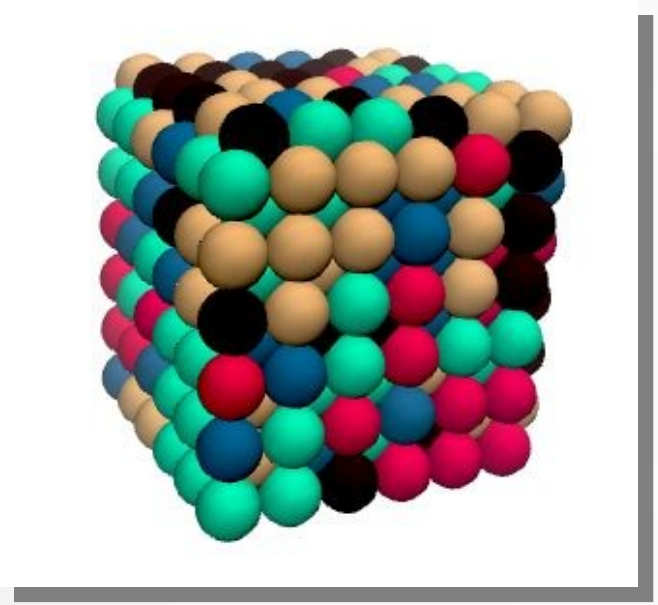
Deuterium in WMoTaNbV high-entropy alloy

Anna Liski, Marianna Kemell, Guanying Wei, Jesper Byggmästar, Flyura Djurabekova, Kai Nordlund, Tomi Vuoriheimo, Tommy Ahlgren, Kalle Heinola, Jouni Heino, Yevgen Zayachuk, Anna Widdowson, Ko-Kai Tseng, Ting-En Shen, Che-Wei Tsai, Jien-Wei Yeh, Kenichiro Mizohata

WMoTaNbV high-entropy alloy



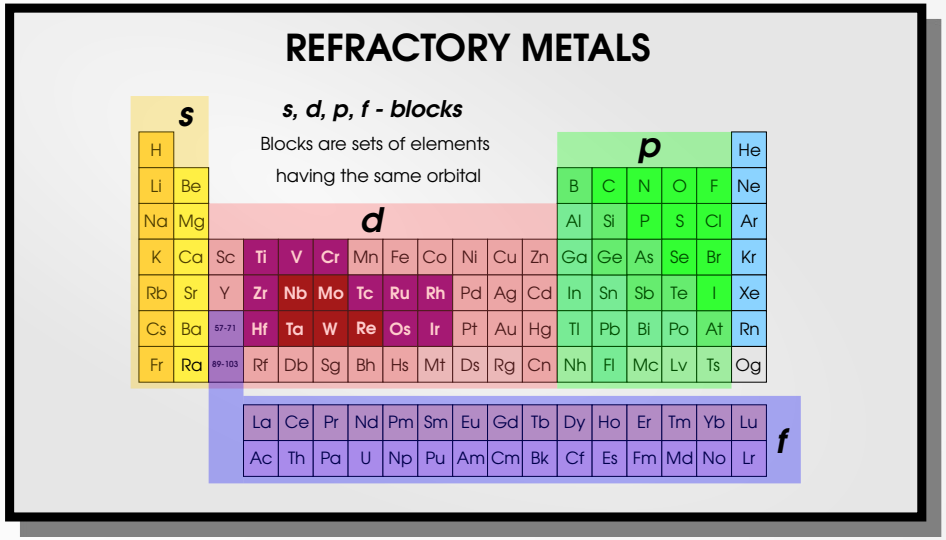
W Mo Ta Nb V

High-entropy alloy

- ≥ 5 components
- Random
- Equimolar

Refractory metals

- High melting point
- Hardness
- Creep resistance
- Corrosion resistant
- Irradiation tolerant

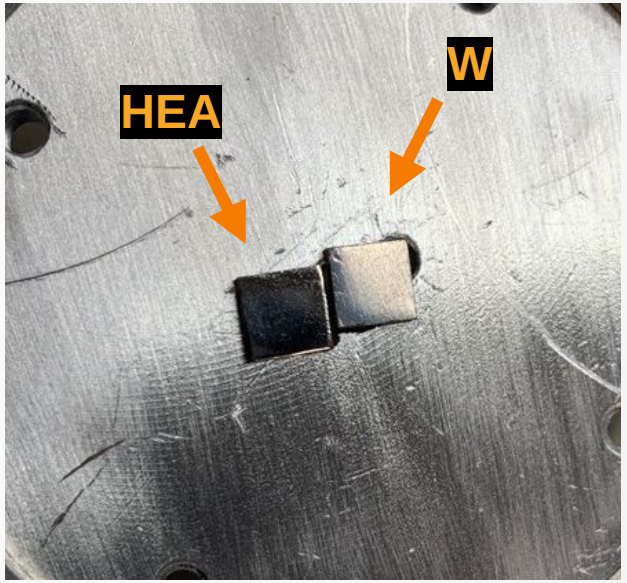


Extreme environments
→ Fusion first wall
Interaction with hydrogen

WMoTaNbV samples

Manufacturing
Powder
→ Vacuum arc meltelting
Impurities of N, C and O
→ from the process

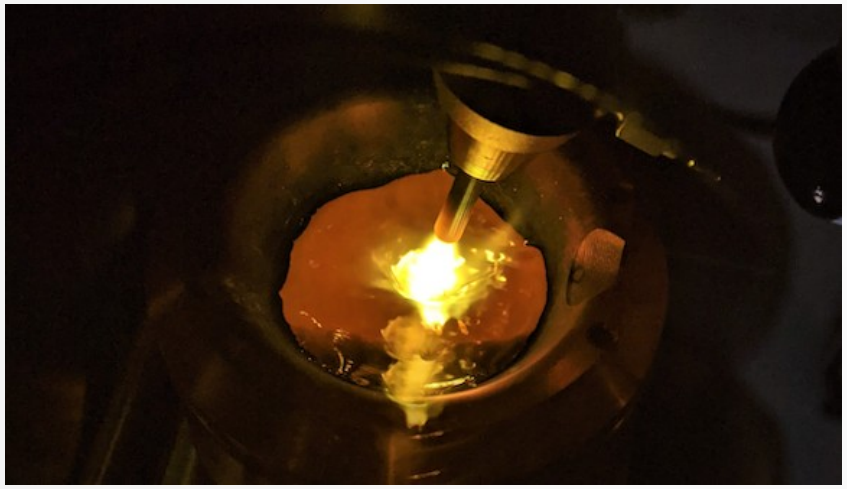
Sample preparation
Polishing
→ mirror surface
Annealing
→ 1000 C° 24 h
→ remove H, N, O and C (partially as CO and CO_2)
→ no recrystallization at T < 1400 C°
→ elemental segregation?



Samples on holder for D implantation

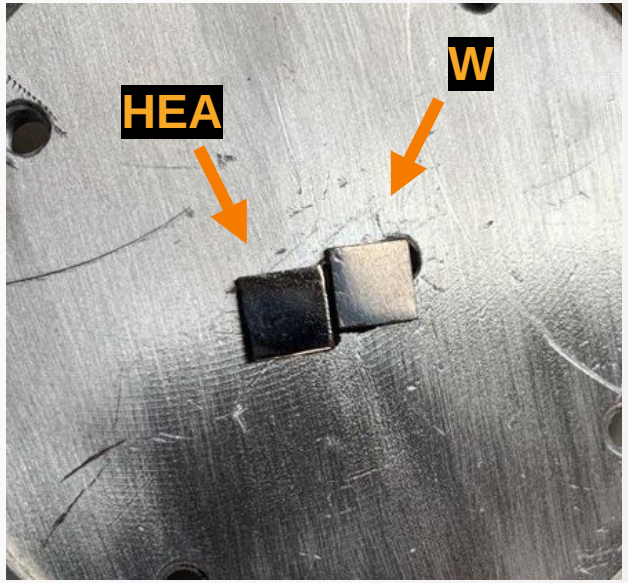
WMoTaNbV samples

Manufacturing
Powder
→ Vacuum arc meltelting
Impurities of N, C and O
→ from the process



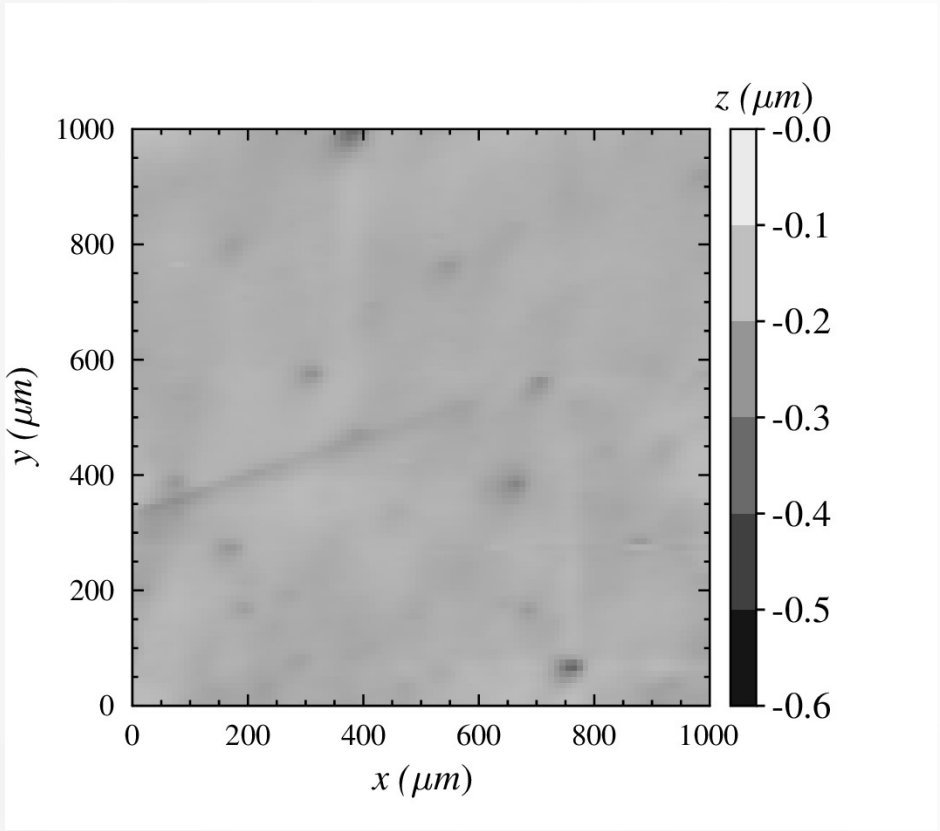
Sample preparation
Polishing
→ mirror surface
Annealing
→ 1000 C° 24 h
→ remove H, N, O and C
(p
–
–

C°

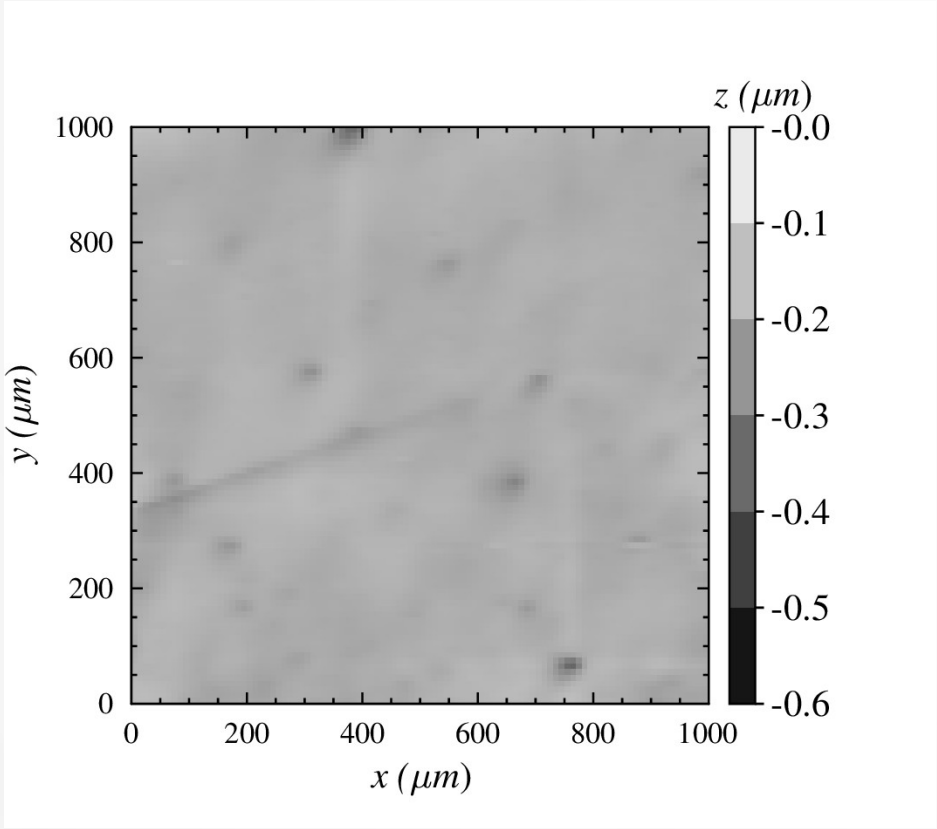


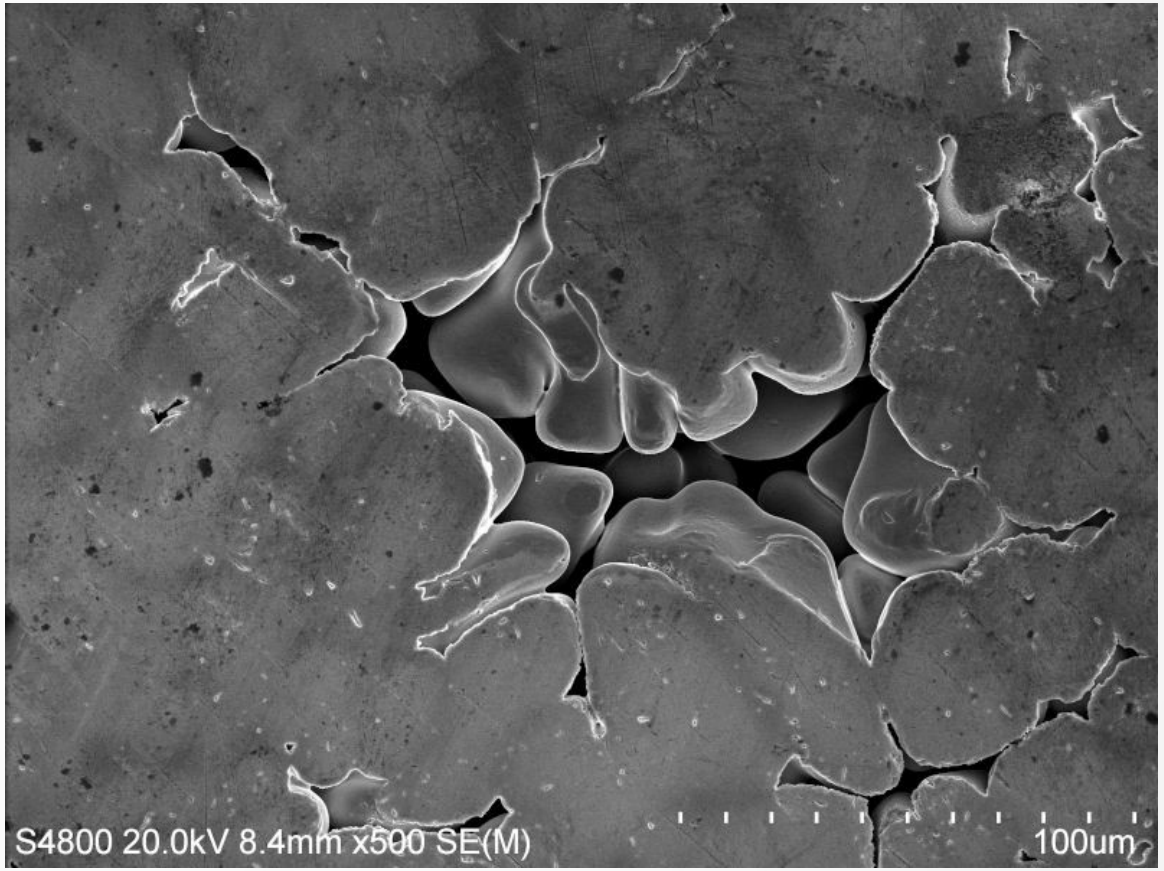
Samples on holder for D implantation

WMoTaNbV samples

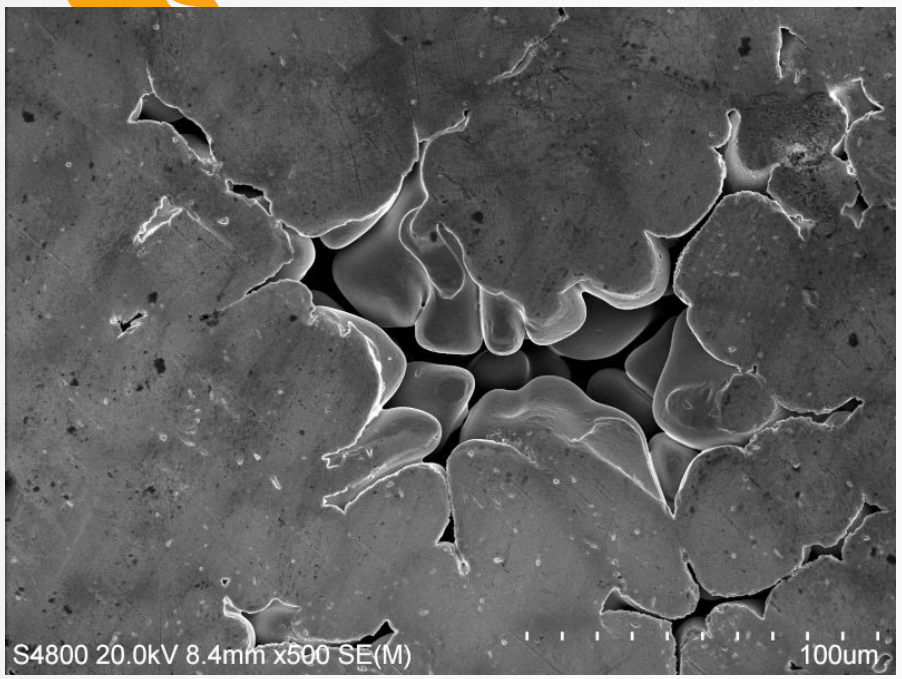


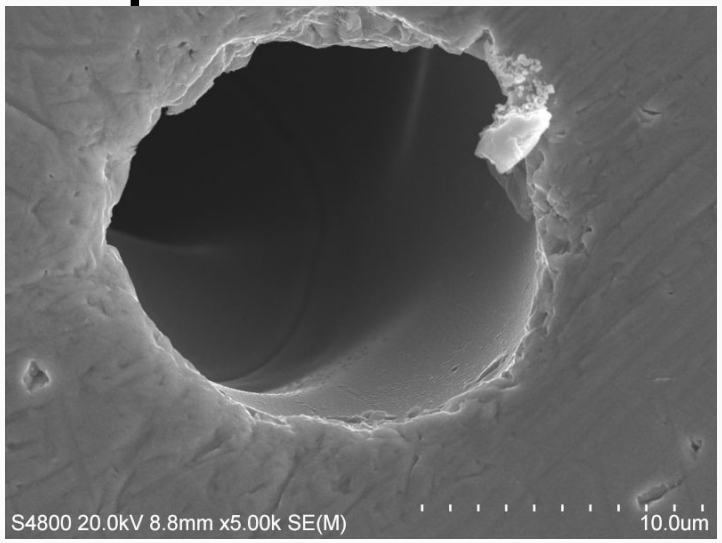
WMoTaNbV samples

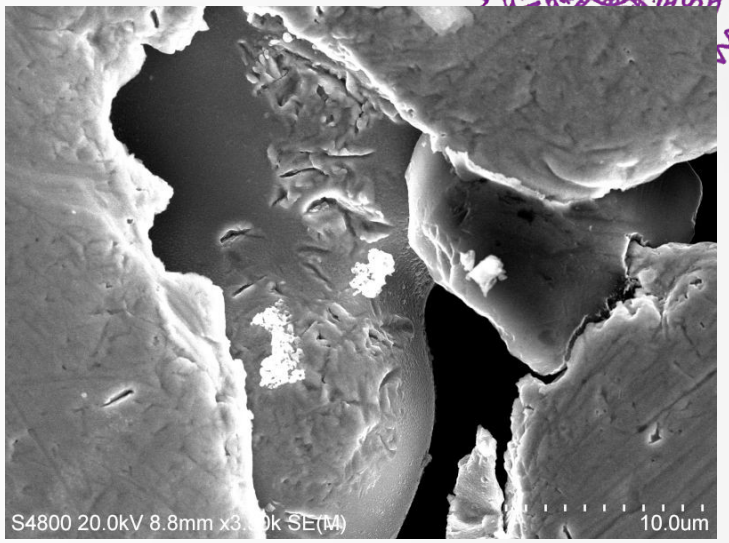


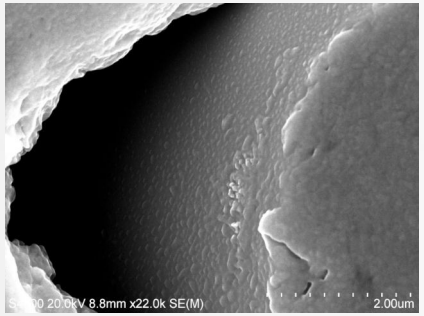


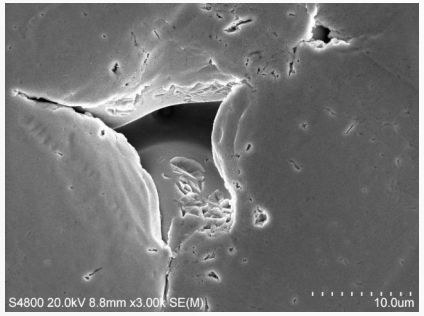
WMoTaNbV samples

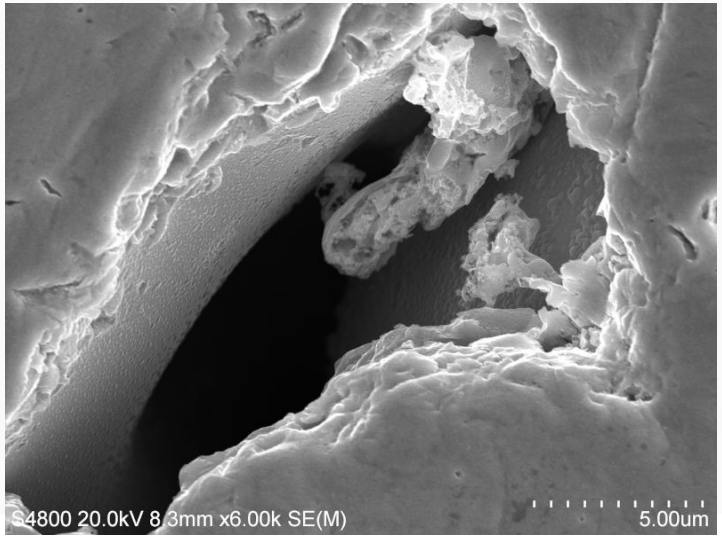


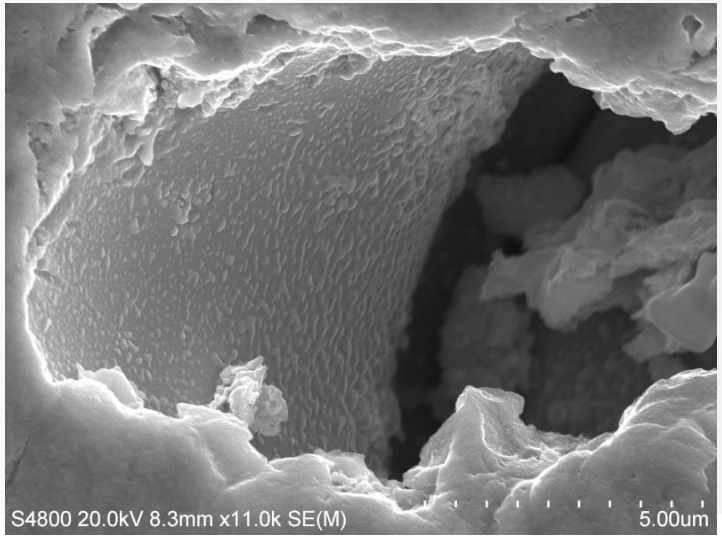




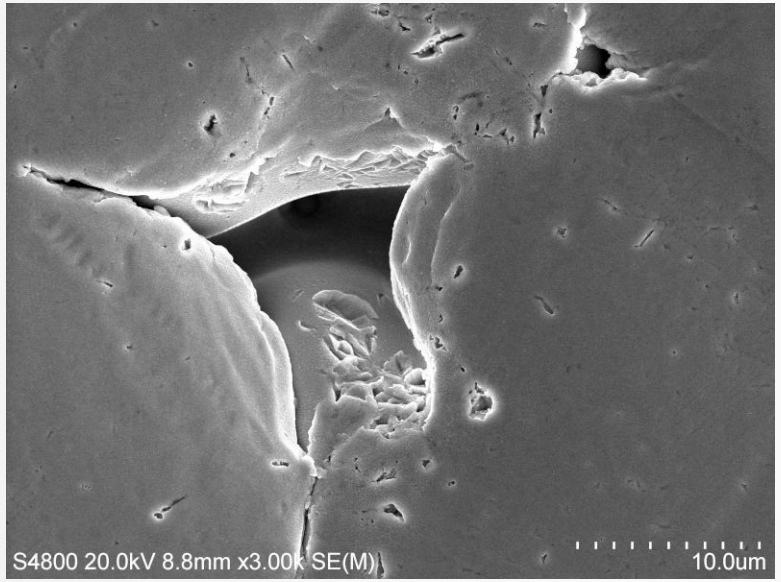


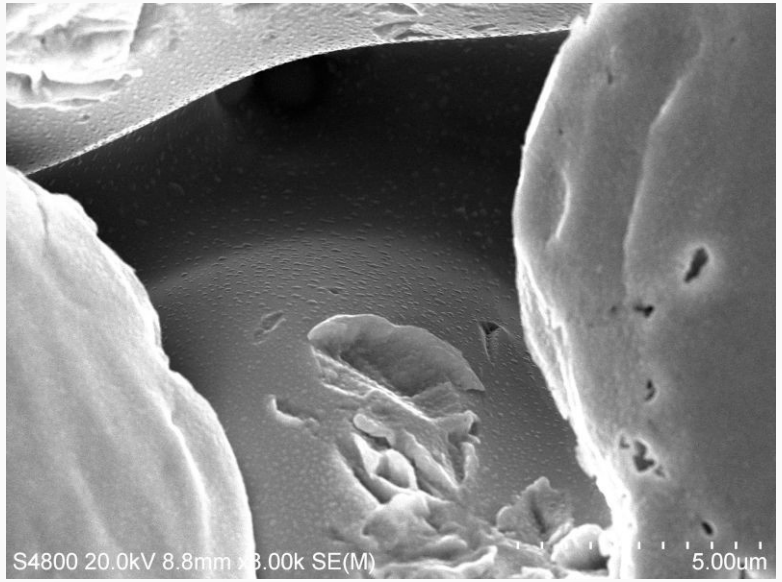


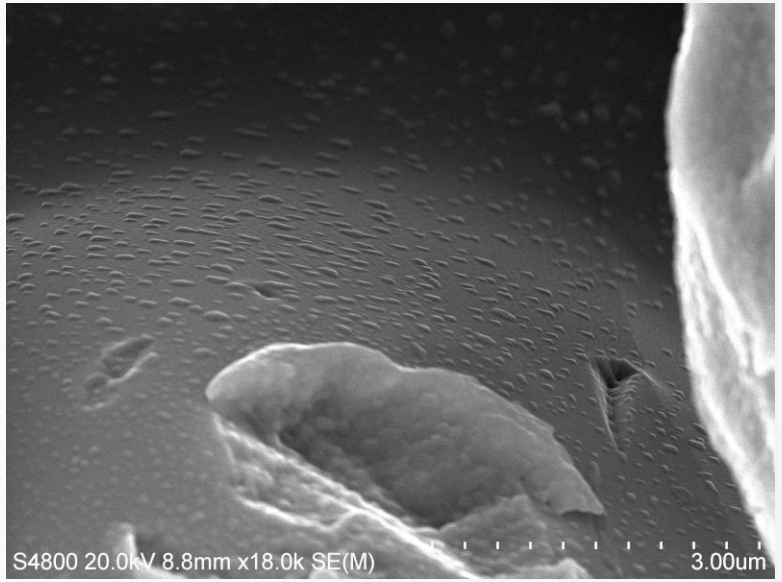




WMoTaNbV samples

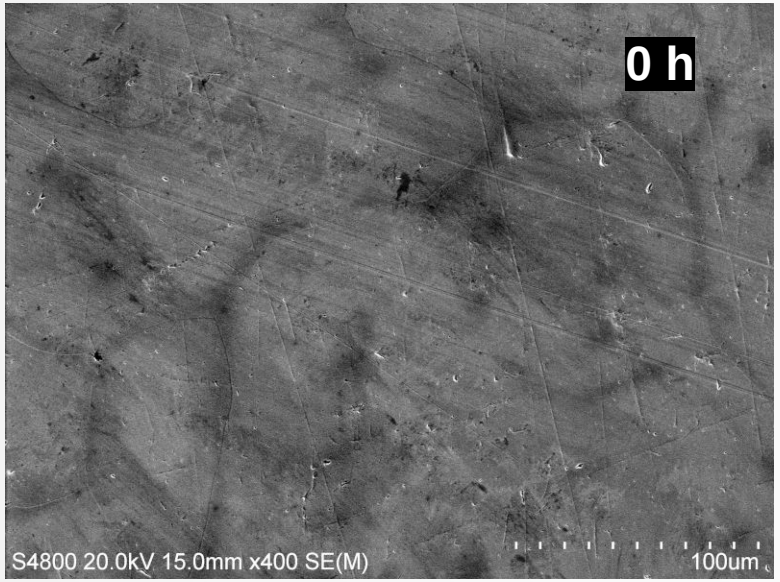


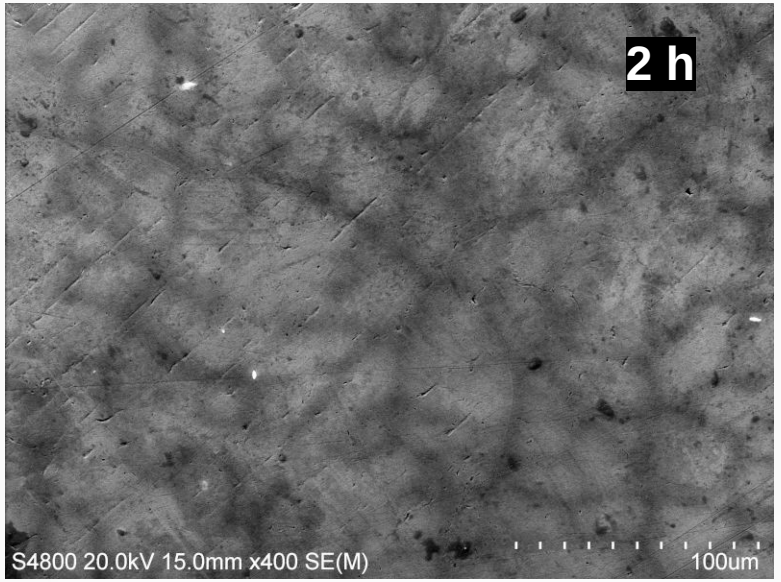


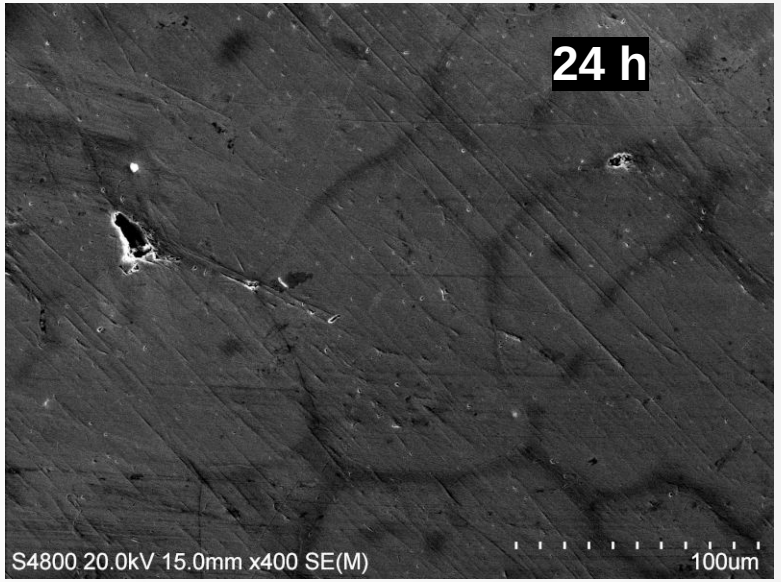


WMoTaNbV hydrogen concentration

1000 C^{o}







WMoTaNbV hydrogen concentration

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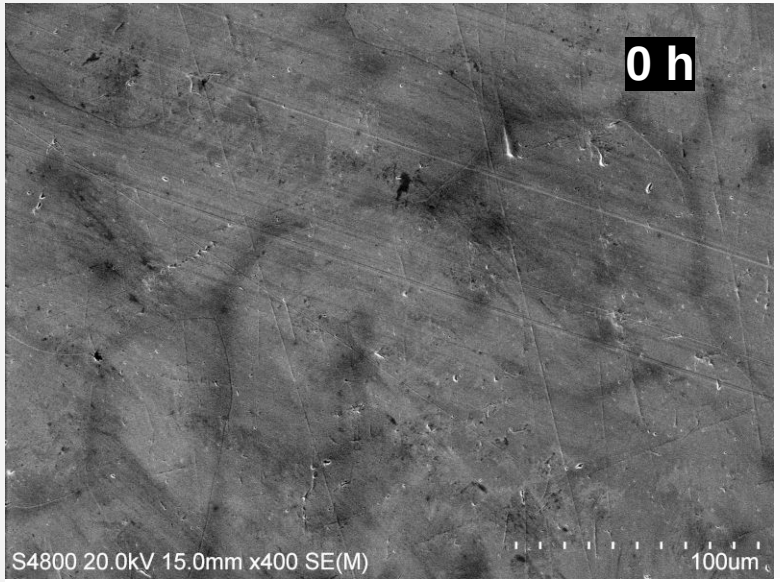
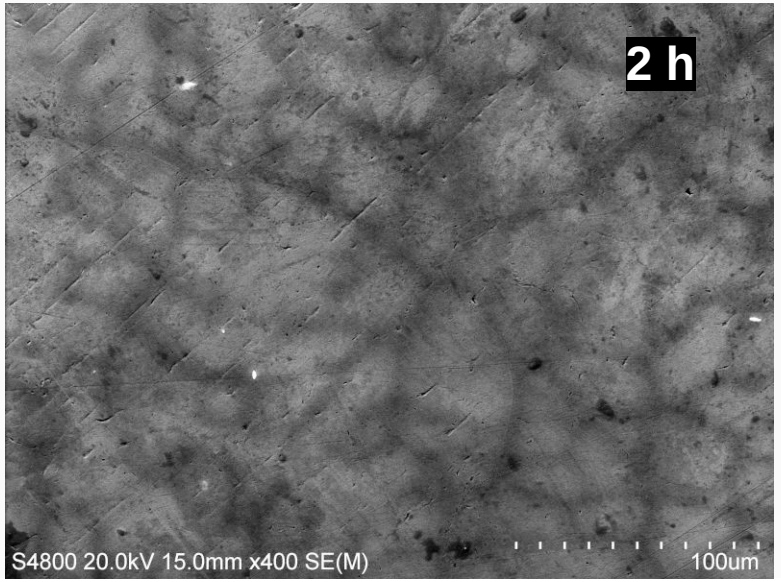
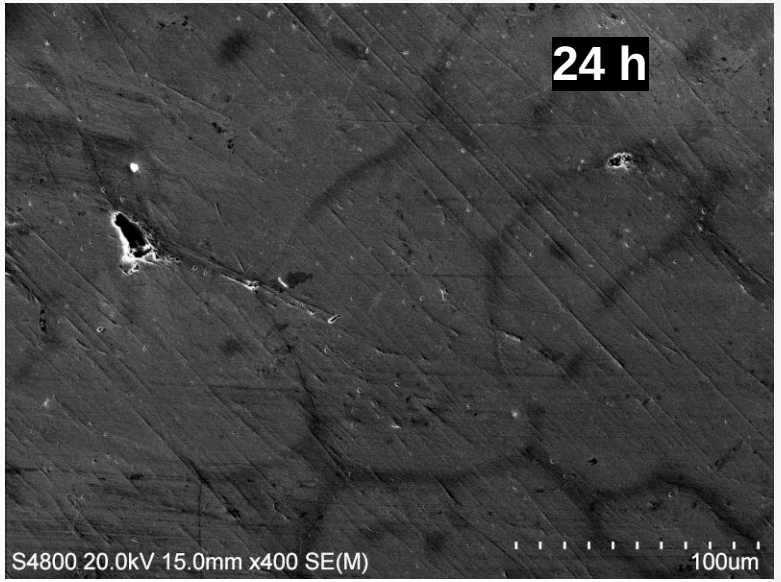
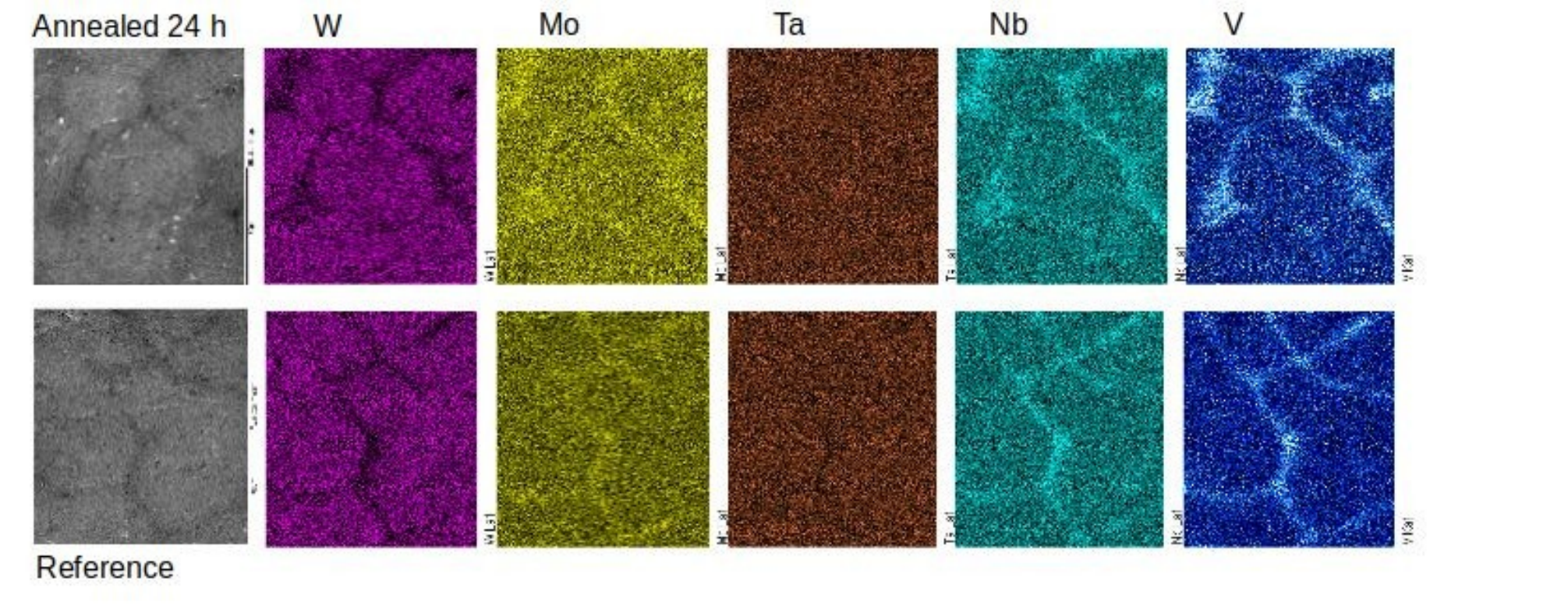




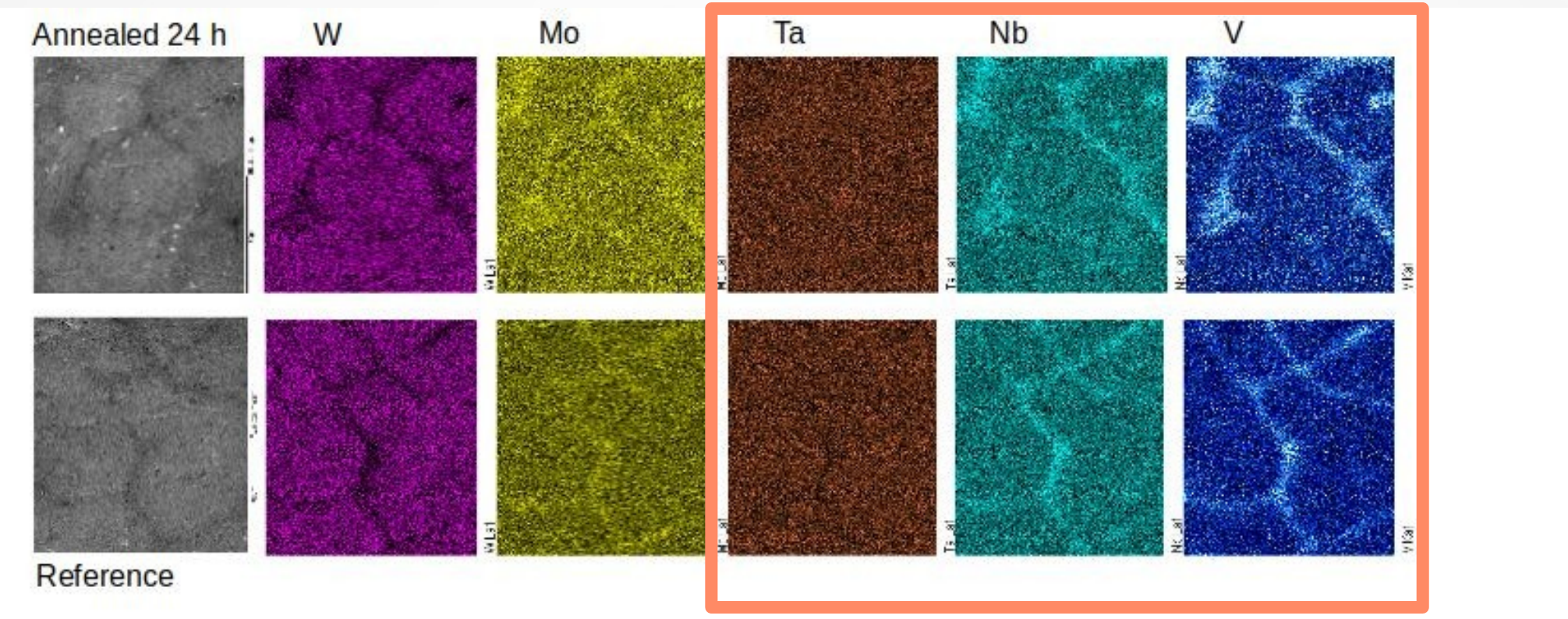


	Grainsize (μm)	Hydrogen concentration (10^{16} H/cm^2)
0 h	120 ± 25	0.42 ± 0.02
2 h	25 ± 7	1.78 ± 0.02
24 h	90 ± 12	0.76 ± 0.03

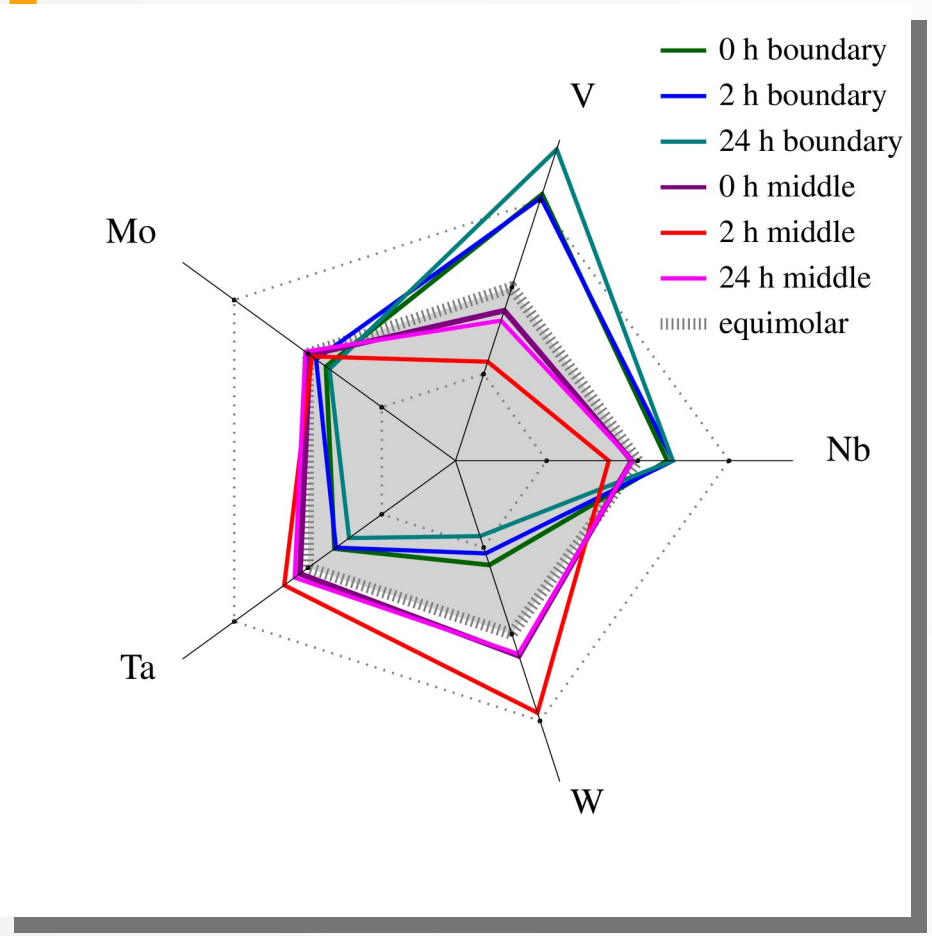
WMoTaNbV elemental segregation



WMoTaNbV elemental segregation



WMoTaNbV elemental segregation



Middle

Relativeley even composition

- \+ W
- \- V

Boundary

Clear differences

- \+ V
- \+ Nb
- \- Ta
- \- W

Annealing time has no effect on the segregation

WMoTaNbV hydrogen concentration

Option #1

Hydrogen absorbed by the elements with negative solution energy

→ Nb and V more prominent at GB

Option #2

Hydrogen attaching to the GB
→ structural defect

BOTH?

	Grainsize (μm)	Hydrogen concentration (10^{16} H/cm^2)
0 h	120 ± 25	0.42 ± 0.02
2 h	25 ± 7	1.78 ± 0.02
24 h	90 ± 12	0.76 ± 0.03

Deuterium implantations to W-irradiated samples

TAMIA – 5 MV electrostatic tandem accelerator
All elements (excluding noble gases)

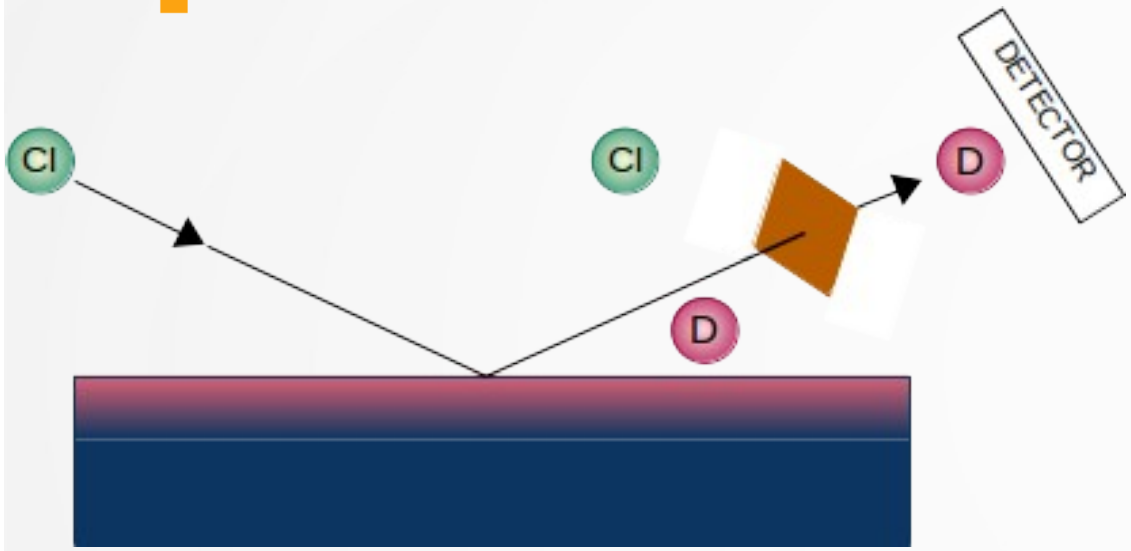
HEA and W
pre-irradiated with W
→ 0, 0.007, 0.03, 0.07, 0.3, 0.7 dpa

KIIA – 500 keV ion implanter
Energy range ~ 50 eV – 500 keV
Beam current max 100 uA
All elements (including noble gases)

Deuterium implantation
Energy → 1 keV/D
Dose → 10^{17} D/cm^2

Retained D measured with ERDA and TDS

Elastic Recoil Detection Analysis



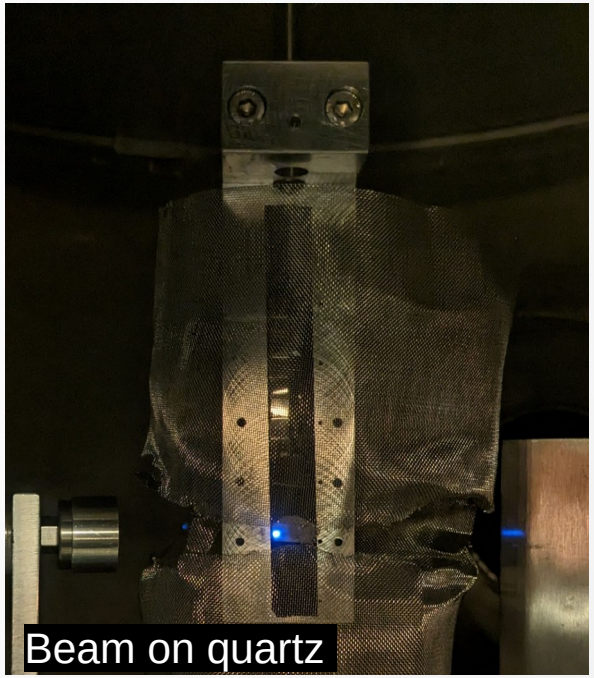

Placement of samples on a holder

Heavy projectile (Cl, Si)

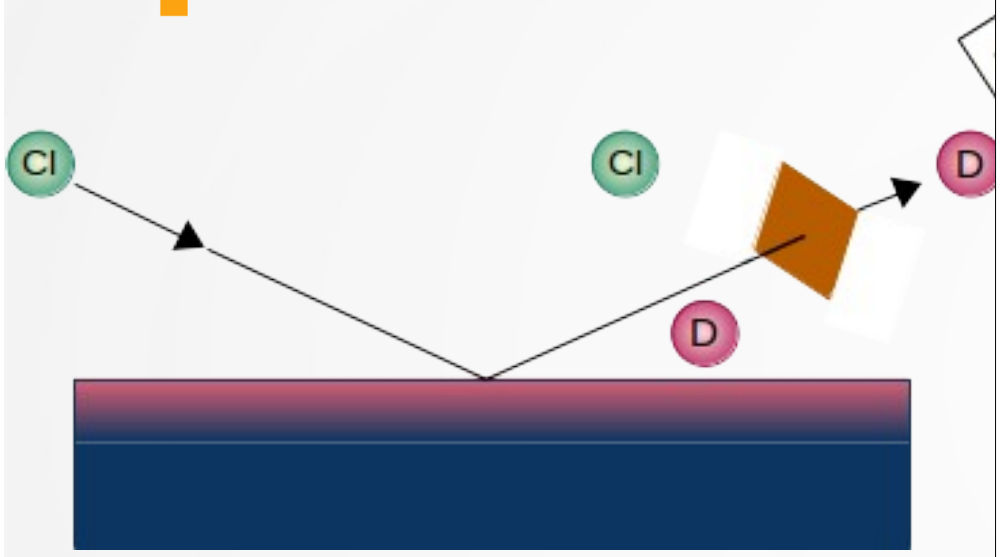
Foil-ERDA
- Light recoils H and D (He possible)
  - → Stopping foil for heavier recolis (havar 4 µm)

TOF-ERDA → All elements

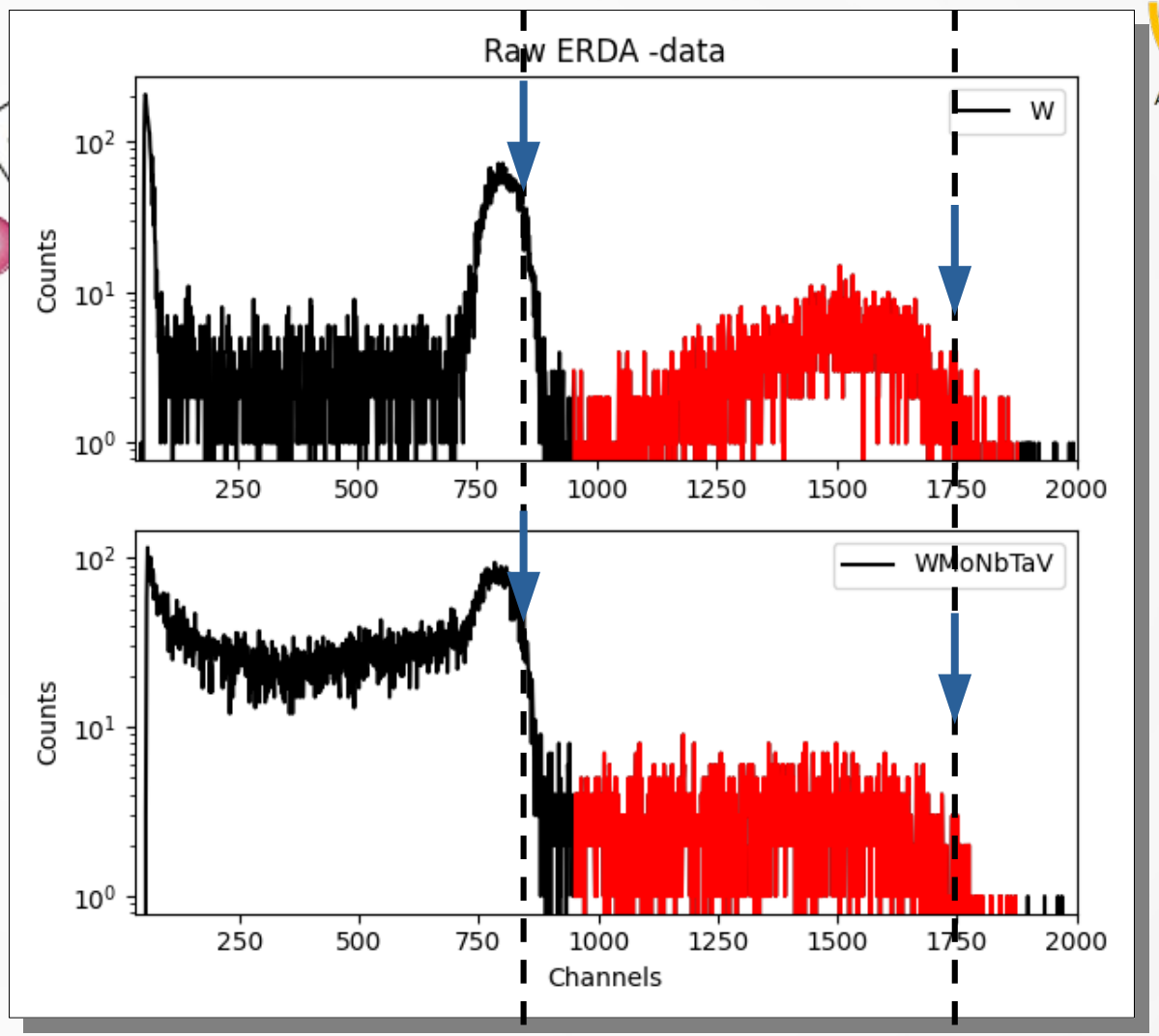
Depth profiling
- → Analysis depth: max 300 – 500 nm


Beam on quartz

Elastic Recoil Detection Analysis



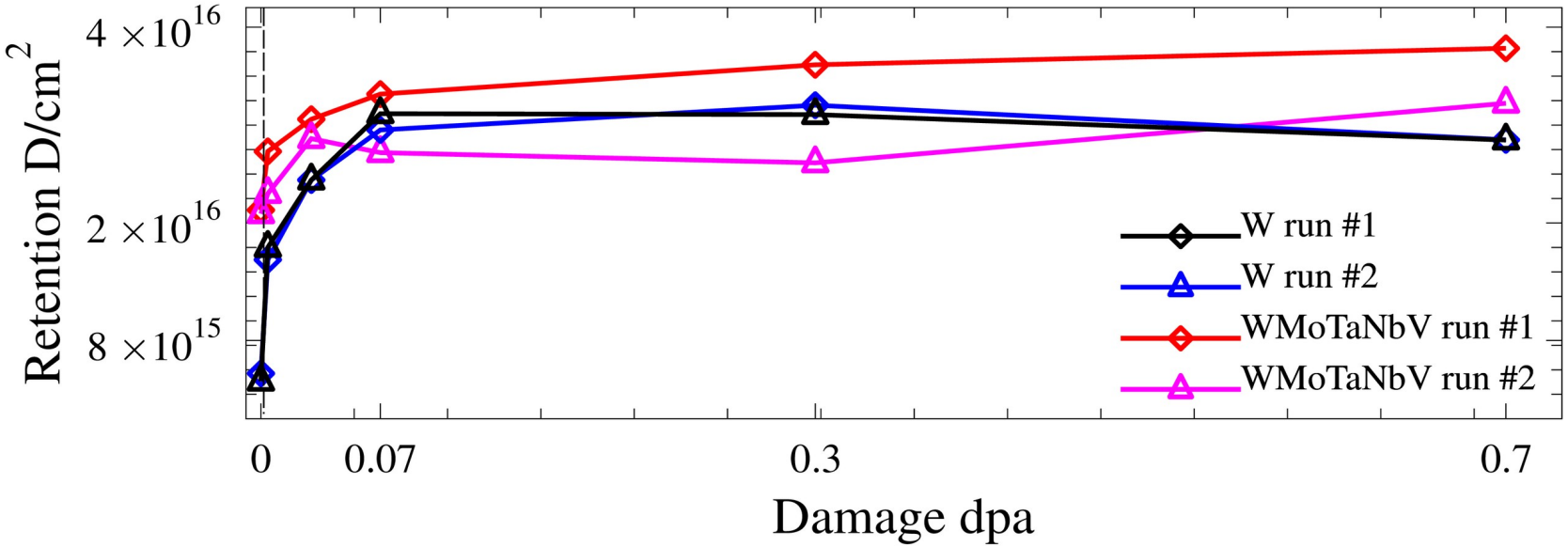

Placement of samples on a holder



Foil-ERDA

HEA and W
pre-irradiated with W
→ 0, 0.007, 0.03, 0.07, 0.3, 0.7 dpa

D implanted 1 keV/D

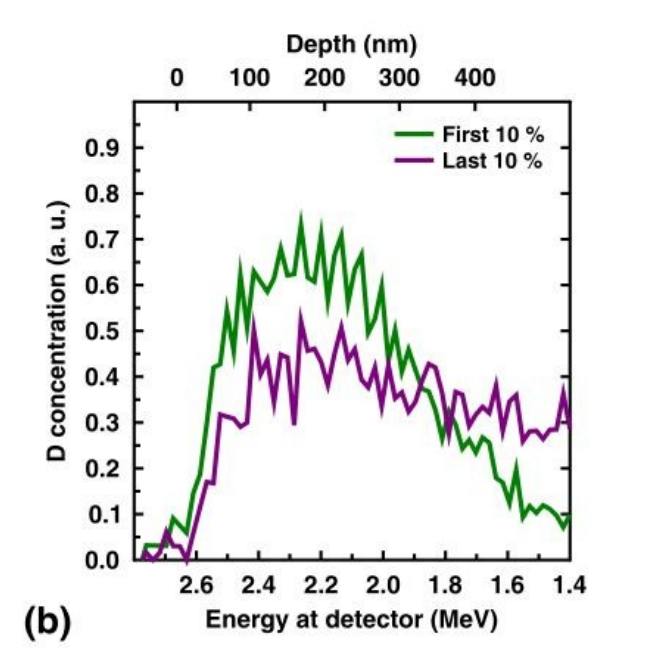


Foil-ERDA

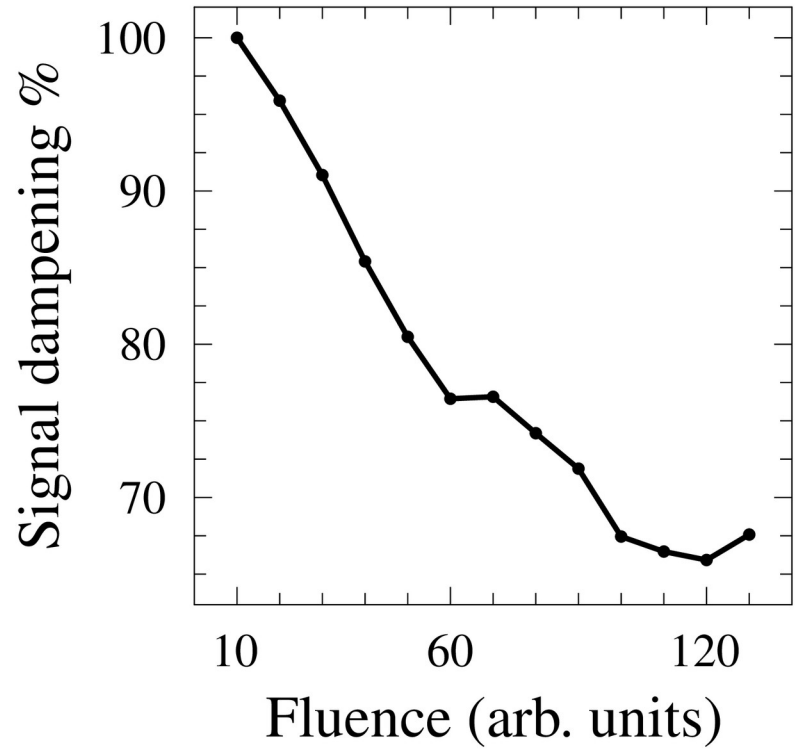
Mobility of D

→ Not trapping

→ Hydrogen absorbing elements



T. Vuoriheimo, et. al., Nuclear Materials and Energy 34 (2023) 101348.



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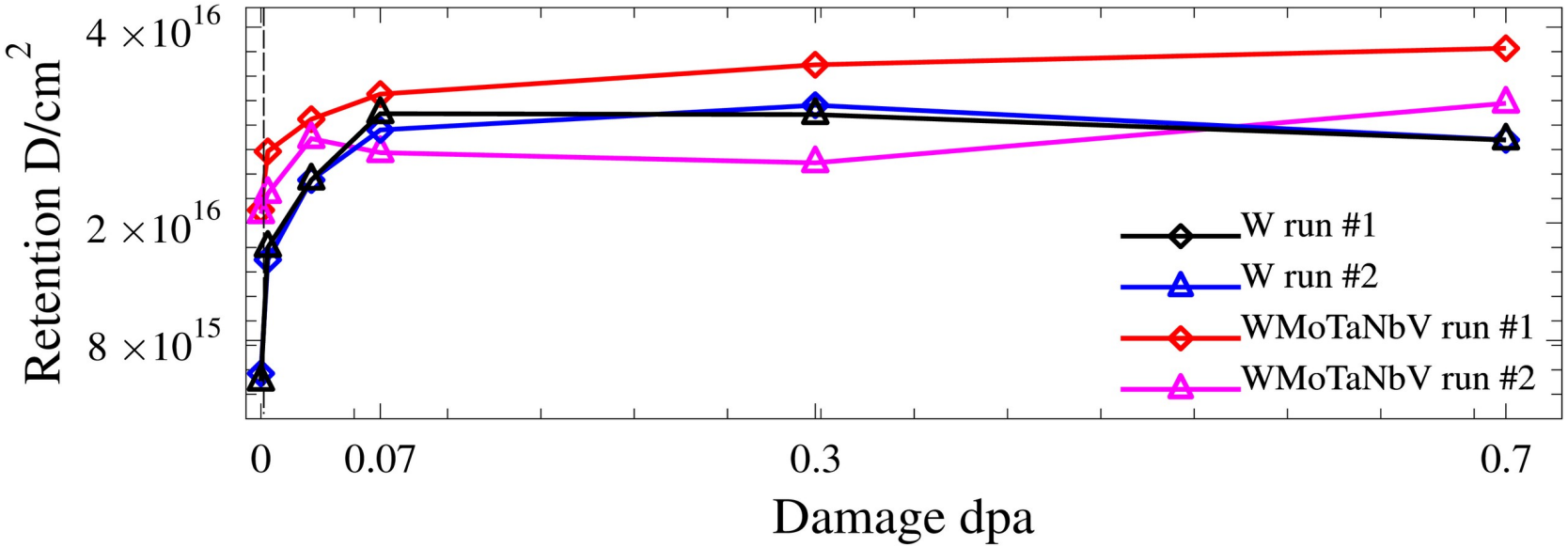
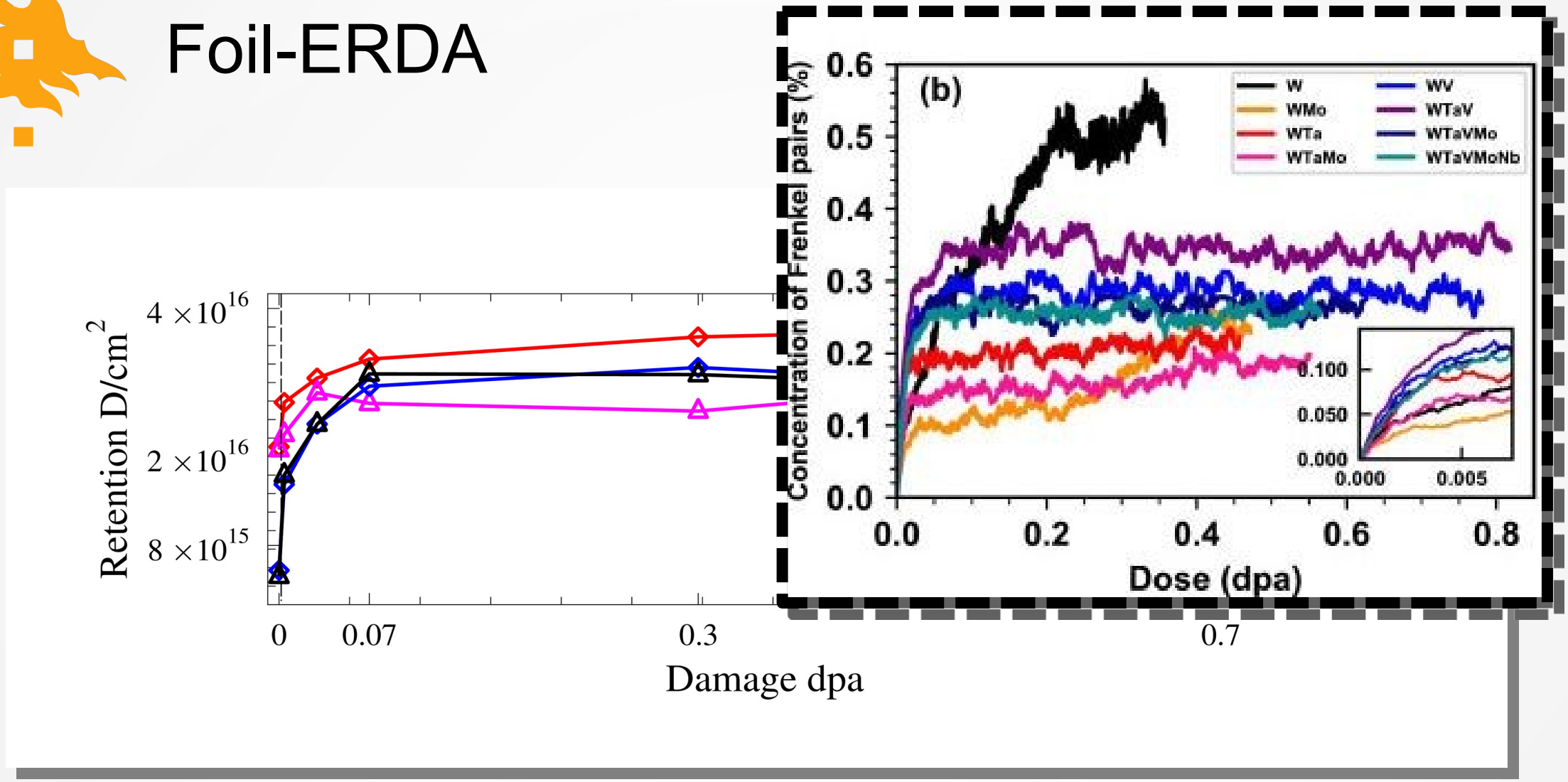
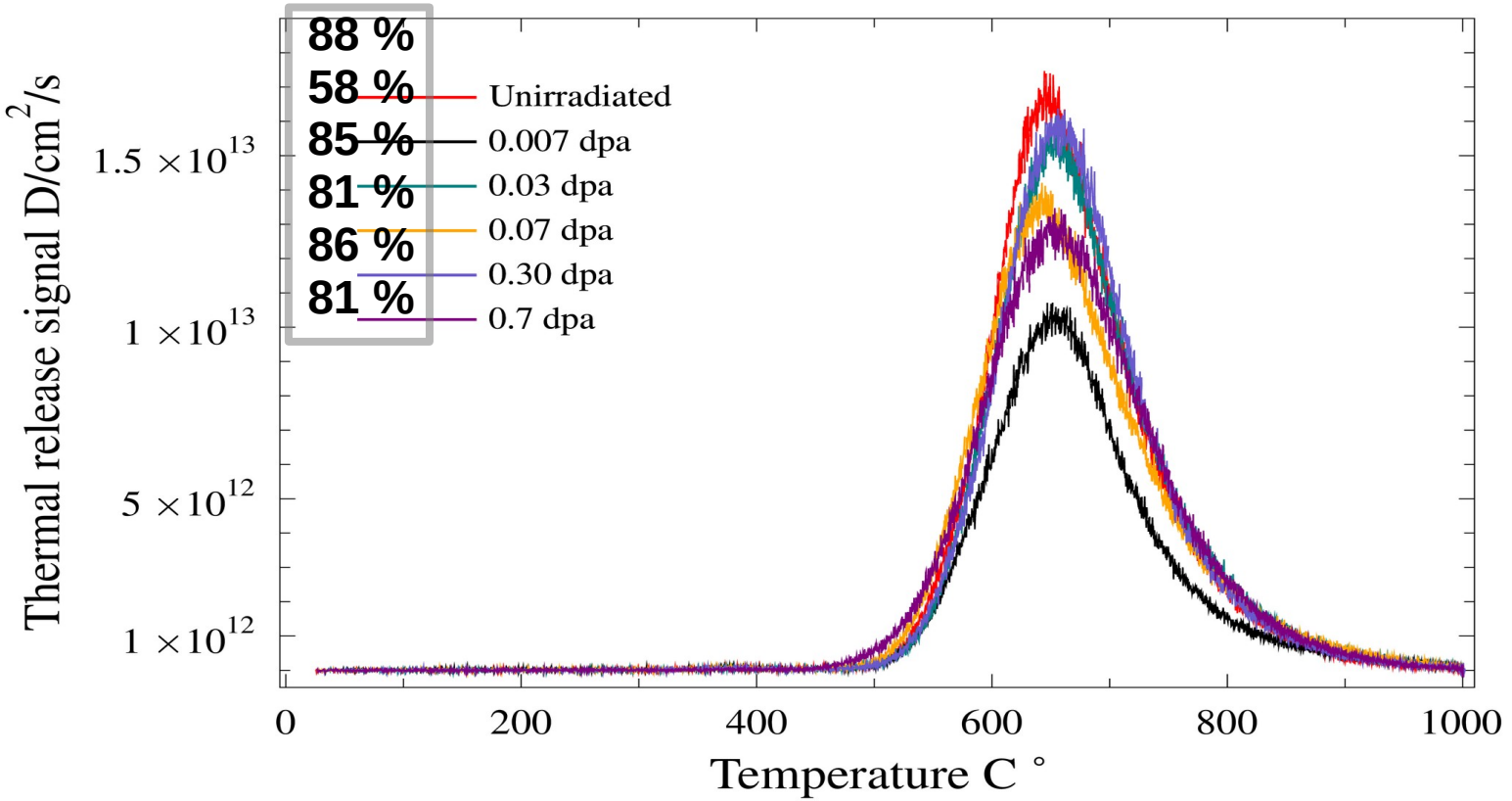


Foil-ERDA

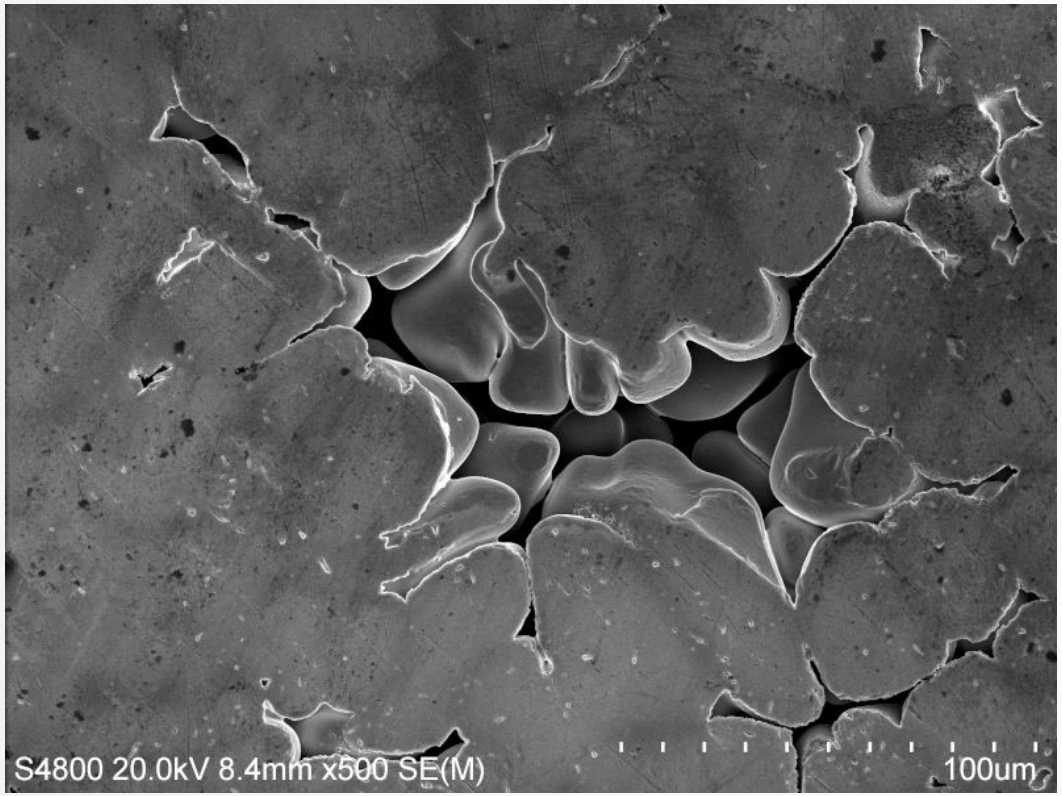
G. Wei, et. al., Acta Materialia, 274 (2024) 119991.



Thermal Desorption Spectrometry

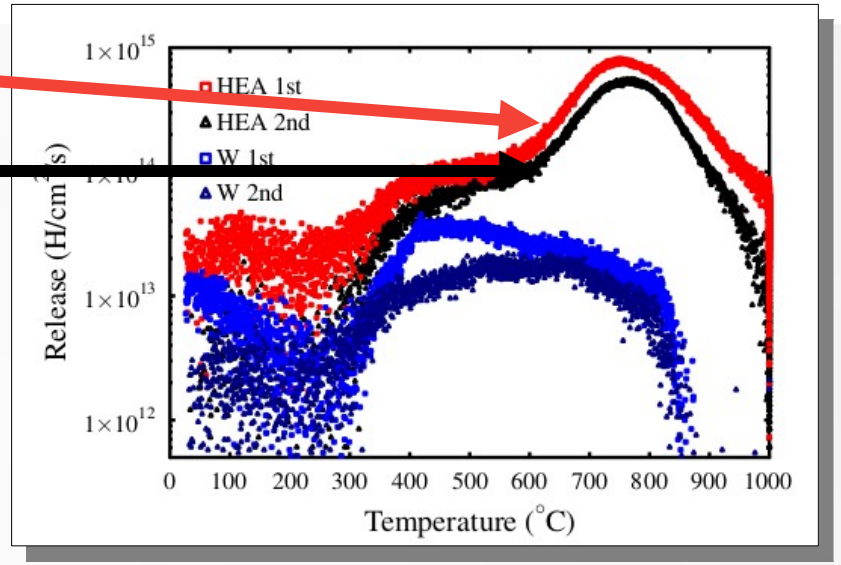


Summary



H in HEA (TDS)

H in HEA (TDS)
- same sample
- many weeks in atmospheric conditions.



WMoTaNbV alloy retains plenty of H
→ Absorbs from atmosphere

Microstructure important for H/D retention
→ H/D trapped in structural defects (GB, vacancies, voids)
→ More defects, more H/D

Quality of samples is crucial.

Thank you!