SAND2019-7627C

Sandia National Laboratories

Helium Radiation Damage in Hot Deformed Tungsten

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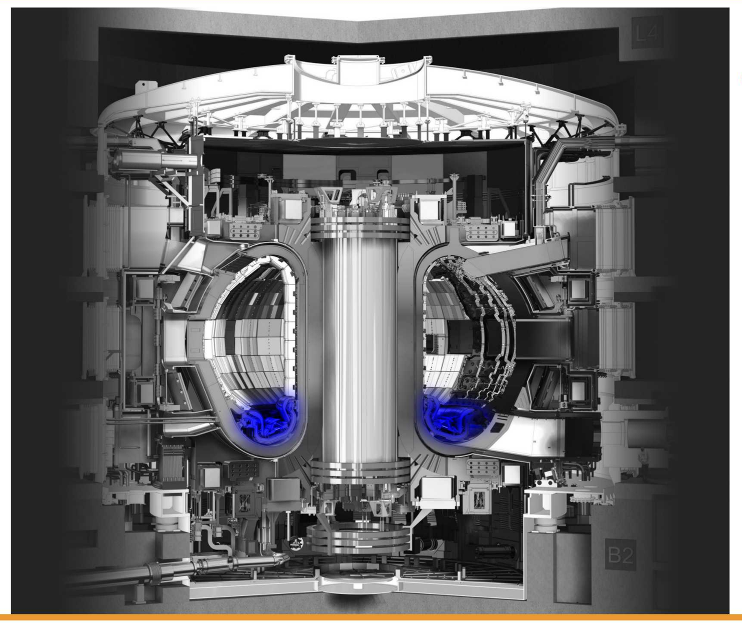
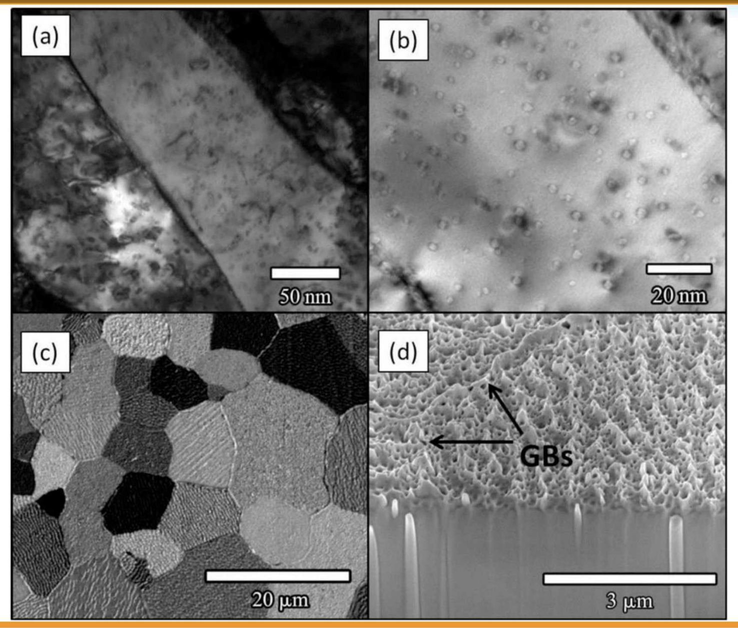
Microstructure Evolution in Extreme Environments

International Thermonuclear Experimental Reactor ITER tokamak fusion reactor

Divertor Region
- Controls the exhaust of waste gas and impurities from the reactor
- Highest surface heat load (20 MW/m^2) (2x spacecraft re-entry)[1]



- Nuclear fusion energy
  - Meets rising energy demands
  - Less green house gas emission
  - Extreme environment
- Plasma facing materials
  - High thermal loads
  - He and H radiation (100 eV-10 keV)
  - Neutron radiation (14 MeV)
- Microstructure changes
  - Defects, voids, dislocations
  - Helium bubble formation
  - Nanofuzz

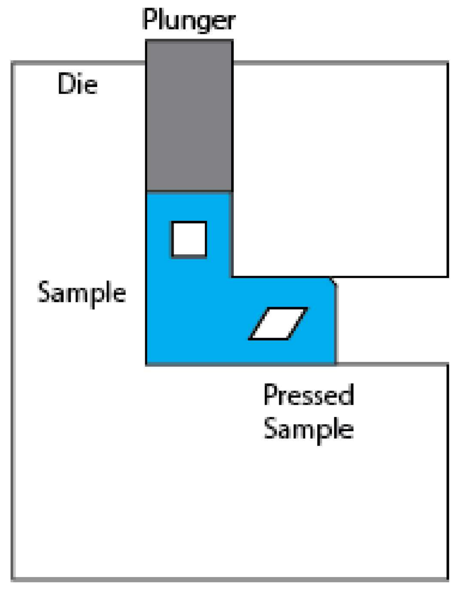


TEM (a,b) of ultrafine grained tungsten after irradiation by 2 keV He^+ radiation to fluence of 3.2 x 10^{19} at a temperature of 950 °C.

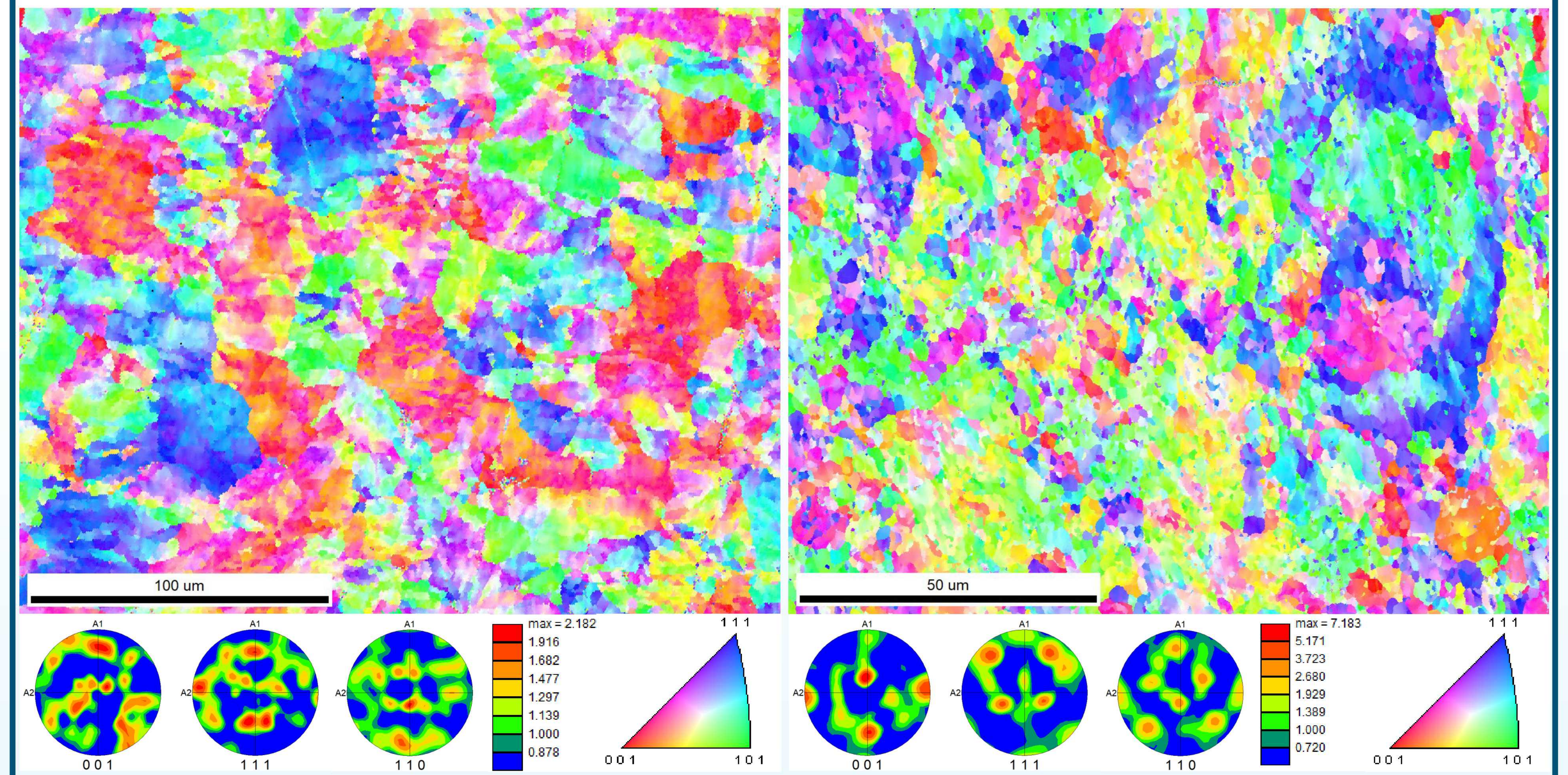
SEM (c,d) of ultrafine grained tungsten after 30 eV He^+ radiation to fluence of 10^{26} at a temperature of 1200 °C. [2]

Equal Channel Angular Extrusion

- Multiple routes
  - Single pass (1A)
  - 2 passes, 180° (2C)
  - 4 passes, 180°, 90°, 180° (4E)
  - 4 passes, 90° ($4B_C$)
- Microstructure
  - Ultrafine grains
  - Sub-grains
  - Highly deformed
  - Elongated grains in extrusion direction
- Helium diffusion pathways



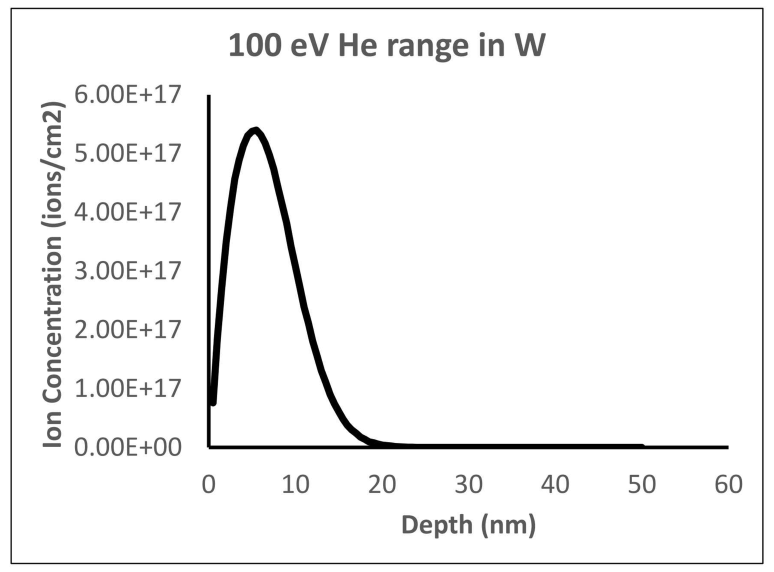
Schematic of equal channel angular extrusion. 90° angle change. Billets were clad in stainless steel then heated to processing temperature of 1000 °C. Tooling was heated to 300 °C. Ram speed was 25 mm/s. [4]



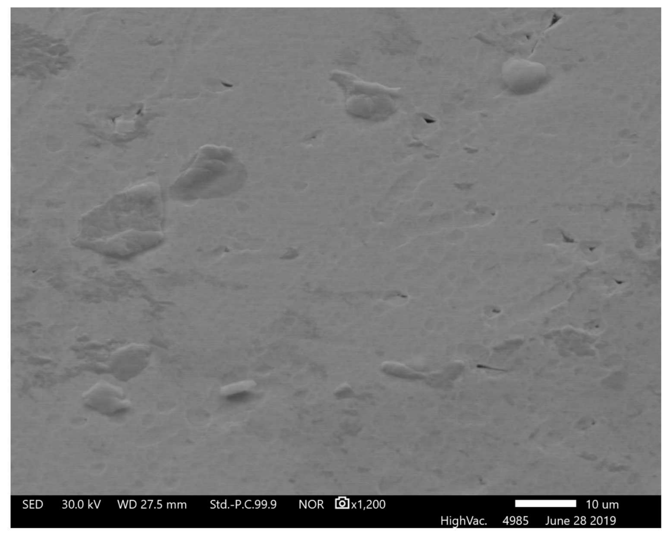
Electron Backscatter Diffraction maps of equal channel angular extrusion processed tungsten depicting elongated grains in the extrusion direction and highly deformed sub-grain structure on the order of micrometers. Pole figures lack strong directional texture.
Route 4E (left) and Route 4BC (right)

Helium Ion Implantation

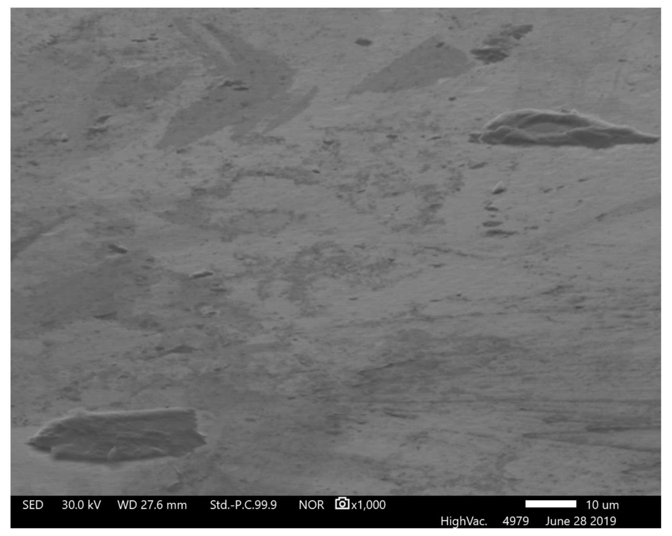
- Room temperature 100 eV He^+ irradiation to fluence of approximately 10^{19} ions/cm^2
- Elongated grain boundaries oriented normal to irradiation surface



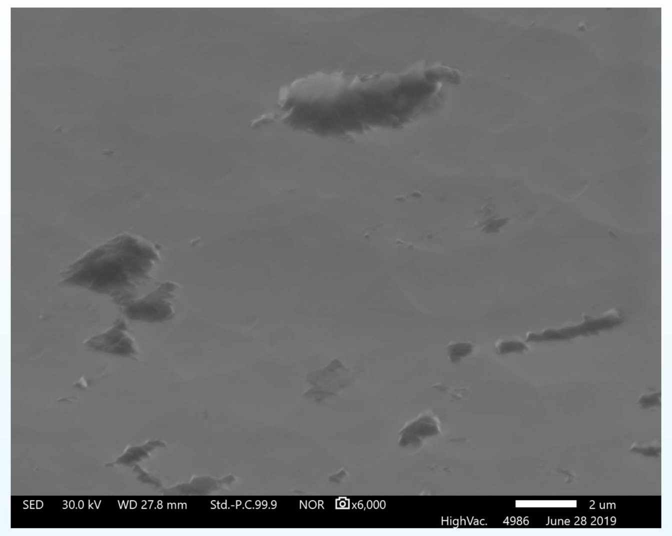
SRIM Monte Carlo simulation of He ion implantation profile into W with fluence of 10^{19}



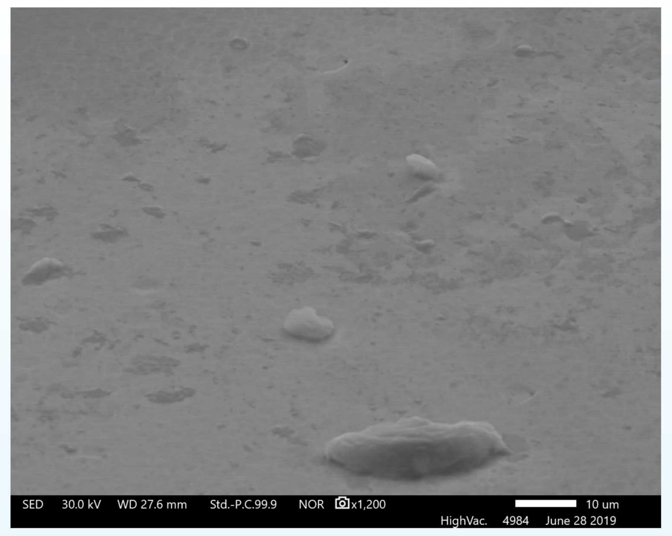
$4B_C$
Blisters on order of 5-10 μm



4E
Blisters on order of 1-30 μm



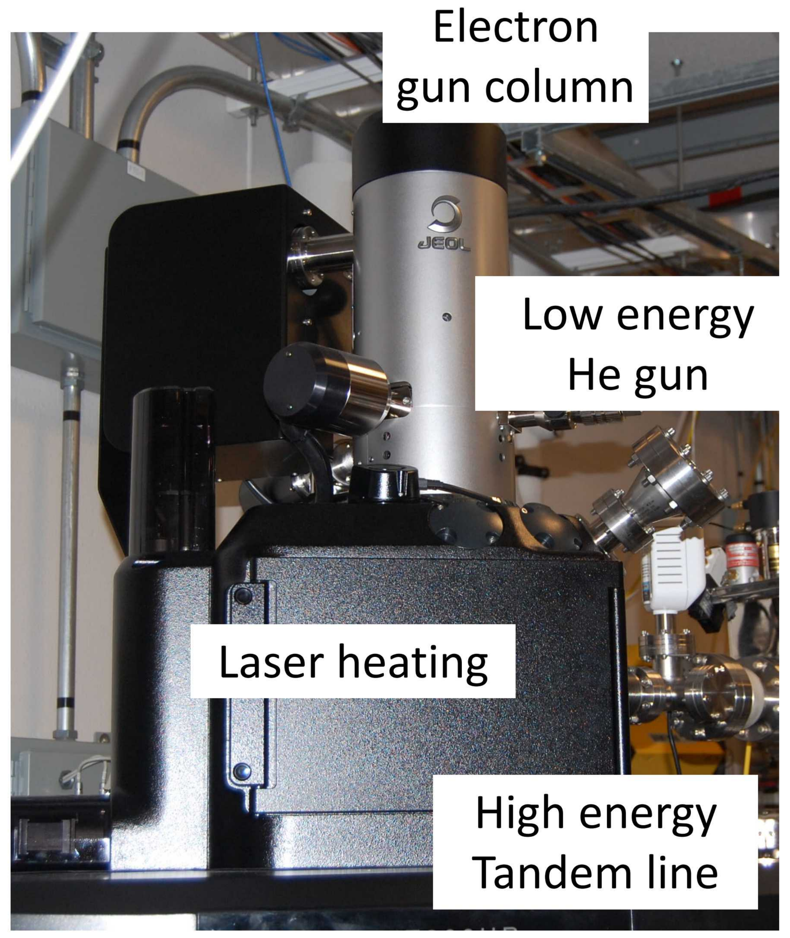
2B
Blisters on order of 0.2-2 μm



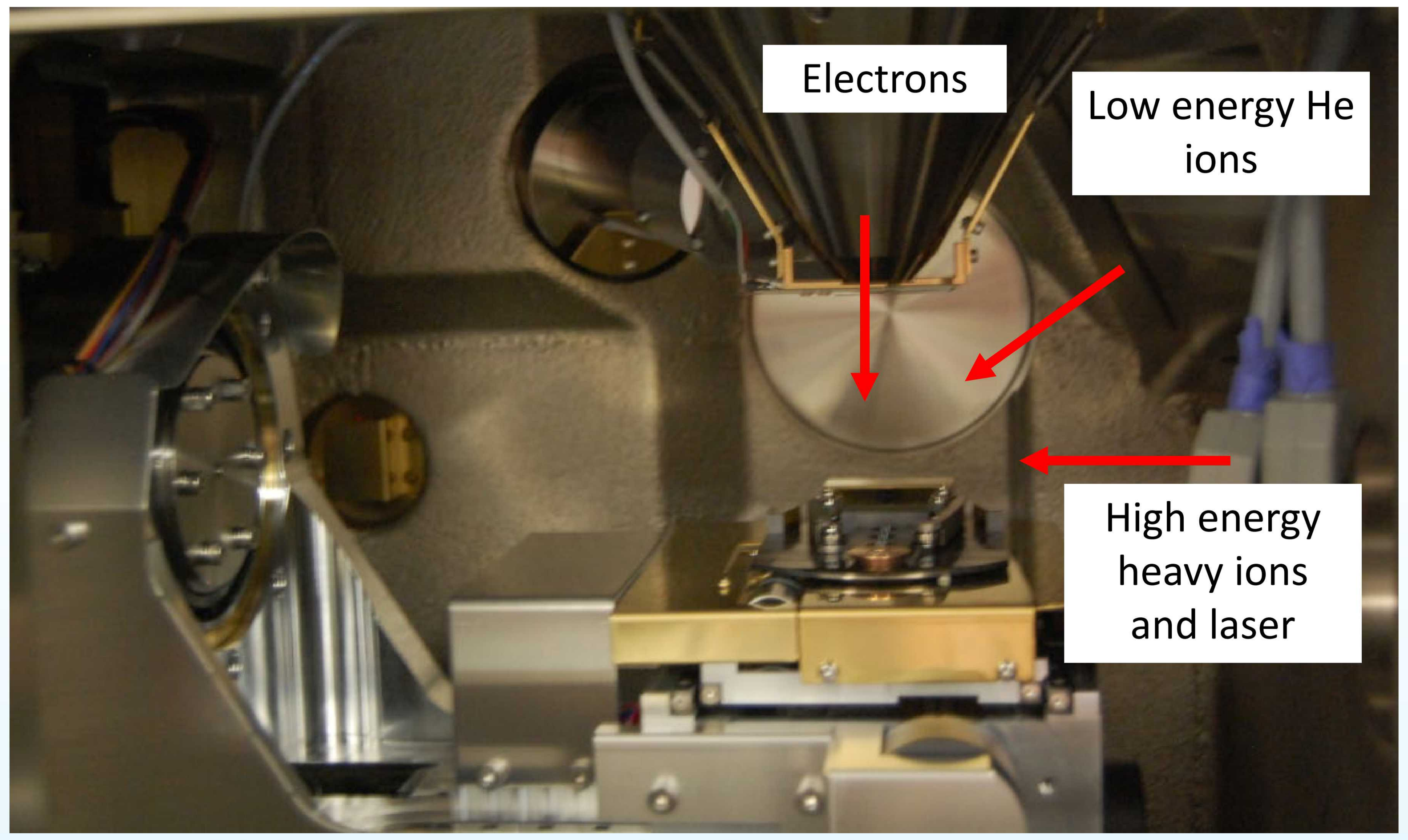
1A
Blisters on order of 2-10 μm

Instrumentation Development

- in-situ SEM
  - Ion Irradiation
  - Heating (Laser, stage)
  - Mechanical testing
- Real time viewing of microstructure and surface evolution
- Simulates high temperature and complex radiation environment



JEOL IT300HRLV scanning electron microscope with attached He ion gun, 1064 nm laser, and tandem beam line.



Interior of SEM depicting stage with ability for simultaneous irradiation by low energy He ion, high energy heavy ion, laser and electron beams.

References

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[3] D. Chen, N. Li, D. Yuryev, J.K. Baldwin, Y. Wang, M. J. Demkowicz, Self-organization of helium precipitates into elongated channels within metal nanolayers, Science Advances, 3:11 (2017)
[4] S. N. Mathaudhu, A. J. Derosset, K.T. Hartwig, L. J. Kecskes, Microstructures and recrystallization behavior of severely hot-deformed tungsten, Materials Science and Engineering: , 3, (2009) p 28-31

Acknowledgements

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