Karlsruher Institut für Technologie

Ductility in ultrafine-grained (UFG) tungsten foil:

Correlation between microstructure and mechanical properties

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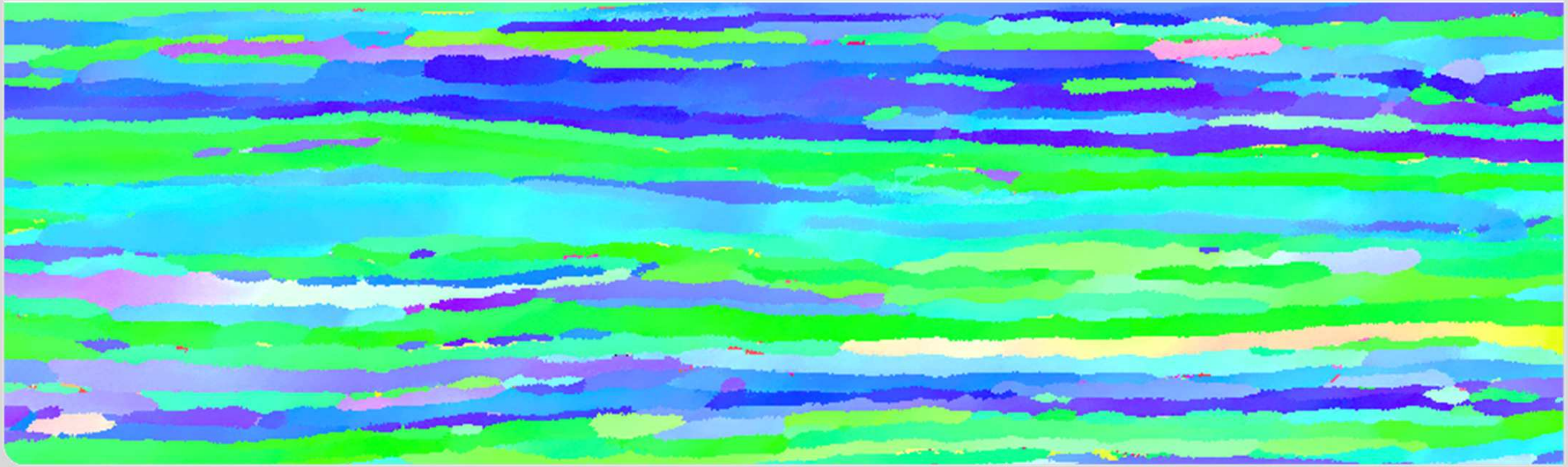
22.09.2015, EUROMAT 2015, Warschau

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



I. MOTIVATION

II. RESULTS

a) microstructure & direct analysis of deformation mechanisms

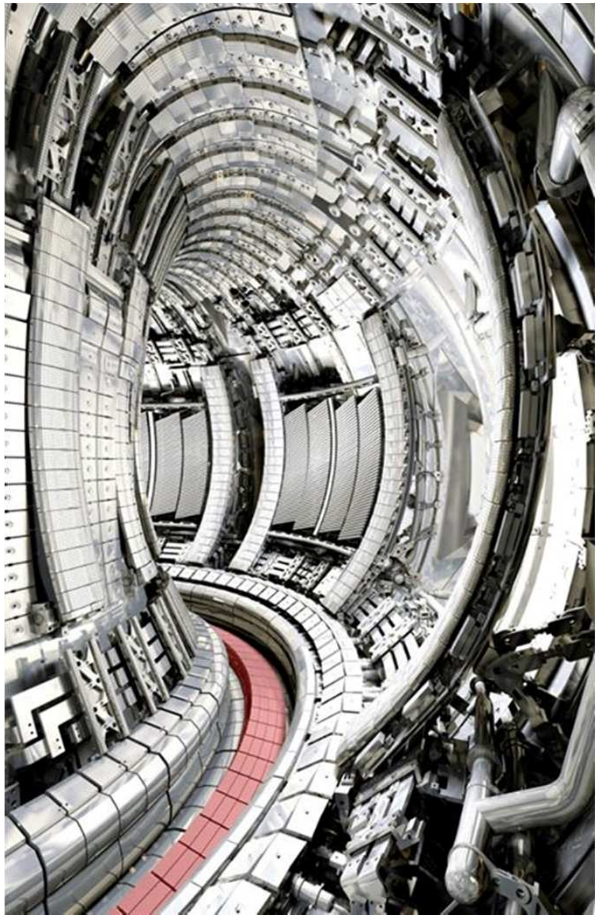
b) mechanical properties & indirect analysis of deformation mechanisms

III. CONCLUSION

High-temperature applications

High-temperature materials

fusion reactor



[EFDA-JET - "ITER-like Wall„]

thermomechanical and thermophysical requirements:

- high-temperature strength
- creep resistant
- heat conductor
- high recrystallization temperature

} **TUNGSTEN**

Problem: brittleness of commercial tungsten

solar thermal power plant

[National Geographic – „A Pioneering Plant in Andalucía"]

W foils

tungsten as structural material

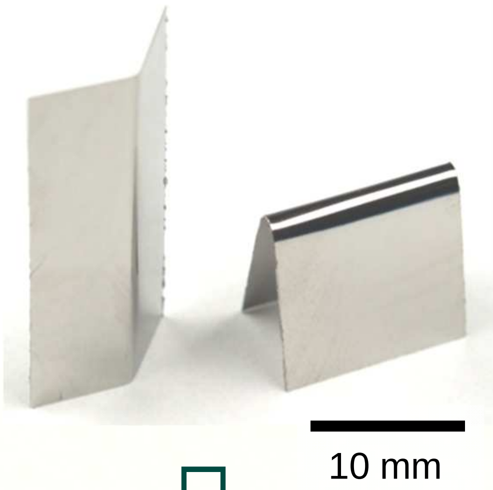
alloying | **modification of microstructure** | **compound material**

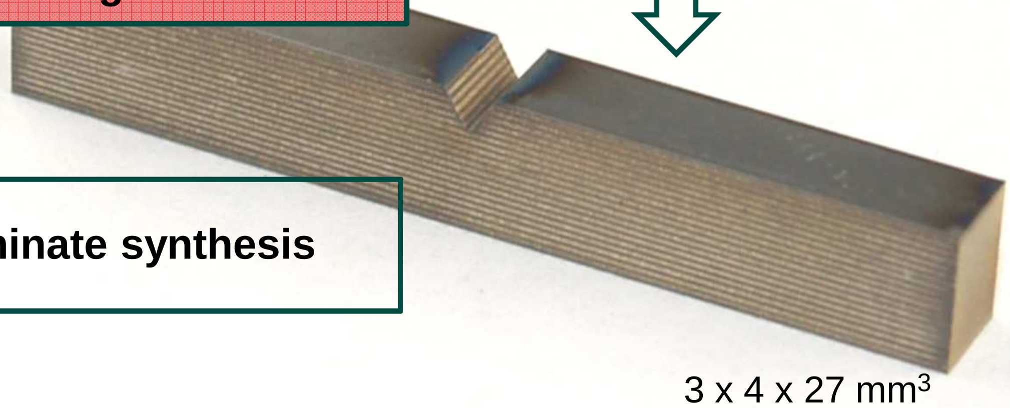
⇩

„ultrafine-grained“ (UFG) tungsten foil by accumulative roll bonding

⇩

up-scaling to components by laminate synthesis





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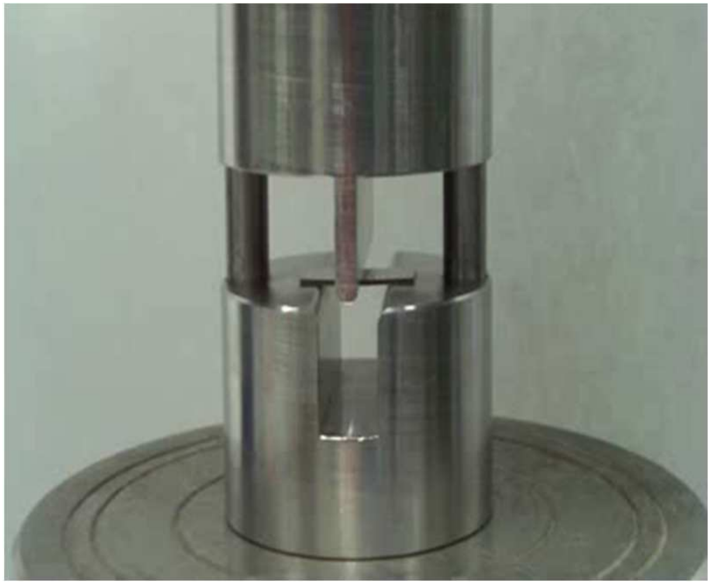
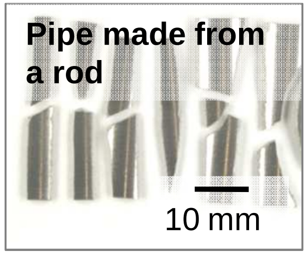
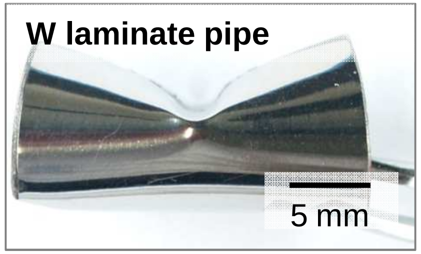
W laminates



Charpy impact test at 300°C





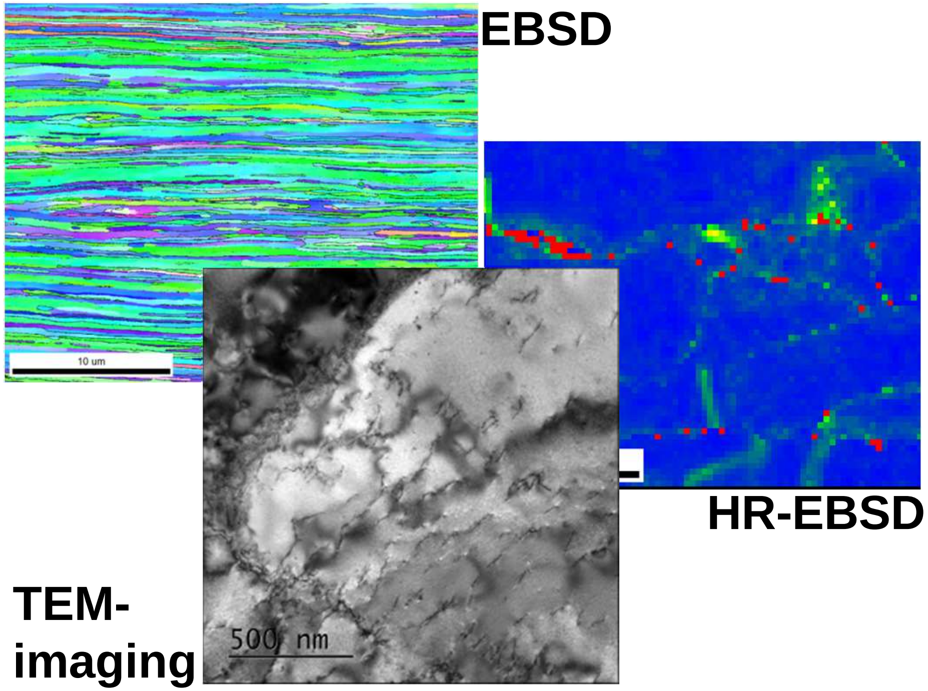
[J. Reiser et al., Adv. Eng. Mater. 17(4) (2010) 491 - 501]

- **contribution of foils**
- **foil properties**
- **deformation mechanisms**

Project overview

identification of deformation mechanisms in ufg-tungsten foils

direct analysis

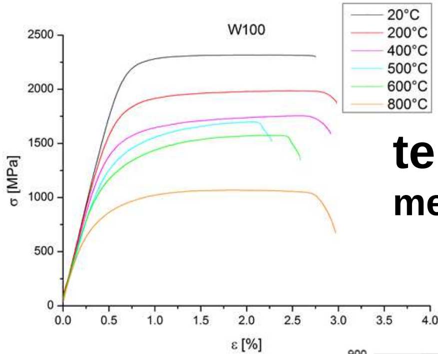


EBSD

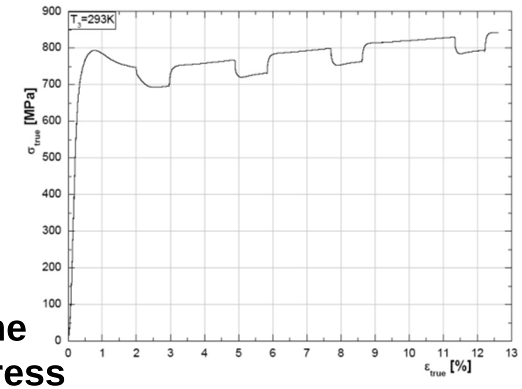
HR-EBSD

TEM-imaging

indirect analysis



tensile tests:
mechanical properties



SRJ-test:
activation volume
modelling yield stress

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EUROMAT 2015

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Direct analysis of deformation mechanisms

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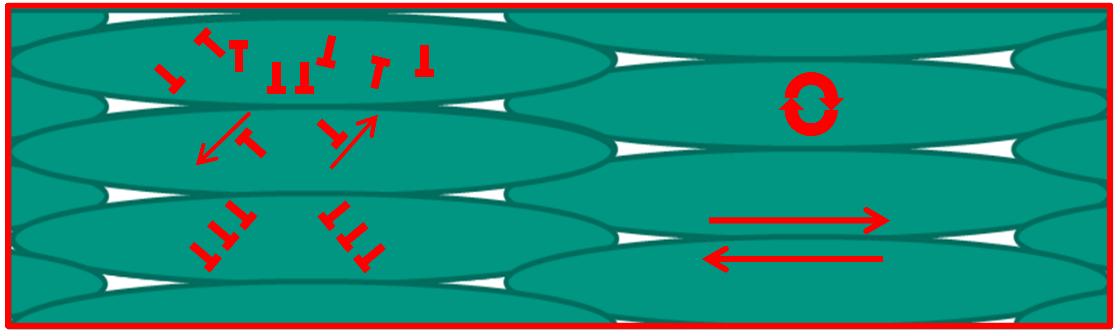
deformation mechanisms

density & nature of dislocations

emission/absorption

dislocation boundaries

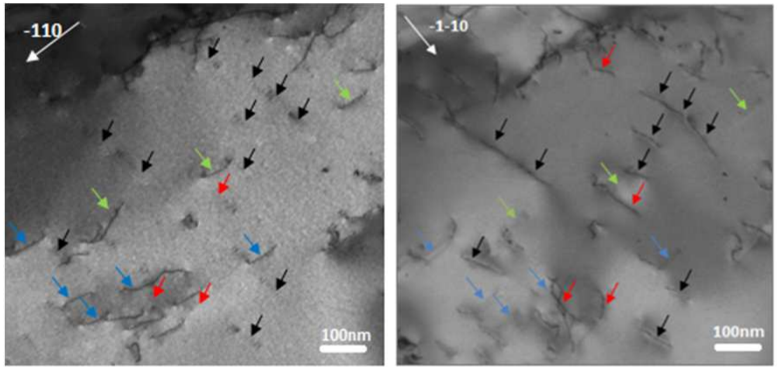


microstructure

grain rotation

grain boundary sliding

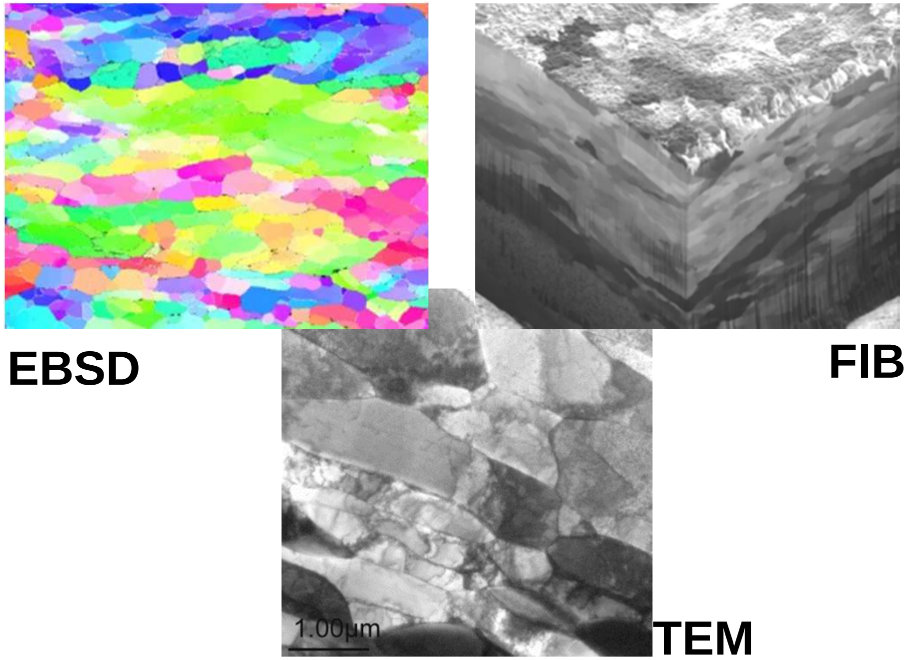
nature of dislocations



screw		edge
red arrow	b=±½[111] or ±½[11-1]	black arrow
green arrow	b=±½[-111] or ±½[1-11]	blue arrow

[X. Yi (Oxford, 2012)]

microstructure



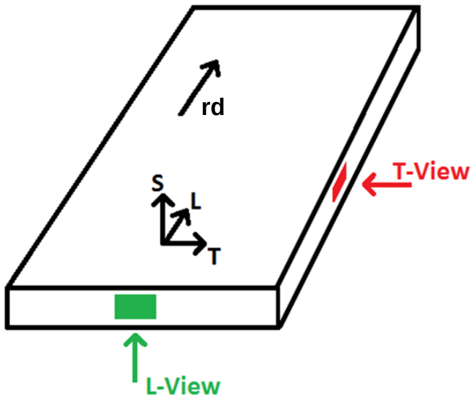
EBSD

FIB

TEM

Materials

- exclusive tungsten foils from PLANSEE SE:
  - 1 mm – 0,5 mm – 0,3 mm – 0,2 mm – 0,1 mm
  - 1 sintered compact (> 99.97 wt.-% W)
  - „cold rolling“ (rolling temperature << 1200°C)



degree of deformation & rolling paramter

thickness [mm]	sintered compact	5,5	1	0,5	0,3	0,2	0,1
φ_{TOTAL}	/	/	1,7	2,4	2,91	3,31	4
$T_{ROLLING}$	/	hot-rolling	cold-rolling				cold-rolling

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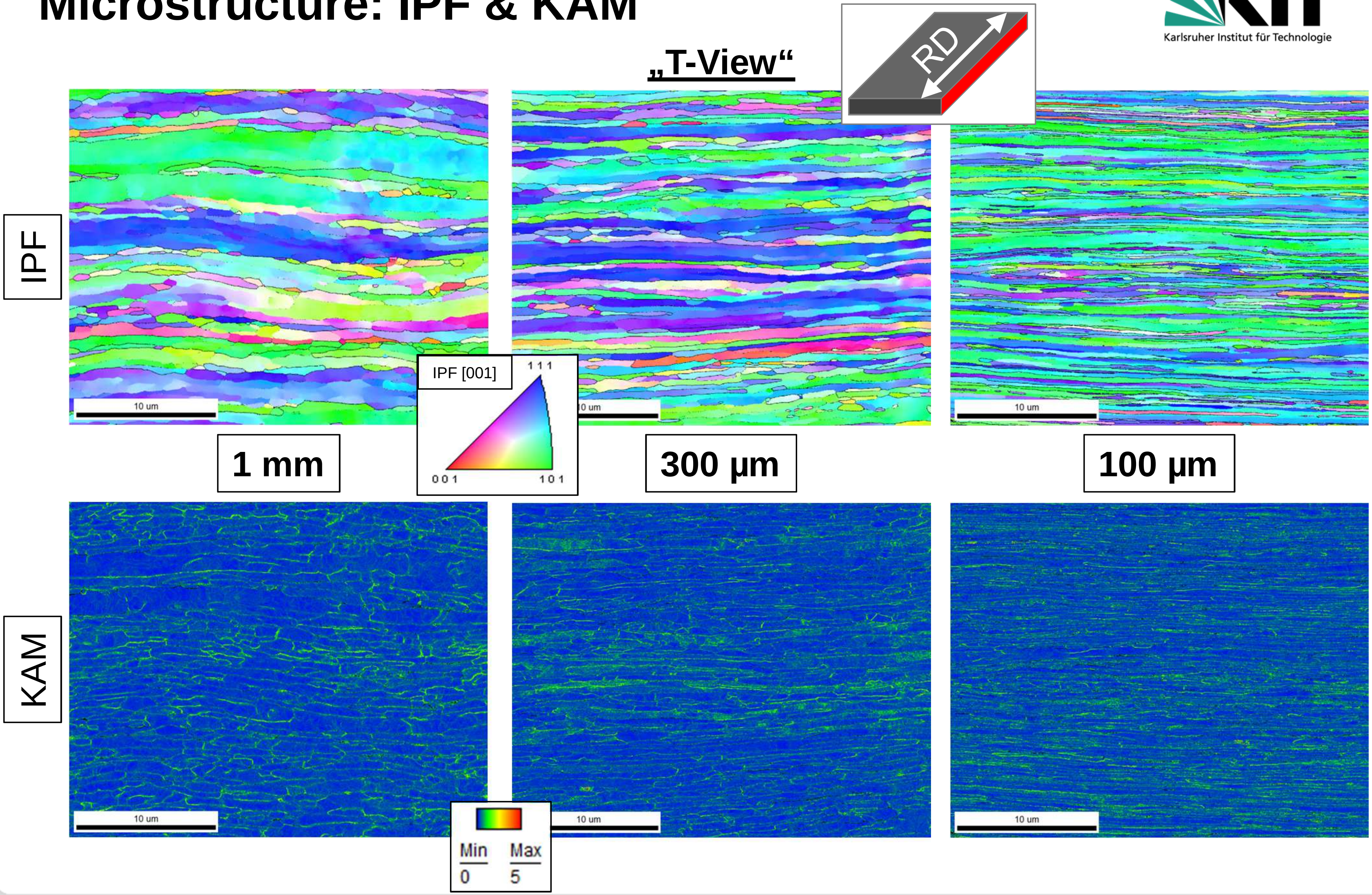
Microstructure: IPF & KAM



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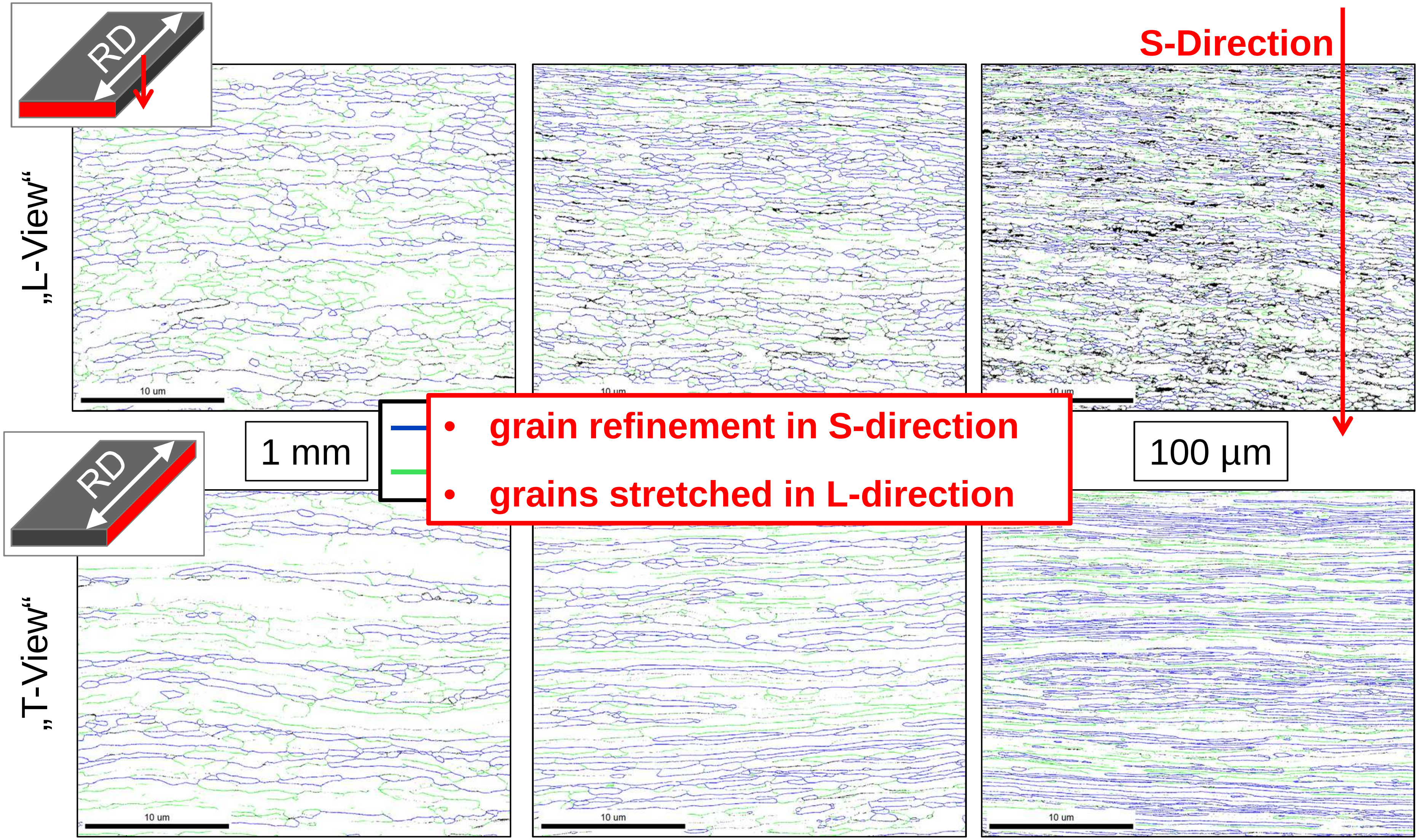
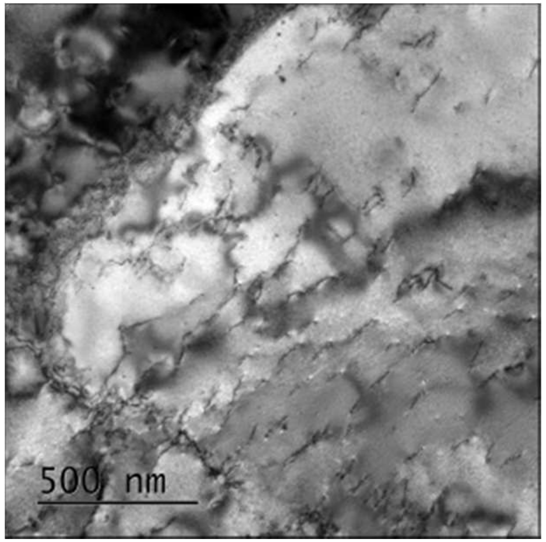
Microstructure: grain boundaries



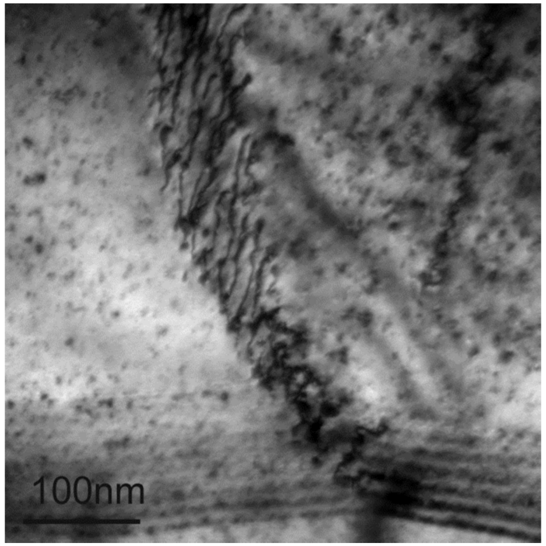
- grain refinement in S-direction
- grains stretched in L-direction

TEM imaging of dislocations in tungsten

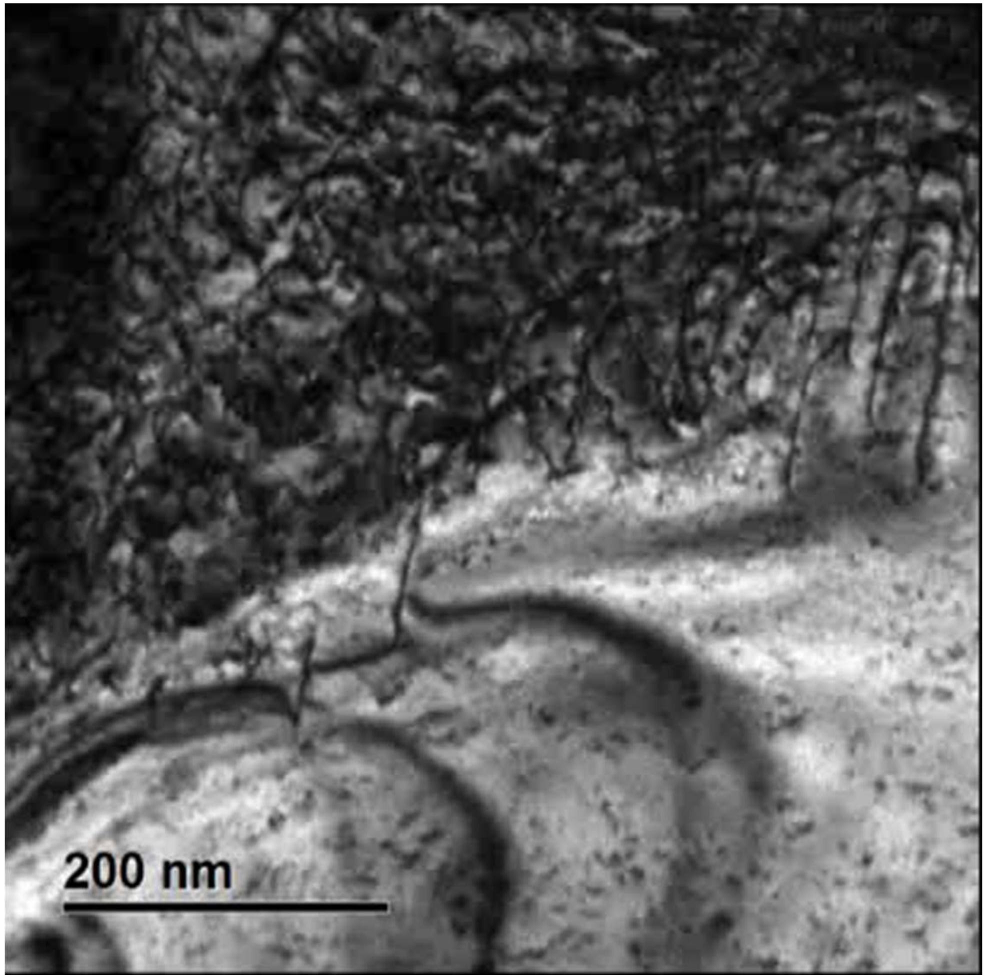
dislocations



dislocation boundaries



in situ tensile test



[M. Klimenkov, IAM-AWP, KIT, 2015]

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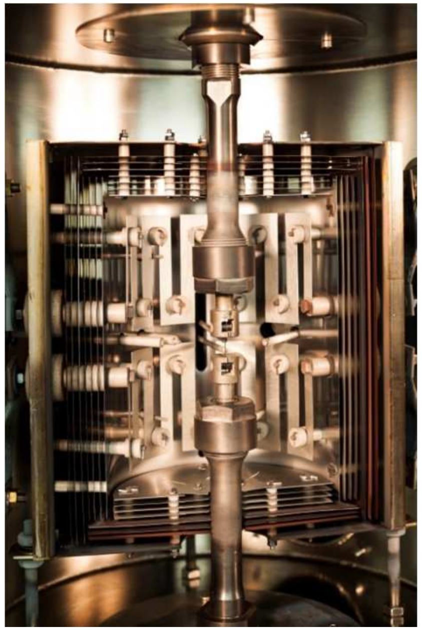
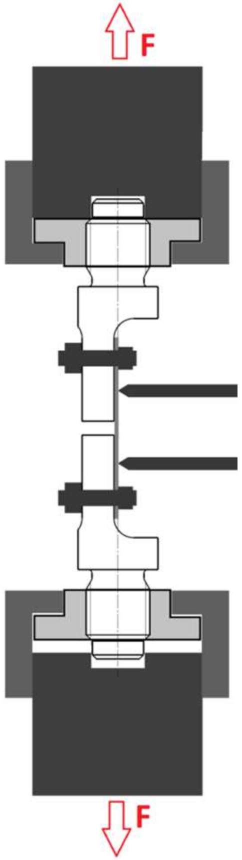
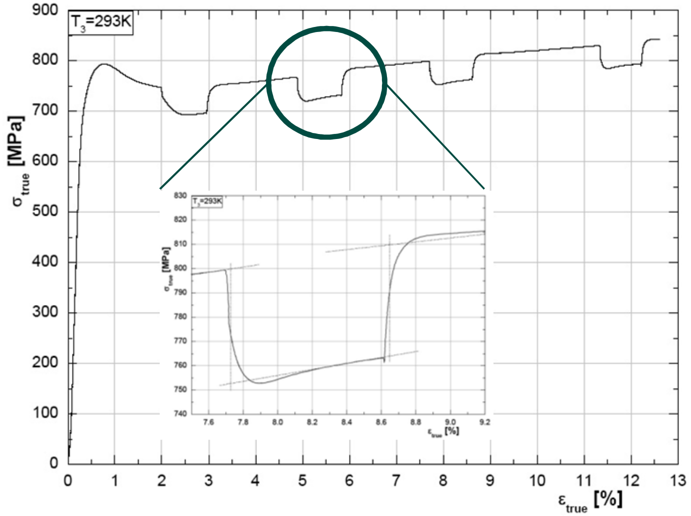
Indirect analysis of deformation mechanisms

tensile tests
&
hardness measurement





strain rate jump test



activation volume: $\vartheta = M_T \cdot k \cdot T \cdot (\frac{\Delta ln\dot{\varepsilon}}{\Delta\sigma^*})$

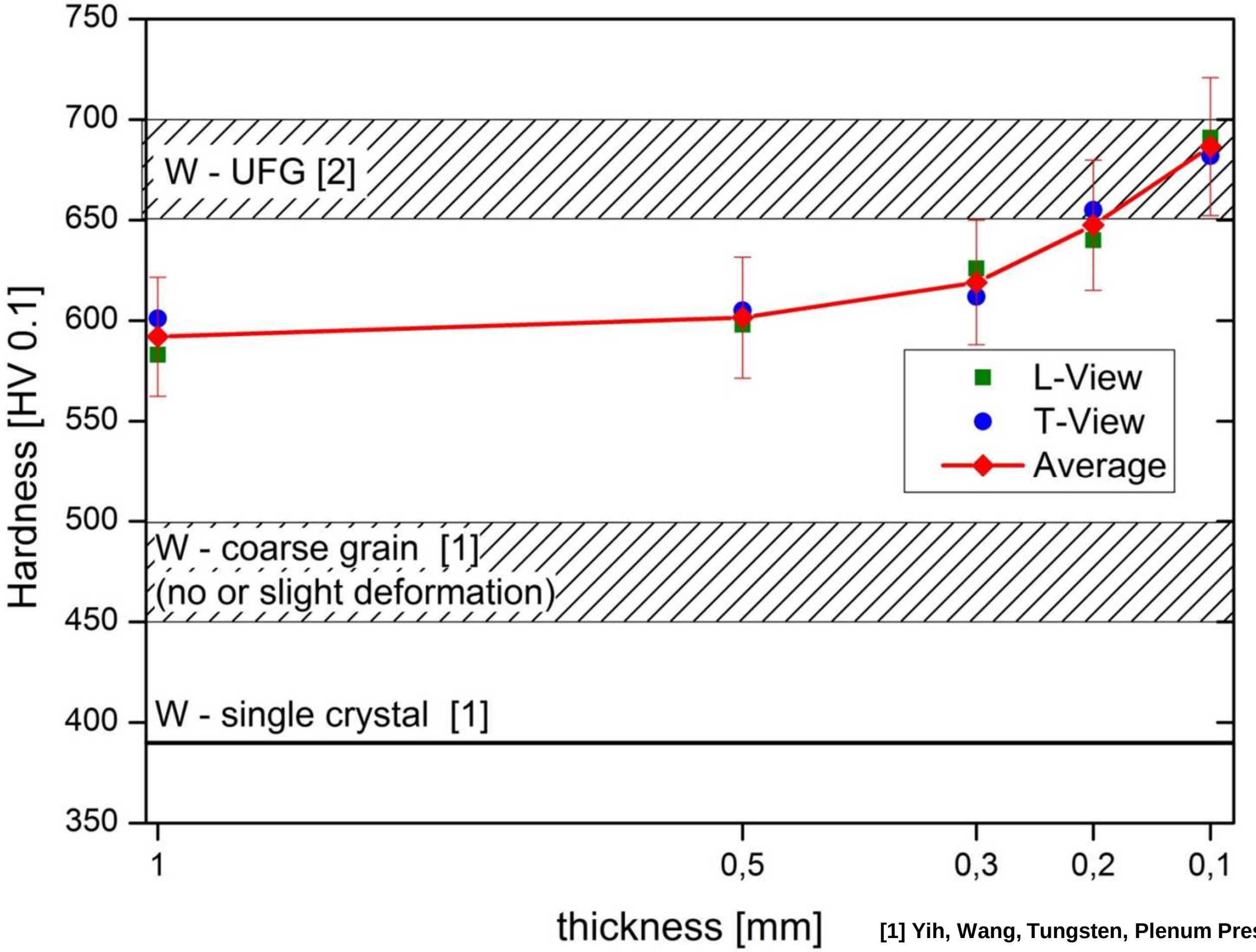
(M_T: Taylor factor, k: Boltzmann constant)

constitutive equation:

$$\sigma = \sigma_G + \sigma_0^* \cdot [1 - (\frac{kT}{\Delta G_0} \cdot \ln(\frac{\dot{\varepsilon}_0}{\dot{\varepsilon}}))^n]^m$$

[V. Schulze, O. Vöhringer, Encyclopedia of Materials: Science and Technology, 2001]

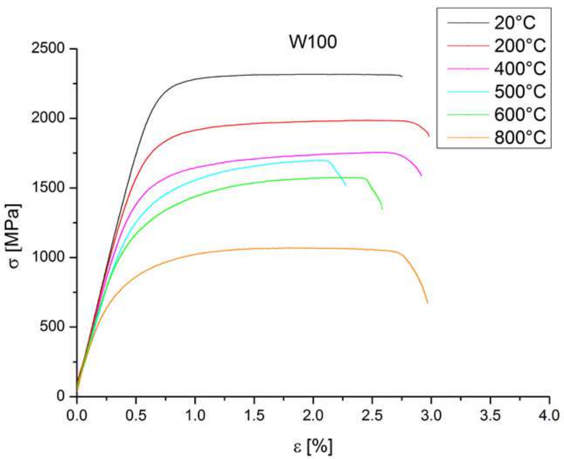
Mechanical Properties: hardness

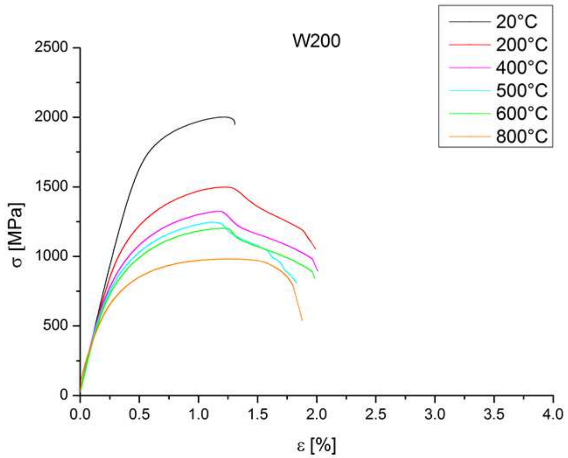


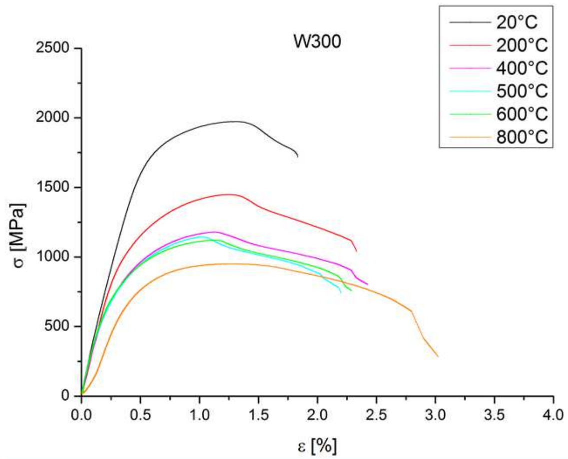
[1] Yih, Wang, Tungsten, Plenum Press, New York 1979

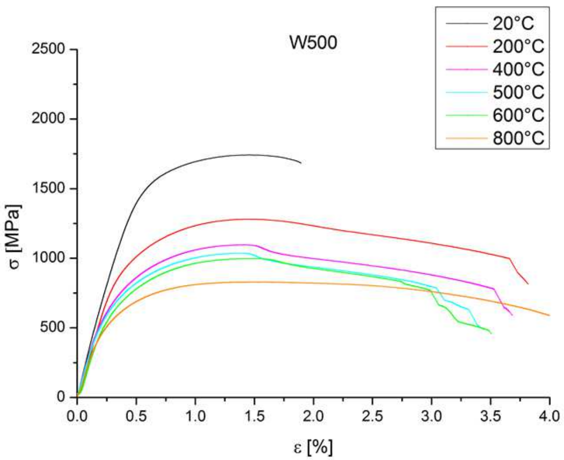
[2] Wei, Kecskes, Effect of low-temperature rolling on the tensile behavior of commercially pure tungsten, Mat. Sci. Eng.A 2008 (491) p.62-69

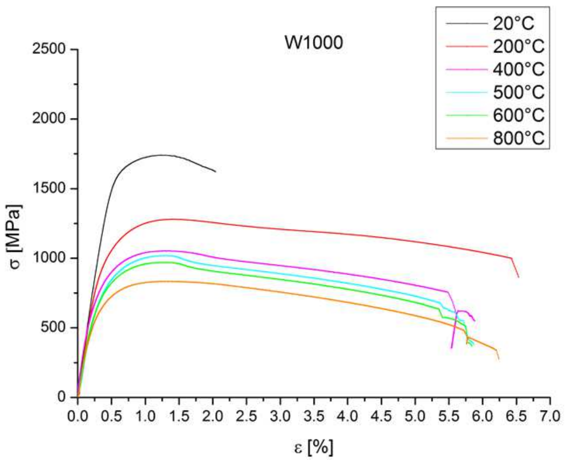
Mechanical Properties: tensile tests











- **W100 shape:**
  elastic – ideal plastic
- **W200-W300 (W500):**
  yield phenomenon after R_m
  similar to W_{sc} in [110]
  [Argon, Acta Metall. Mater. 14 (1966)]
- **W500-W1000:**
  early onset of yielding
  pronounced hardening

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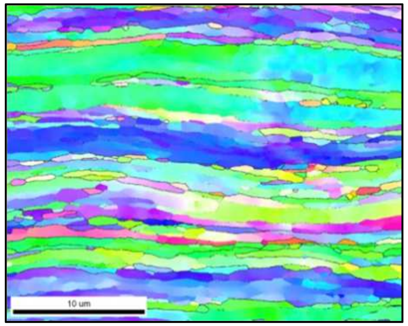
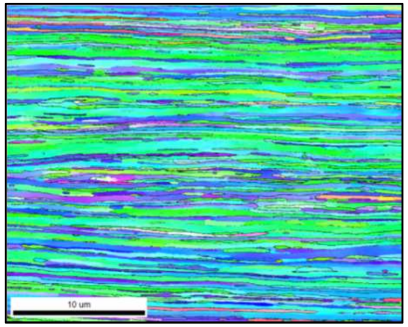
Identification of deformation mechanisms

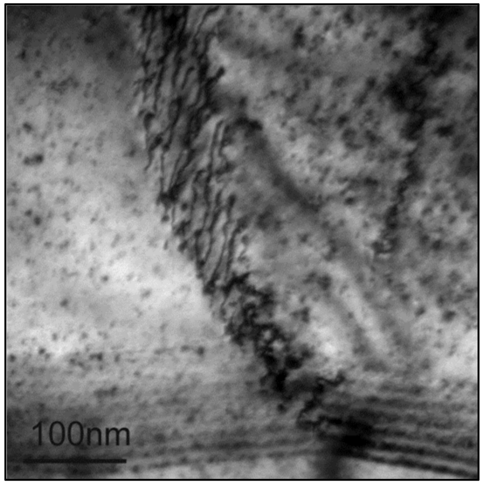
direct

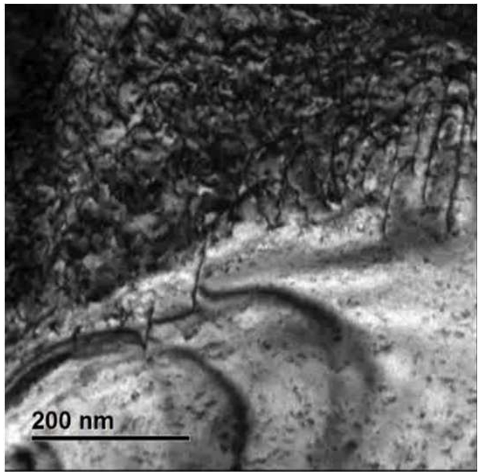
microstructure

dislocations



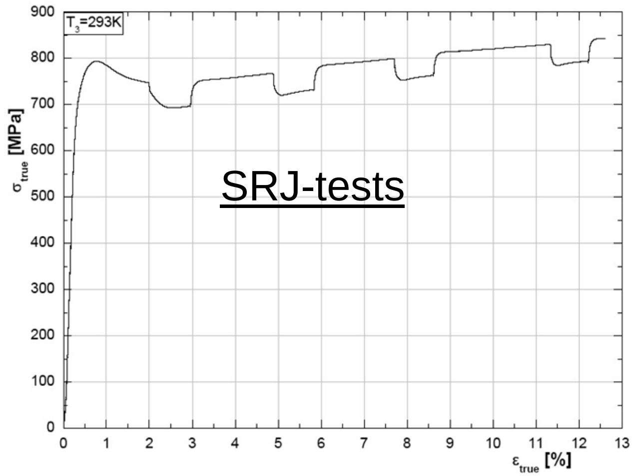






indirect

tensile tests



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Thank you for your attention!

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