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STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

TEC
TRILATERAL
EUREGIO CLUSTER

Tungsten R&D at SCK-CEN

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Major activities carried in 2014-2015

- Testing after neutron and ion irradiation
- High temperature mechanical testing (cold)
- Microstructural examination
- Electron irradiation
- Large-scale plastic deformation
- Micro-mechanical testing
- Positron Annihilation Spectroscopy
- Integrated Modelling

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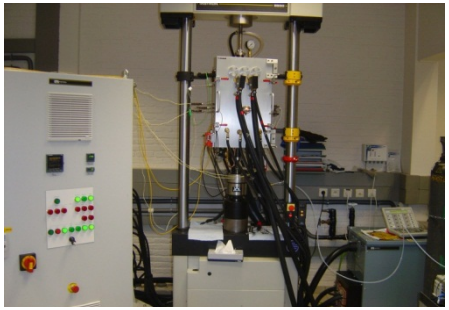
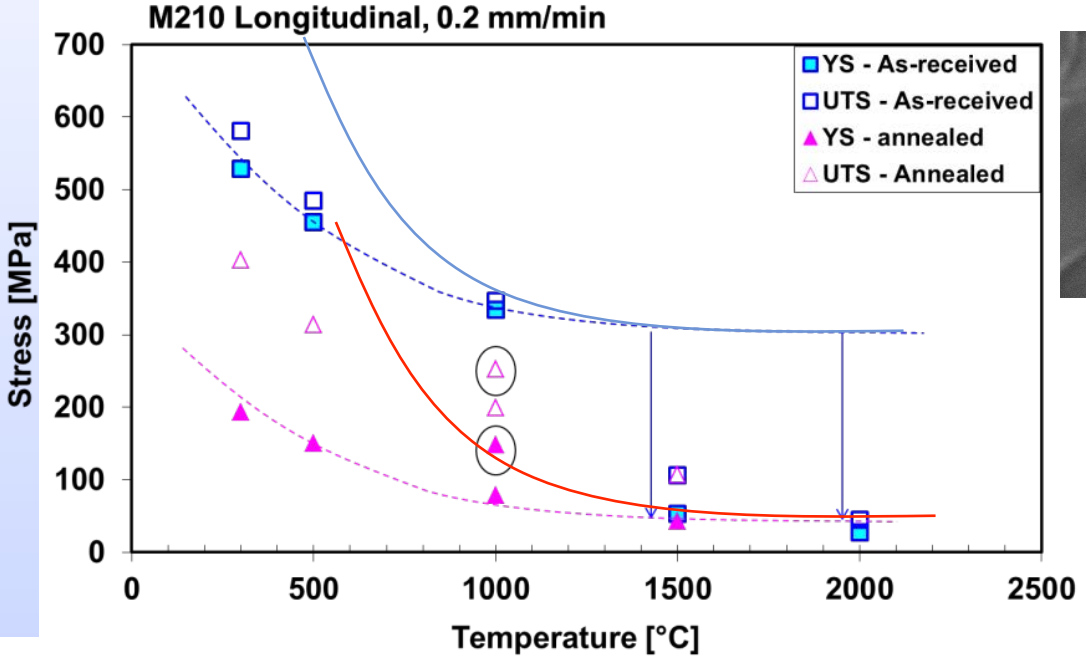
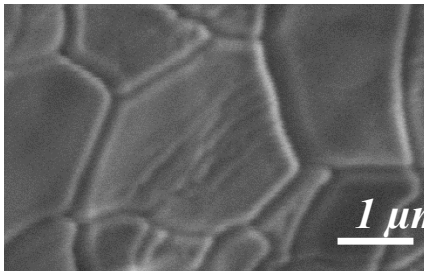
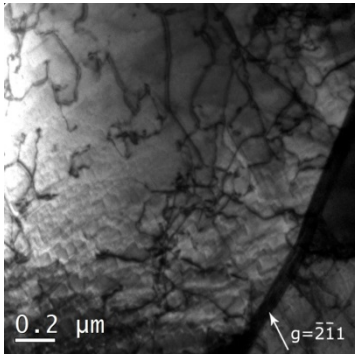
High temperature tensile tests

- Tensile tests up to 2000 C in vacuum
  - Fracture surface
  - SEM-visible shear bands
  - in-depth TEM analysis









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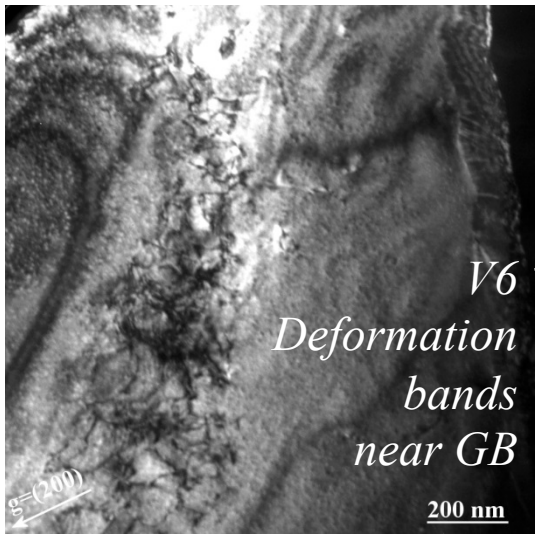
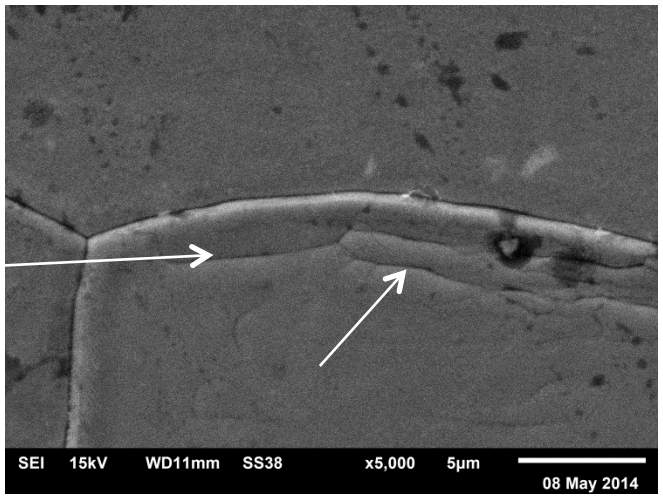
SEM & TEM after high heat load

- Depending on deposited power density and # cycles
  - No surface modification
  - Slip bands (pre-cursor of cracking)
  - Crack and pits
  - Grain boundaries control release of plastic deformation





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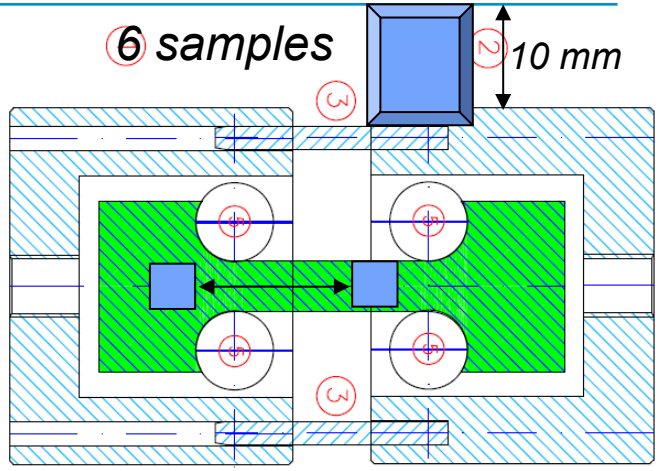
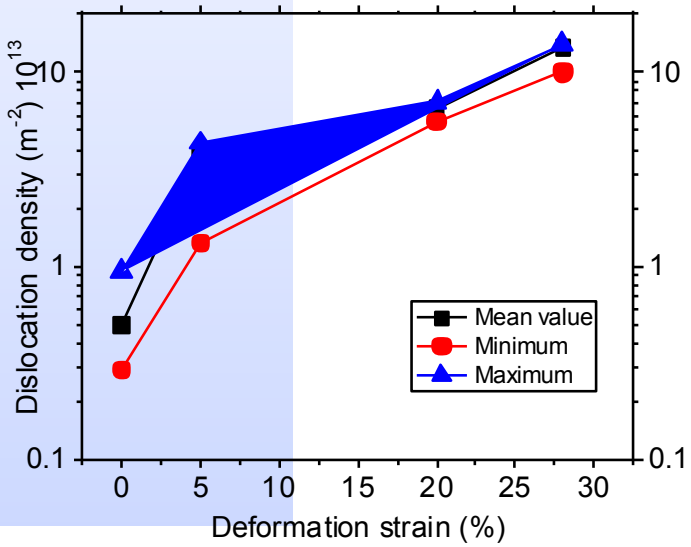
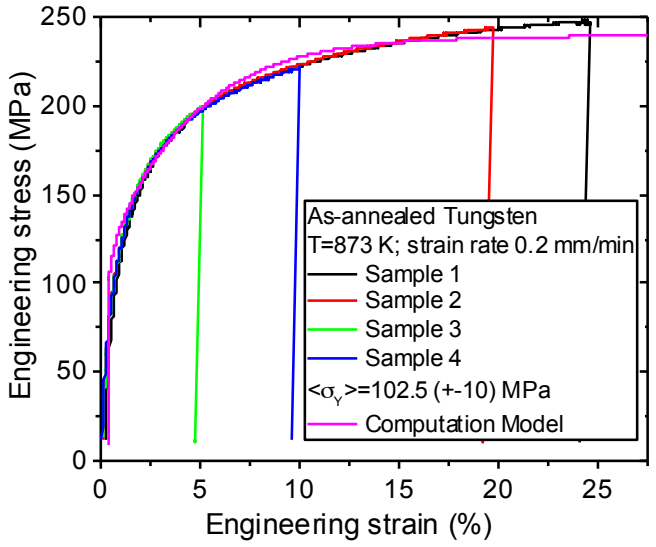
Large-scale plastic deformation

- Large grain material: Recrystallized W
- Perform controlled deformation at 600 C:
- Homogeneous plastic deformation over 10*10 mm
- Produced samples are used for:
  - Plasma exposure
  - Electron/ion/neutron exposure
  - HHF testing





TEM & EBSD study



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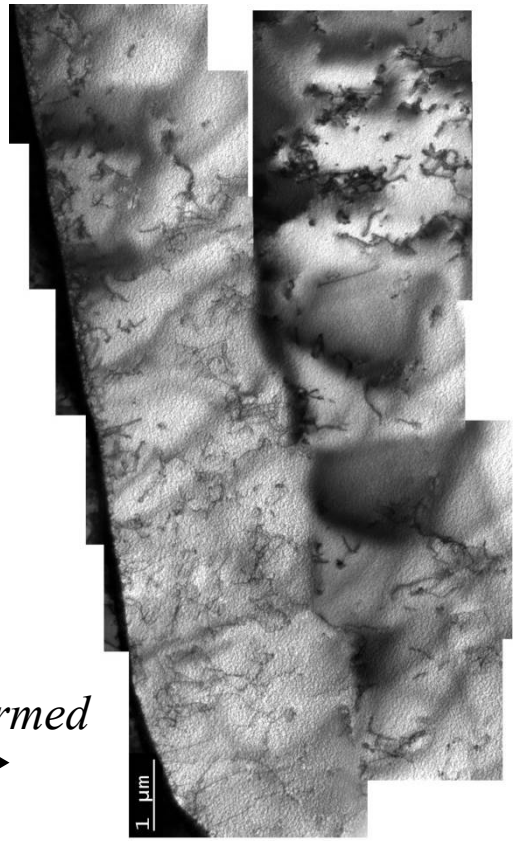
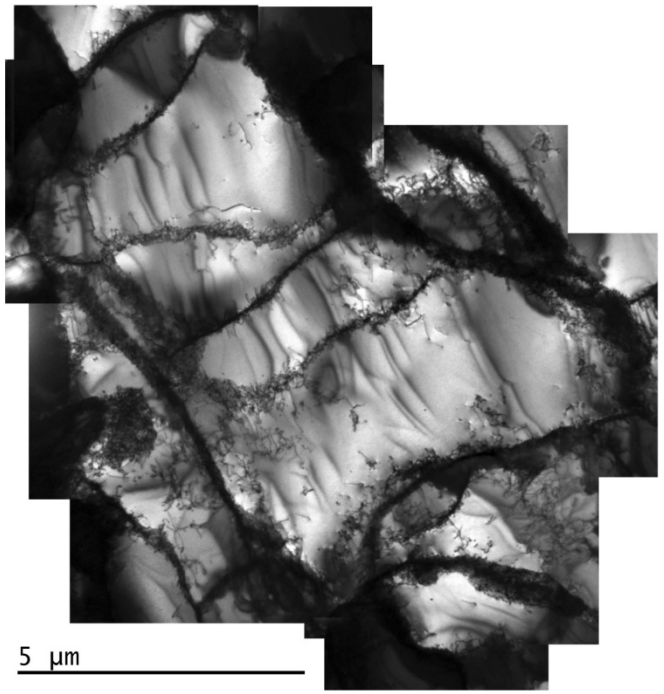
EBSD & TEM after maro-plastic deformation

- Identification of dislocation density and grain-refinement

5% deformed →





20% deformed →

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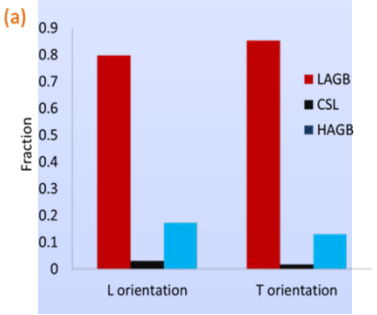
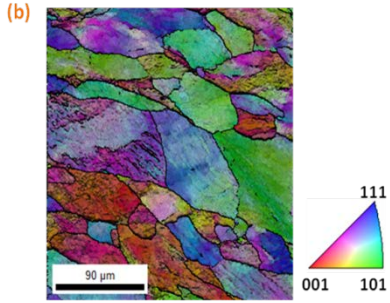
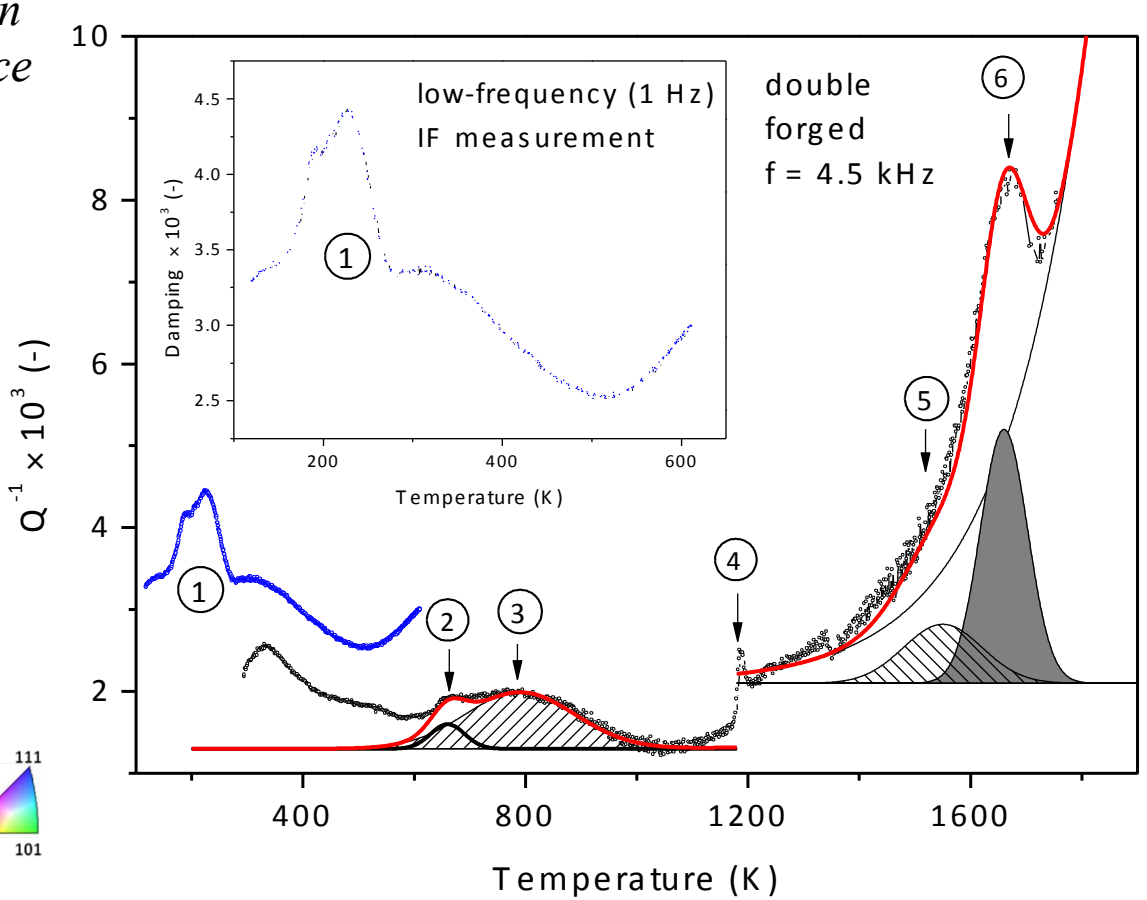
High temperature Internal friction

1 – α peak(s) – dislocation activation
2 – Carbon migration
3 – γ peak – dislocation activation
4 – layer oxide formation - surface
5 – Dislocation-Carbon
6 – recrystallization







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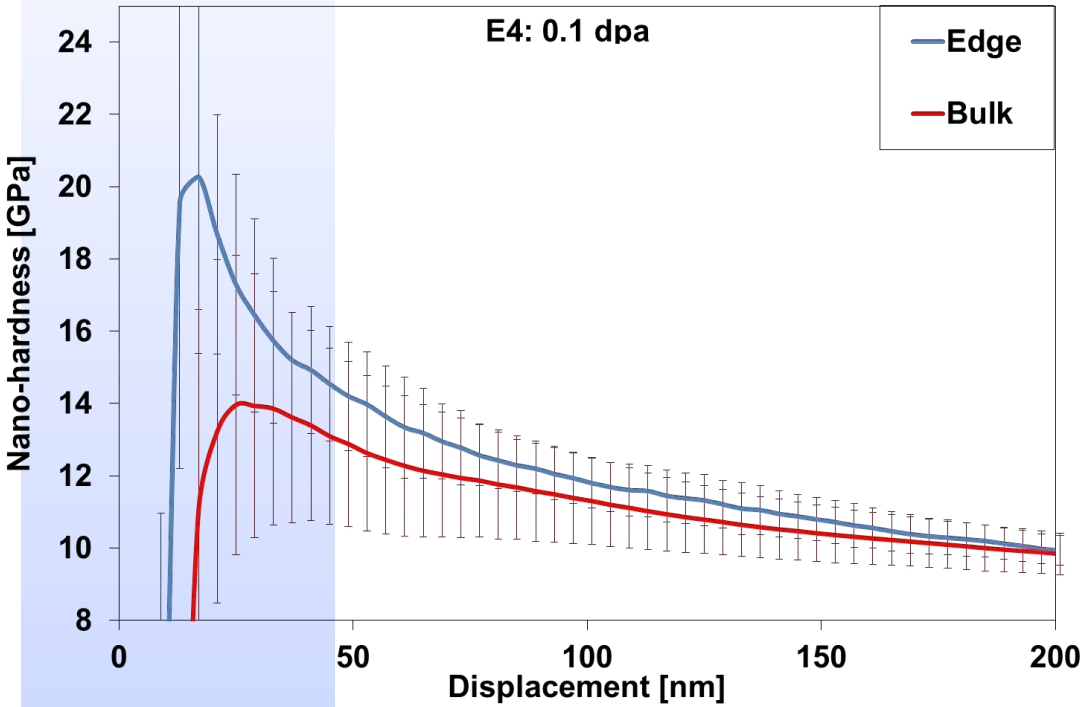
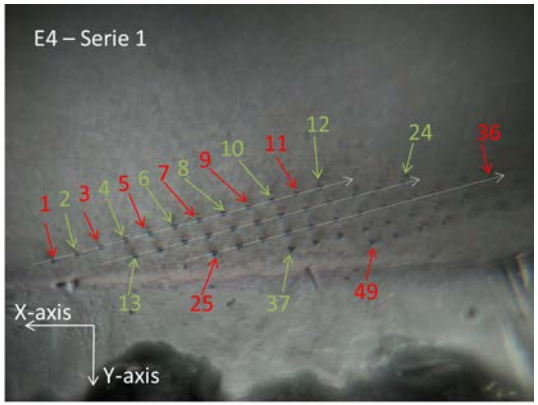
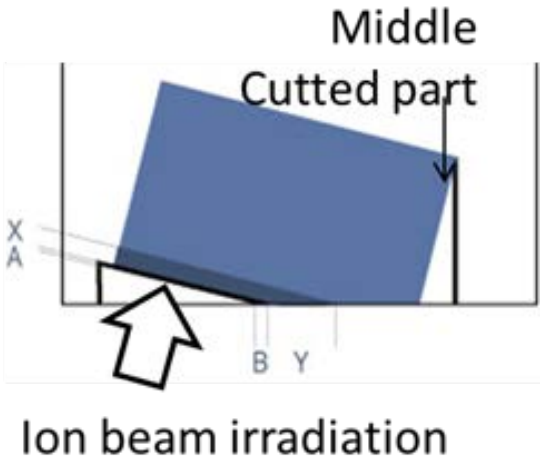
Nano-indentation: ion irradiation

- Detection of radiation damage
  - 20MeV W ions (E_{disp} = 90eV)
  - Max. damage depth ~1.4µm







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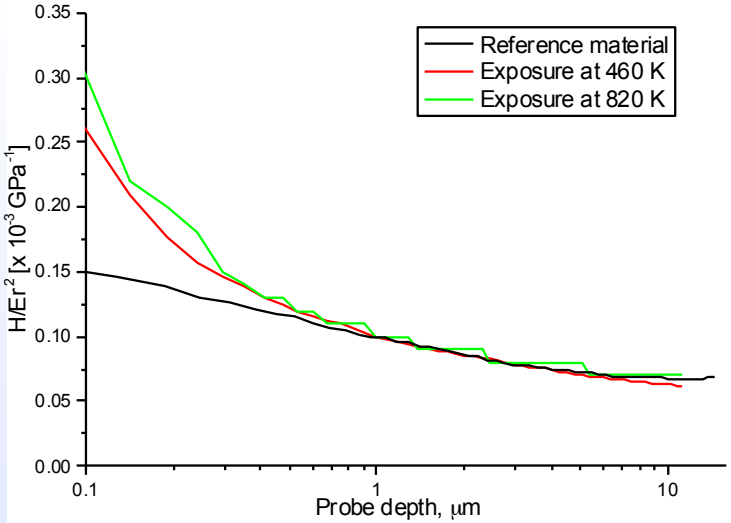
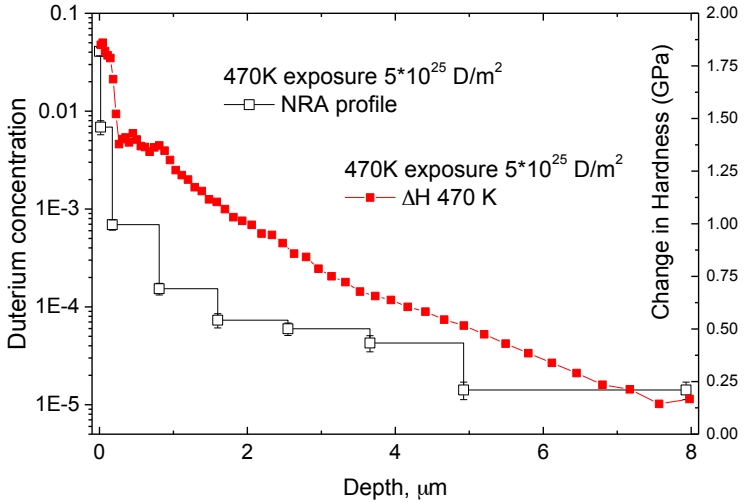
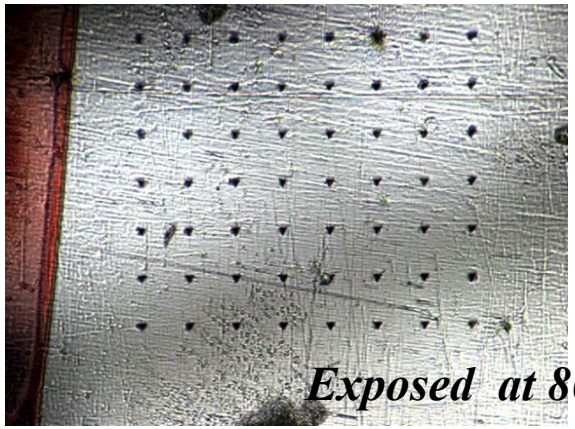
Nano-indentation: exposure in Pilot-PSI

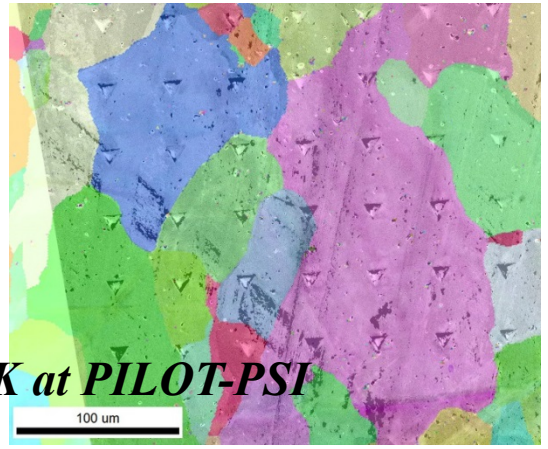
- Detection of plasma-induced damage

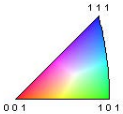






Exposed at 800K at PILOT-PSI





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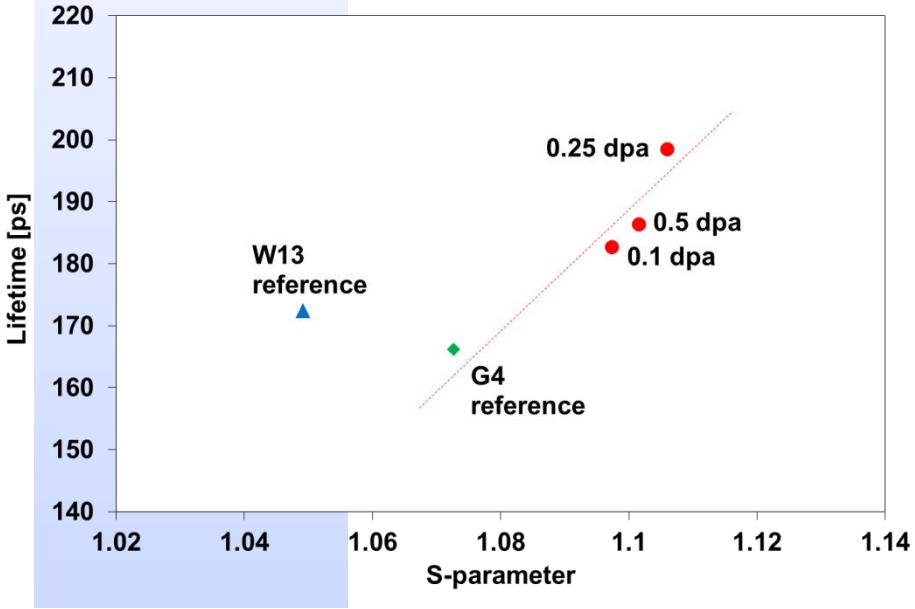
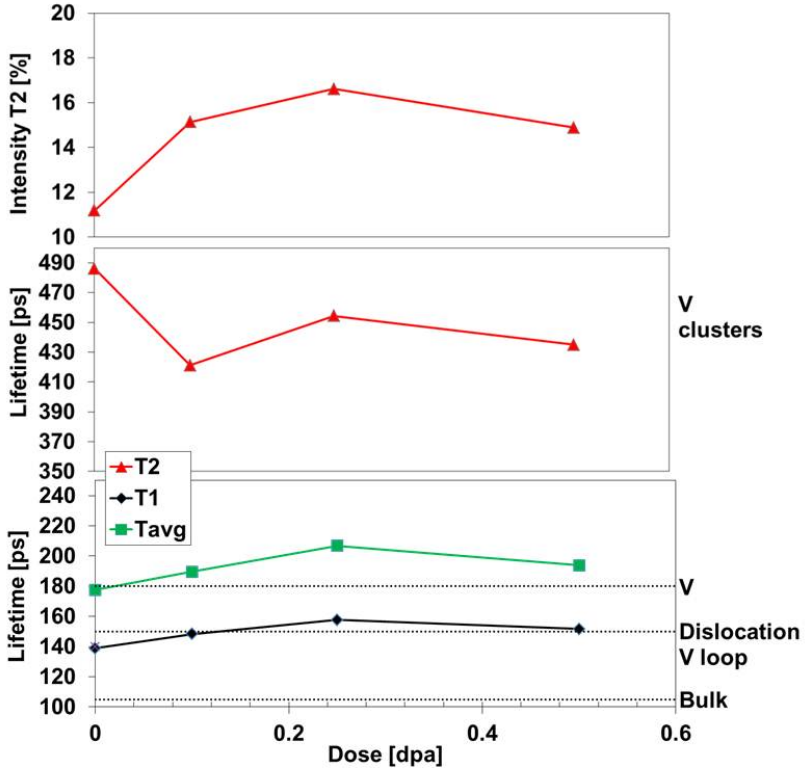
Positron Annihilation Spectroscopy

- Ion irradiation produces both
  - Vacancy clusters
  - Dislocation loops
- Correlation between DB and PALS





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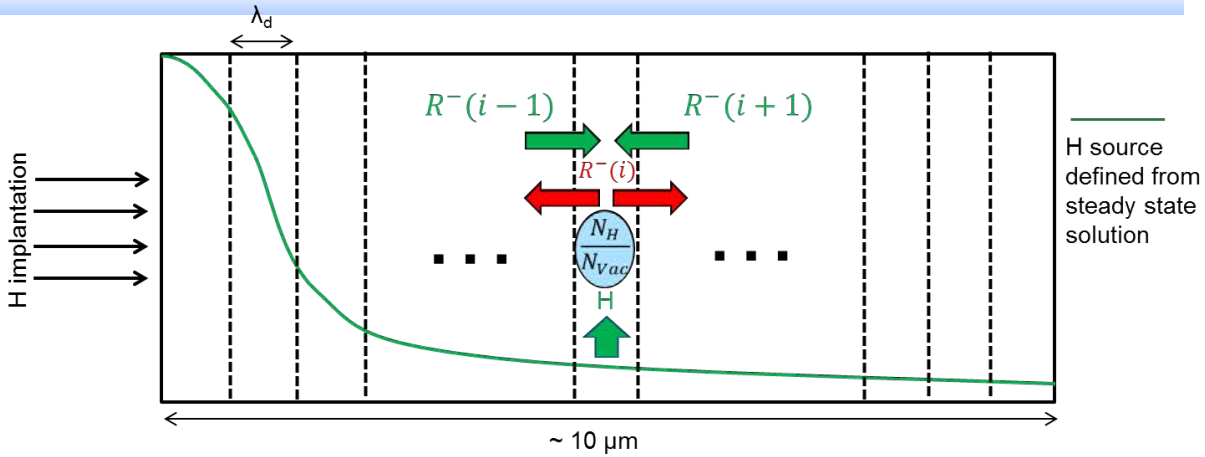
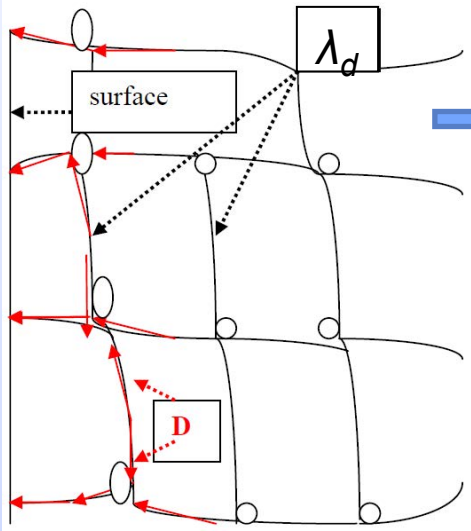
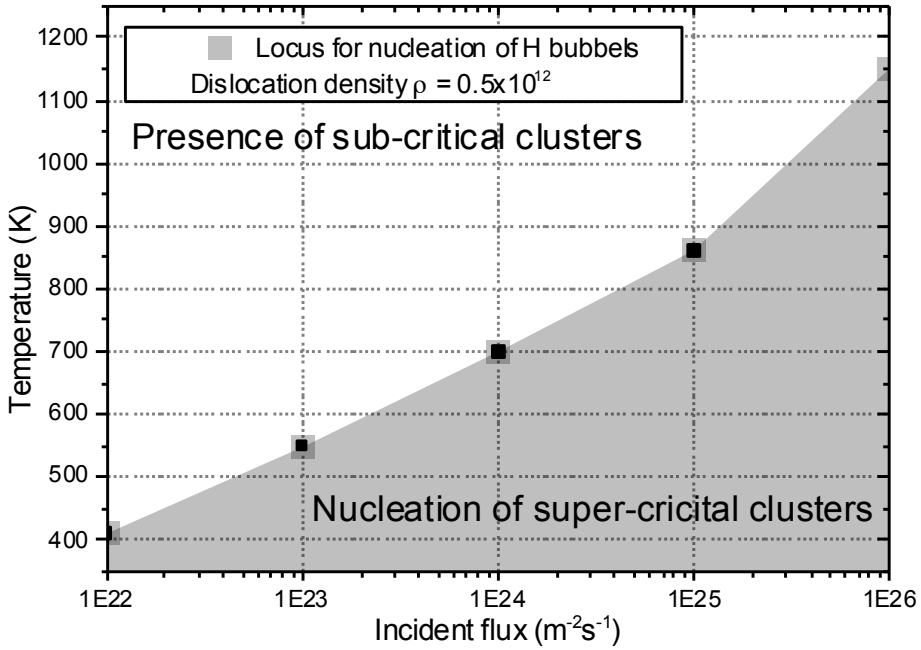
Integrated modelling (I): Retention & microstructure

$$R^-(i) = \upsilon \exp\left(-\frac{E_b}{kT}\right)$$

$$E_b = f\left(\frac{N_H}{N_{Vac}}\right)$$

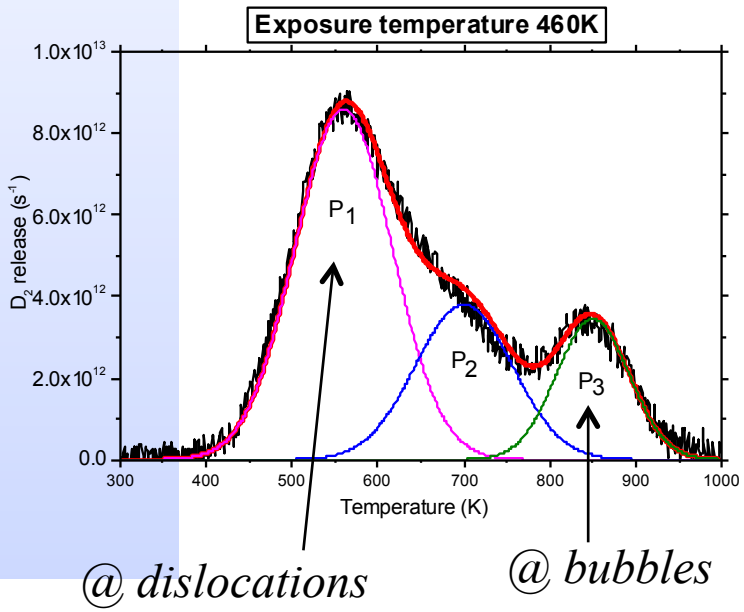


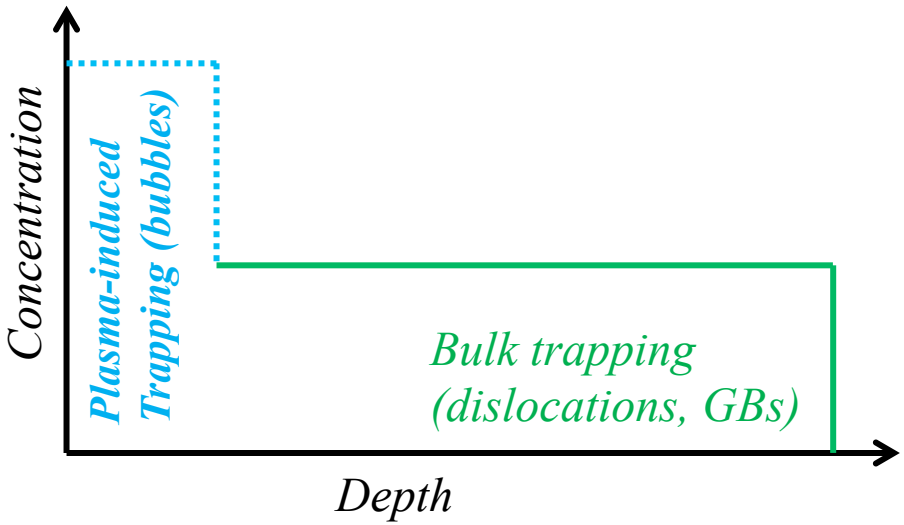




Integrated modelling (II): Retention & microstructure

- Fundamental study
  - Role of natural defects: dislocations and GBs
  - Synergy of He and D interaction
- Mean field rate theory
  - Separating contribution from plasma-induced and bulk trapping





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Outlook 2016-2017

- Dedicated electron irradiation exposure
  - MEPHI, Moscow (3.5 MeV)
  - Russian Academy of Science (5 MeV)
- High temperature NI:
  - 300-700 C (JRC, Petten)
- Investigating role of annealing & plastic deformation in ITER-grade W
  - Pure D and He-D mixed beam (FOM)
  - Accumulation of radiation damage: ion irradiation (Jianming Xue @ Ion Beam Lab, Pekin Univ.)
- Design of “blind capsule” irradiation in BR2
  - 300 - 1000 C
  - From 0.1 up to 0.5 dpa / cycle (21 day)