Stacking fault energy measurements in modified Cantor alloys

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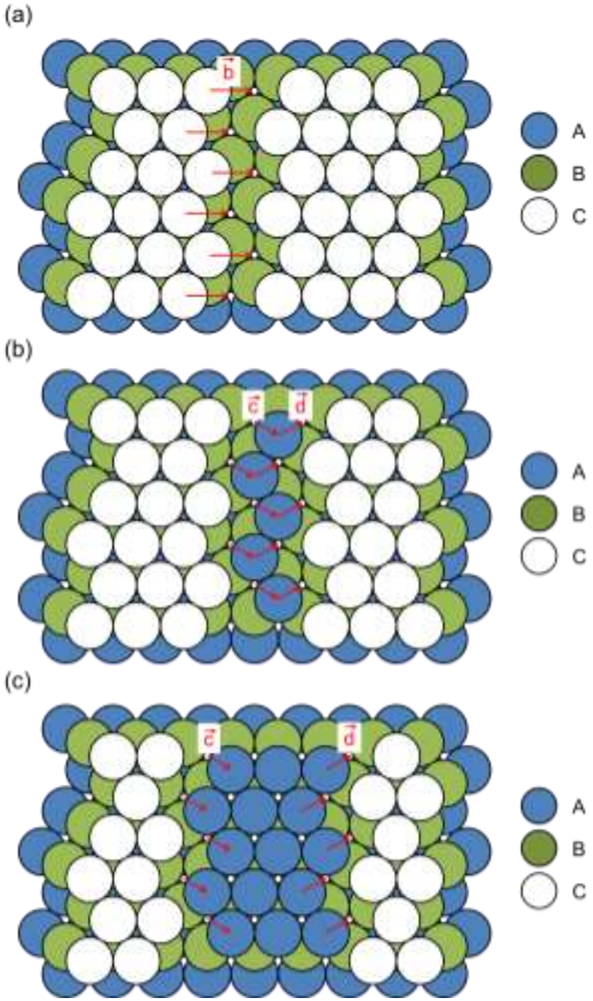
Introduction



(a)
Full dislocation with Burgers Vector b of type ½<110>

(b)
Beginning of a dissociated dislocation
(Local hexagonal stacking: ABA)

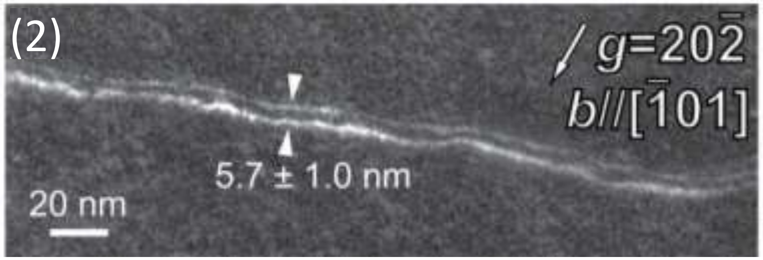
(c)
Full dislocation dissociated in two Shockley partials with a stacking fault in between.
Vector c and d of type 1/6<112>

State of the art

Stacking fault energy (SFE)

Effect of chemical composition on SFE

(1) Alloy	Stacking fault energy (mJ/m^2)
$Cr_{14}Mn_{20}Fe_{20}Co_{20}Ni_{26}$	57.7
$Cr_{20}Mn_{20}Fe_{20}Co_{20}Ni_{20}$	25.5
$Cr_{26}Mn_{20}Fe_{20}Co_{20}Ni_{14}$	3.5



→ SFE measured: 30 mJ/m^2

(1) Zaddach et al. Mechanical Properties and Stacking Fault Energies of NiFeCrCoMn High-Entropy Alloy (2013)
(2) Okamoto et al. Size effect, critical resolved shear stress, stacking fault energy, and solid solution strengthening in the CrMnFeCoNi high-entropy alloy (2016)

Processing

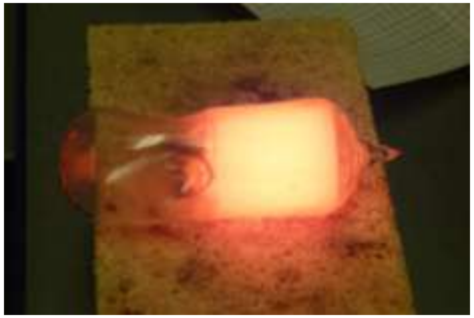
As-cast ingot

Ø 45 mm

Vacuum induction melting

500 mbar Ar

Ingot after homogenization at 1200 °C / 48h



Ø 40 mm

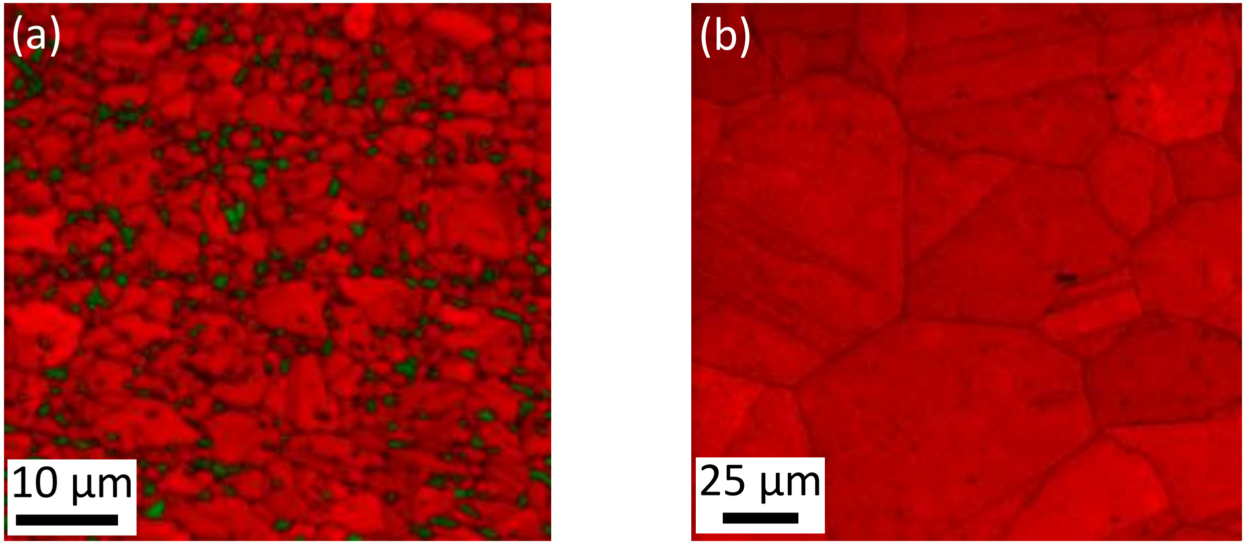
Swaged from 40 down to 16.5 mm

Ø 16.5 mm

Annealing temperatures (1h) 900 °C

Results - Microstructure

Alloy	Heat treatment	Grain size
$Cr_{14}Mn_{20}Fe_{20}Co_{20}Ni_{26}$	900 °C / 1h	18 µm
$Cr_{26}Mn_{20}Fe_{20}Co_{20}Ni_{14}$	1100 °C / 15 min	100 µm

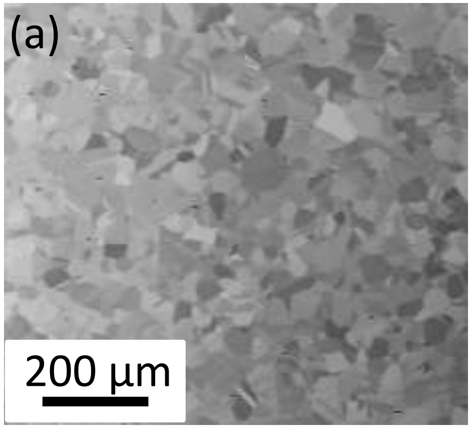


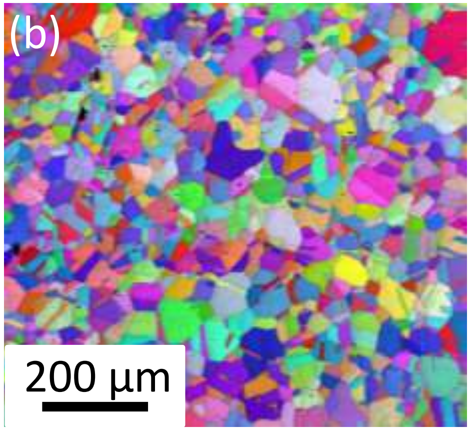
$Cr_{26}Mn_{20}Fe_{20}Co_{20}Ni_{14}$ after recrystallization (a) 900 °C for 1 h (b) 1100 °C for 15 min

Results - Microstructure

Alloy	Heat treatment	Grain size
$Cr_{14}Mn_{20}Fe_{20}Co_{20}Ni_{26}$	900 °C / 1h	18 µm
$Cr_{26}Mn_{20}Fe_{20}Co_{20}Ni_{14}$	1100 °C / 15 min	100 µm

- Both alloys have a single FCC solid-solution phase
- No texture was observed
- Stacking fault energy is independent of the grain size





$Cr_{14}Mn_{20}Fe_{20}Co_{20}Ni_{26}$ after recrystallization at 900 °C for 1 h (a) BSD picture (b) EBSD mapping

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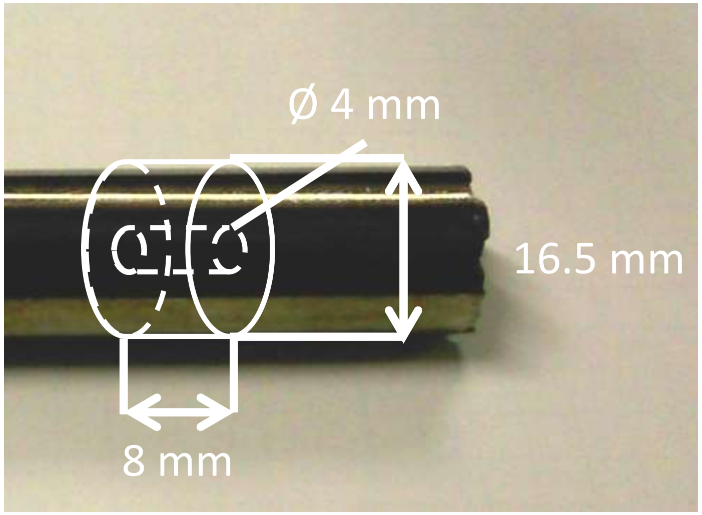
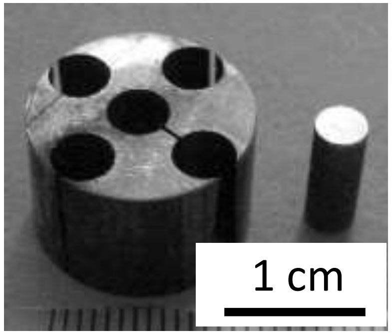
Processing

Results

Sample preparation

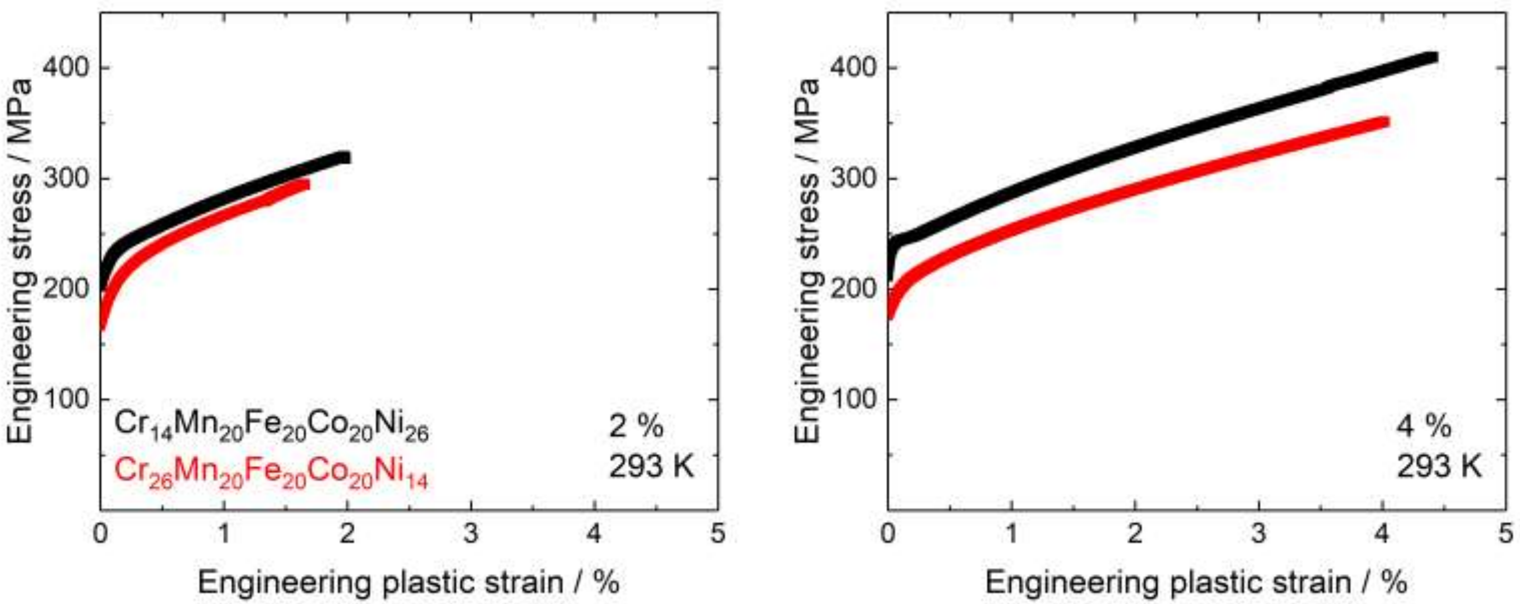




Advantages:

- Many samples out of small amount of material
- Samples are easy and fast to produce

Results – compression tests



- Different yield stress $Cr_{14}Mn_{20}Fe_{20}Co_{20}Ni_{26}$: 253 MPa
  (grain size: 18 µm)
  $Cr_{26}Mn_{20}Fe_{20}Co_{20}Ni_{14}$: 216 MPa
  (grain size: 100 µm)

Stacking fault energy analysis

RUB

Alloy	Stacking fault energy (mJ/m²)
$Cr_{14}Mn_{20}Fe_{20}Co_{20}Ni_{26}$	57.7
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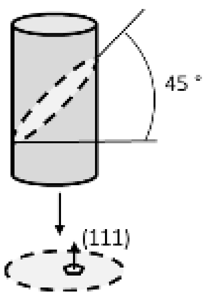
If in $Cr_{14}MnFeCoNi_{26}$ SFE is 57 mJ/m²

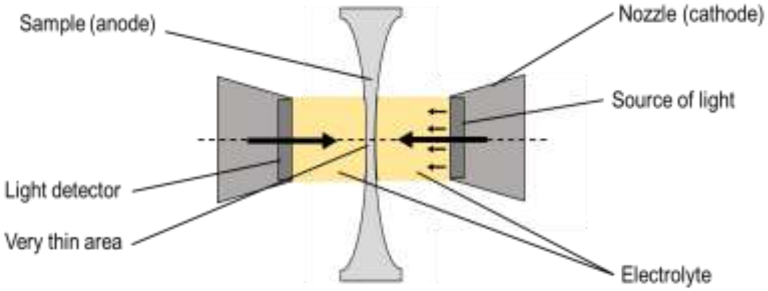
- edge dislocation spacing of 3.4 nm
- screw dislocation spacing of 1.8 nm

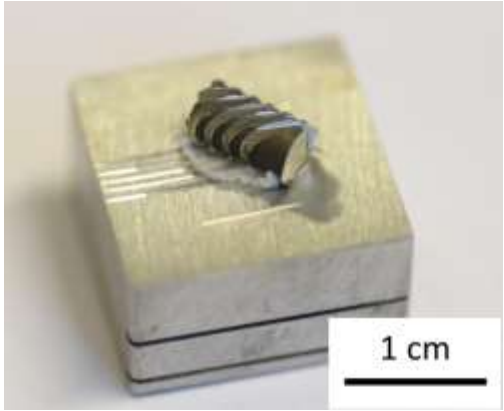
Stacking fault energy analysis

Two methods to produce TEM samples

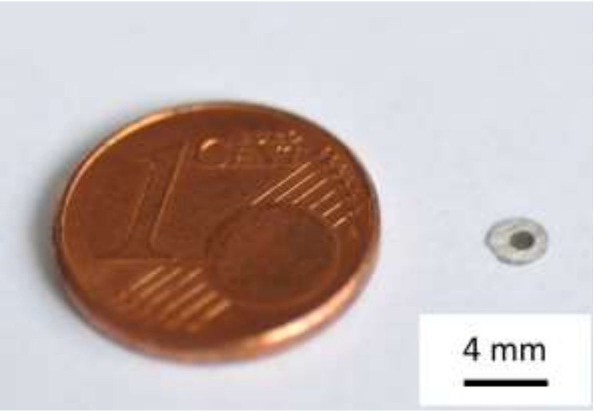
(1) Twin jet electro polishing







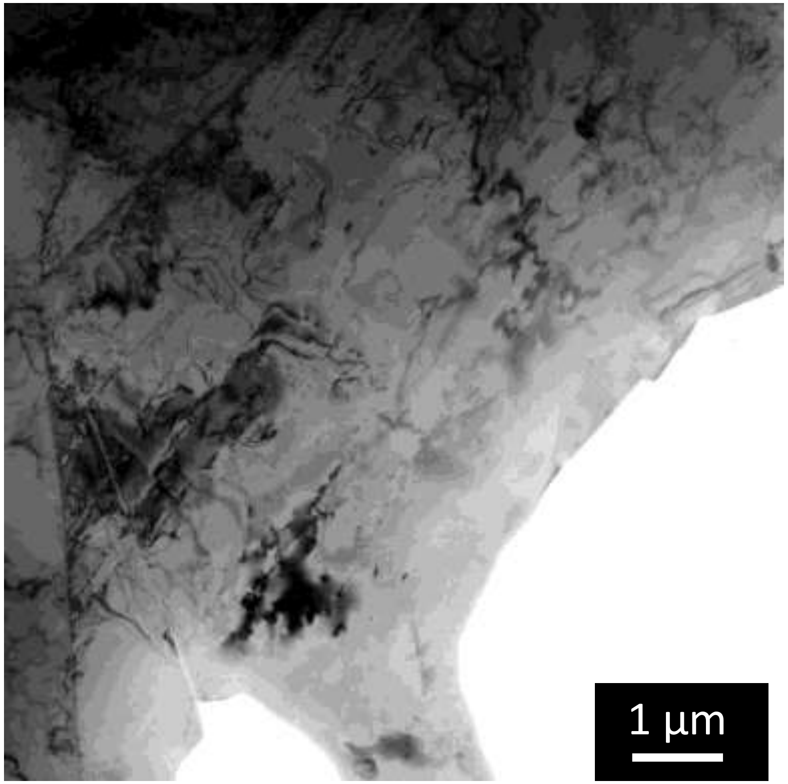
Compression sample cut in slices



TEM sample after the electro polishing

Stacking fault energy analysis

Twin jet electro polishing



Bright field picture
$Cr_{14}Mn_{20}Fe_{20}Co_{20}Ni_{26}$ after 4 % compression

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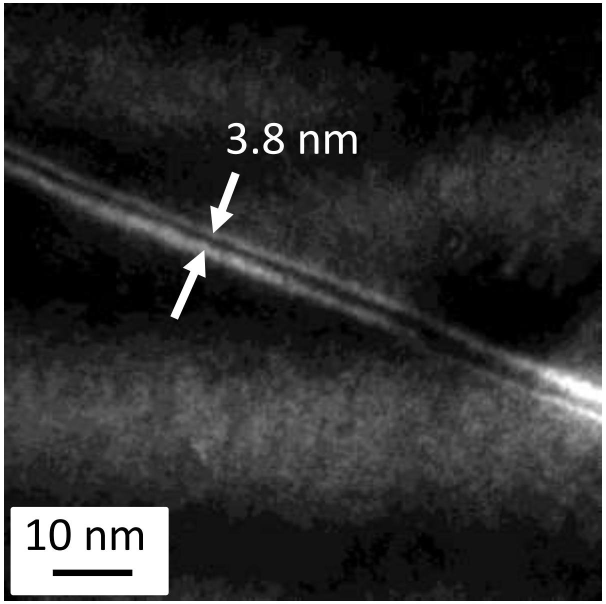
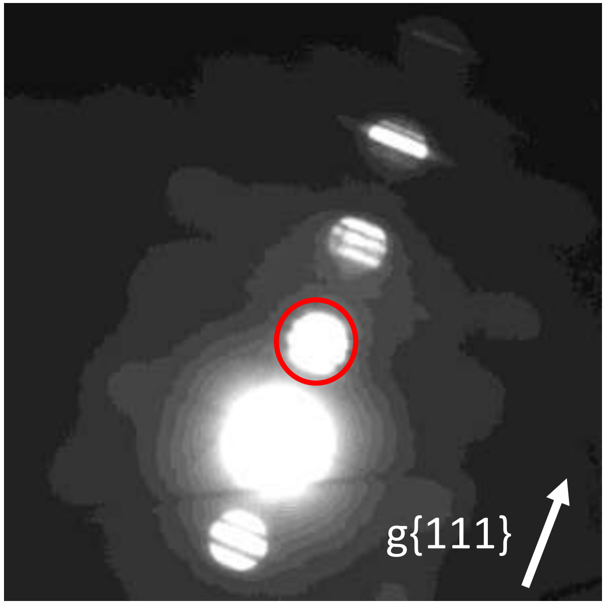
Two methods to produce TEM samples

(1) Twin jet electro polishing



Weak Beam Dark Field g/3g



Diffraction

Advantages:

- Good sample quality

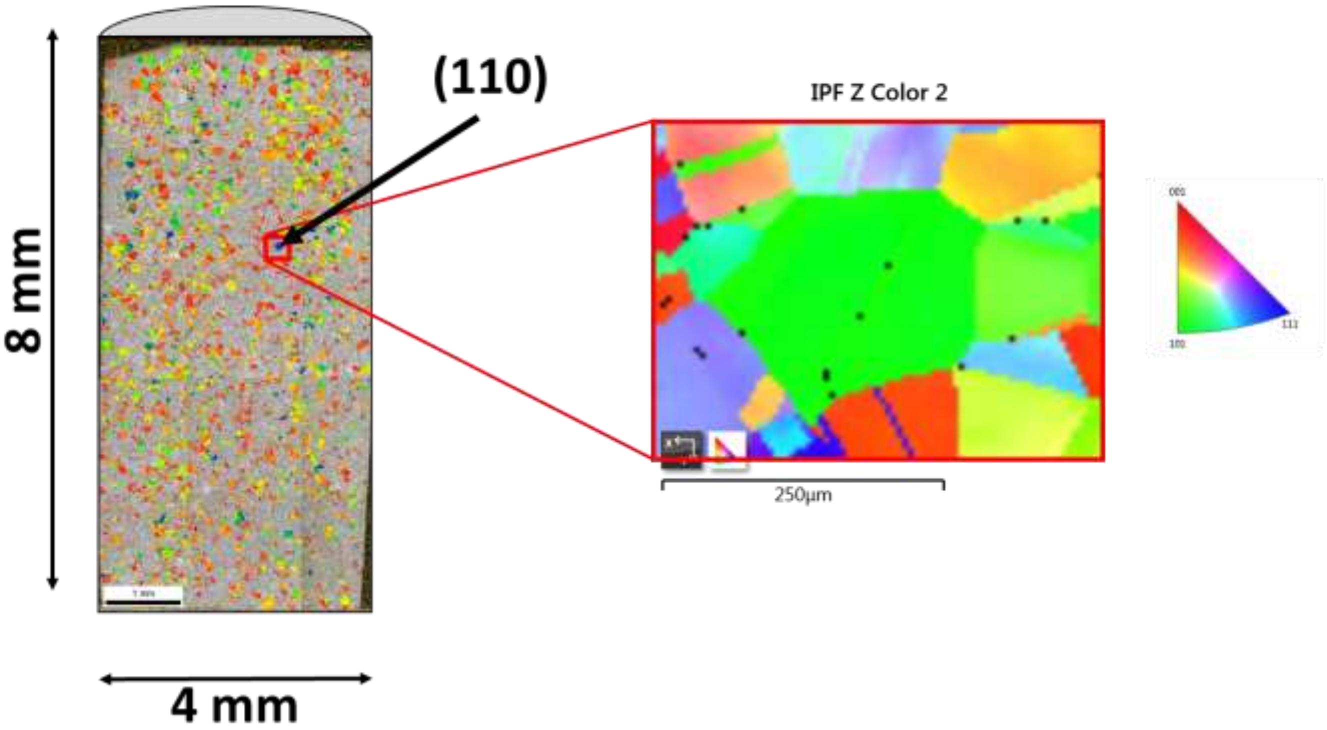
Disadvantages:

- Orientation of analyzed grains cannot be influenced

Stacking fault energy analysis

Two methods to produce TEM samples

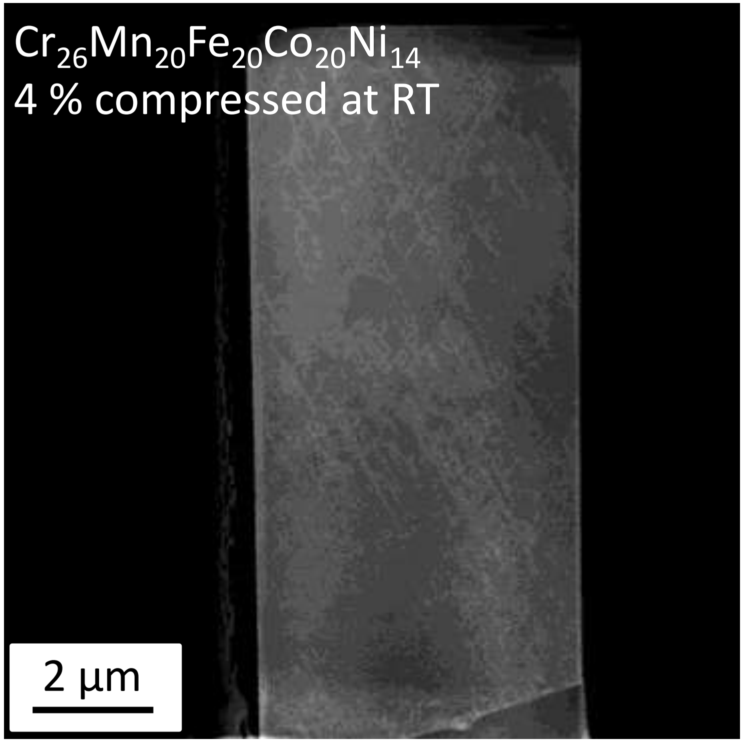
(1) Focused Ion Beam (FIB)

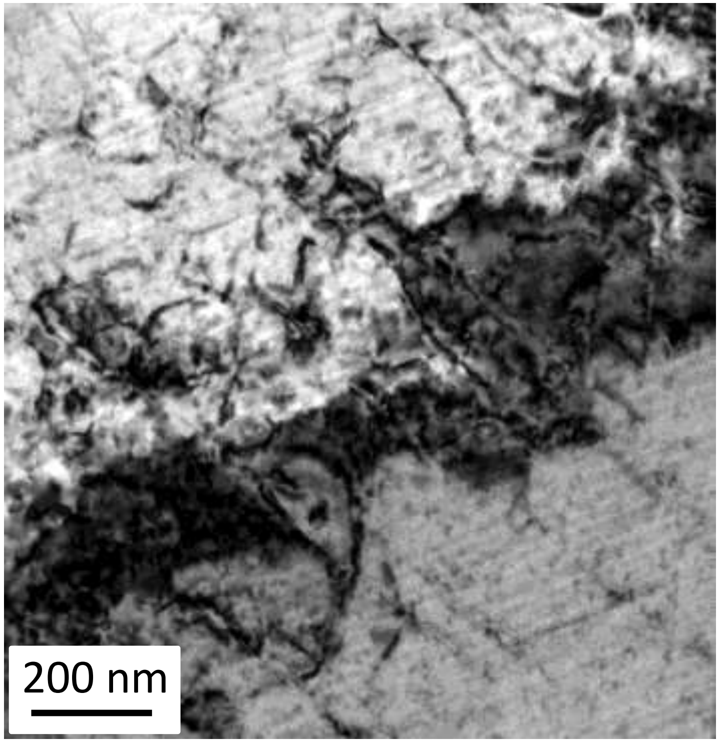


Stacking fault energy analysis

Two methods to produce TEM samples

(2) Focused Ion Beam (FIB)





Advantages:

- Perfect orientation of grain

Disadvantages:

- Bad sample quality

Introduction

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Future

Introduction

Processing

Results

- SFE for the alloys $Cr_{14}Mn_{20}Fe_{20}Co_{20}Ni_{26}$ and $Cr_{26}Mn_{20}Fe_{20}Co_{20}Ni_{14}$
- Processing route to produce singe phase FCC $Cr_{26}Mn_{20}Fe_{20}Co_{20}Ni_{14}$ with grain size ~ 20 µm
- Critical twining stress for the alloy $Cr_{14}Mn_{20}Fe_{20}Co_{20}Ni_{26}$ and $Cr_{26}Mn_{20}Fe_{20}Co_{20}Ni_{14}$

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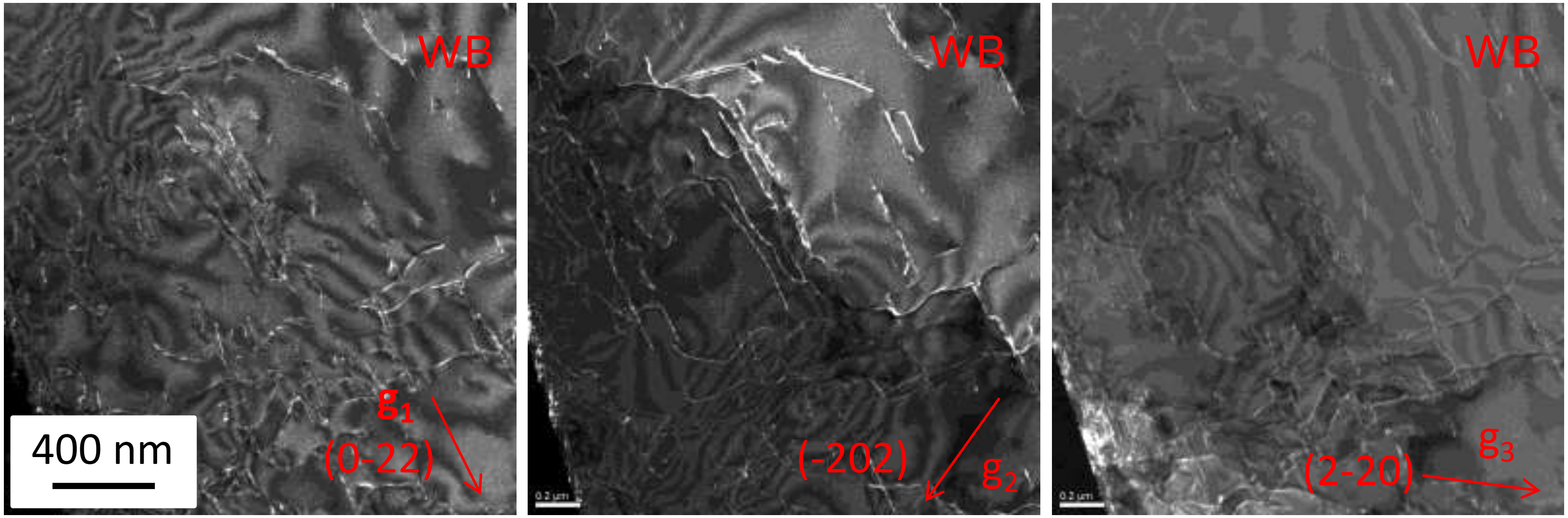
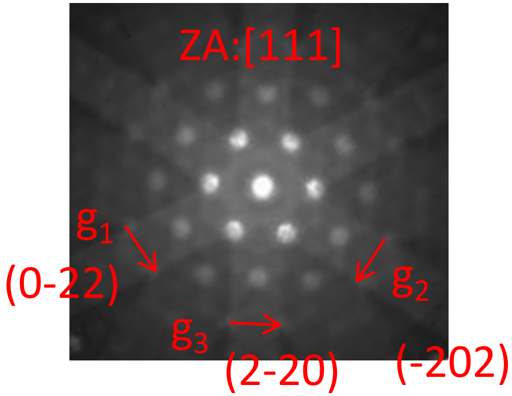
Norbert Lindner
Claudia Brügge
The whole chair Werkstoffwissentschaft

Thanks for your attention

Results – Work hardening rate

Stacking fault energy (SFE)





- $Cr_{14}MnFeCoNi_{26}$ at RT 4 % compressed
- Spacing could not be measured exactly

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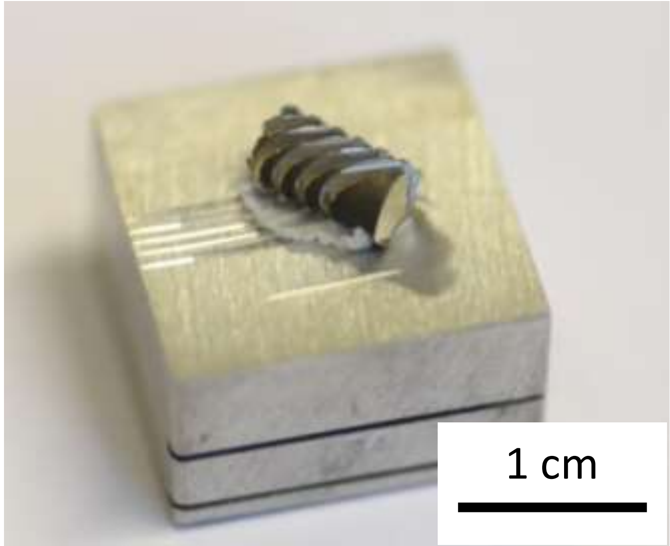
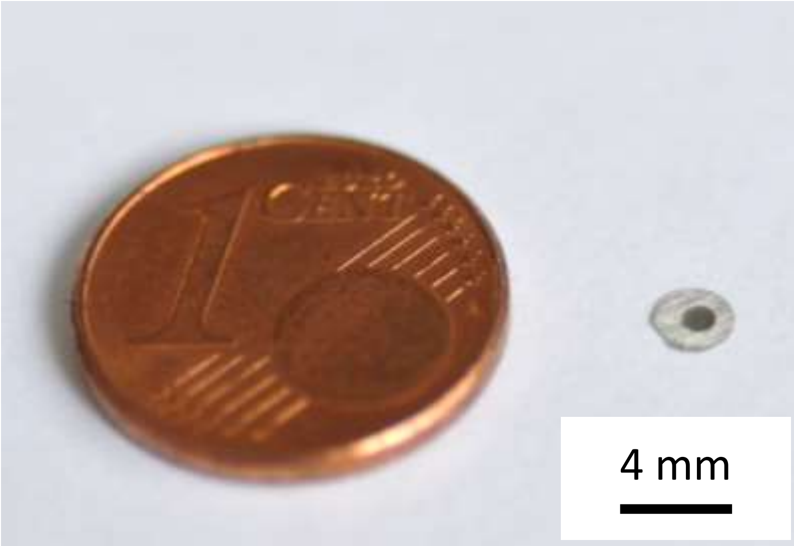
Stacking fault energy analysis

Twin jet electro polishing



Compression sample cut in slices



TEM sample after the electro polishing

Compression sample