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Ductilisation of tungsten (W) through cold-rolling:

Correlation of microstructure and mechanical properties

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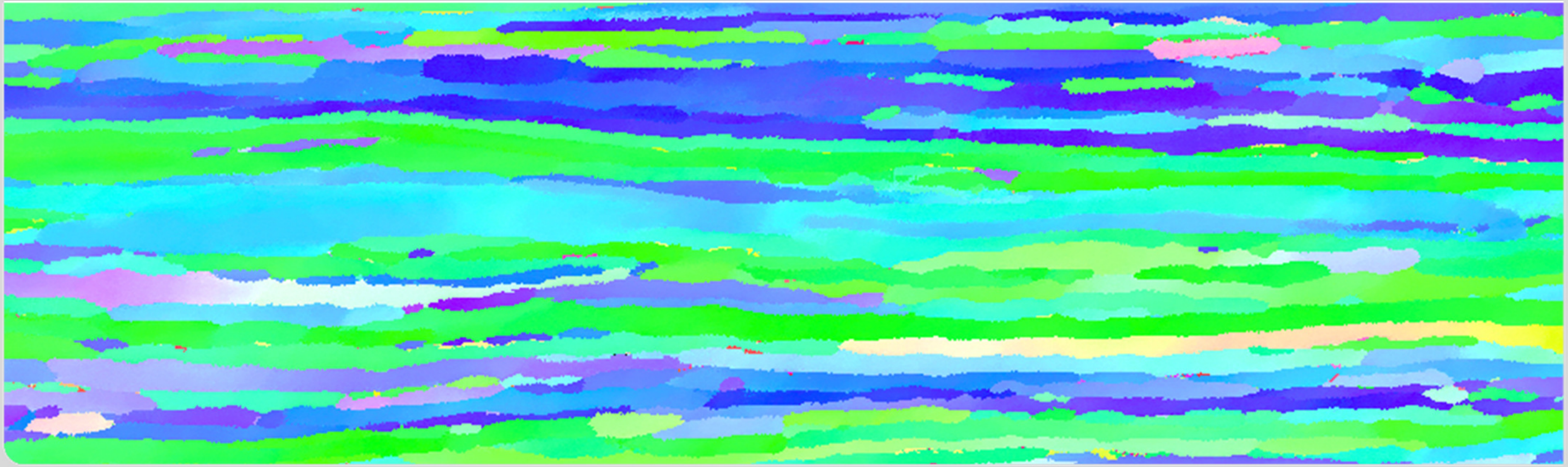
22.09.2017, EUROMAT, Thessaloniki, Greece

Institute for Applied Materials – Applied Materials Physics (IAM-AWP)



Outline

I. MATERIAL: COLD ROLLED TUNGSTEN SHEETS

II. INDIRECT ANALYSIS: MECHANICAL TESTING

III. DIRECT ANALYSIS: ELECTRON MICROSCOPY

IV. SUMMARY

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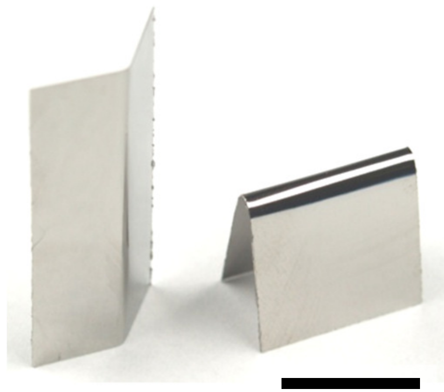
Motivation

Goal: tungsten as structural material for high temperature applications

[1]

Why are tungsten foils ductile?



Focus:

- What are the deformation mechanisms of ultrafine-grained tungsten foils?
- What is the impact of the lattice defects induced by cold rolling on the improved strength AND tensile ductility?
  (i.e. vacancies, dislocations, grain boundaries)

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[1] http://www.proteadiamonds.com

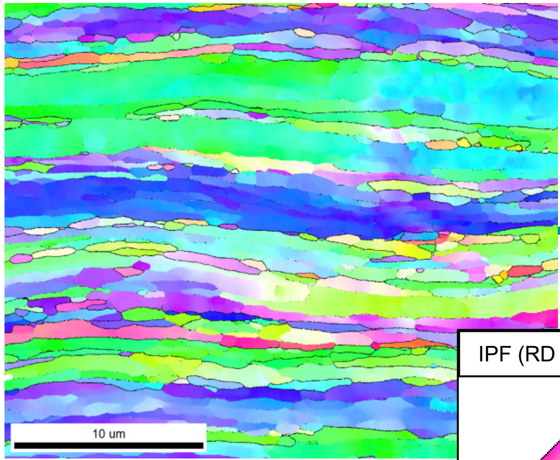
Material: Cold rolled tungsten sheets & foils

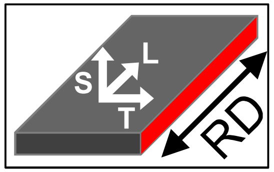
Materials

hot rolled
↓ **cr**
1000 µm
↓ **cr**
500 µm
↓ **cr**
300 µm
↓ **cr**
200 µm
↓ **cr**
100 µm

(PLANSEE SE)

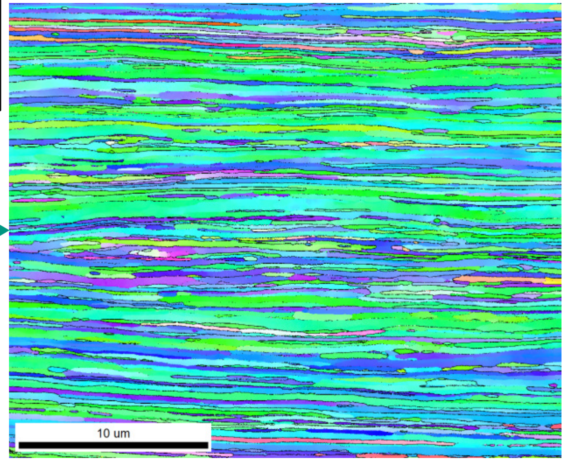
1000 µm sheet

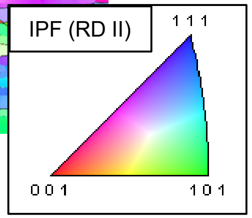




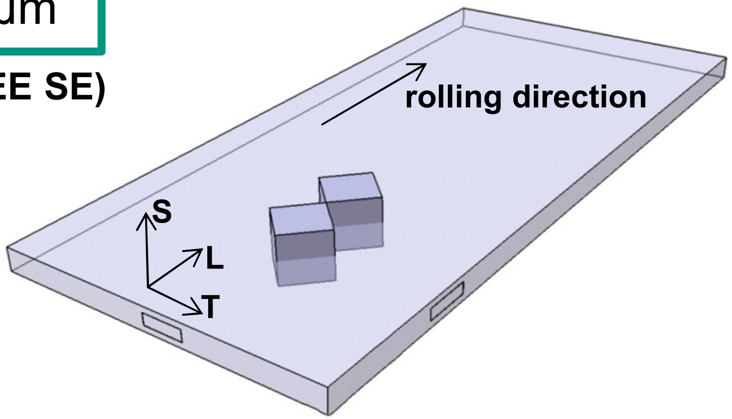
cold rolling

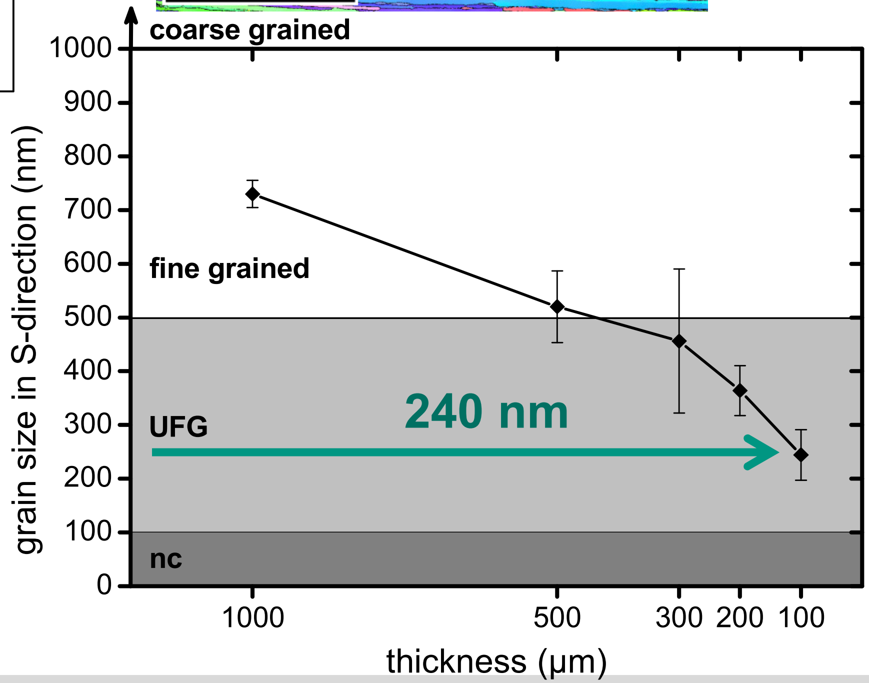
100 µm foil





(001)<110> texture





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II. INDIRECT ANALYSIS: MECHANICAL TESTING

  a) Tensile tests

  b) Strain rate jump tests

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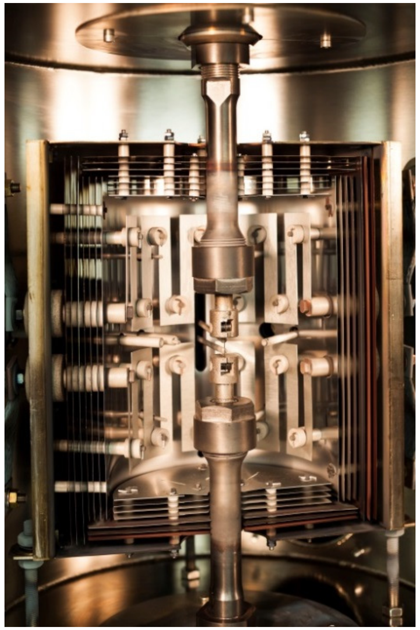
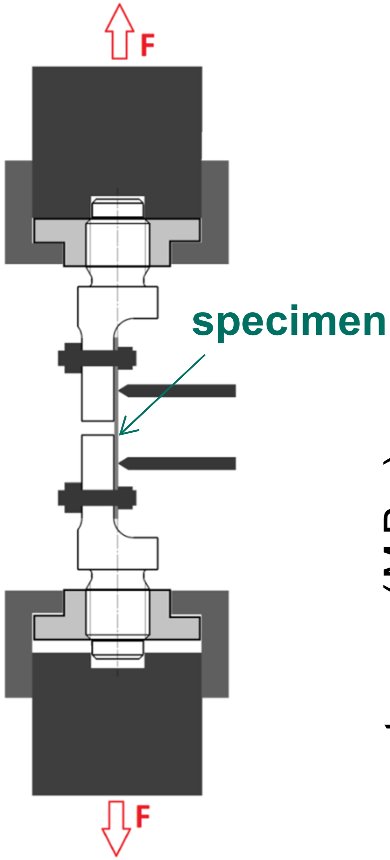
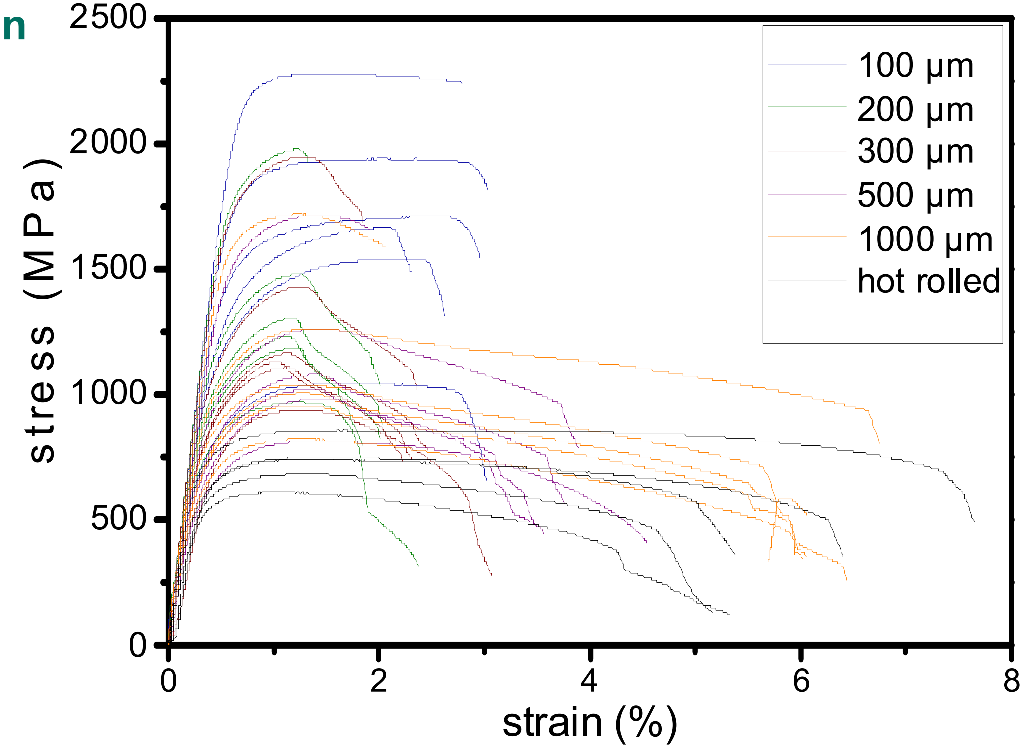
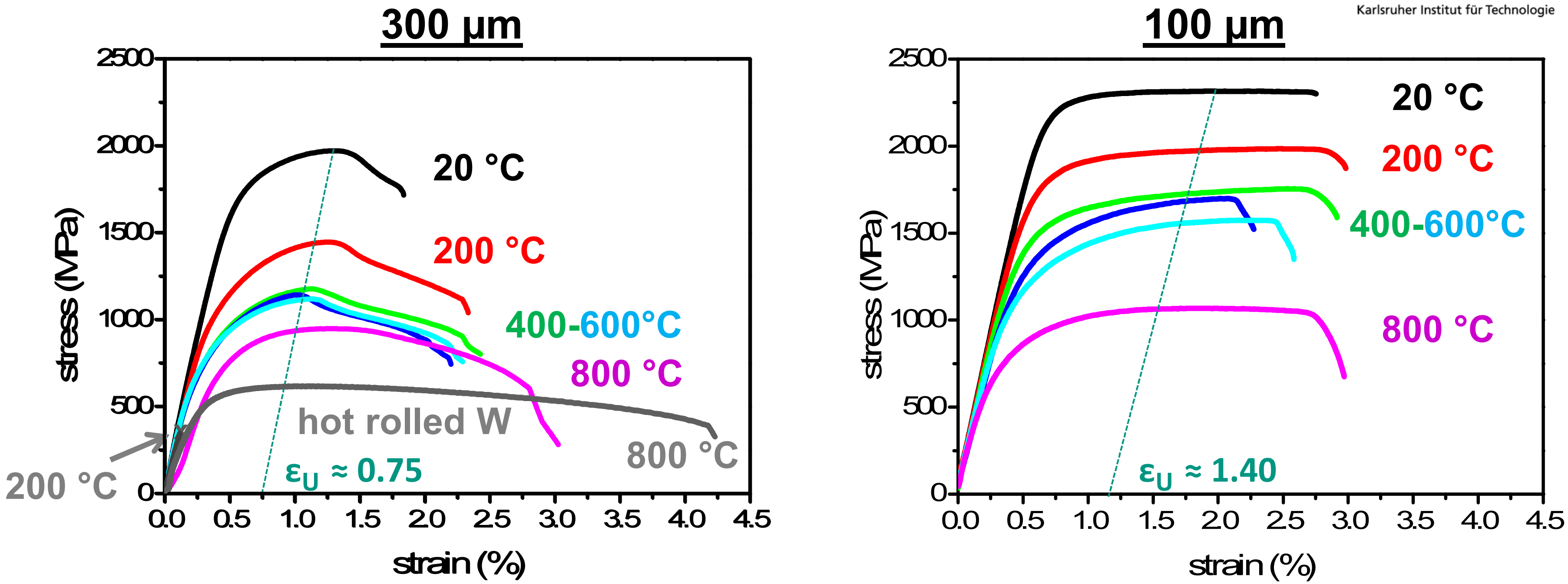
Tensile tests







Tensile tests



Cold rolling:

- Increased strength
- Room temperature ductility
- Fast hardening & plateau for **100 µm foil** (independent of testing temperature)

→ **Change in deformation mechanisms!**

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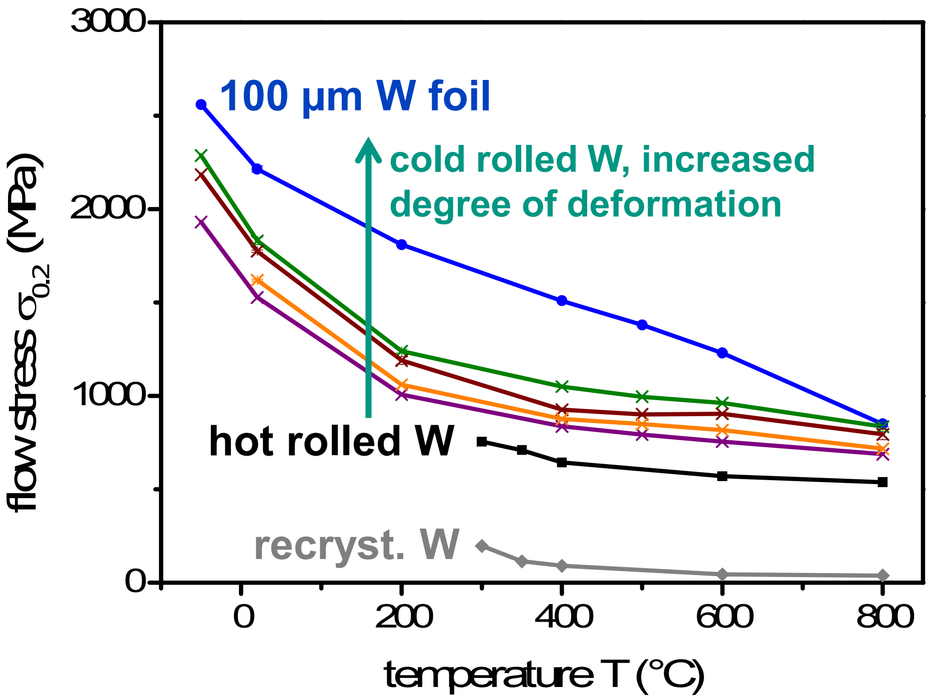
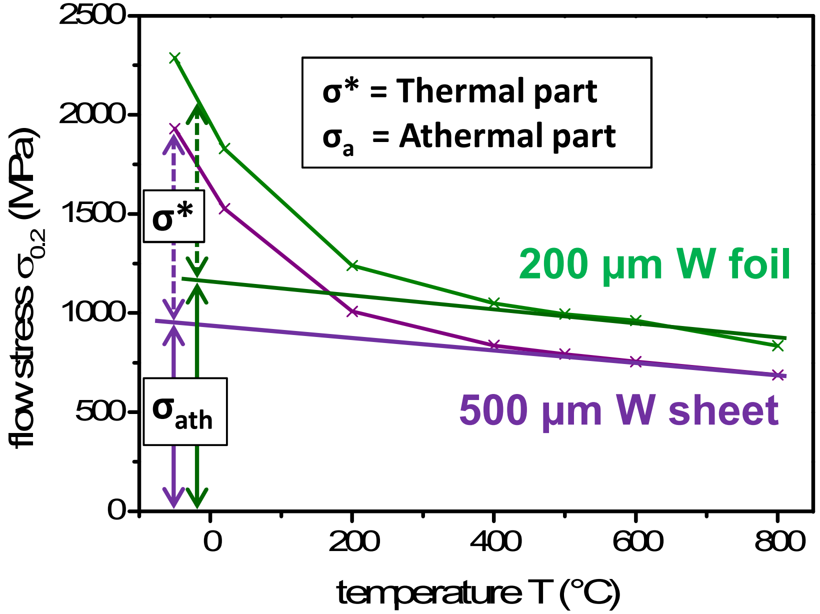
Mechanical properties: flow stress over T



Split flow stress:



- Cold rolling: significant increase of $\sigma_{p0.2}$
- Decreasing $\sigma_{p0.2}$ with increasing T

  → **Screw dislocation still dominant!**
- 100 µm foil: atypical behaviour

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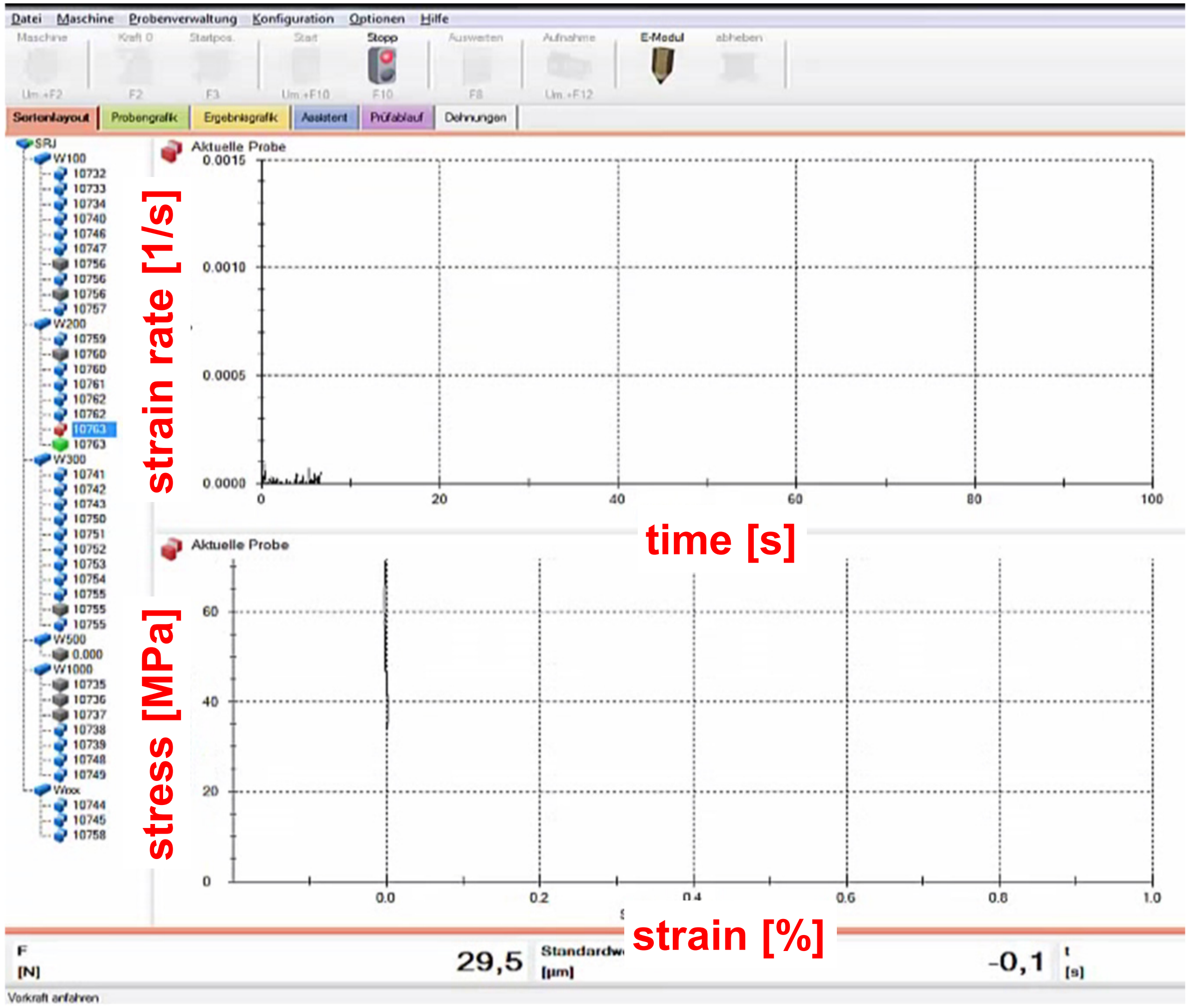
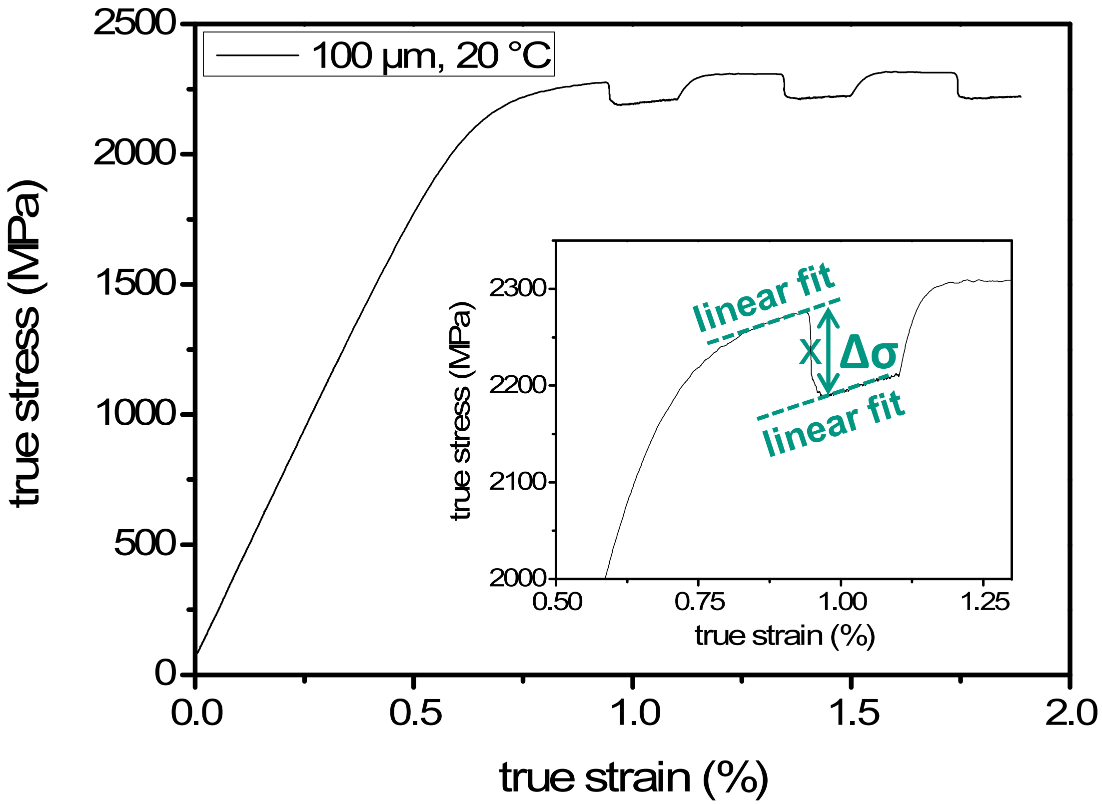
Strain rate jump tests: procedure



Strain rate sensitivity measurement

- Jump during tensile test (constant conditions)
- Strain-controlled testing
- Jumps @ ε_{pl} = const.
- Strain rates:
  $10^{-3}\ {}^{1}/_{s} \leftrightarrow 10^{-4}\ {}^{1}/_{s}$
- Temperature range:
  20 °C – 800 °C

Strain rate jump tests: evaluation



Strain rate sensitivity: $m = \left(\frac{\Delta ln\sigma^*}{\Delta ln\dot{\varepsilon}}\right)_{T,\,\varepsilon_{pl}}$

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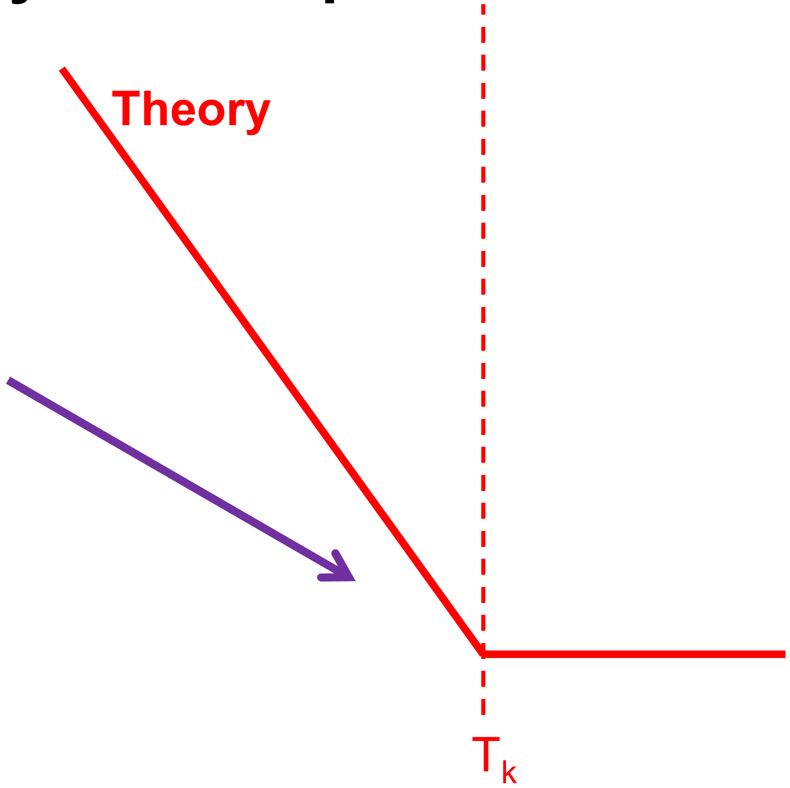
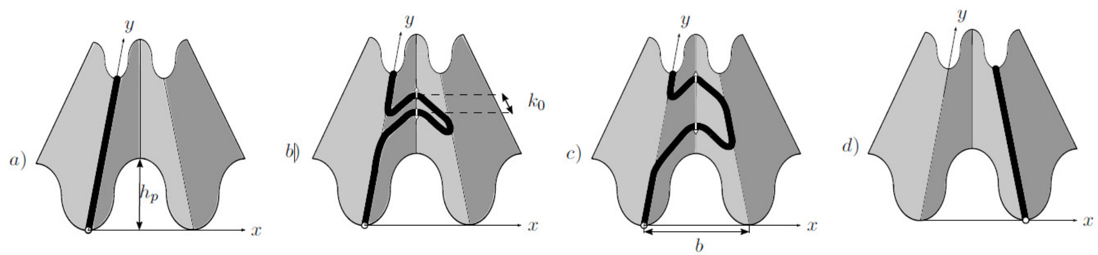
Strain rate sensitivity: low temperature behaviour





Screw dislocations dominant at low temperatures

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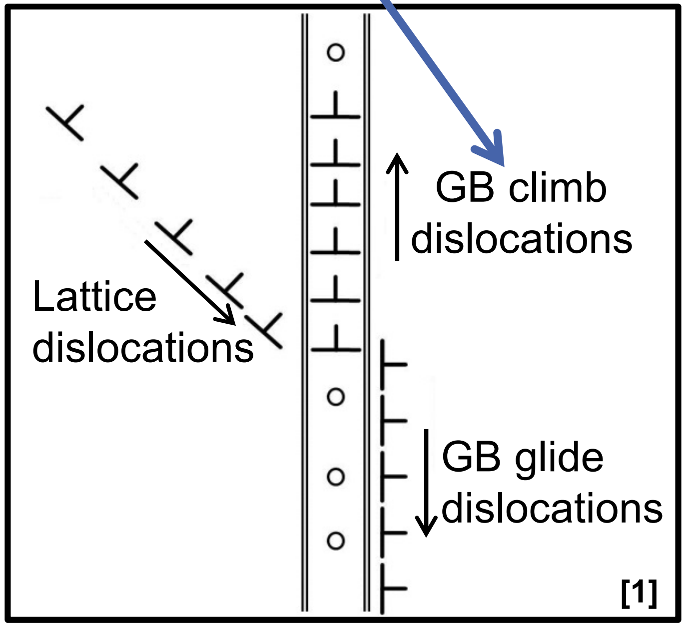
Strain rate sensitivity: high temperature behaviour

diffusion controlled!

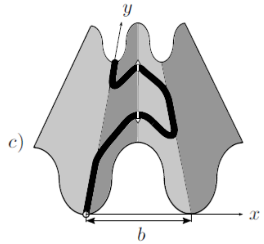
further mechanism(s)!
(thermally activated)



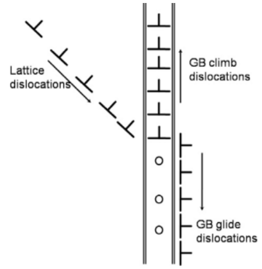
Change of dislocation grain boundary interaction: from blocking to absorption

[1] Ahmed, Hartmaier, Acta Materialia 59 (2011) p. 4323-4334

Strain rate sensitivity: influence of grain size



change of controlling mechanism in UFG W



Screw dislocation | **GB mediated processes**

decreasing grain size

decreasing grain size

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a) TEM imaging of dislocations

b) HR-EBSD

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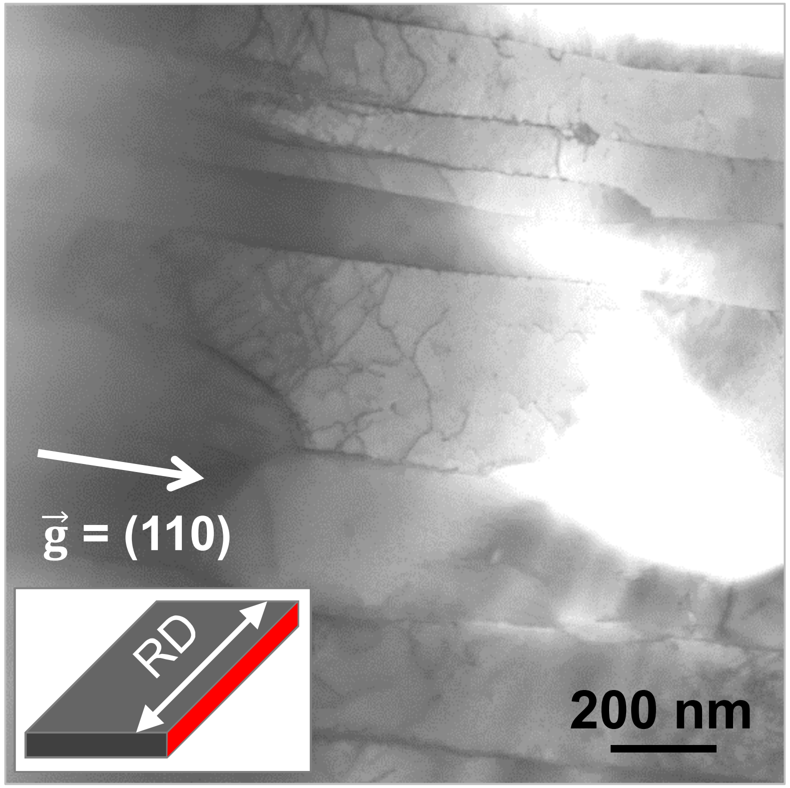
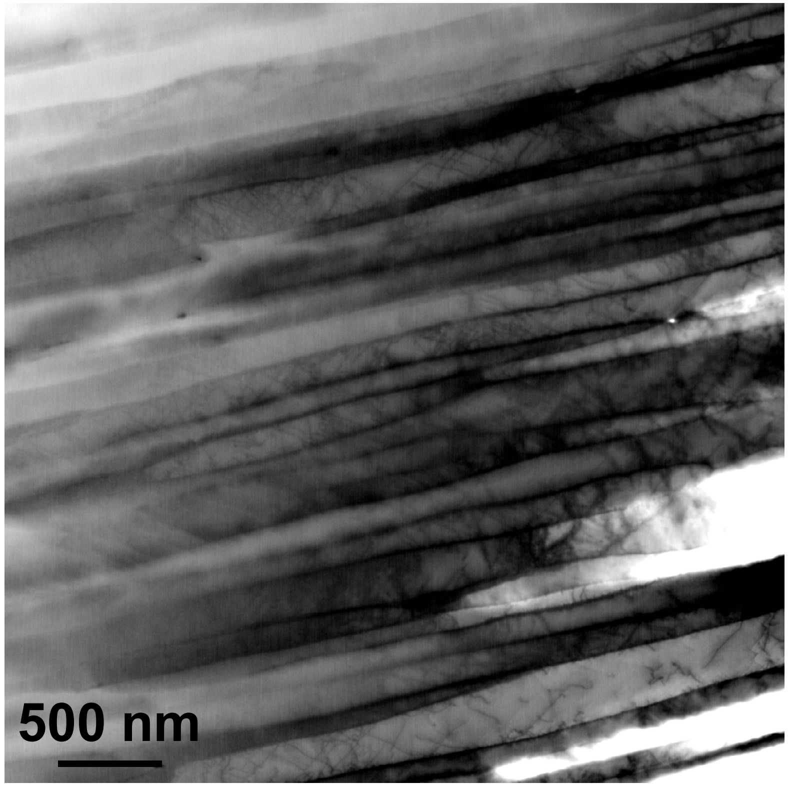
TEM imaging of dislocations in tungsten





Hypothesis "unhindered dislocation motion"

Ordered glide of screw dislocations that move along HAGBs channels (confined plastic slip)

→ **Quantitative support by HR-EBSD?**

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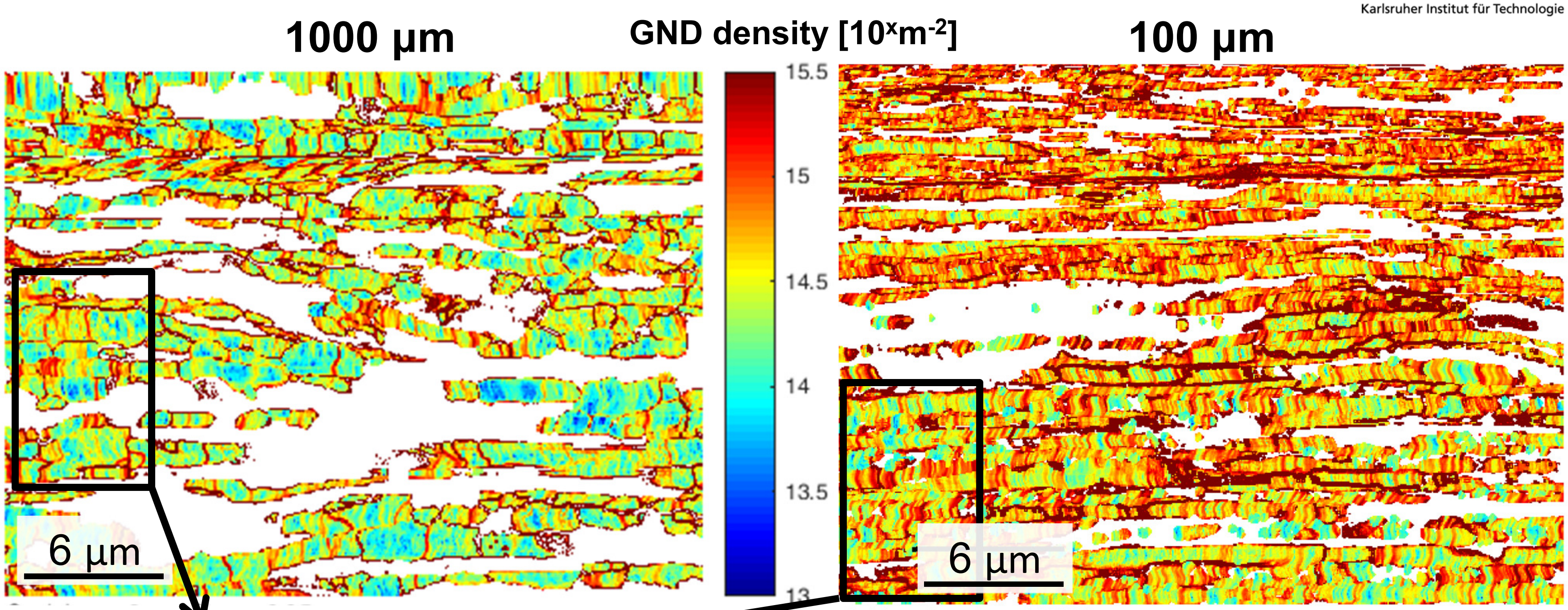
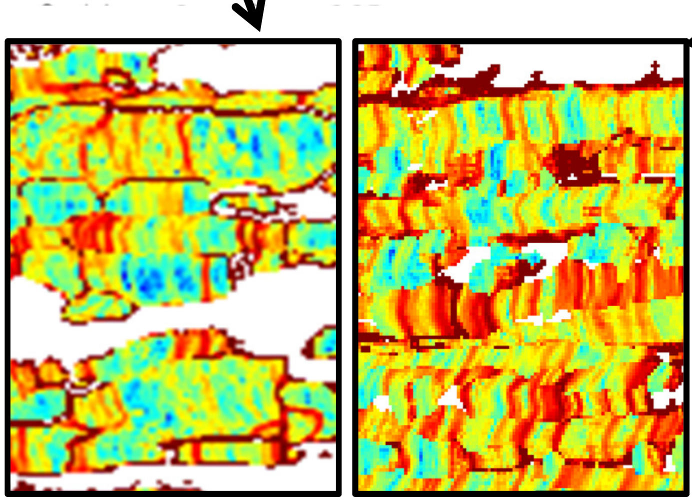
HR-EBSD: results from as-received condition





- 100 µm foil:
  - Higher dislocation density
  - Channels of high dislocation density (between two grain boundaries)
- 1000 µm sheet: more branching

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Identification of deformation mechanisms

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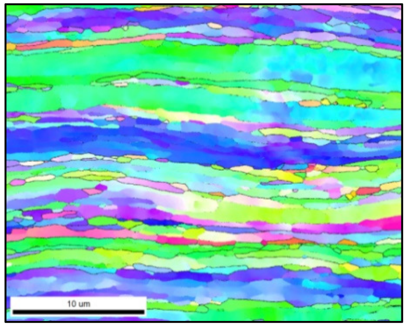
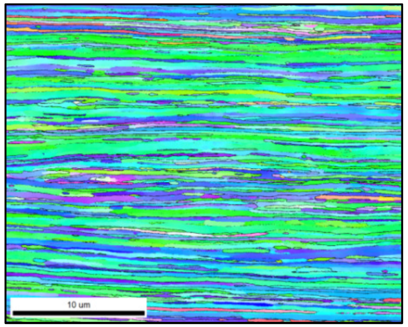
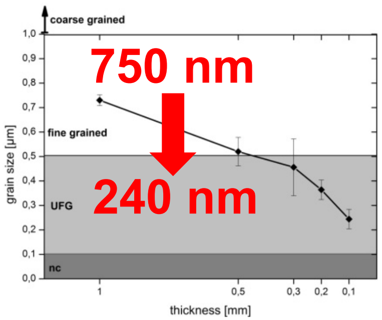
material

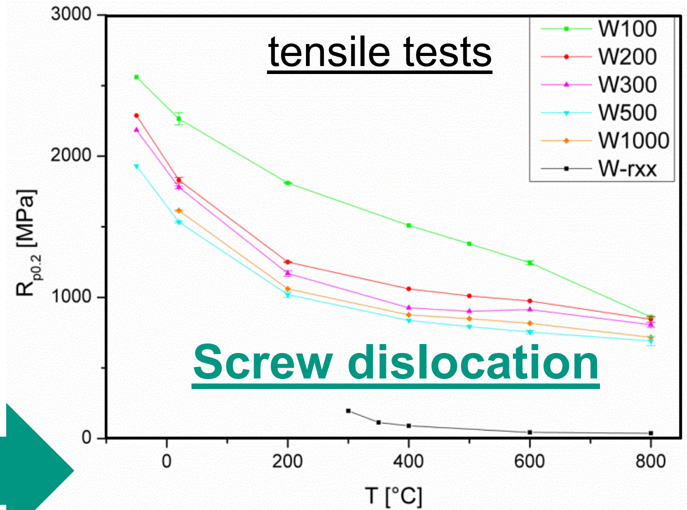
microstructure







indirect

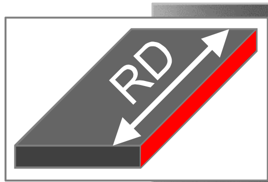


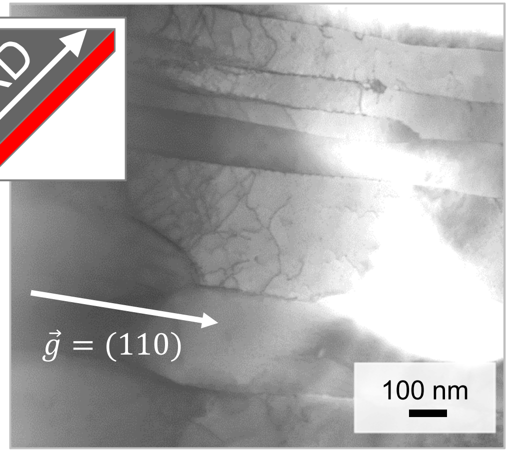
SRJ tests

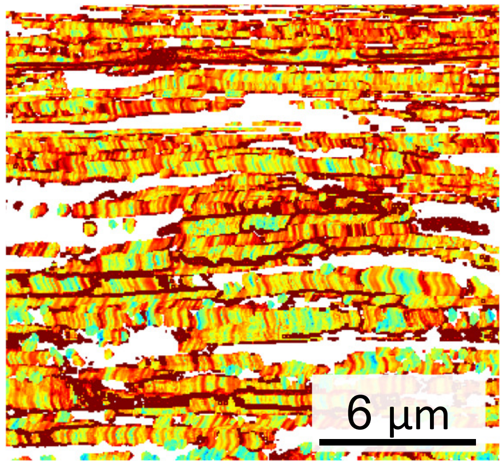
GB-mediated plasticity

direct

dislocation substructure







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Thank you for your attention!

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