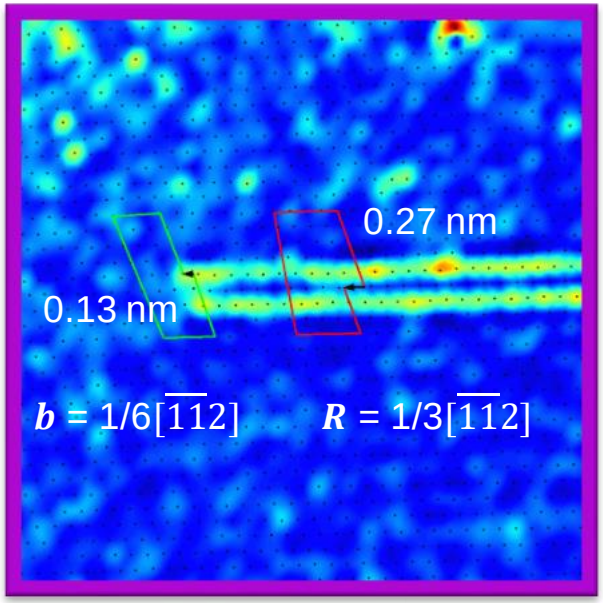


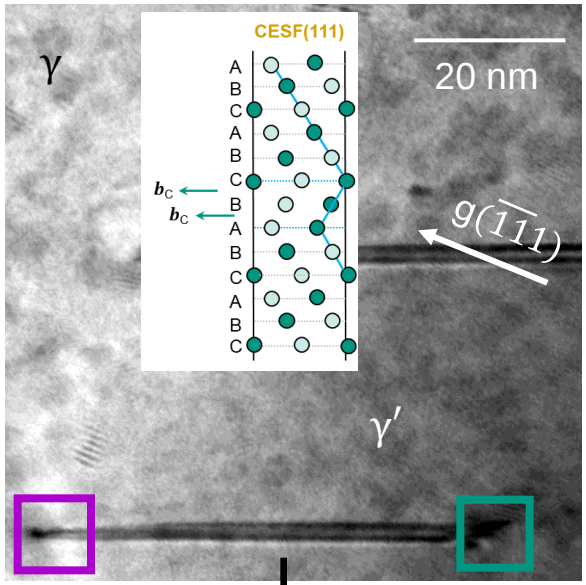
Extrinsic SF

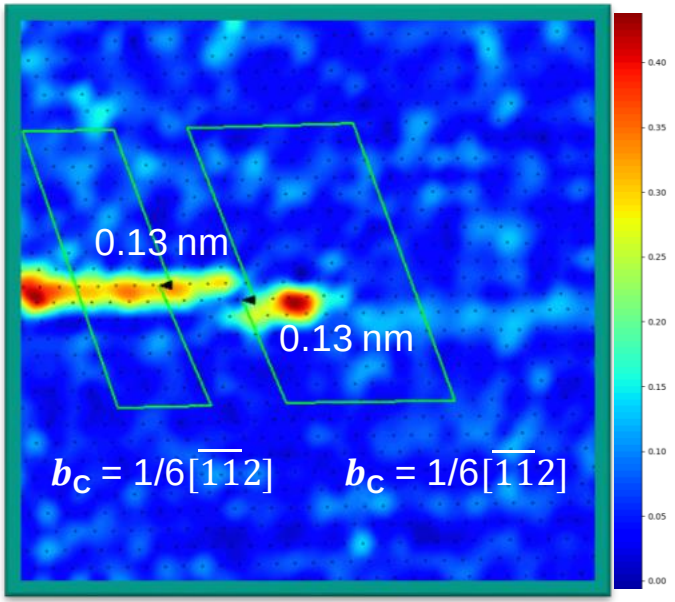
[111]
[1$\bar{1}$0]
[11$\bar{2}$]

Creep induced CESF of 2%

- Trailing dislocation
- Stacking faults
- A pair of leading dislocations



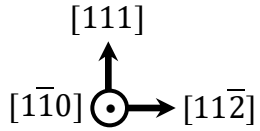




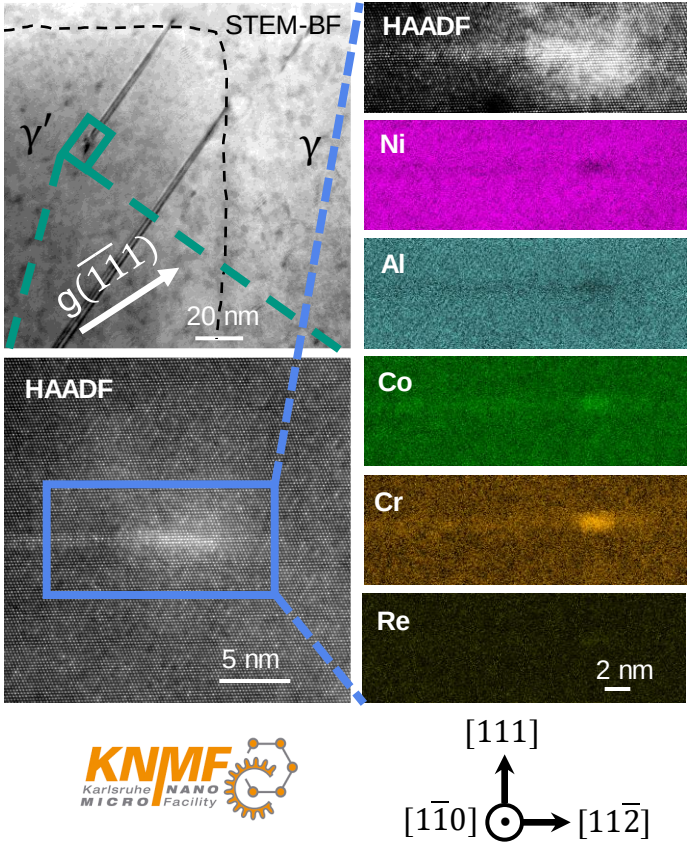
b = 1/6[$\bar{1}\bar{1}$2]
R_{CESF} = 1/3[$\bar{1}\bar{1}$2]

CESF

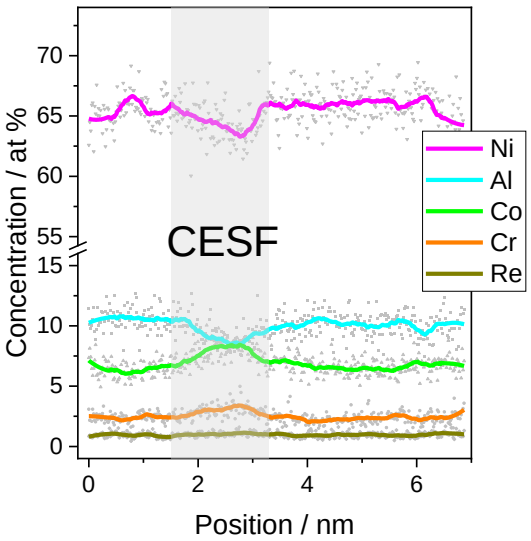
b_C = 1/6[$\bar{1}\bar{1}$2]
b_C = 1/6[$\bar{1}\bar{1}$2]



EDX of CESF and leading dislocations of 2%

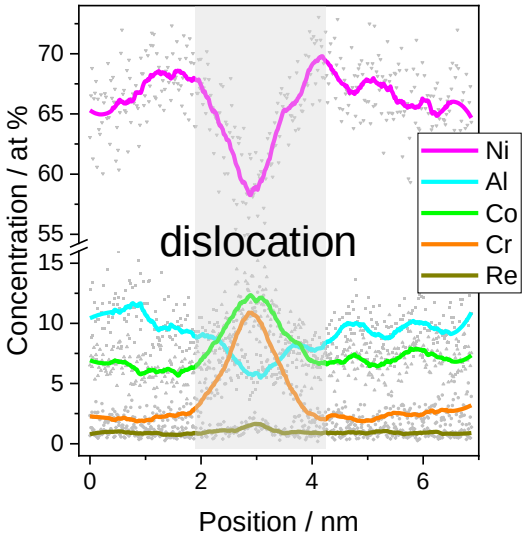


- Cross the CESF



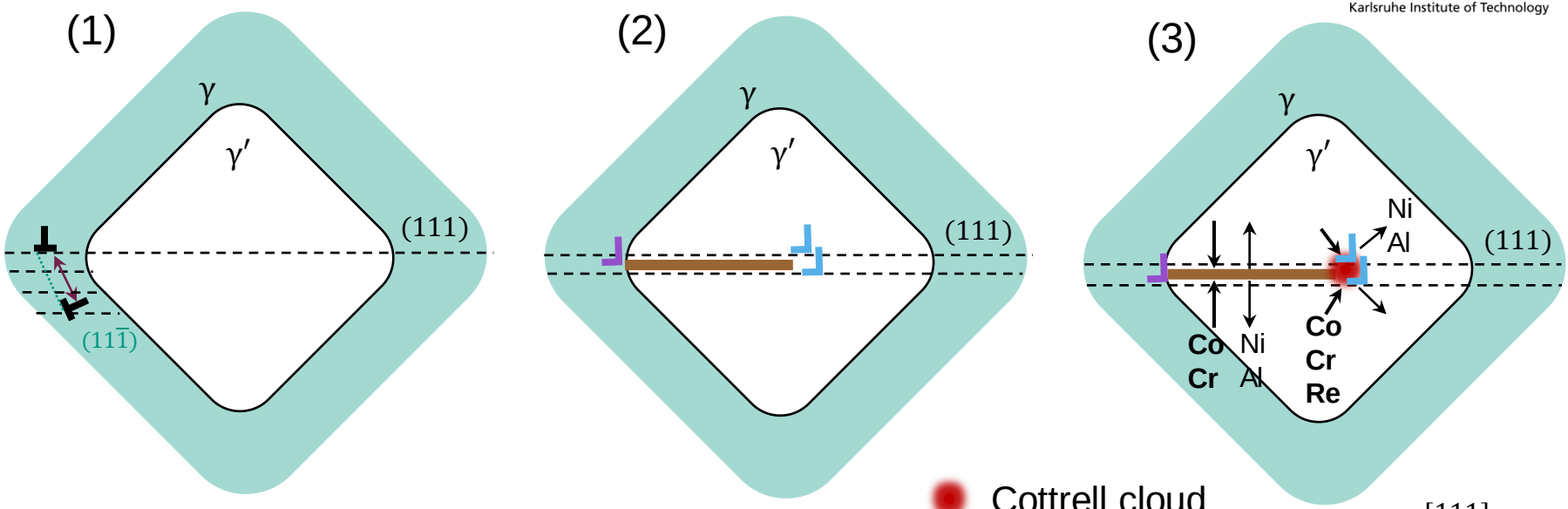
- Depletion: Al, Ni
- Enrichment: Co, Cr

- Cross the dislocation



- Cottrell atmosphere
- Depletion: Al, Ni
- Enrichment: Co, Cr, Re

Shear mechanism of CESF of 2%

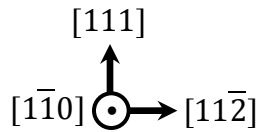


Cottrell cloud

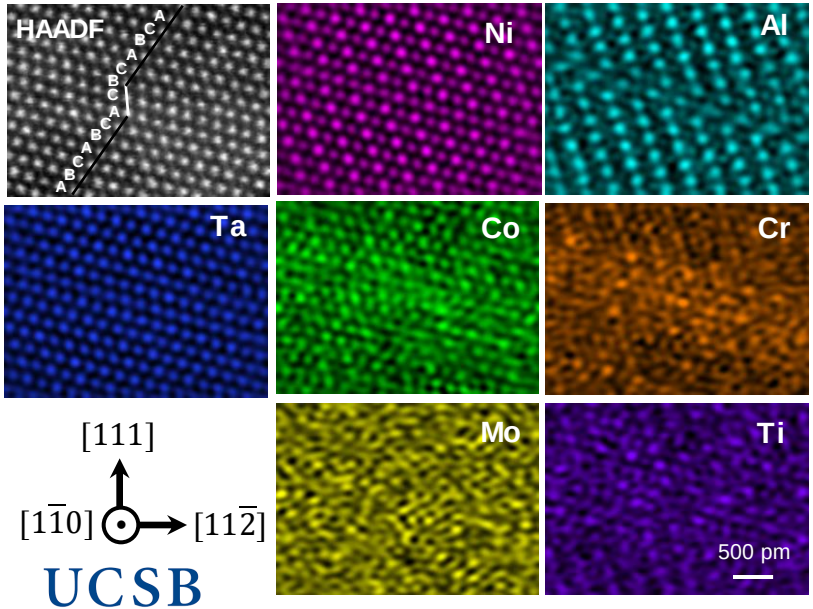
$1/2[\bar{1}01] + 1/2[0\bar{1}1] = 1/6[\bar{1}\bar{1}2] + CESF + 1/6[\bar{1}\bar{1}2] + 1/6[\bar{1}\bar{1}2]$

Trailing partial dislocation

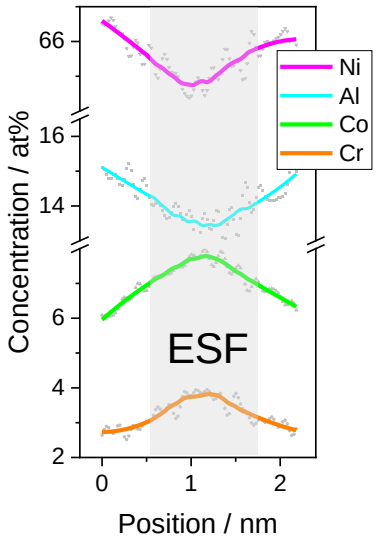
A pair of leading dislocations

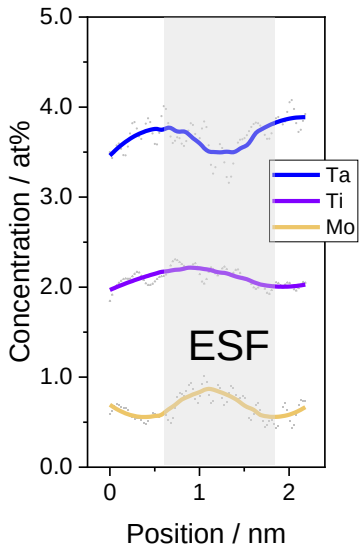


EDX of S(C)ESF of 1%



- Concentration profile





- Depletion: Ni, Al, **Ta**
- Enrichment: Co, Cr, **Ti, Mo**

- When does elemental segregation start?
- Creep time of 1%: 13.2 h; 2%: 35.5 h.
- To quantitatively compare the segregation of 1% and 2%: planar fault, microscope parameters, thickness.

Conclusion

Creep microstructure of Ni-base SX superalloys which were deformed at 750 °C and 250 MPa to plastic strains 1% and 2% with shear system [11-2](111) are analyzed:

- Stacking faults (SESF/CESF) examined are enriched with γ-stabilizers—Cr and Co accompanied by a simultaneous depletion of γ′-stabilizers Ni and Al.
- The shearing process of CESF are experimentally observed:

$$1/2[\bar{1}01] + 1/2[0\bar{1}1] = 1/6[\bar{1}\bar{1}2] + \text{CESF} + 1/6\,[\bar{1}\bar{1}2] + 1/6[\bar{1}\bar{1}2]$$

- Cottrell cloud around a pair of leading dislocations of CESF hinders the movement of leading dislocations.

Acknowledgment

Thank you for your attention!

Microscopy of Nanoscale Structures & Mechanisms (MNM)