EUROfusion

ID: 1225

LATEST RESULTS OF EUROFUSION PLASMA- FACING COMPONENTS RESEARCH IN THE AREAS OF POWER LOADING, MATERIAL EROSION AND FUEL RETENTION

M. Reinhart[1]*, S. Brezinsek[1], J.W. Coenen[1,2], A. Kirschner[1], T. Schwarz-Selinger[3], K. Schmid[3], A. Hakola[4], H. van der Meiden[5], R. Dejarnac[6], E. Tsitrone[7], E. Bernard[7], R. Doerner[8], M. Baldwin[8], D. Nishijima[8], and the WP PFC Team[9]

1 Forschungszentrum Jülich, Institut für Energie- und Klimaforschung – Plasmaphysik Jülich, Germany, 2 Department of Engineering Physics, University of Wisconsin Madison, WI 53706 Madison, USA, 3 Max-Planck-Institut für Plasmaphysik, D-85748 Garching, Germany, 4 VTT Technical Research Centre of Finland Ltd, VTT, Finland, 5 Dutch Institute for Fundamental Energy Research, Eindhoven, The Netherlands, 6 Institute of Plasma Physics of the CAS, Prague, Czech Republic, 7 Institut de Recherche sur la Fusion par confinement Magnétique, CEA, Saint-Paul-lez-Durance, France, 8 Center for Energy Research, University of California at San Diego, La Jolla, USA, 9 www.euro-fusionscipub.org/PFC

Abstract

- The EUROfusion Work Package Plasma-Facing Components focuses on critical plasma-surface interaction studies. Experiments from the lab-scale to tokamak scale are performed and supported by dedicated modelling activities.
- The wide range of experiments allows the investigation of single aspects as well as synergistic effects.

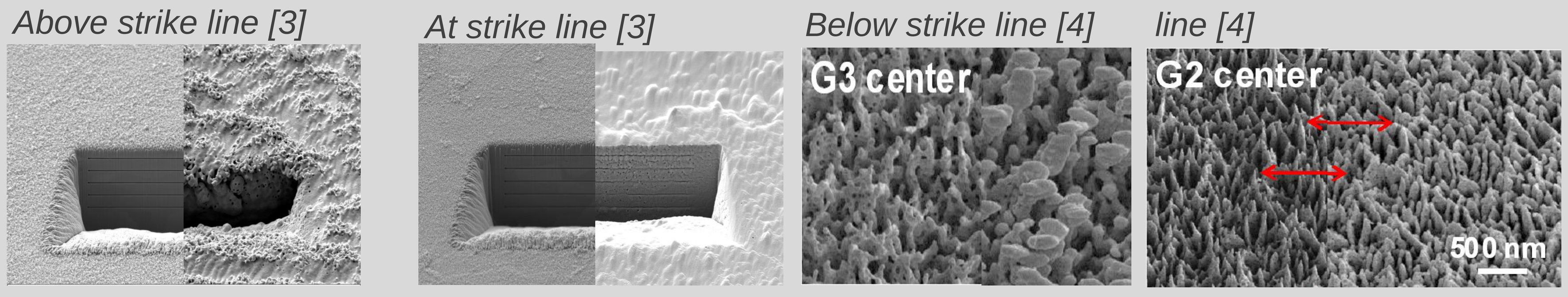
The most important highlight results from 2018-2020 are presented here:

- **W-He interaction observed under a variation of exposure parameters**
- **W surface modification and erosion is modelled and benchmarked against experiments**
- **High fluence-, shaping- and ELM-simulation experiments with ITER-like monoblocks**
- **Fuel retention studies with the influence of seeding gasses and neutron damage**

W-He interaction / tungsten fuzz

Tungsten samples pre-damaged by ion beam (GLADIS [1]) or plasma exposure (PSI-2 [2]), inducing tungsten fuzz. Exposure to Tokamak He plasmas (ASDEX-U, WEST). Results:

AUG H-Mode, ELMs, Above strike line [3] | *AUG H-Mode, ELMs, At strike line [3]* | *AUG H-Mode, ELMs, Below strike line [4]* | *AUG L-Mode, at strike line [4]*



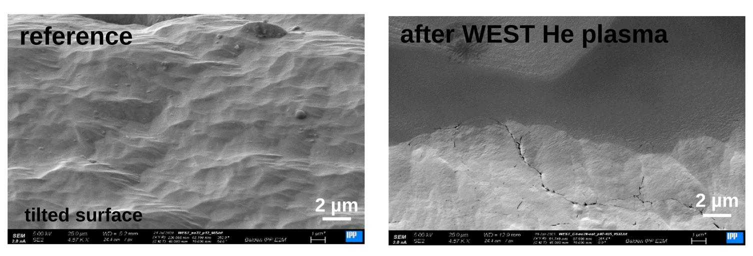
New tungsten fuzz formed. Independent of initial surface structure. Fuzz and He nanobubbles also formed inside FIB cut.

Erosion of 200 nm of pre-established tungsten fuzz.

Arcing occurs at pre-established tungsten fuzz. Net deposition with more dense structure on top of tungsten fuzz.

Only marginal erosion and deposition in pre-established tungsten fuzz

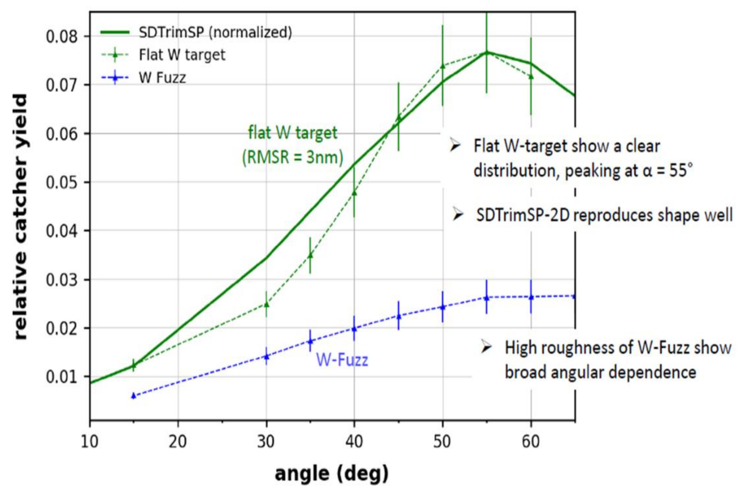
WEST long pulse L-Mode He plasma with W fuzz conditions on W coated surface [3]:

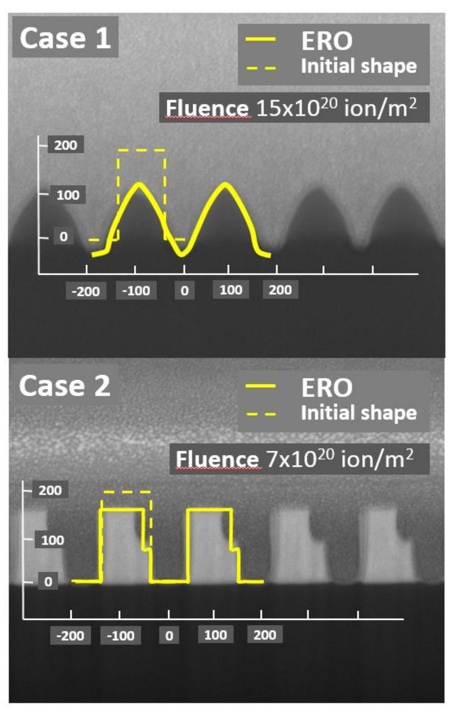


No evidence of W nanostructure after exposure.
Different behaviour of W coating / other WEST specific conditions?

W surface modifications and erosion

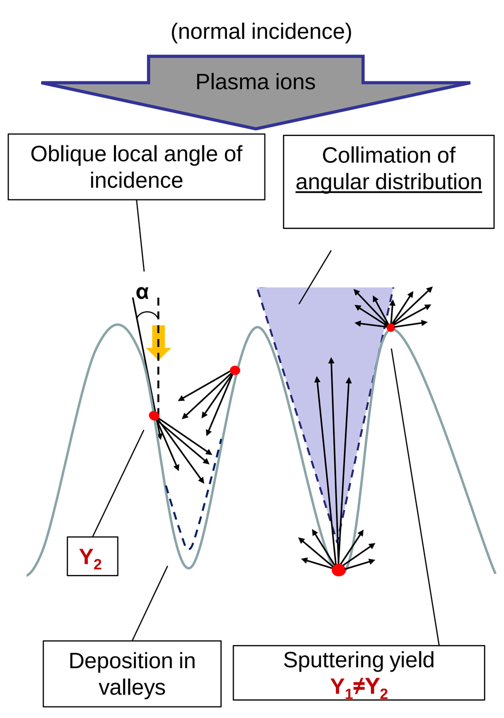
Sputtering yield of W fuzz also investigated under laboratory conditions:
Ion beam experiments [5] show lower sputtering and weaker angular dependence compared to flat target and standard SDTrim modelling.



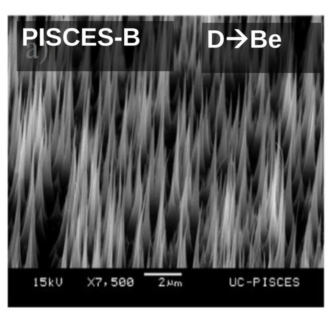


Improved models with implemented 3D surface structure [6] can reproduce the reduced sputtering yield and surface structure development.

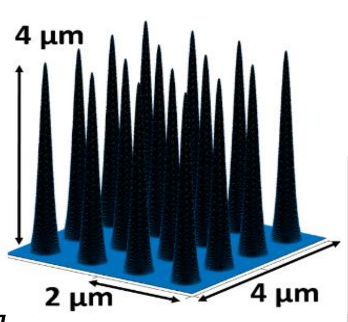
PISCES-B cooperation between WP PFC and UCSD for studies related to Be:

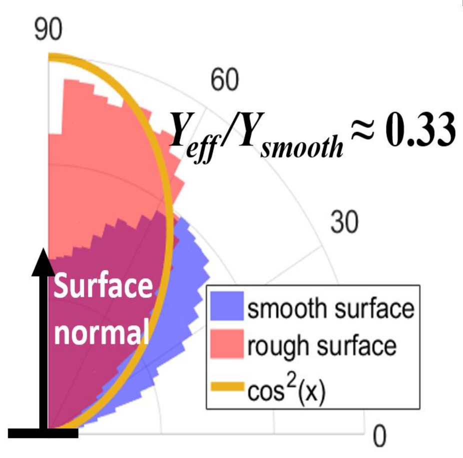


Interpretation of sputtering inside the needle structure [7]



Needle structure on Be in PISCES-B [8]

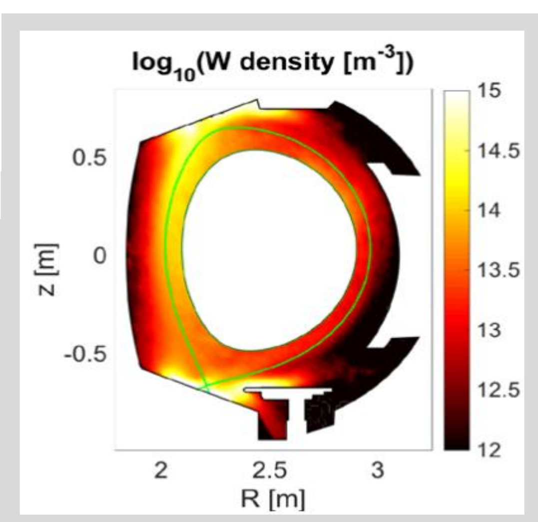




Angular dependence of the effective sputtering yield [7]

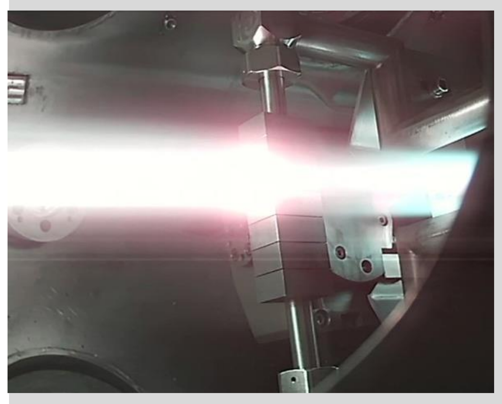
Typical needle structure of Be samples from PISCES-B USCD [8] was successfully implemented and interpreted with modelling.

3D modelling utilising the ERO2.0 code [9] without surface roughness module has been applied to benchmark JET (Be, W) and WEST (W) experiments as well as to predict the Be migration in ITER.

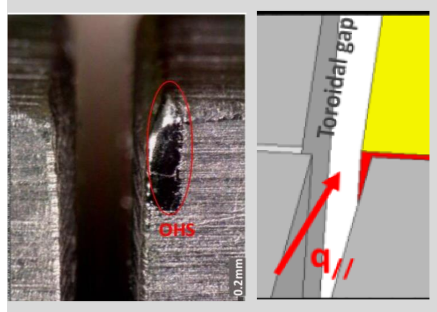


ERO2.0 modelling of W erosion at WEST

Qualification of ITER-like monoblocks



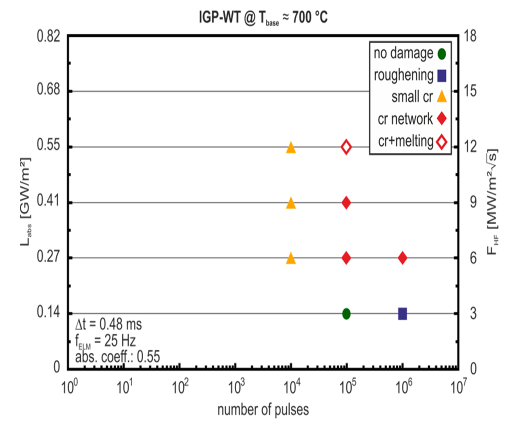
High-fluence exposure of ITER-like monoblocks in MAGNUM-PSI [10], record fluence of 10^{31} D/m2, no visible damages and very low fuel retention.



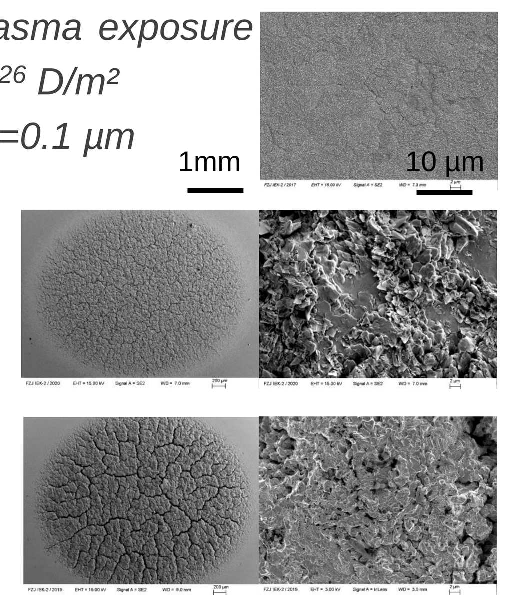
Local damage of optical hotspots on shaped/misaligned monoblocks in WEST [11].

Particle and power flux modelled by PIC simulations and applied for ITER predictions about castellation and shaping. [12]

ELM-Simulations with combined plasma and laser exposure at PSI-2 [13].



Damage threshold map shows variation of damage types up to record number of 10^6 transients.



Plasma exposure 10^{26} D/m² *R_a=0.1 µm*

Laser exposure 0.2 GW/m² *R_a=1.8 µm*

Plasma + laser exposure *R_a=7.1 µm*

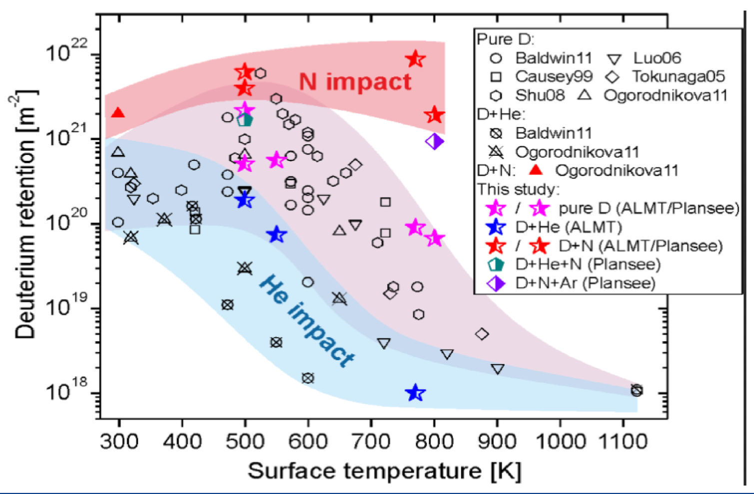
Synergistic effects (plasma+laser exposure) reduce the damage threshold compared to pure laser exposure.

Newly developed advanced materials (microstructured tungsten) [14] have higher damage thresholds under the same conditions.

Fuel retention

Impact of nitrogen seeding on fuel retention in tungsten [15]:

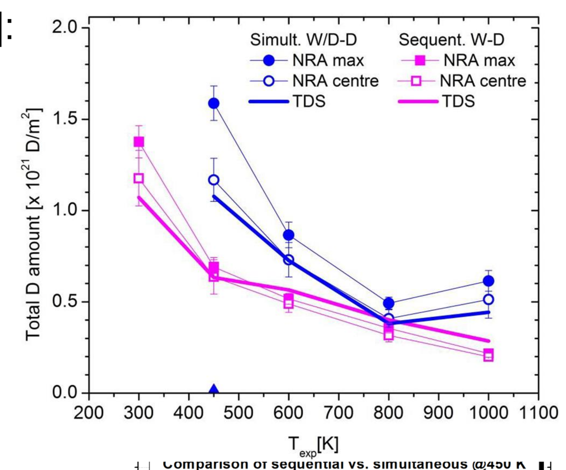
1) N : increased fuel retention
2) N+He: reduces the positive effect of He on fuel retention
3) N+Ar: Lower fuel retention increase than case (1) due to erosion

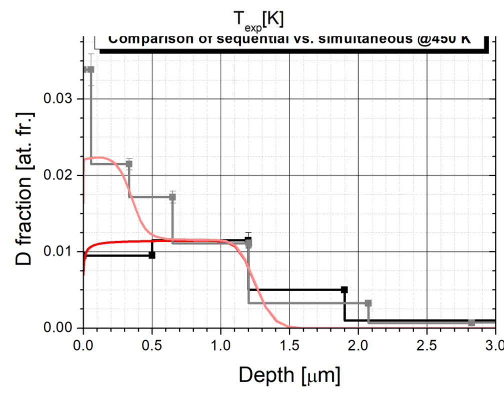


Impact of neutron damages (W Ion self damage as proxy) on fuel retention [16]:

Simultaneous ion damaging and plasma exposure enhances fuel retention compared to sequential damaging and exposure: defect stabilization by trapped deuterium.

The defect stabilization mechanism was implemented successfully in fuel retention modelling [17].





Conclusions

- **W-He interaction and W fuzz creation (relevant for lifetime estimations of the ITER divertor): W fuzz creation extremely dependent on location w.r.t. strike point and machine parameters**
- **3D W erosion models are applied to benchmark JET and WEST experiments and to predict Be migration in ITER. Successful implementation of surface effects was demonstrated as well.**
- **High fluence-, shaping- and ELM-simulation experiments giving valuable input to the qualification of the operational window of the W divertor: ITER-like monoblocks withstand high-fluence plasma exposure with no visible damage and low fuel retention, but synergistic effects (plasma + heat load) could lower the damage thresholds**
- **Results from fuel retention studies show that nitrogen can increase the fuel retention significantly in the surface region of the sample, while simultaneous ion damaging and plasma exposure leads to an increase in fuel retention due to damage stabilization by implanted deuterium**

References

[1] H. Greuner et al., *Investigation of W components exposed to high thermal and high H/He fluxes*, Journal of Nuclear Materials Volume 417, Issues 1–3, 1 October 2011, Pages 495-498
[2] S. Möller et al., *In situ investigation of helium fuzz growth on tungsten in relation to ion flux, fluence, surface temperature and ion energy using infrared imaging in PSI-2*, Phys. Scr. 2017 014017
[3] S. Brezinsek et al.,*The competition between metallic nanostructures formation, erosion and co-deposition in He plasmas of the tokamaks EAST, WEST, and ASDEX Upgrade,* 24th International Conference on Plasma Surface Interactions in Controlled Fusion Devices (PSI 2020), Jeju, Korea, 25th January 2021
[4] M. Balden et al., *Microscopy study of the growth and erosion of fuzz on tungsten by helium plasma exposure on ASDEX Upgrade*, 24th International Conference on Plasma Surface Interactions in Controlled Fusion Devices (PSI 2020), Jeju, Korea, 25th January 2021
[5] R. Stadlmayr et al., *Sputtering of nanostructured tungsten and comparison to modelling with TRI3DYN*, Journal of Nuclear Materials Volume 532, 15 April 2020, 152019
[6] A. Eksaeva et al., *ERO2.0 modelling of the effects of surface roughness on molybdenum erosion and redeposition in the PSI-2 linear plasma device*, Phys. Scr. 2020 014057
[7] A. Eksaeva et al., *The impact of surface morphology on the erosion of metallic surfaces -modelling with the 3D Monte-Carlo code ERO2.0*, DPG-Frühjahrstagung der Sektion Atome, Moleküle, Quantenoptik und Plasmen (SAMOP), 2020
[8] R.P. Doerner et al. *Impact of surface morphology on sputtering during high-fluence plasma exposure*, Phys. Scr. 2014 014040
[9] A. Gallo et al., *First efforts in numerical modeling of tungsten migration in WEST with SolEdge2D-EIRENE and ERO2.0*, Phys. Scr. 2020 014013
[10] T.W. Morgan et al., *ITER monoblock performance under lifetime loading conditions in Magnum-PSI*, Phys. Scr. 2020 014065
[11] M. Diez et al., *First evidence of optical hot spots on ITER-like plasma facing units in the WEST tokamak*, Nucl. Fusion 60 054001
[12] M. Komm et al., *Simulations of thermionic suppression during tungsten transient melting experiments*, Phys. Scr. 2017 014069
[13] M. Gago et al., *Synergistic and separate effects of plasma and transient heat loads on the microstructure and physical properties of ITER-grade tungsten*, 18th International Conference on Plasma-Facing Materials and Components for Fusion Applications (PFMC-18), On-line, organised by Forschungszentrum Juelich, Germany, 17th May 2021
[14] A. Terra et al., *Micro-structured tungsten, a high heat flux pulse proof material, Nuclear Materials and Energy*, Volume 25, December 2020, Article number 100789
[15] A. Kreter et al., Interdependent effects of multiple plasma impurities on the fuel retention in tungsten, 24th International Conference on Plasma Surface Interactions in Controlled Fusion Devices (PSI 2020), Jeju, Korea, 25th January 2021
[16] S. Markelj et al., Displacement damage stabilization by hydrogen presence under simultaneous W ion damage and D ion exposure, Nucl. Fusion 59 086050
[17] M. pecovnik et al., Effect of D on the creation of displacement damage in tungsten during multiple sequential irradiations with MeV W ions, 29th International Conference Nuclear Energy for New Europe, Portoroz, Slovenia, 7th September 2020

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.