EUROfusion

WP PWIE meeting, Prague, Czech Republic 24-27 March 2025

Production of W and B reference layers for different PWIE experiments

David Dellasega

On behalf of

G. Alberti, L. Bana, D. Vavassori, A. Maffini, D. Orecchia, F. Gaspari, M. Passoni – Politecnico di Milano

A. Uccello, E. Vassallo, M. Pedroni – ISTP CNR Milan

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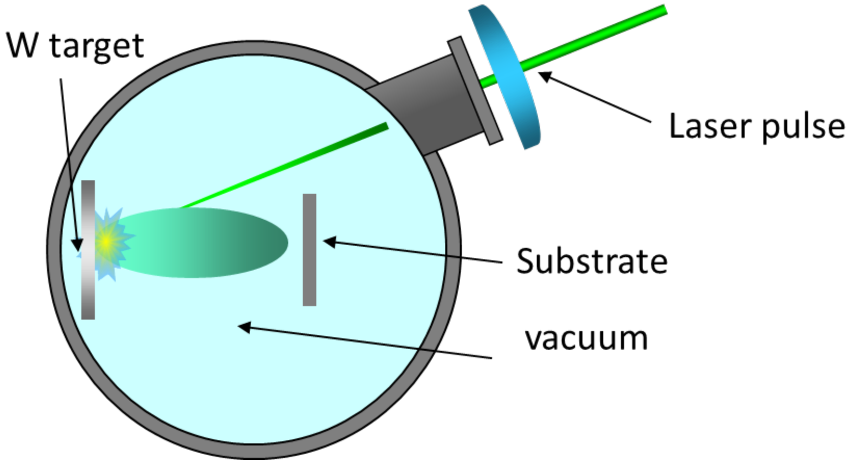
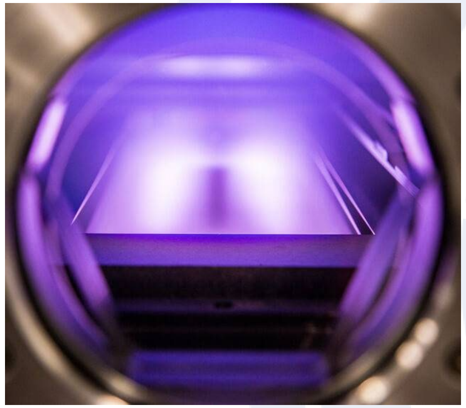
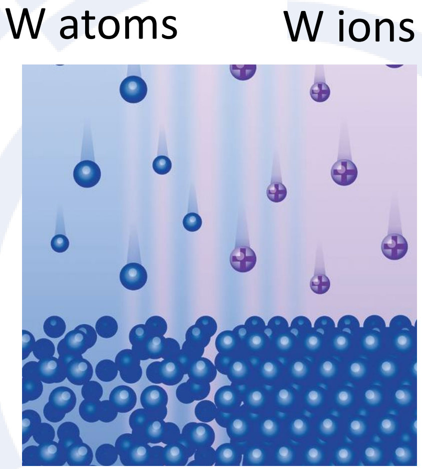
Production of W reference coatings by PVD techniques

Pulsed Laser Deposition (PLD)



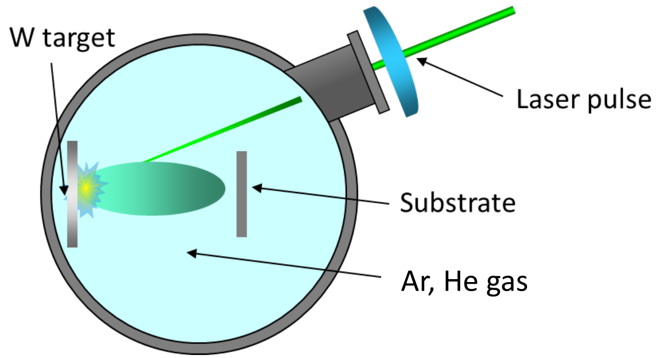
High Power Impulse Magnetron Sputtering (HiPIMS)

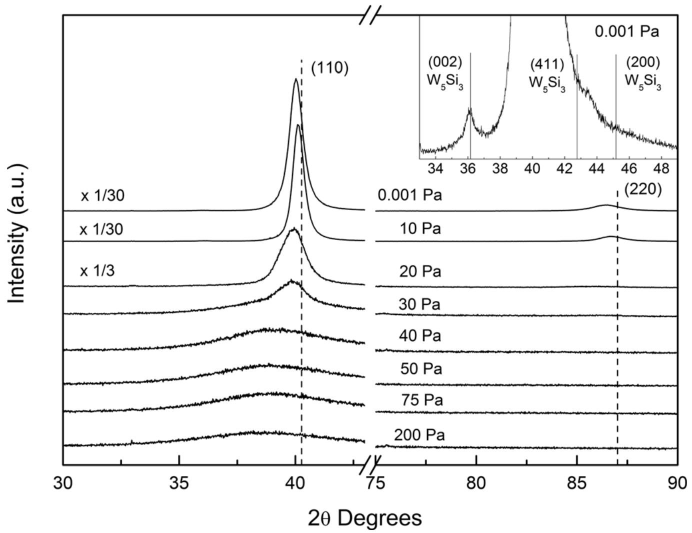


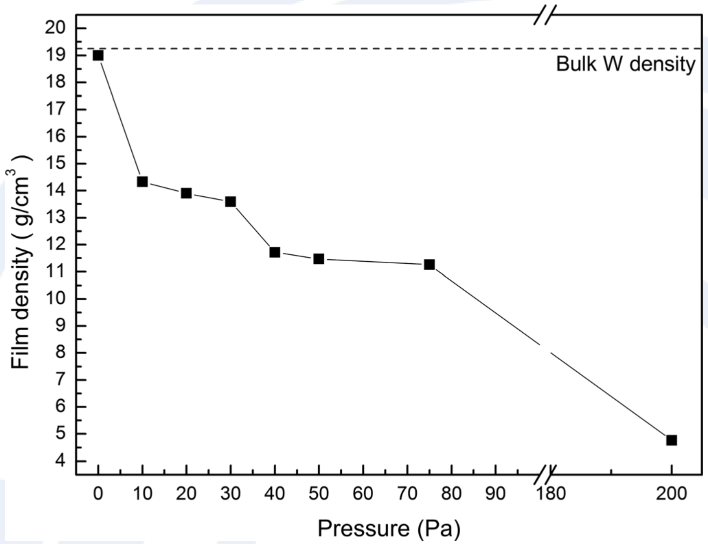


Properly exploiting the features of PLD and HiPIMS it is possible to tailor the structure and morphology of the growing films at the nanoscale understanding their role in the PWI

ns pulsed laser deposition

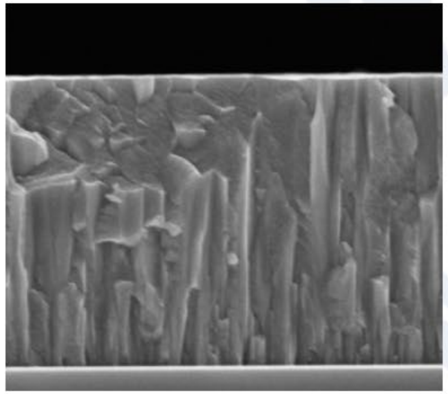




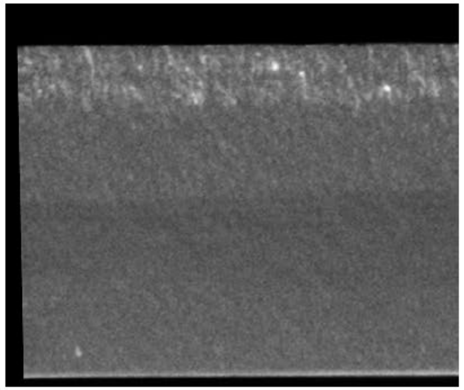


High energy of the W species

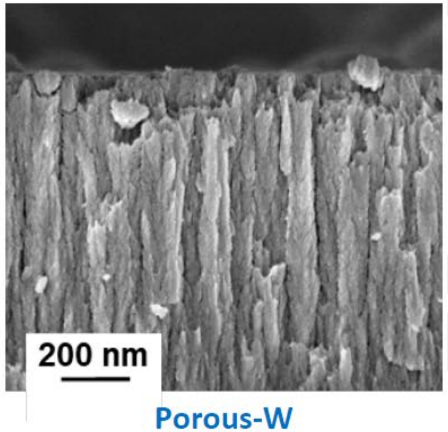
Increasing Ar, He pressure energy of species lowers



Compact-W



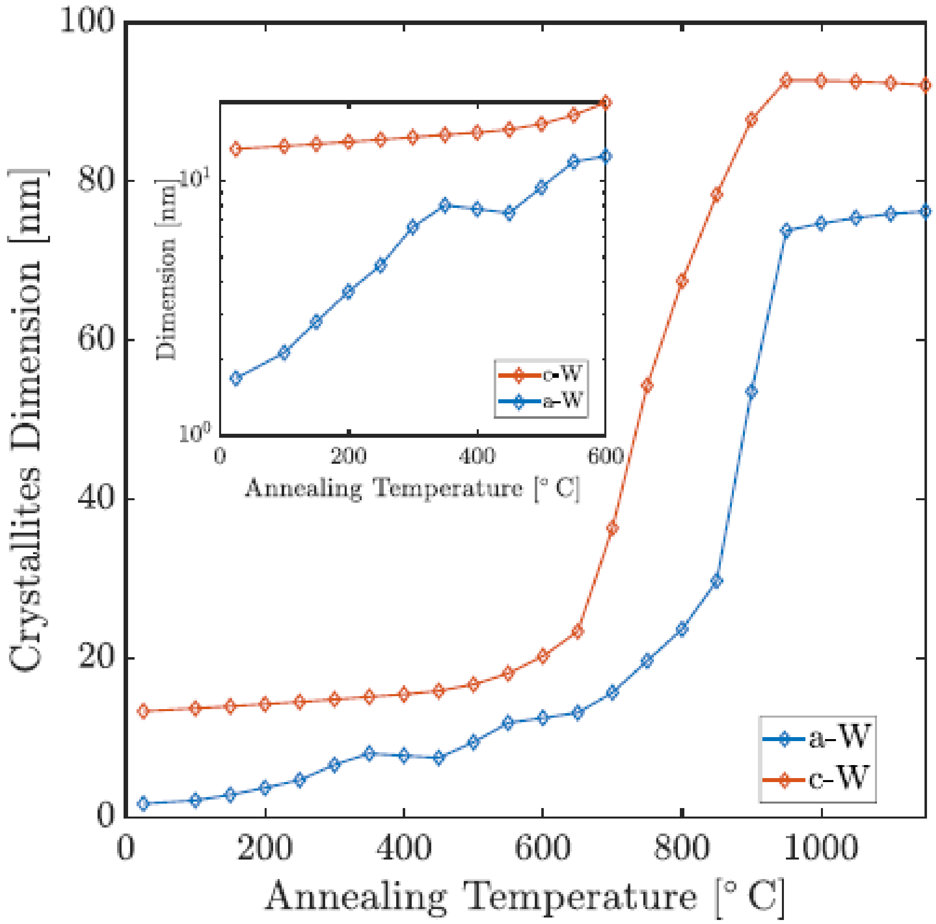
Amorphous-W

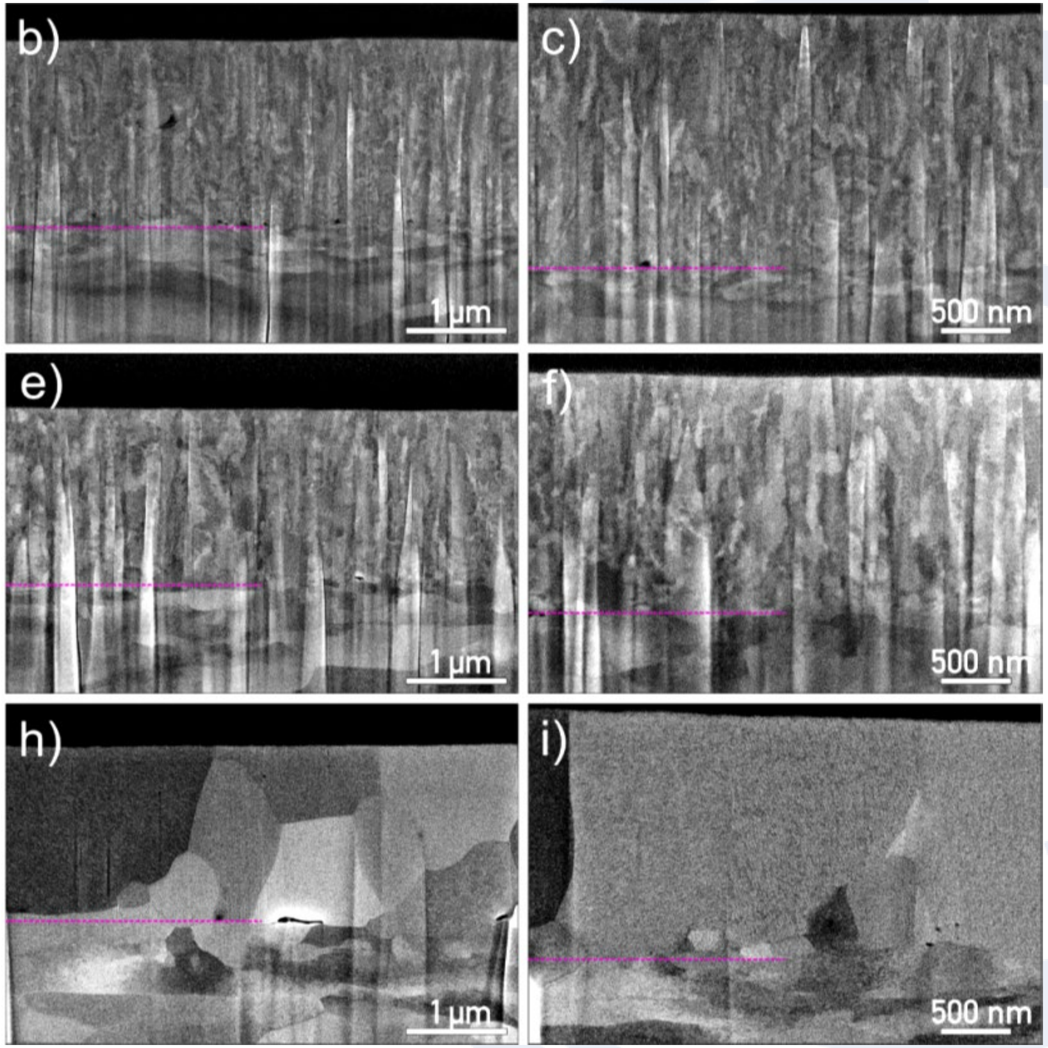


Porous-W

Fine control of crystallinity, density and morphology

Further crystallinity control – vacuum annealing

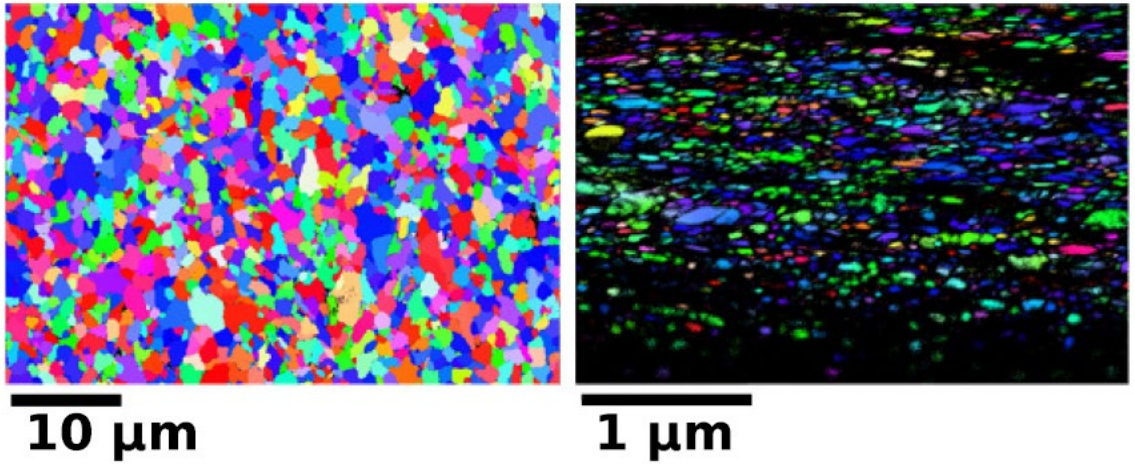


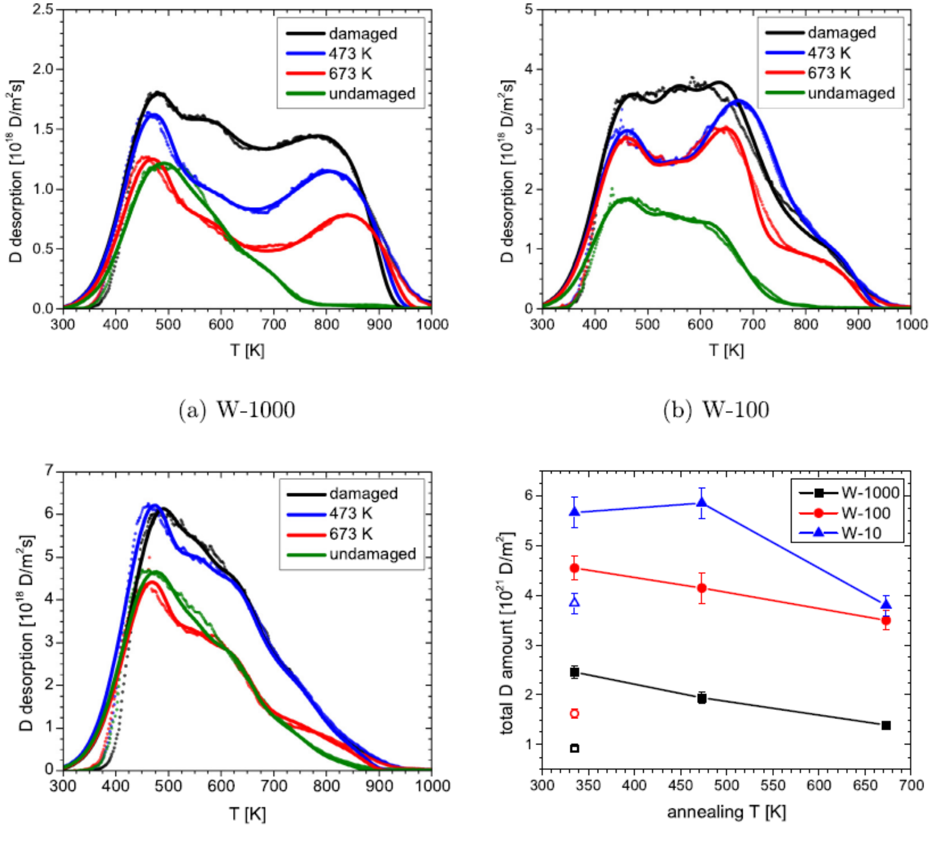


Tailoring the crystallinity from the nano to the micro scale!→ understanding the role of grain boundaries

PWI Studies: D transport and retention

Compact W films with different grain size have been used to investigate the role of grain boundaries and crystallinity in D transport and retention.



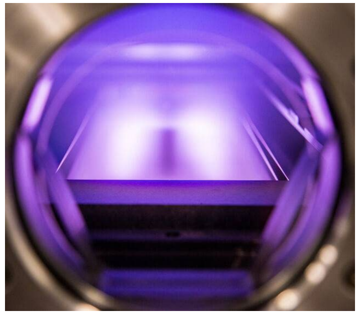


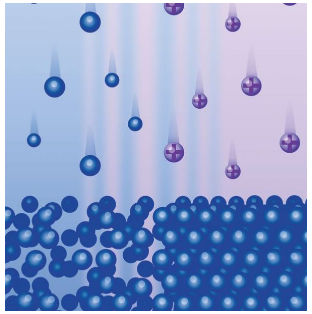
(a) W-1000 (b) W-100 (c) W-10 (d) total D amounts

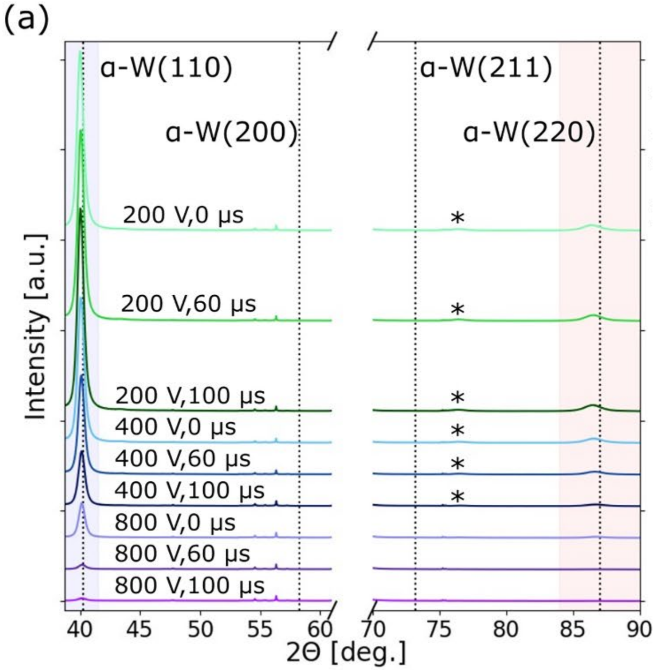
S. Markelj Nuclear Materials and Energy 37 (2023) 101509
A.Založnik Nuclear Materials and Energy 39 (2024) 101674;
S. Markelj Nuclear Materials and Energy 38 (2024) 101589

HiPIMS

High Power Impulse Magnetron Sputtering (HiPIMS)

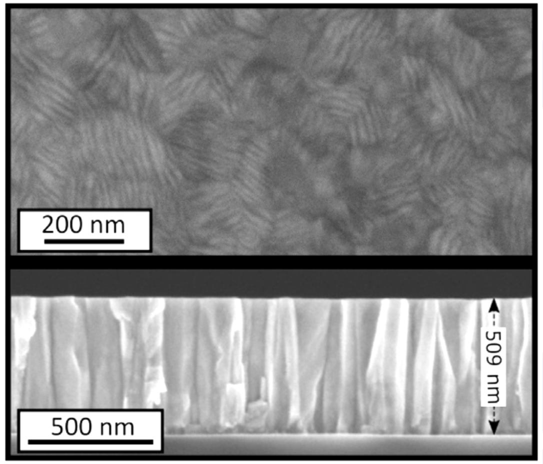




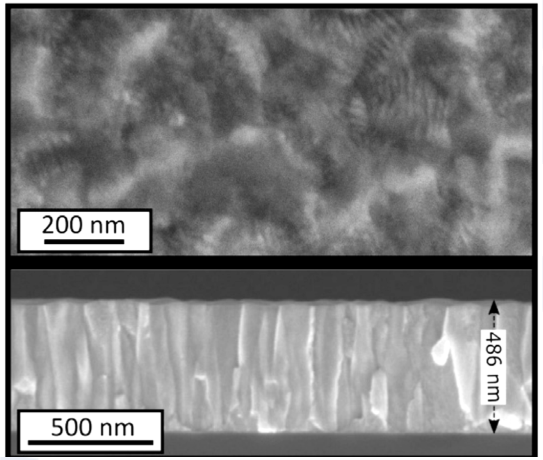


D. Vavassori, Surf. Coat Tech, 458 (2023) 129343

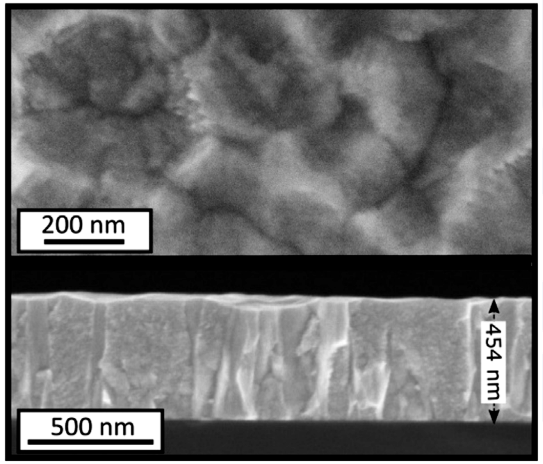
(c) U_S=200 V, Δτ=100 μs



(f) U_S=400 V, Δτ=100 μs

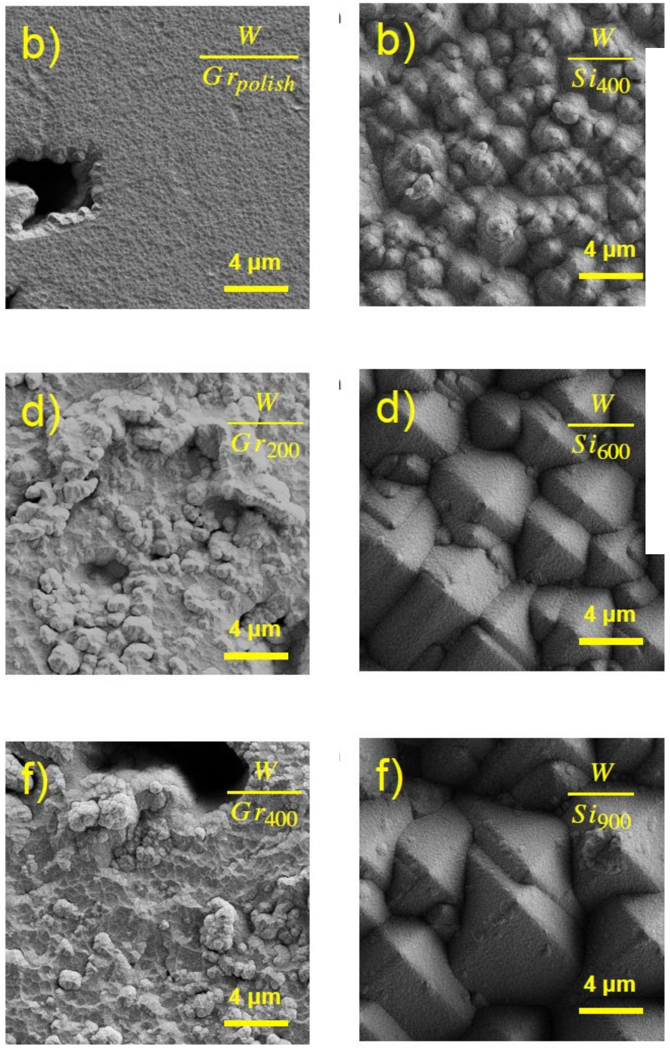


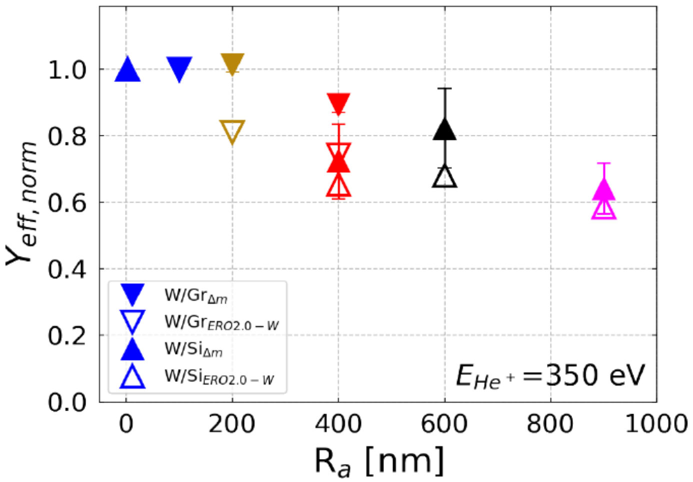
(i) U_S=800 V, Δτ=100 μs

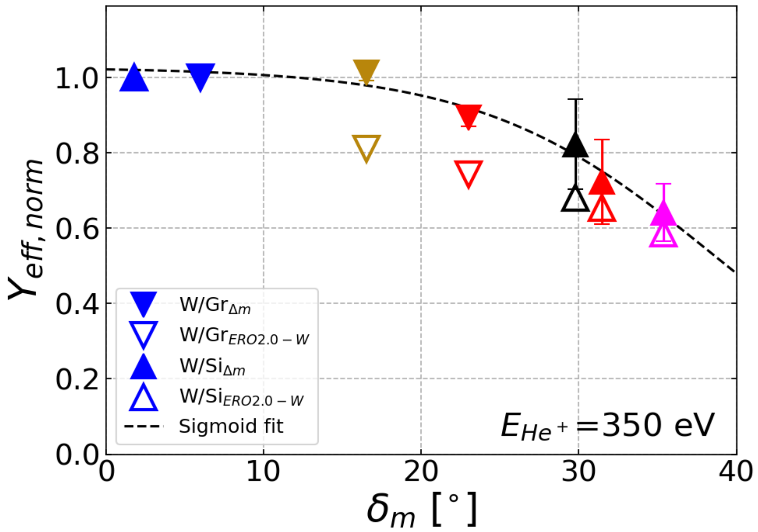


Very compact films,
crystallographically oriented,
Tune crystallinity varying bias

Exploring the role of topography in the sputtering process of tungsten by GyM helium plasma





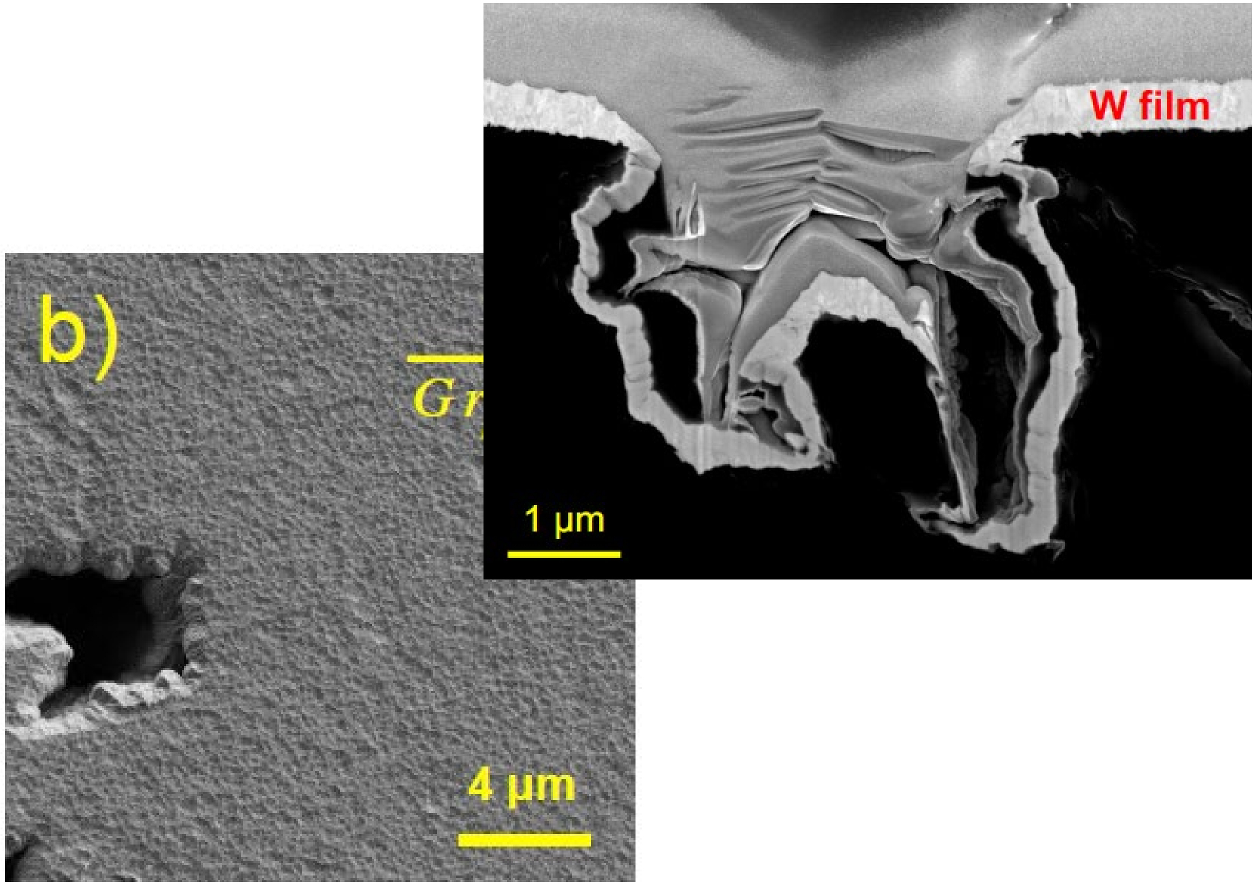


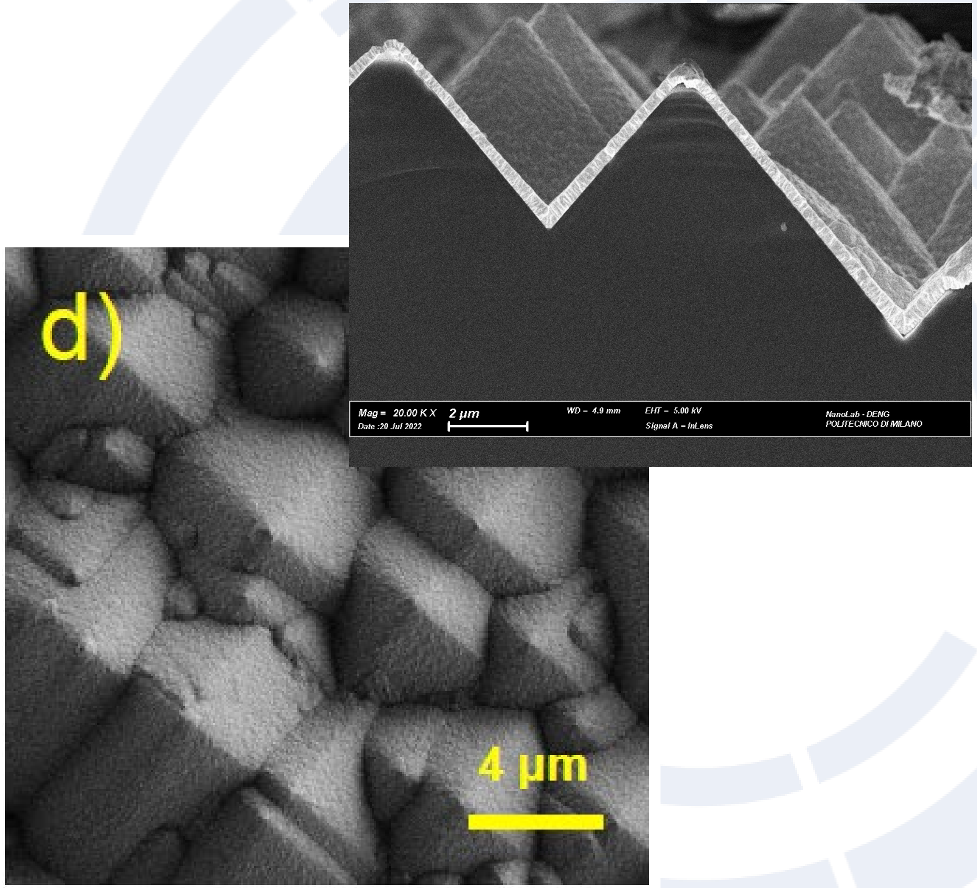
Different rough substrates (Graphite and etched Silicon) covered with W are exposed to He plasma in GyM to assess sputtering properties + ERO 2.0 simulations.

The most important parameter is not roughness but the surface inclination angle

A. Uccello et al, Nuclear Fus. 2025, accepted

Exploring the role of topography in the sputtering process of tungsten by GyM helium plasma





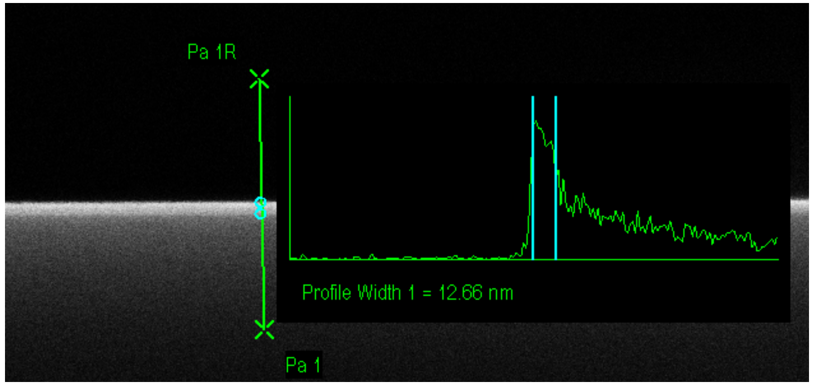
The high energy of the W species during HiPIMS process allows the covering of deep holes and a good uniformity even on oblique surfaces

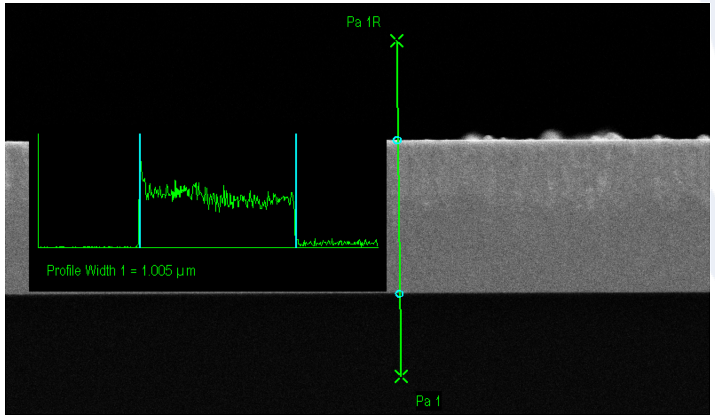
A. Uccello et al, Nuclear Fus. 2025, accepted

In 2025: Sputtering studies related to crystalline orientation and new nanostructures

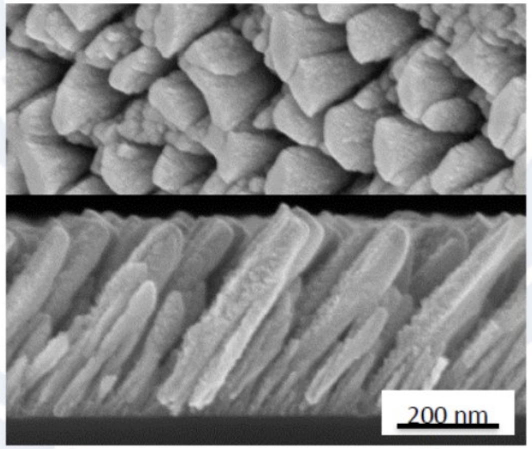
There is a lot of interest in understanding the role of crystalline orientation respect to sputtering yield and energy losses of light ions in tungsten.

- In this regard amorphous W is a very interesting model since…it does not have any crystallinity. Collaboration with **Martin Balden (IPP)** and **Eduardo Pitthan Filho (Uppsala University)**
- Compact W is crystallographically oriented along the 110 direction perpendicularly to the substrate. Collaboration with **M. Fellinger (OAW Wien)**
- Nanocolumnar morphology (produced by tilted magnetron sputtering) is a perfect benchmark for ERO 2.0 erosion simulations.





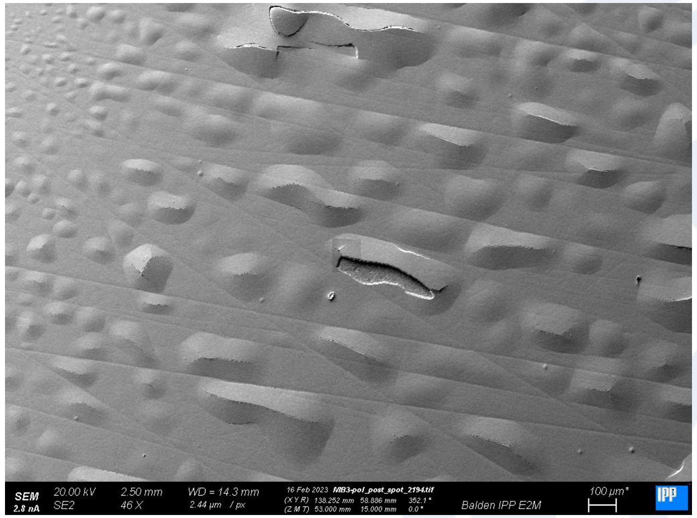
amorphous - W

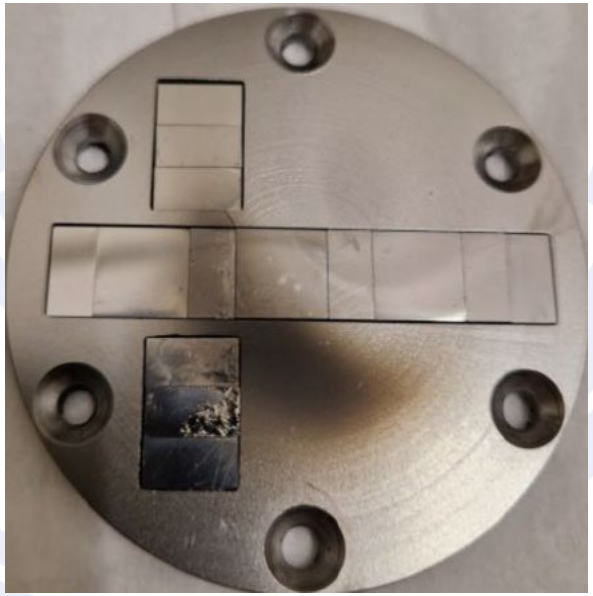


Nanocolumnar-W

W redeposits with a sputtering & redeposition setup in Magnum-PSI

- Create “realistic” W redeposits with a sputtering & redeposition setup in Magnum-PSI;
- Compare redeposited W to redeposited-like W layers from HiPIMS
- Adopt a «material science» point of view in understanding the role of process parameters

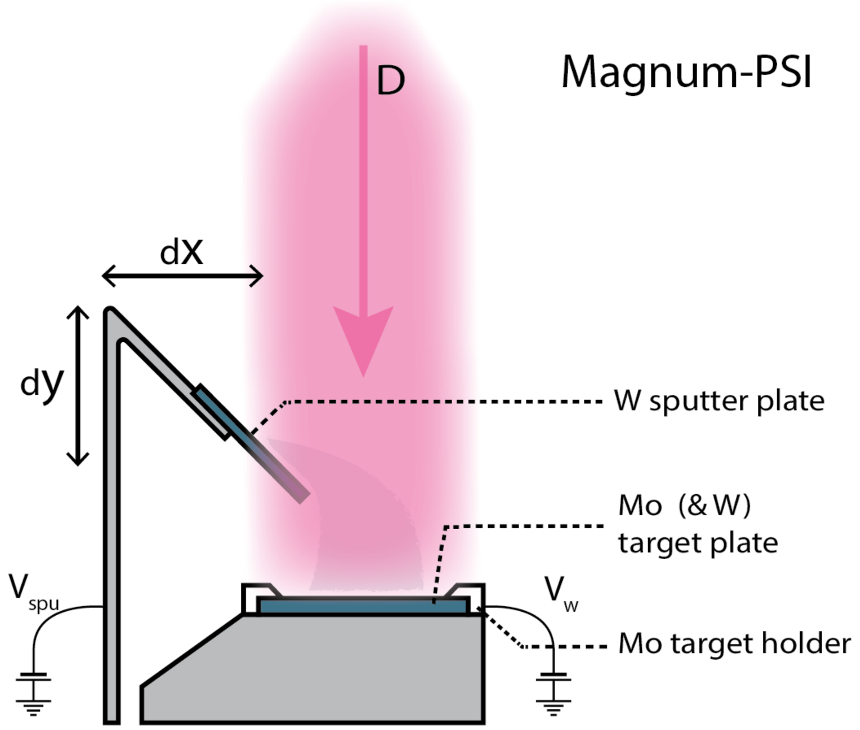


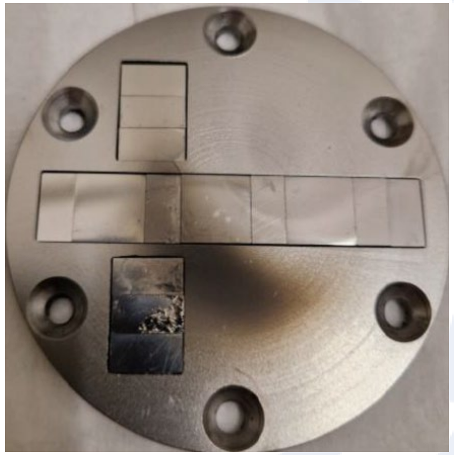


In collaboration with: Thomas Morgan and Luc Bouwmeester | DIFFER SPA.

W redeposits with a sputtering & redeposition setup in Magnum-PSI

Investigated parameters:
Ar plasma
Different bias
Different substrate roughness





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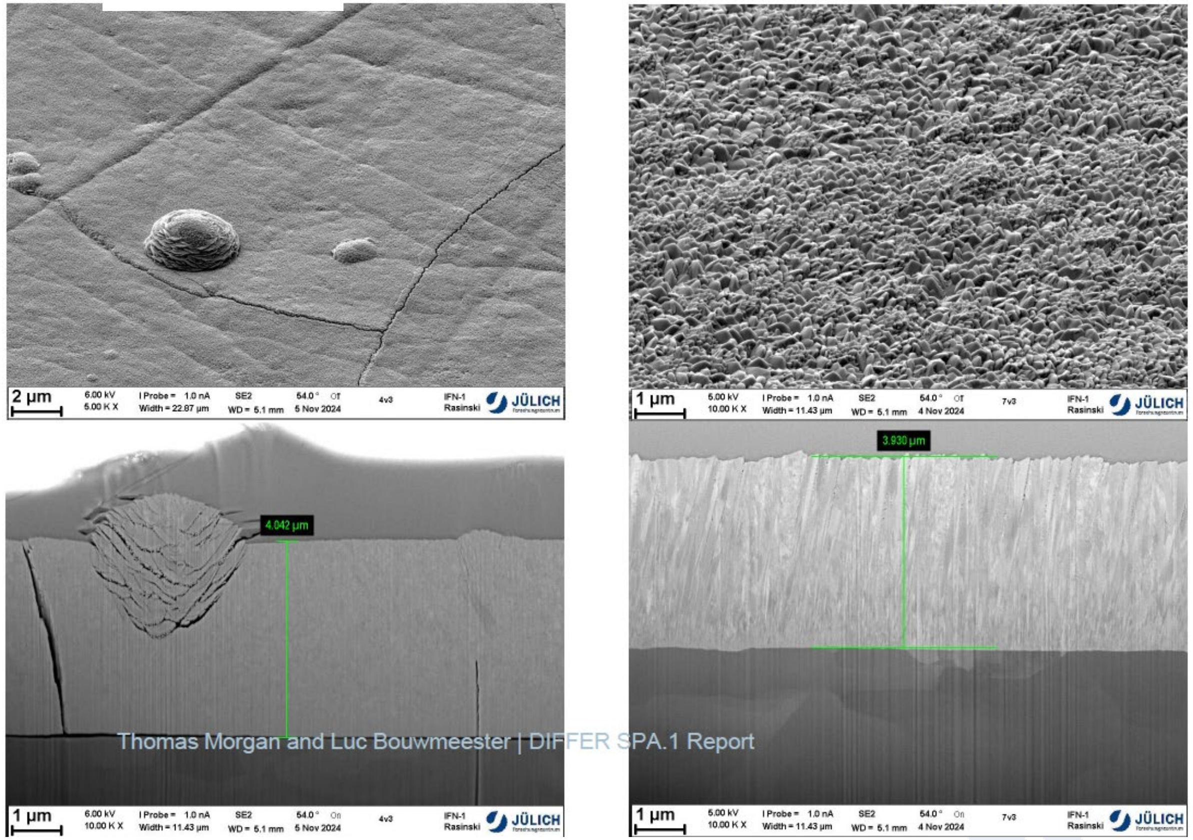
W redeposits with a sputtering & redeposition setup in Magnum-PSI

Different sputtering energy determines a different growth dynamic

60 eV bias

100 eV bias

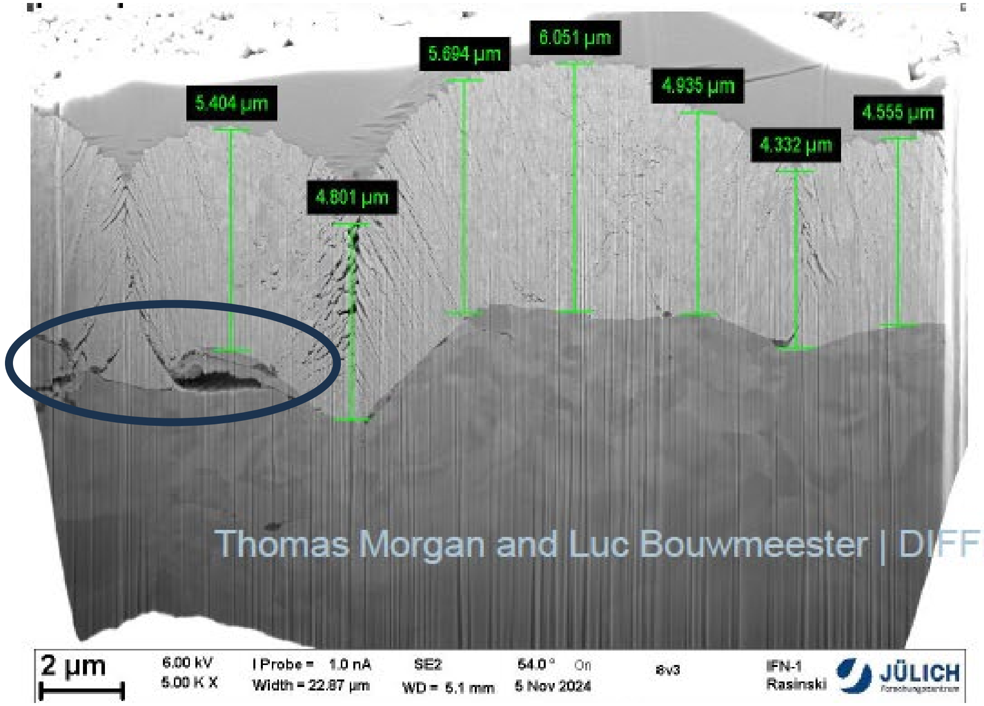


Small columns, smooth surface, delamination

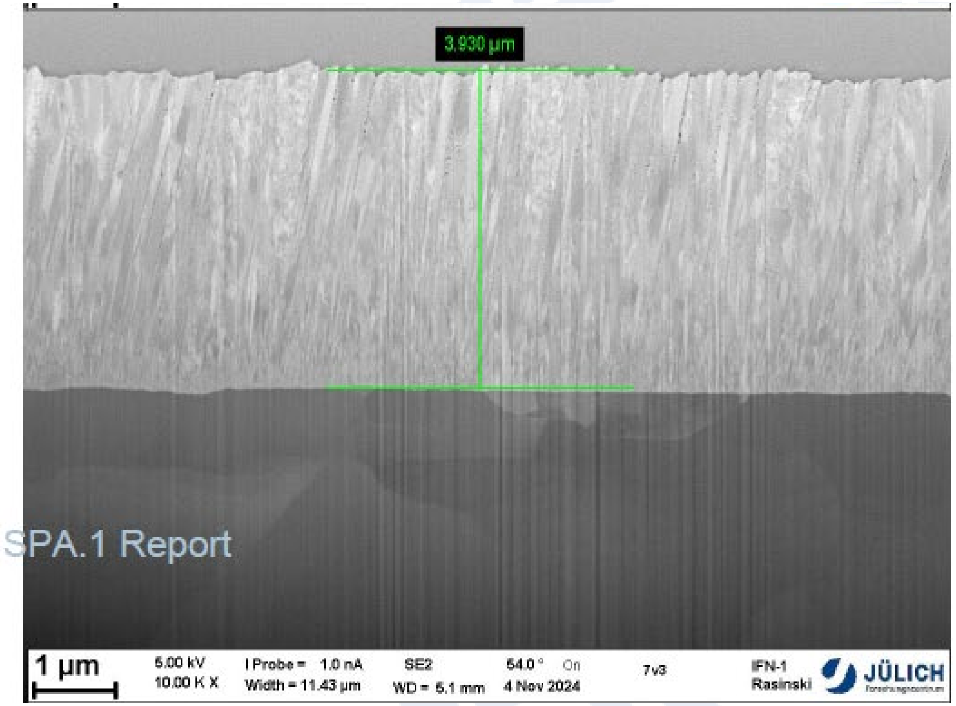
bigger columns, faceted surface, good adhesion

In collaboration with: Thomas Morgan and Luc Bouwmeester | DIFFER SPA.

W redeposits with a sputtering & redeposition setup in Magnum-PSI



Sandblasted



Polished

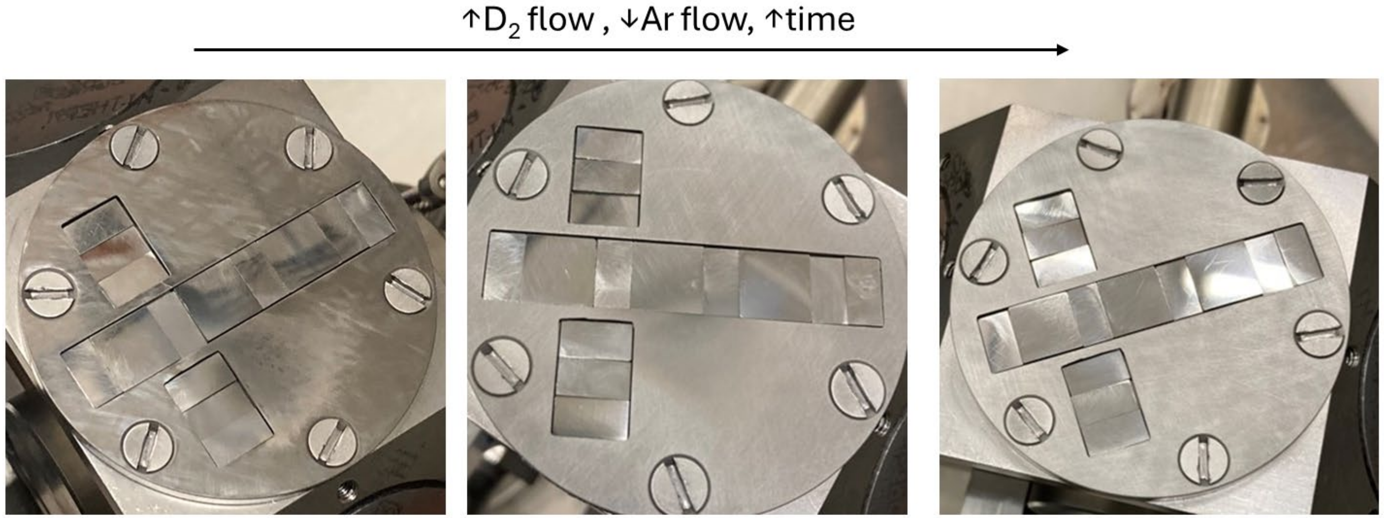
Rough substrate perturbs film nucleation and growth leads to the formation of «cauliflower defects» + growth in separated columns

In collaboration with: Thomas Morgan and Luc Bouwmeester | DIFFER SPA.

W redeposits with a sputtering & redeposition setup in Magnum-PSI

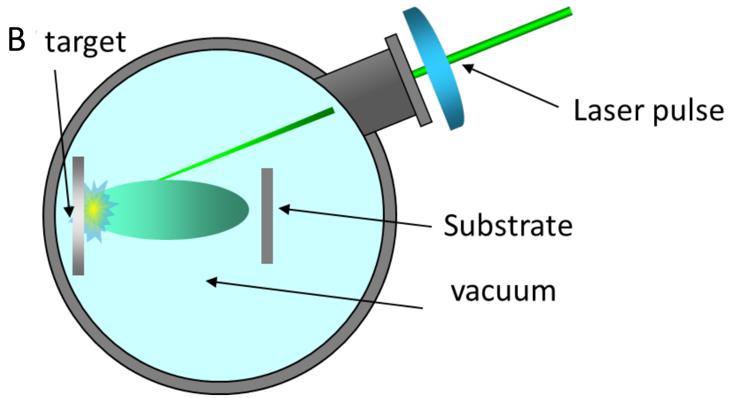
New joint experiments done in 2025

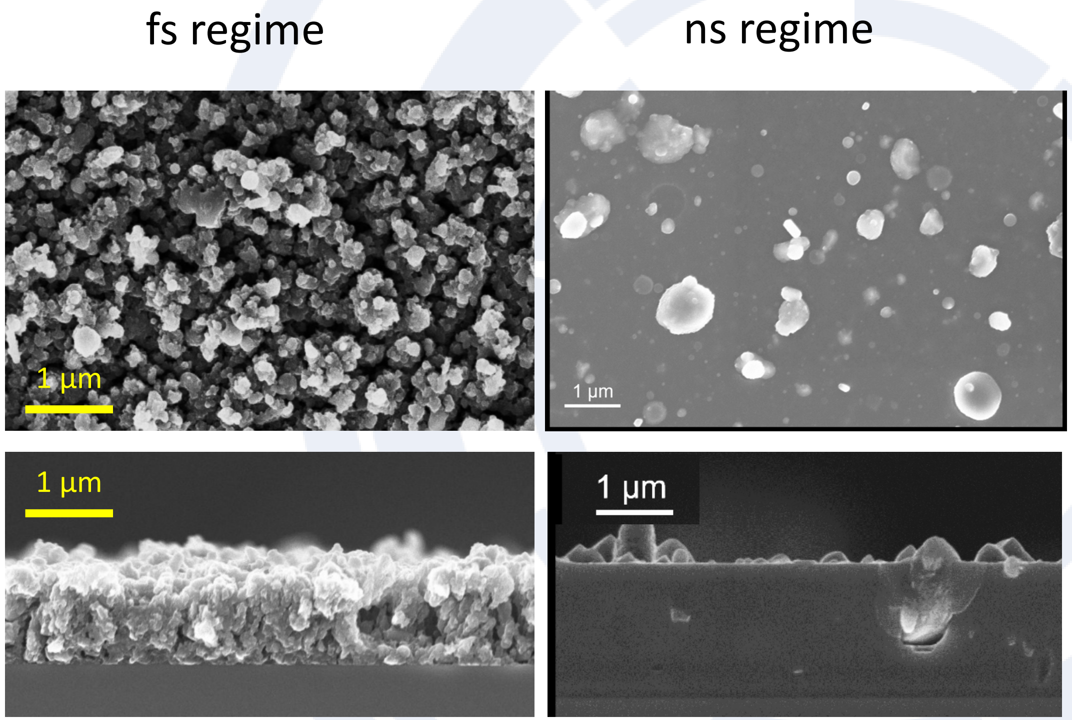
- D plasma exposure with simultaneous laser irradiation of redeposited W layers
- New redeposits experiments using an Ar/D plasma
- XRD, SEM/EDX and scratch test (adhesion) on the deposited layers (ongoing)
- Comparison with HiPIMS deposited W samples to assess similarities and differences



In collaboration with: Thomas Morgan and Luc Bouwmeester | DIFFER SPA.
Abstract submitted at PFMC

Production of B reference coatings by PLD



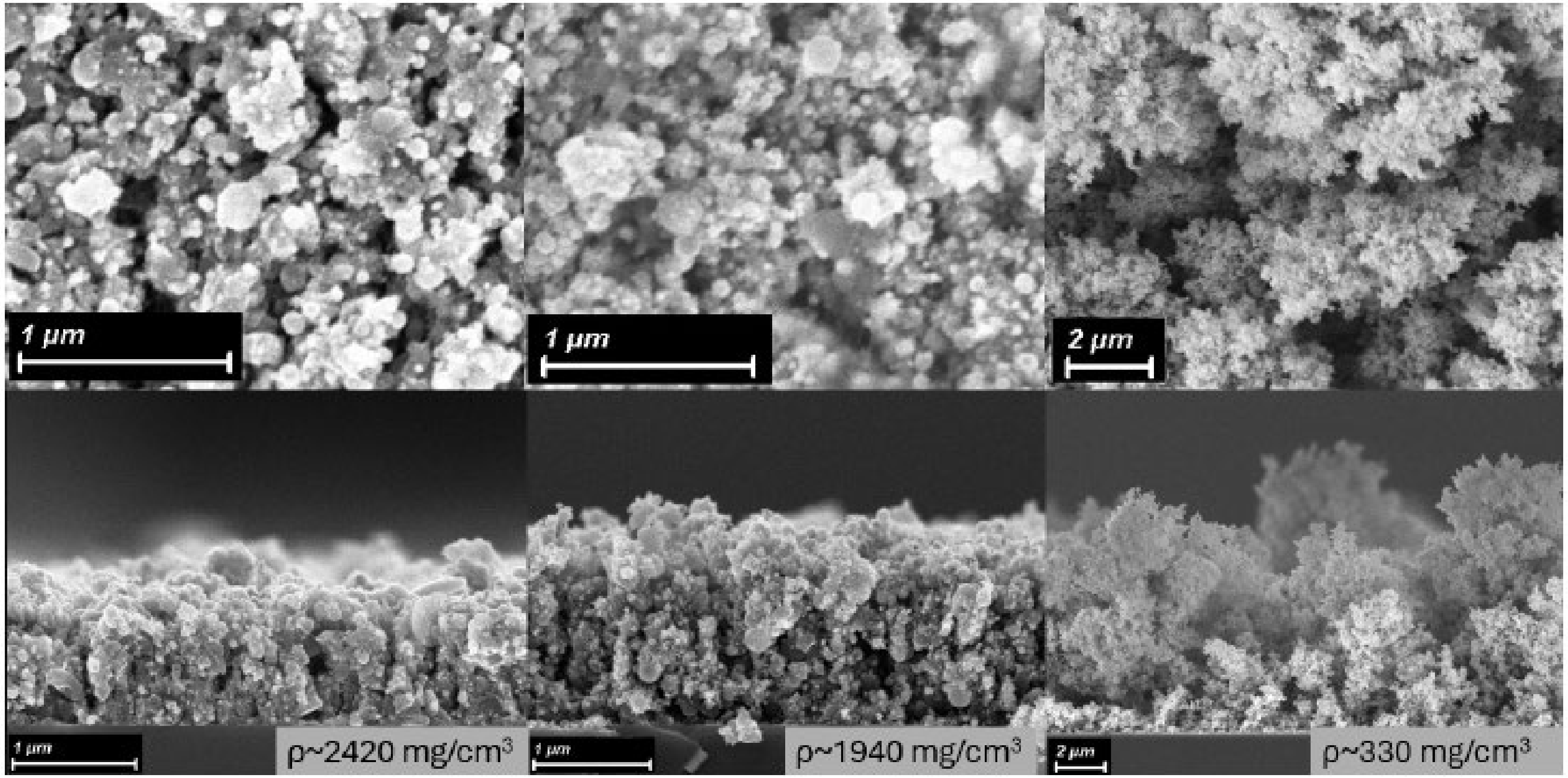


To produce B layers two PLD systems with different pulse duration have been used:

- Nano second PLD – atom by atom deposition: homogeneous, compact, amorphous B films
- Femto second PLD – nanoparticle generation and deposition: porous nanostructured B films

B and coatings grown by femto PLD

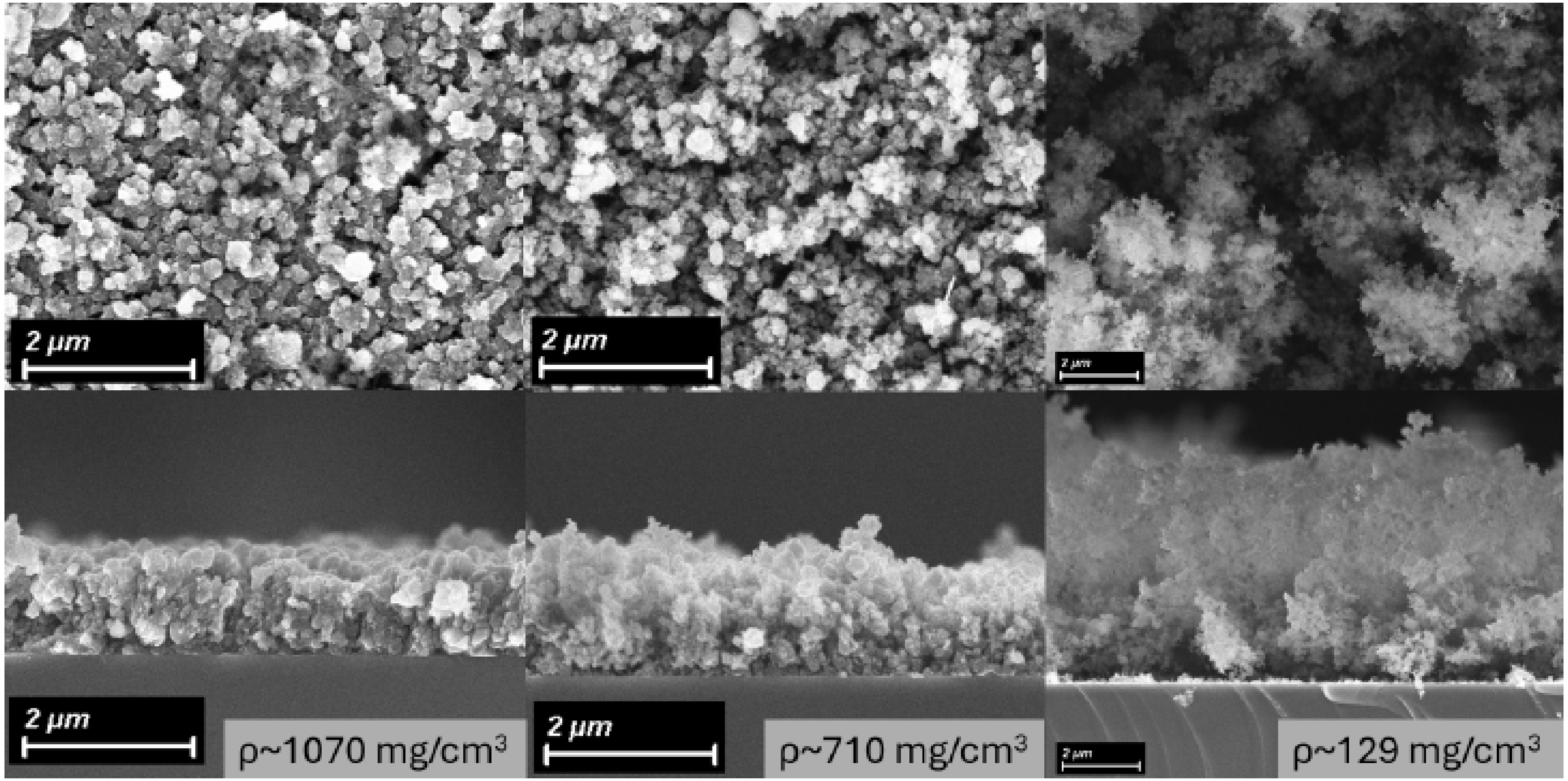
Increaing Ar pressure, even more nanostructured films are obtained: «dusty Boron»



In collaboration with: A. Maffini, D. Orecchia, F. Gaspari – ENEA Polimi

B-W coatings grown by femto PLD

Using a composed B-W target mixed porous layers are deposited



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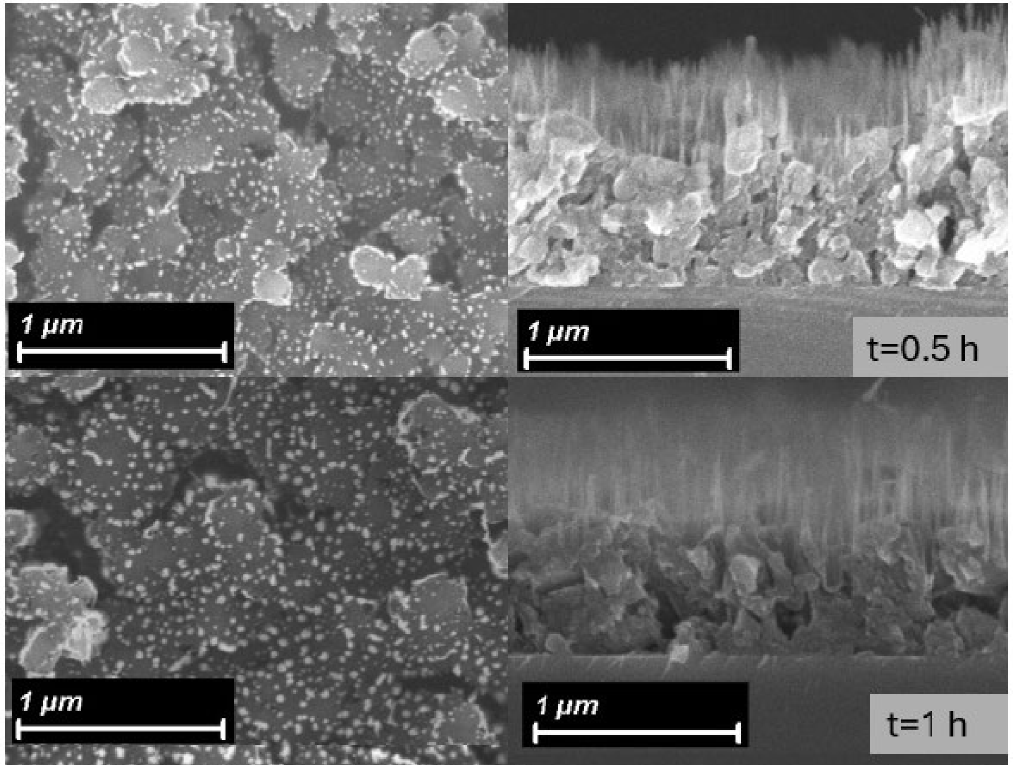
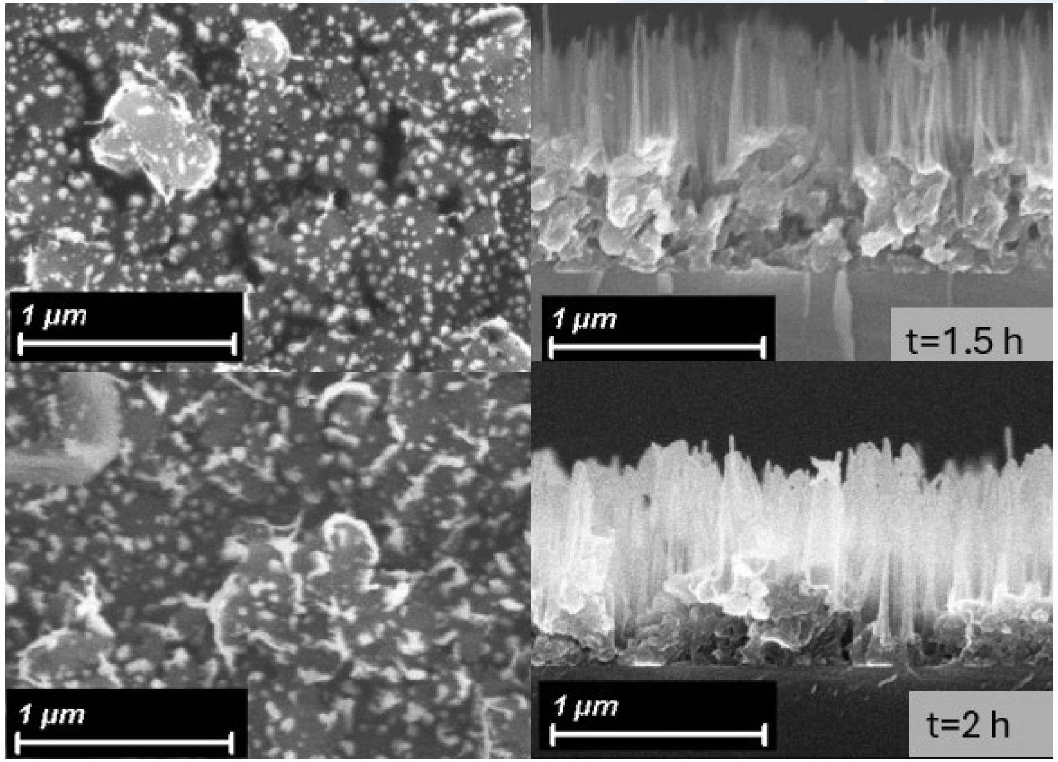
B coatings exposed to D plasma in Gym varying energy and fluence

(GyM $\Gamma \approx 3.8 \cdot 10^{20}$ ions/m^2s and E ≈ 200 eV).

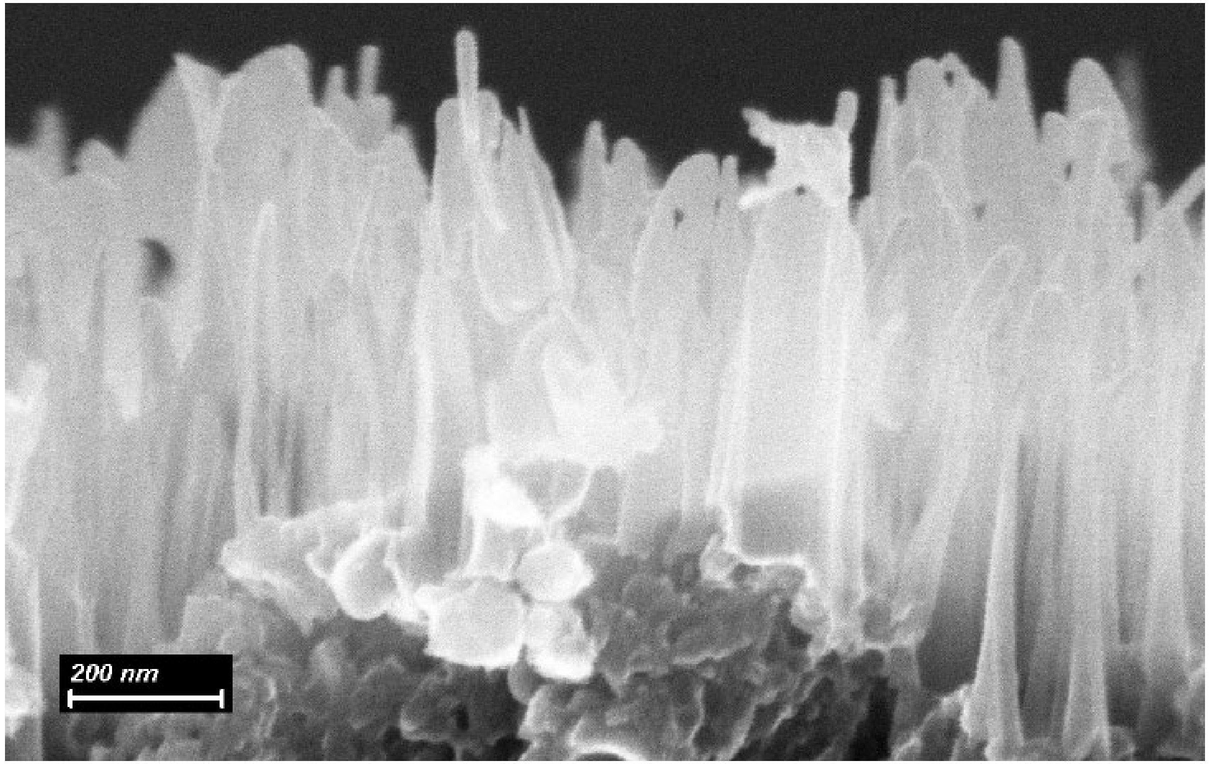




Needle-like nanostructures at the edges of the nanoparticles are formed!

In collaboration with: A. Maffini, D. Orecchia, F. Gaspari, A. Uccello – ENEA Milan
Submitted abstract at PFMC 25

B coatings exposed to D plasma in Gym varying energy and fluence



Needle-like structures, preferential sputtering? Role of impurities?

In collaboration with: A. Maffini, D. Orecchia, F. Gaspari, A. Uccello – ENEA Milan
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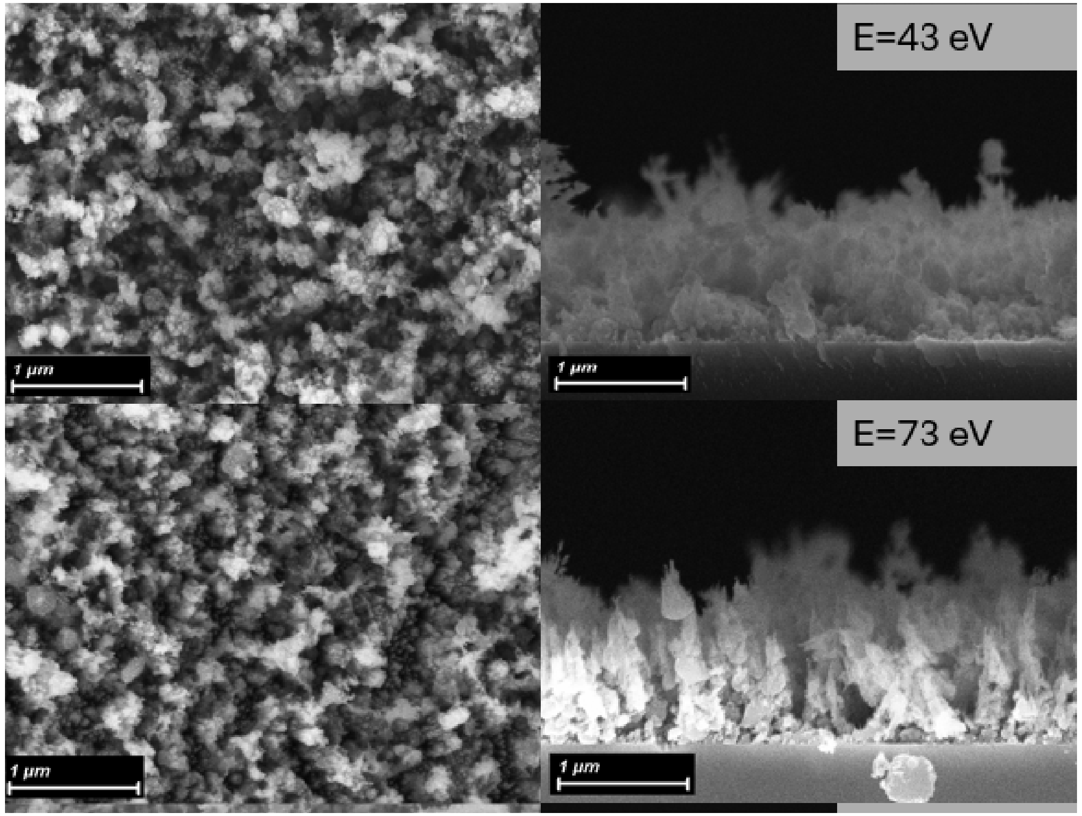
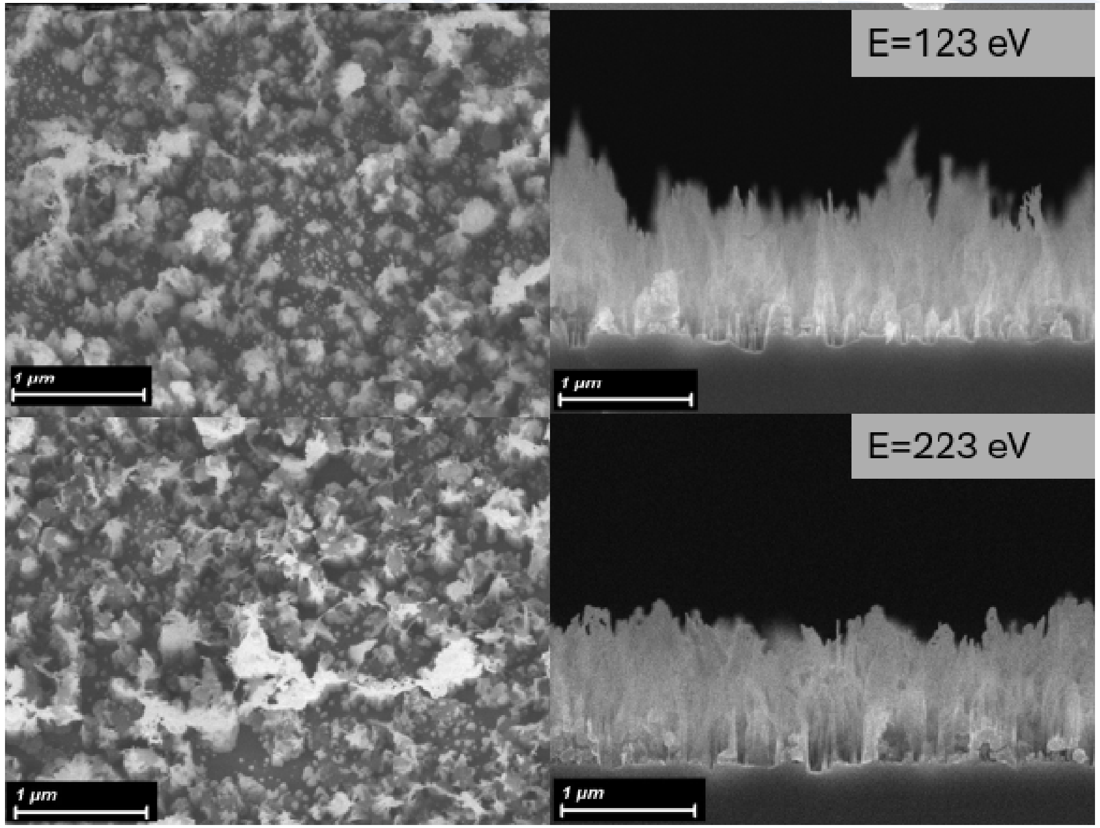
B coatings exposed to D plasma in Gym varying energy and fluence

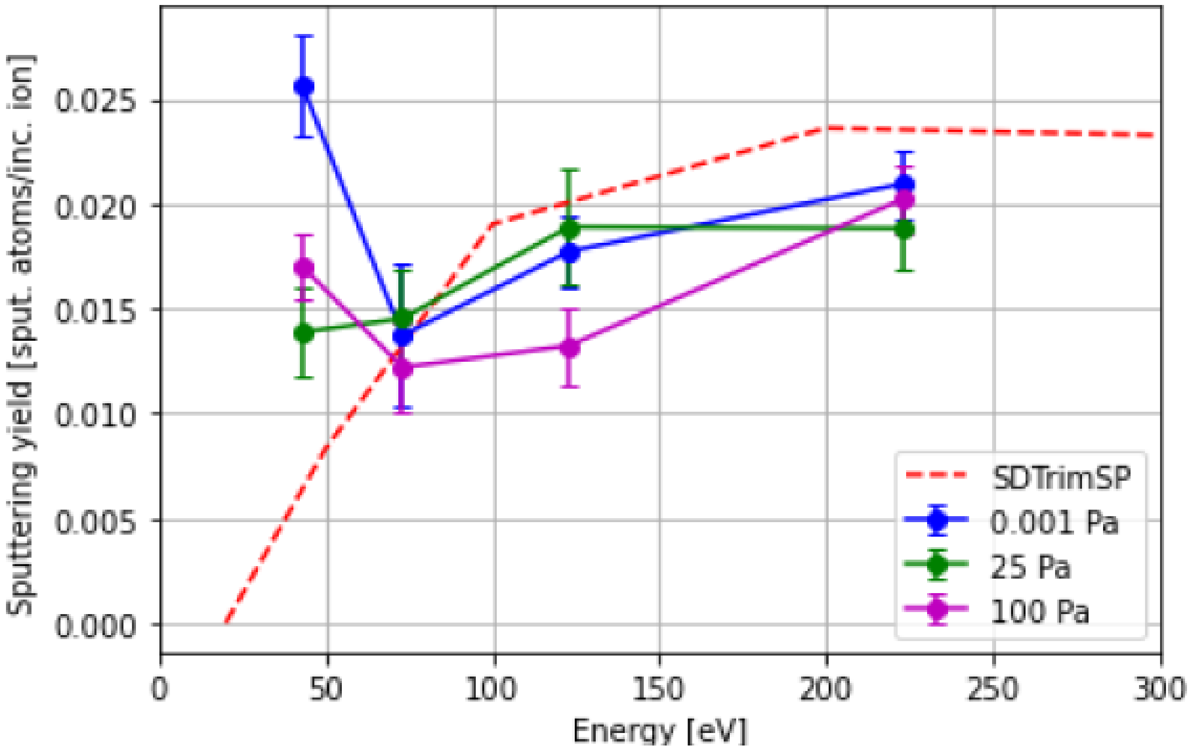




Morphology of the structures is related to film nanostructure and energy of the ions

In collaboration with: A. Maffini, D. Orecchia, F. Gaspari, A. Uccello – ENEA Milan
Submitted abstract at PFMC 25

Sputtering yield of B coatings



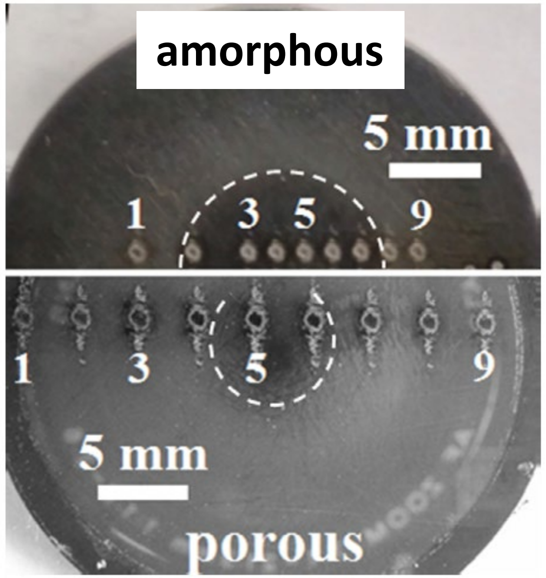
Sputtering yield obtained through eroded mass measurement. At high energies close to the simulations Deviations at low energies, role of chemical sputtering?

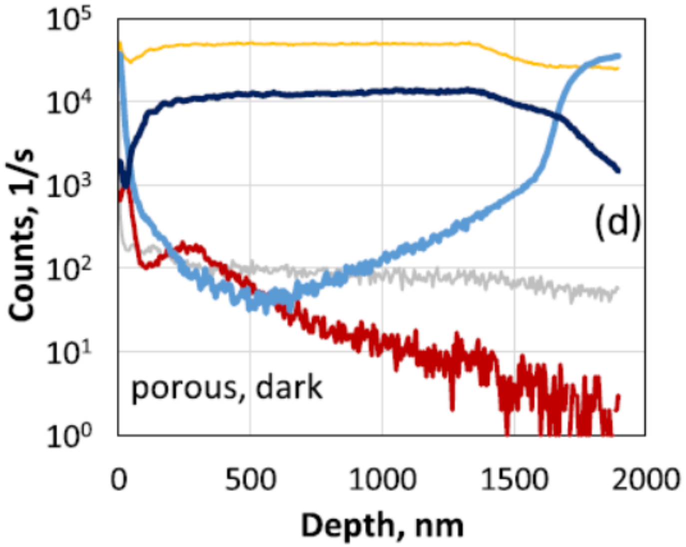
In collaboration with: A. Maffini, D. Orecchia, F. Gaspari, A. Uccello – ENEA Milan
Submitted abstract at PFMC 25

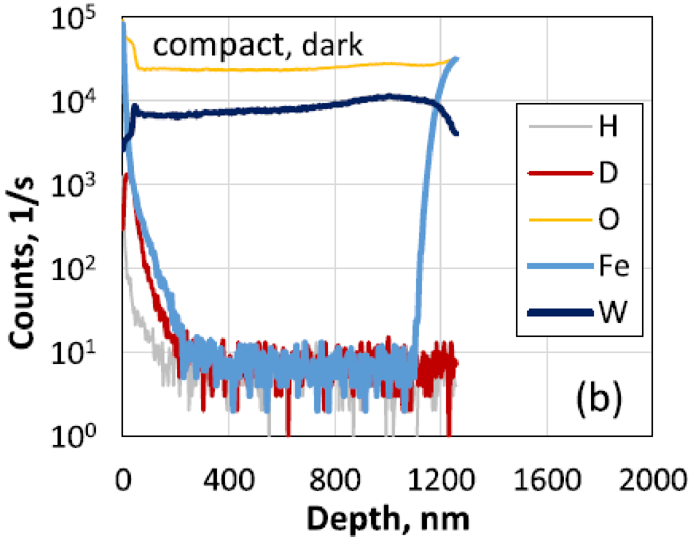
Thanks for your kind attention!

Exploiting the different morphologies: LIBS studies

Porous and amorphous W films have been exposed to MAGNUM plasma and then analysed by LIBS.
Different depth profiles depending on the morphology of the film



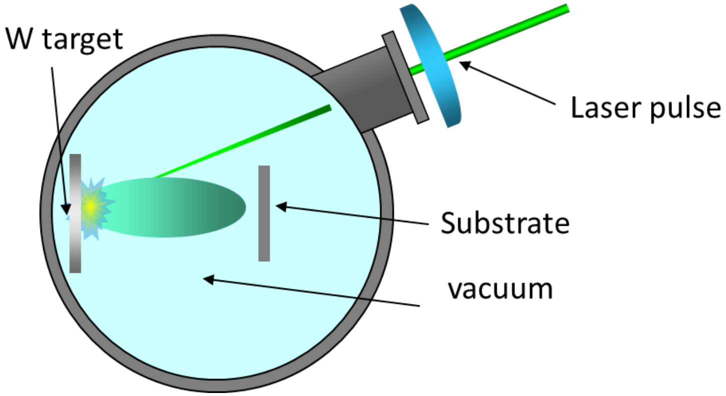




Jõgi, I. et al., Journal of Nuclear Materials, 2021 , 544, art. no. 152660.
Paris, P., et al. Fus. Eng. and Des., 2021, 168, art. no. 112403.

Production of W coatings by PVD techniques

Pulsed Laser Deposition (PLD)



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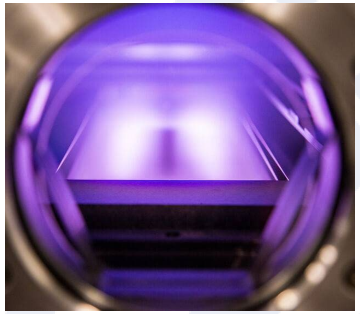

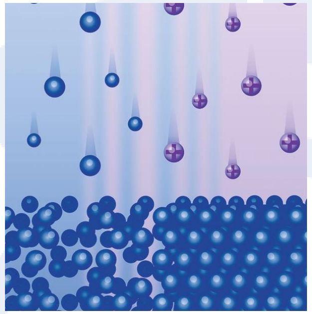

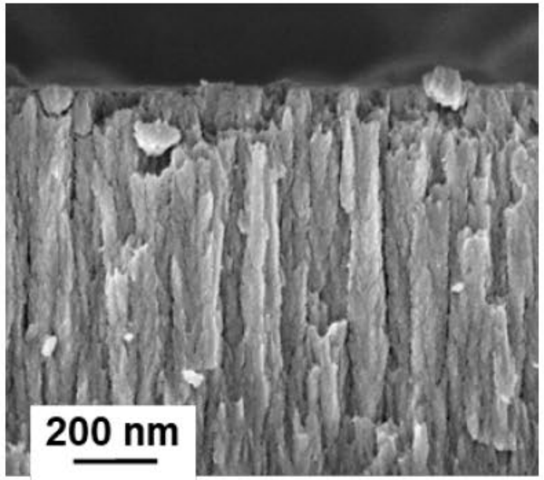

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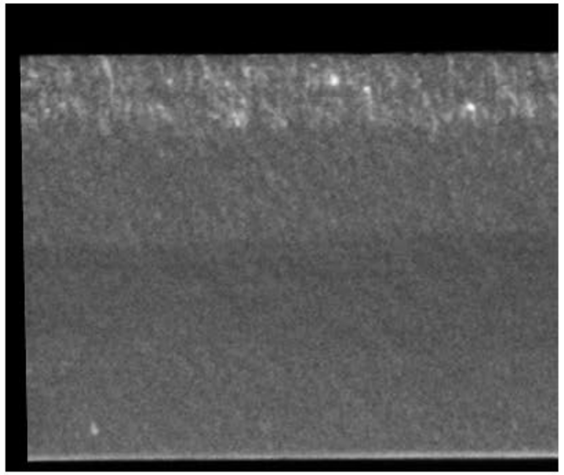

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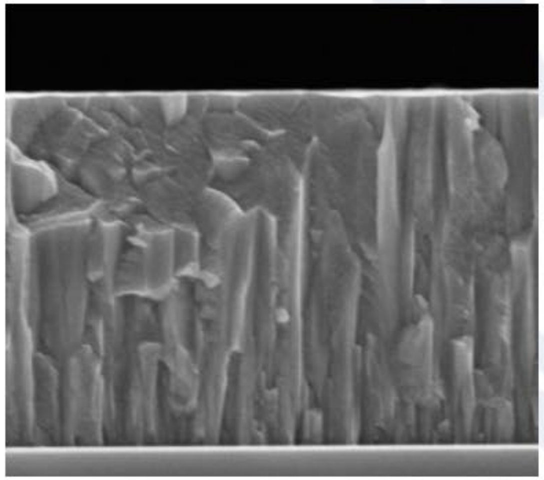

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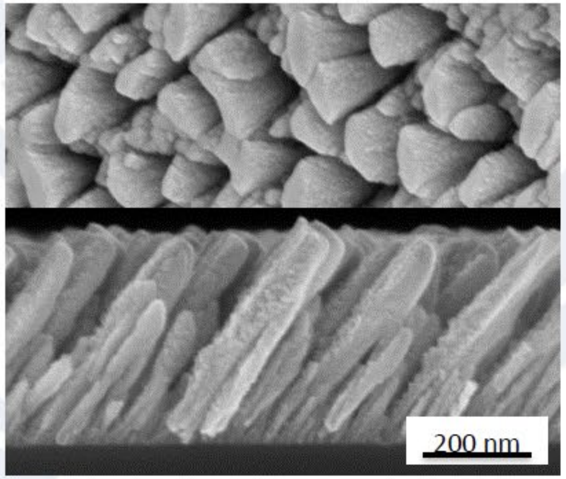

Nanocolumnar-W