Samples for helium plasma studies on AUG and JET

M. Rasiński, et al.

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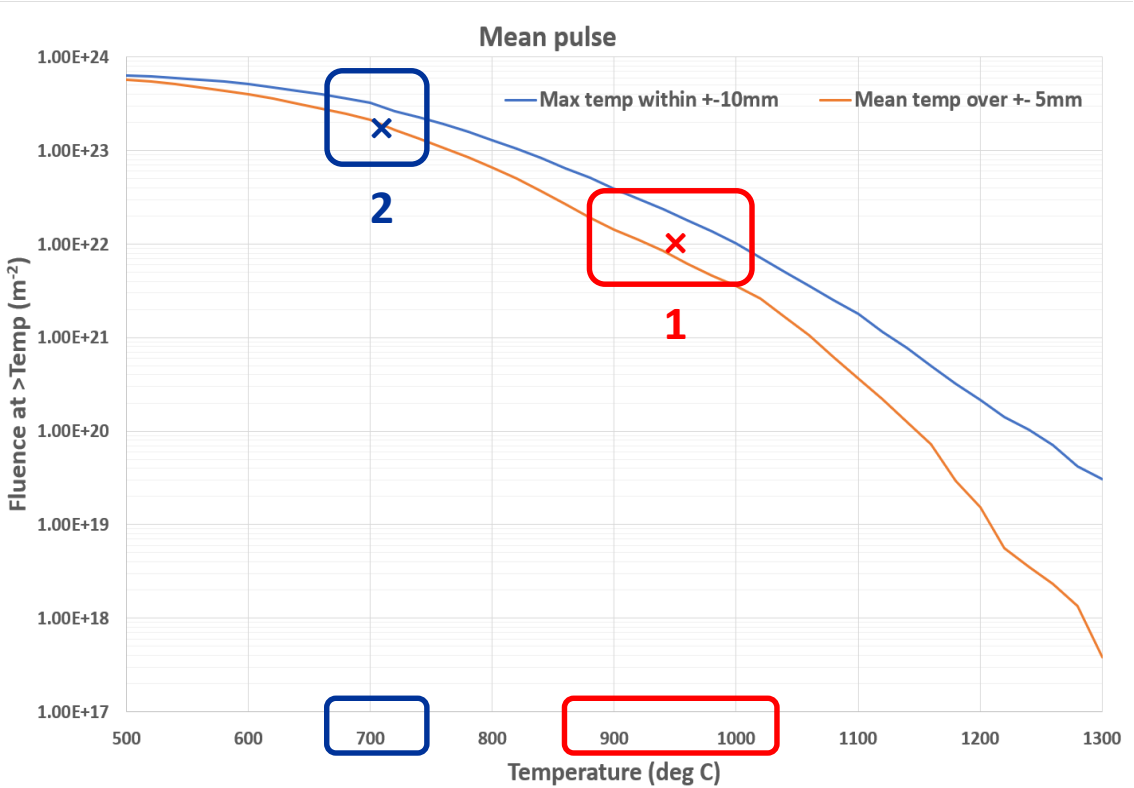
Exposure aims



For 1000 pulses

1st scenario – Fuzz formation
Temperature ~900-1000 ˚C
Fluence ~ 1.5E25 m^{-2}

For 1000 pulses

2nd scenario – He campaign conditions
Temperature - 700 ˚C
Fluence ~ 2E26 m^{-2}

Plot based on probe 26 data in Tile 6 of the fluence per pulse against time spent above a certain temperature as determined by IR.
The plotted are for the average pulse

Experimental set-up

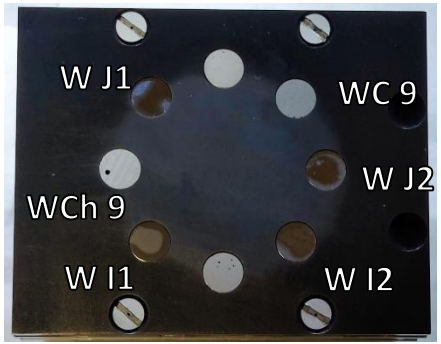
Samples: W-CFC, bulk W JET lamella and W-polished-ITER grade(FZJ), Bias: -100V ~ 80 eV

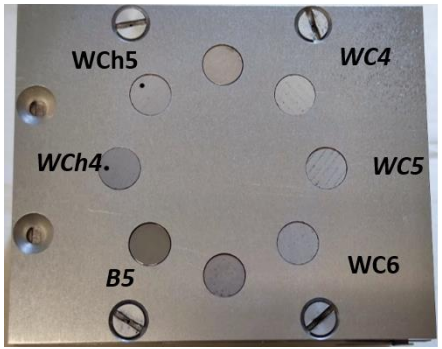
1st exposure – Fuzz formation
Temperature ~ 950 °C
Ion Flux ~ 4.5×10^{22} $m^{-2}s^{-1}$
Fluence ~ 1.5×10^{25} m^{-2}

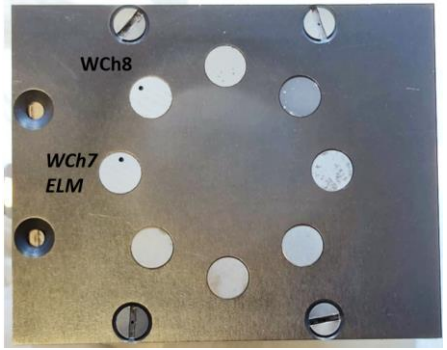
2nd exposure – He campaign
Temperature ~ 700 ˚C
Ion Flux ~ $1.1\text{-}1.2 \times 10^{22}$ $m^{-2}s^{-1}$
Fluence ~ 2×10^{26} m^{-2}

3rd exposure: ELM-like heat pulse
Temperature ~ **730 ^{0}C**
Ion Flux ~ $1.1\text{-}1.2 \times 10^{22}$ $m^{-2}s^{-1}$
Fluence ~ 2×10^{26} m^{-2}

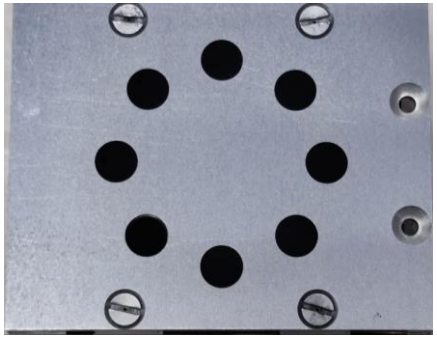
BEFORE

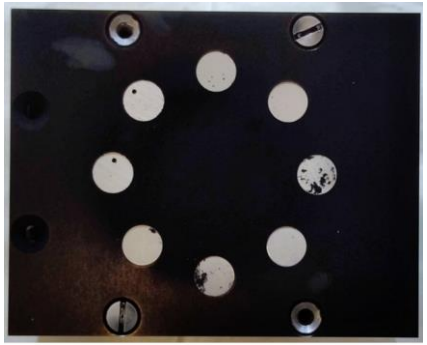






AFTER





Samples for helium plasma studies on JET

1st exposure – Fuzz formation

Temperature ~ 950 °C

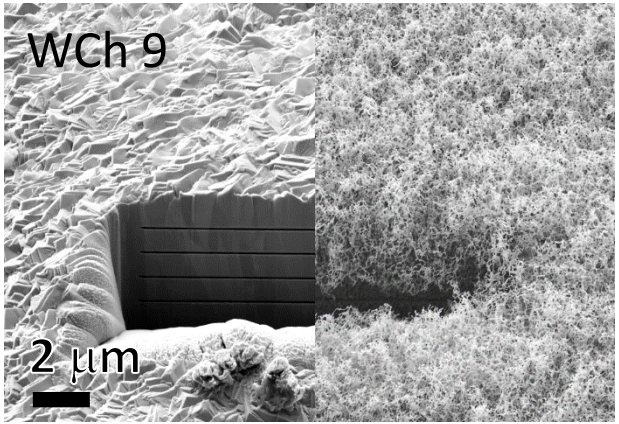
Ion Flux ~ 4.5×10^{22} $m^{-2}s^{-1}$

Fluence ~ 1.5×10^{25} m^{-2}

Energy ~ 80 eV

W bulk JET lamella

W bulk ITER grade (FZJ)



W coating on CFC

All three types of materials show similar fuzz formation

Samples for helium plasma studies on JET

1st exposure – Fuzz formation

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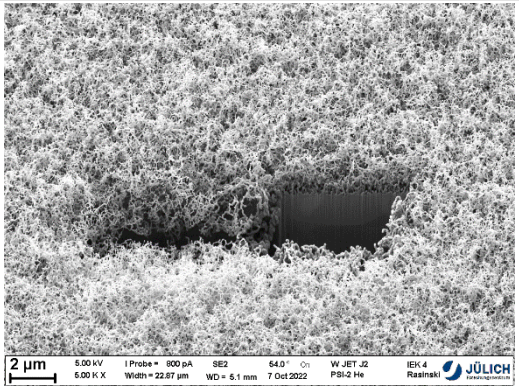
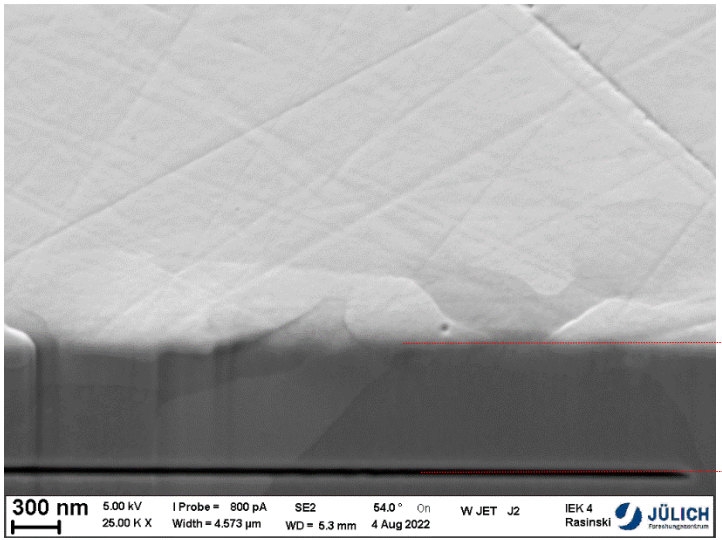
Fluence ~ 1.5×10^{25} m^{-2}

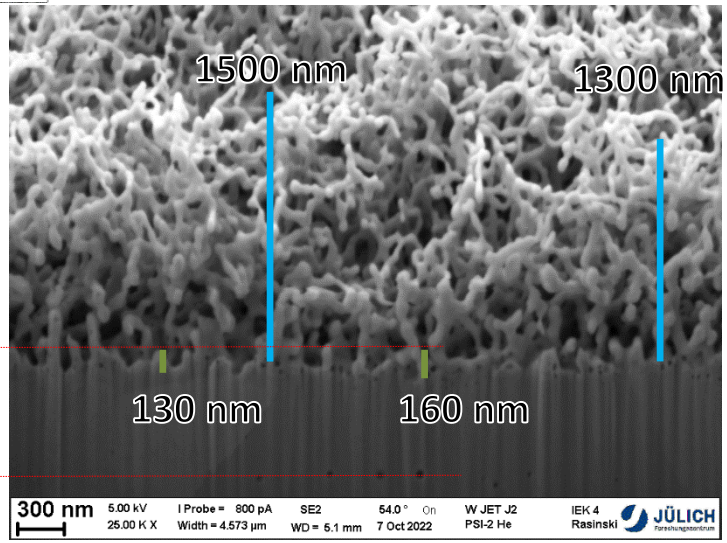
Energy ~ 80 eV

W JET 2



Fuzz – 1300 – 1500 nm





Samples for helium plasma studies on JET

1st exposure – Fuzz formation

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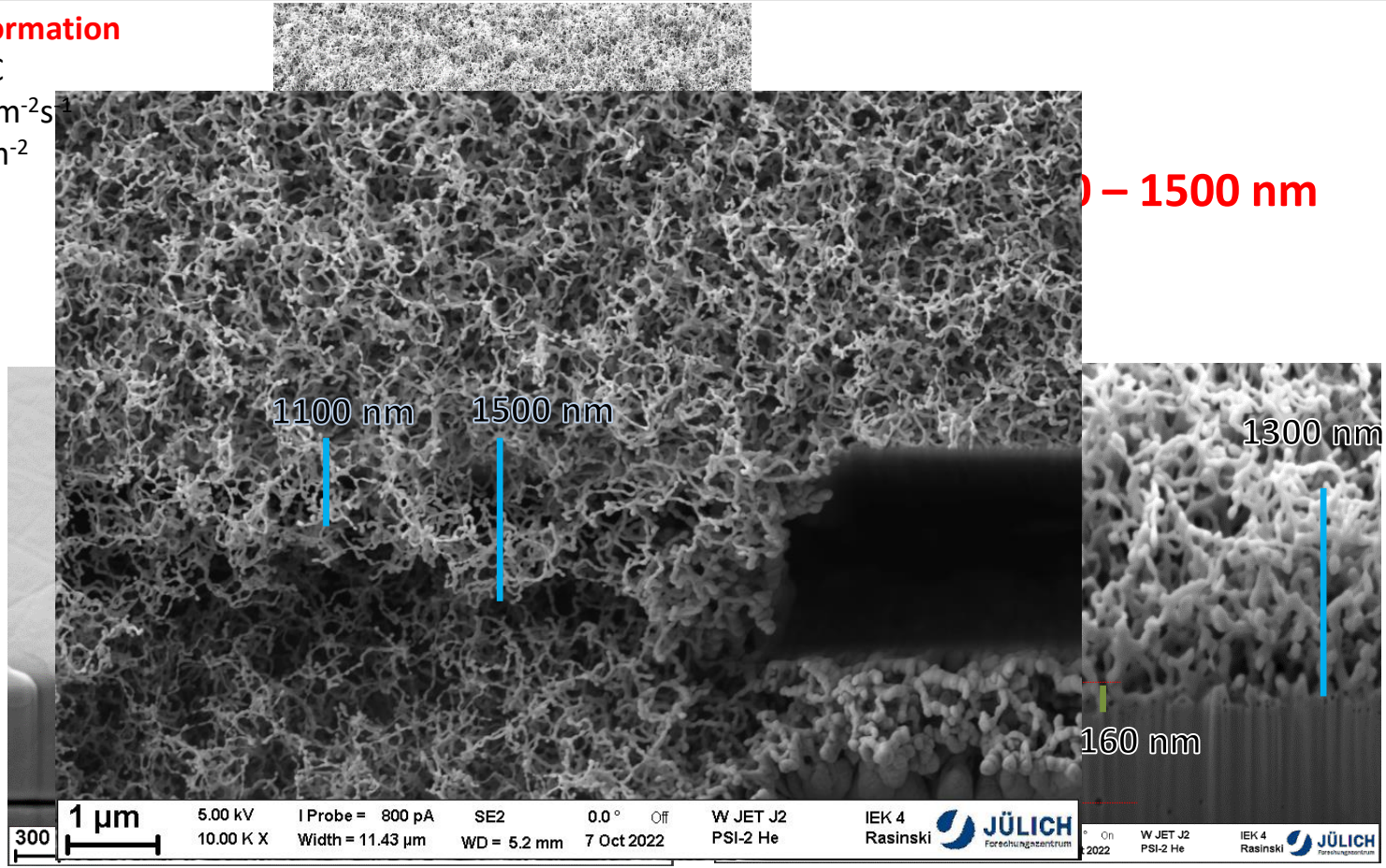
Energy ~ 80 eV

W JET 2

) – 1500 nm



Samples for helium plasma studies on JET

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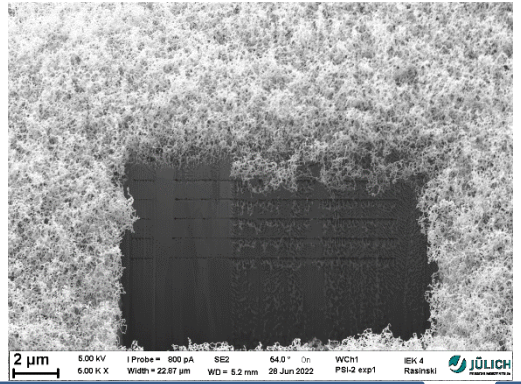
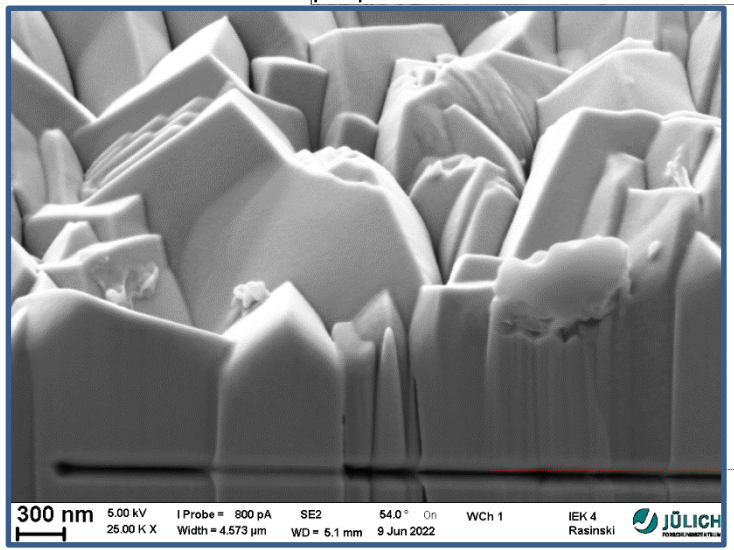
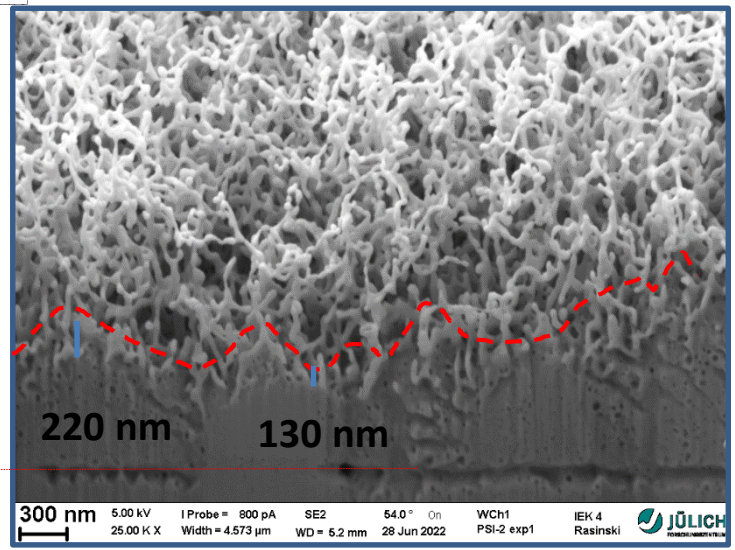
Energy ~ 80 eV

W Ch 1







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1st exposure – Fuzz formation

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Energy ~ 80 eV

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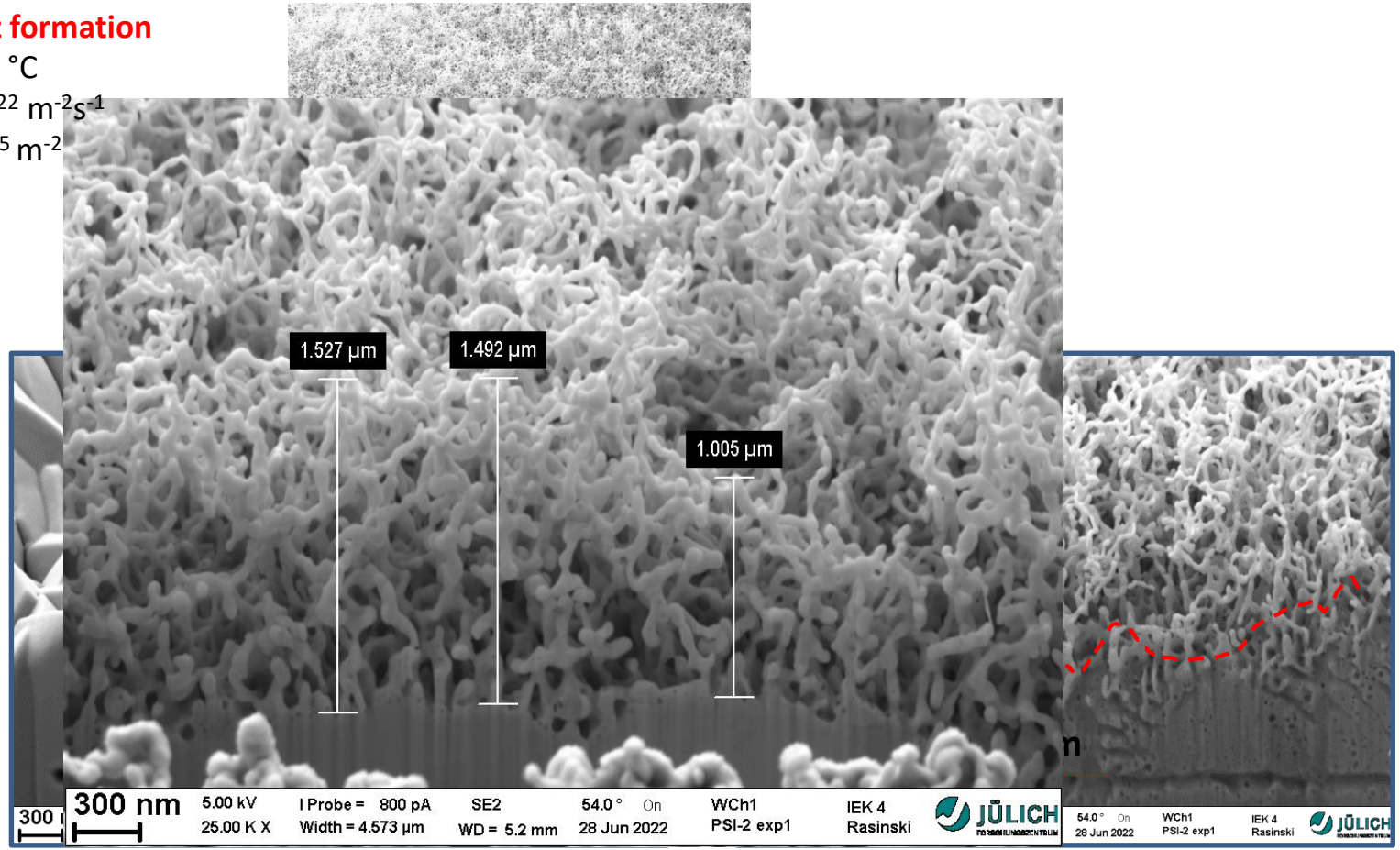
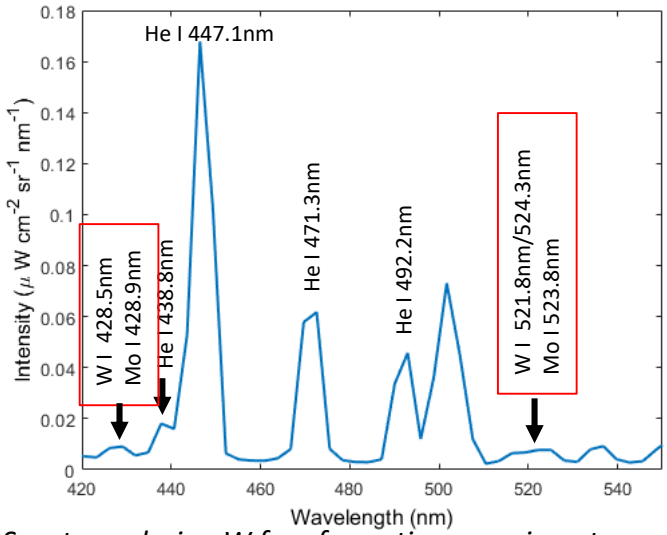


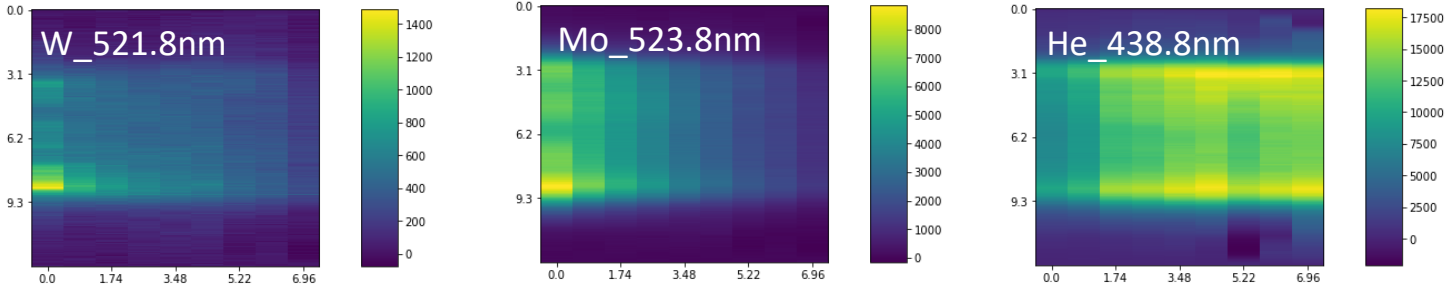
Spectroscopy



Spectrum during W fuzz formation experiment

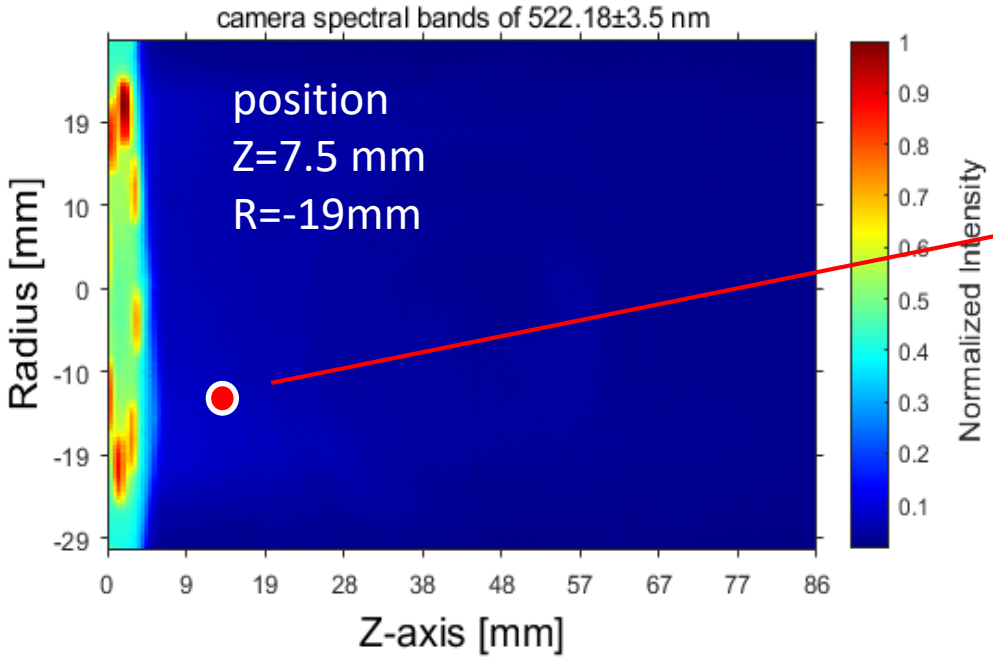
Wavelength range (nm): 400-1000
Spectral resolution (FWHM, nm): 7
Spectral bands: 204
Spatial resolution in this set up (mm/pixel): ~0.48

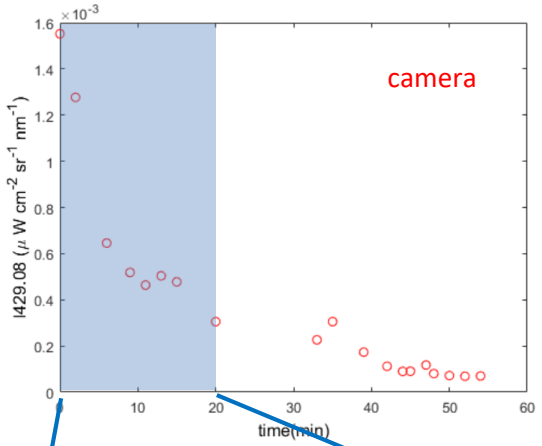
Separation of W and Mo from He plasma

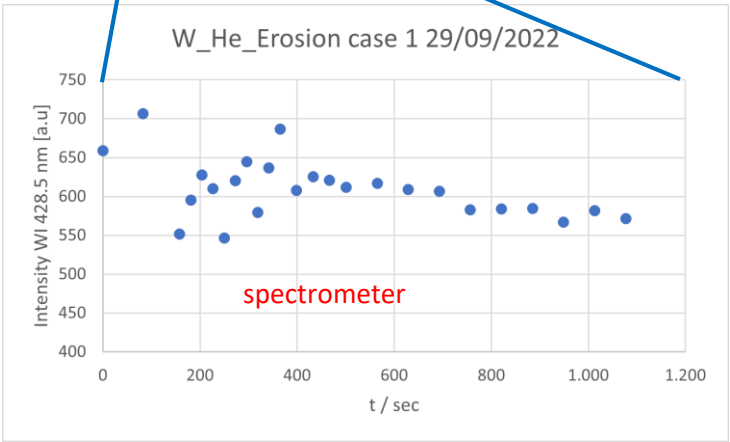


Spatial distribution during W fuzz formation

Spectroscopy - evolution of time







The results of both hyperspectral camera and spectrometer show the downward trend of W I intensity.

Samples for helium plasma studies on JET

1st exposure – Fuzz formation

Temperature ~ 950 °C

Ion Flux ~ 4.5×10^{22} $m^{-2}s^{-1}$

Fluence ~ 1.5×10^{25} m^{-2}

Energy ~ 80 eV

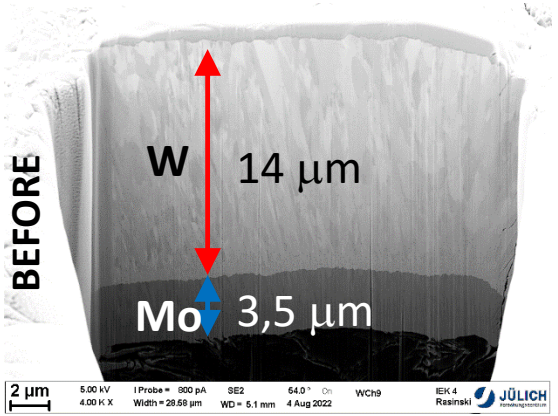
W Ch 9

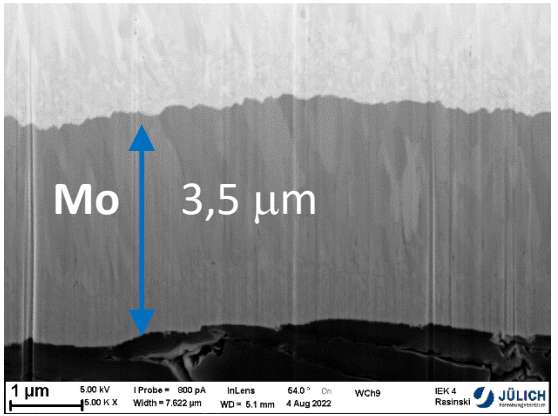
Exposure at 950 °C for 1h leads to formation of Mo_2C at the interface

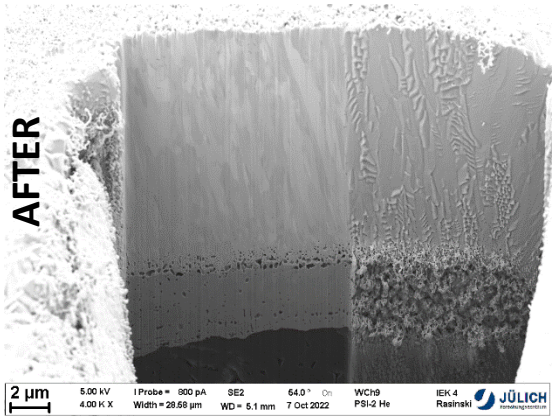
More on carbide formation due to annealing:

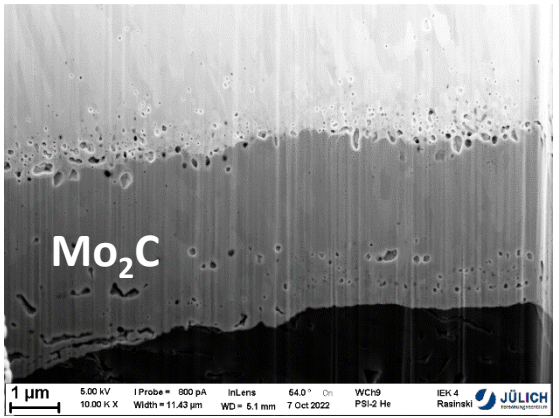
M. Rasinski et al. / Thin Solid Films 2013 531 doi.org/10.1016/j.tsf.2012.10.066

H Maier et al. / Phys. Scr. 2016 014048 doi:10.1088/0031-8949/T167/1/014048









Samples for helium plasma studies on JET

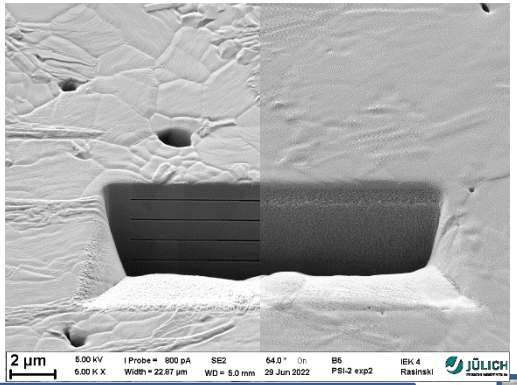
2nd exposure – He campaign

Temperature ~ 700 °C

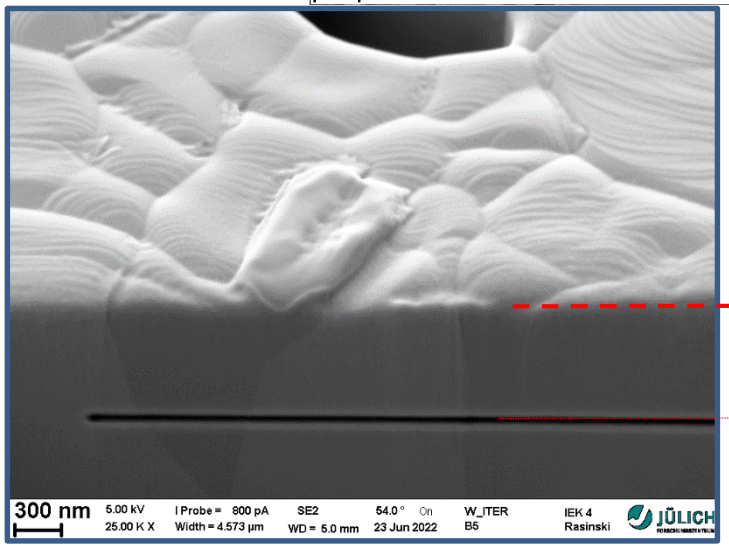
Ion Flux ~ 1.1-1.2 × 10^{22} $m^{-2}s^{-1}$

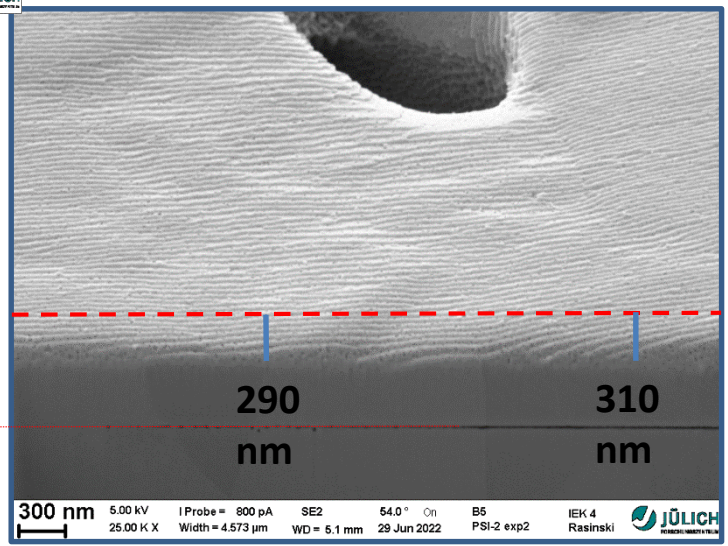
Fluence ~ 2 × 10^{26} m^{-2}

W_ITER5



Erosion – 300 nm





Samples for helium plasma studies on JET

2nd exposure – He campaign

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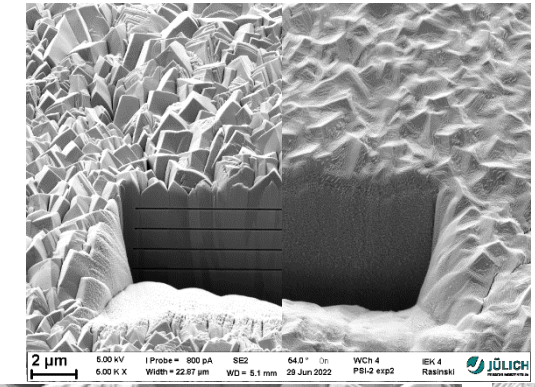
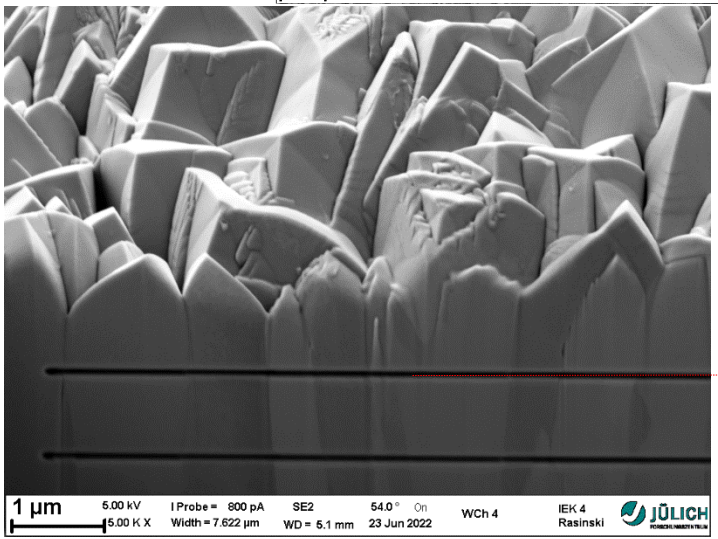
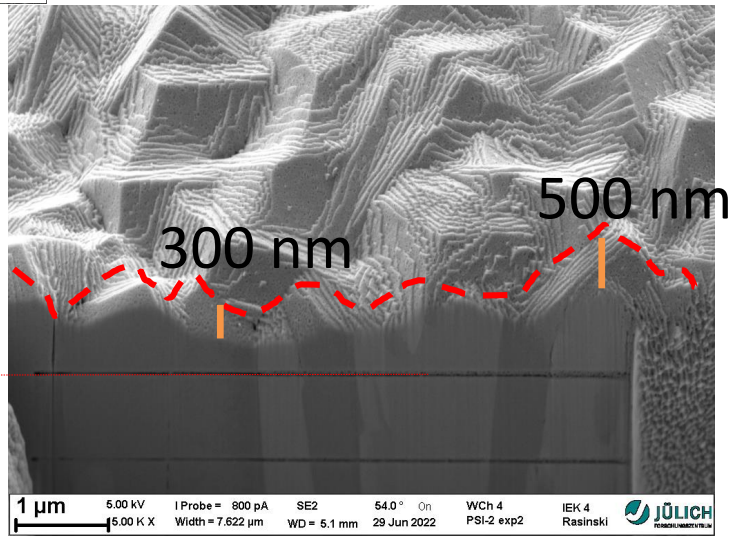


Erosion – 300 - 500 nm

W Ch4





Exposure at $t_s \approx 700°C$ - ELM simulation by laser

fast IR measurements resolving laser pulses

3rd exposure: ELM-like heat pulse
Temperature ~ **730 °C (global)**
800 °C (laser pulse)
Ion Flux ~ 1.1-1.2 × 10^{22} $m^{-2}s^{-1}$
Fluence ~ 2 × 10^{26} m^{-2}

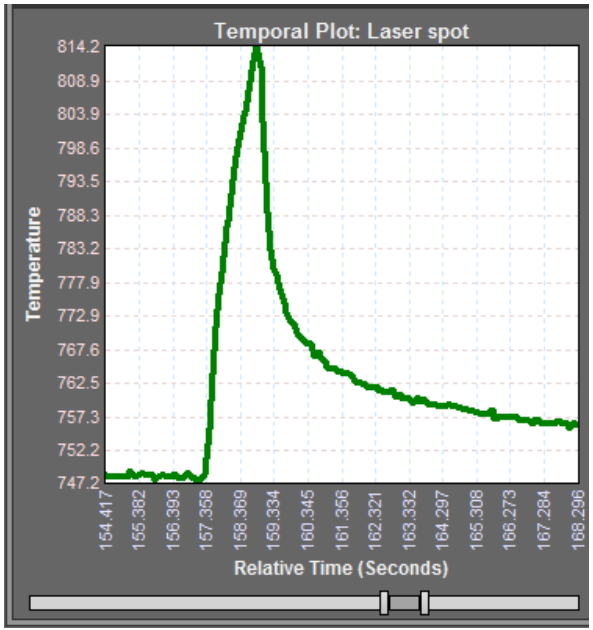
WCh7 - ELM

Frequency: 30 Hz
Pulse duration: 1 ms

Absorbed power density 0.065 GW/m2.

Energy – 1.623 J/pulse
Average power – 48.69 W

- With reduced area of observation, it is possible to increase the **camera frame rate to ≈3600 fps**, thus resolving individual laser heat pulses



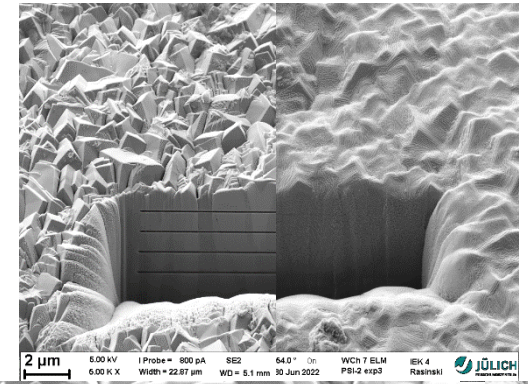
- **Laser pulses increase the local surface temperature by 60-70°C to max of ≈800°C.**

- For steady-state at ≈800°C W fuzz is normally formed. However, here no W fuzz was observed. Laser has probably too low duty cycle to allow for W fuzz formation.

Samples for helium plasma studies on JET

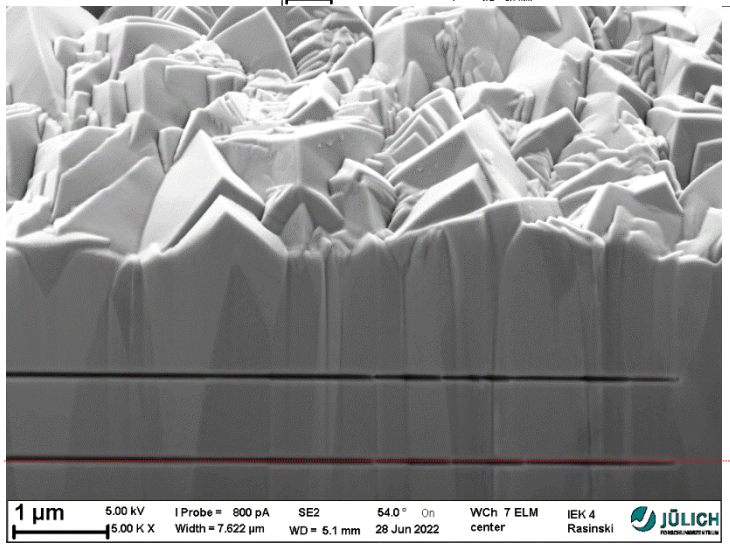
3rd exposure: ELM-like heat pulse
Temperature ~ **730 °C (global)**

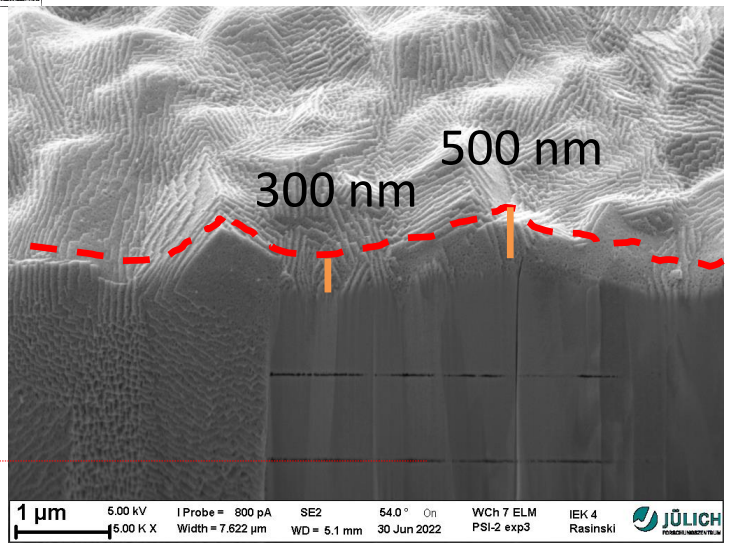
Ion Flux ~ 1.1-1.2 × 10^{22} $m^{-2}s^{-1}$
Fluence ~ 2 × 10^{26} m^{-2}



Erosion – 300 - 500 nm

WCh7 - ELM





Conclusions

1st exposure – Fuzz formation	**2nd exposure – He campaign conditions 700 °C**	**3rd exposure – He campaign conditions 700 °C + ELM-like heat pulse**
Temperature ~ 950 °C Ion Flux ~ 4.5×10^{21} $m^{-2}s^{-1}$ Fluence ~ 1.5×10^{25} m^{-2}	Temperature ~ 700 ^{0}C Ion Flux ~ $1.1\text{-}1.2 \times 10^{22}$ $m^{-2}s^{-1}$ Fluence ~ 2×10^{26} m^{-2}	Temperature ~ 730 °C Ion Flux ~ $1.1\text{-}1.2 \times 10^{22}$ $m^{-2}s^{-1}$ Fluence ~ 2×10^{26} m^{-2}
✓ Clear W-fuzz formation ✓ Fuzz growing in all directions ✓ Fuzz dimension ~ up to 1.5 µm	✓ NO W-fuzz formation ✓ Erosion ripple structure formation ✓ Nano-bubble formation ✓ Predominantly erosion ✓ Estimated erosion ~ 300-500 nm	✓ NO W-fuzz formation ✓ Erosion ripple structure formation ✓ Nano-bubble formation ✓ Predominantly erosion ✓ Estimated erosion ~ 300-500 nm ✓ Not a visible difference as compared with 2nd exposure (without laser interaction)

JET bulk lamella, W-coatings and ITER grade W behaves very similar under given PSI-2 He exposures

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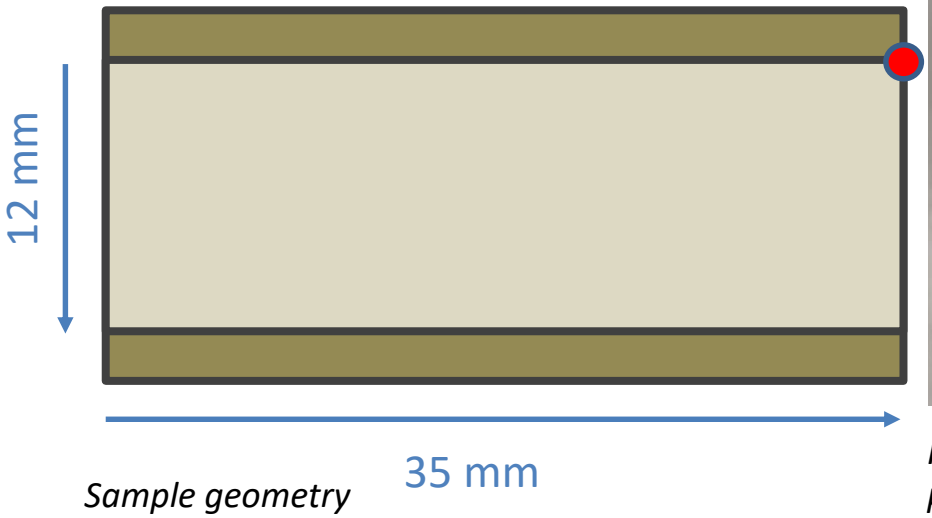
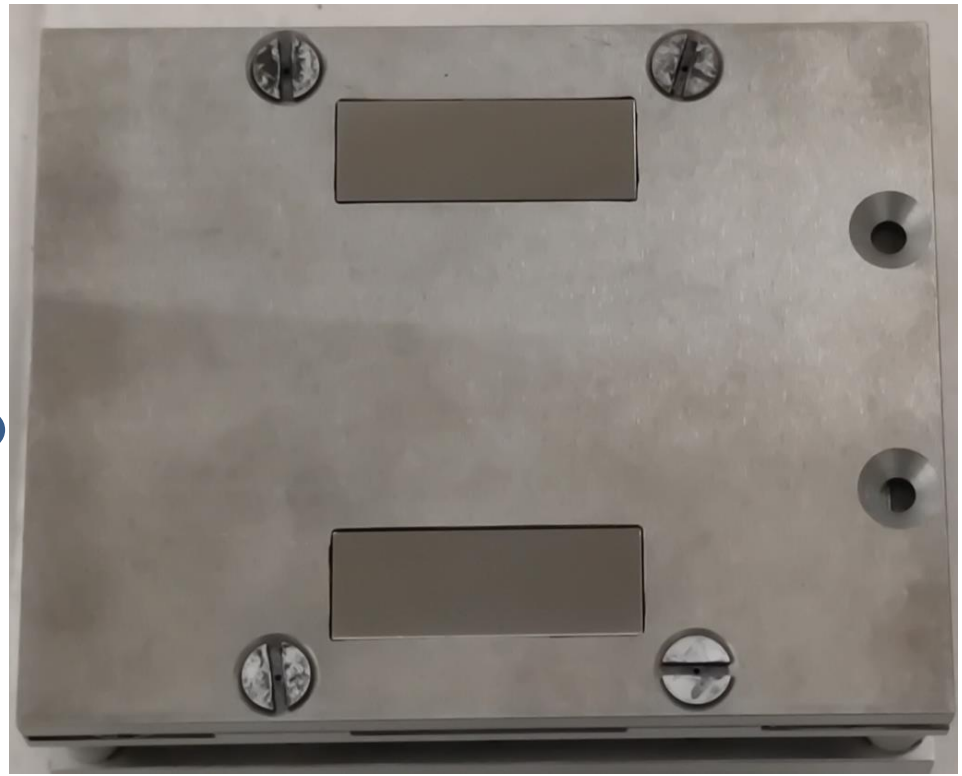
Samples for helium plasma studies on AUG

12 samples for AUG He campaign
6 polished + 6 polished and fuzz

PSI-2 exposure - Fuzz formation
Temperature ~ 900 °C
Ion Flux ~ 8.4×10^{21} $m^{-2}s^{-1}$
Fluence ~ 1.5×10^{25} m^{-2}
Energy ~ 80 eV



Sample geometry



PSI-2 sample holder with 2 samples mounted before He plasma exposure

Samples for helium plasma studies on AUG

PSI-2 exposure - Fuzz formation

Temperature ~ 900 °C

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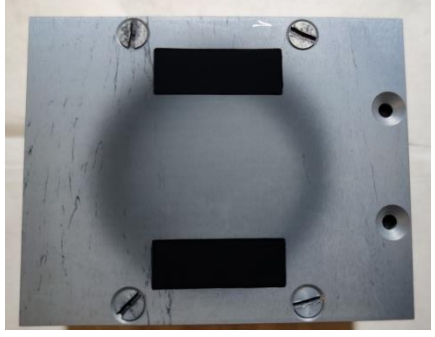
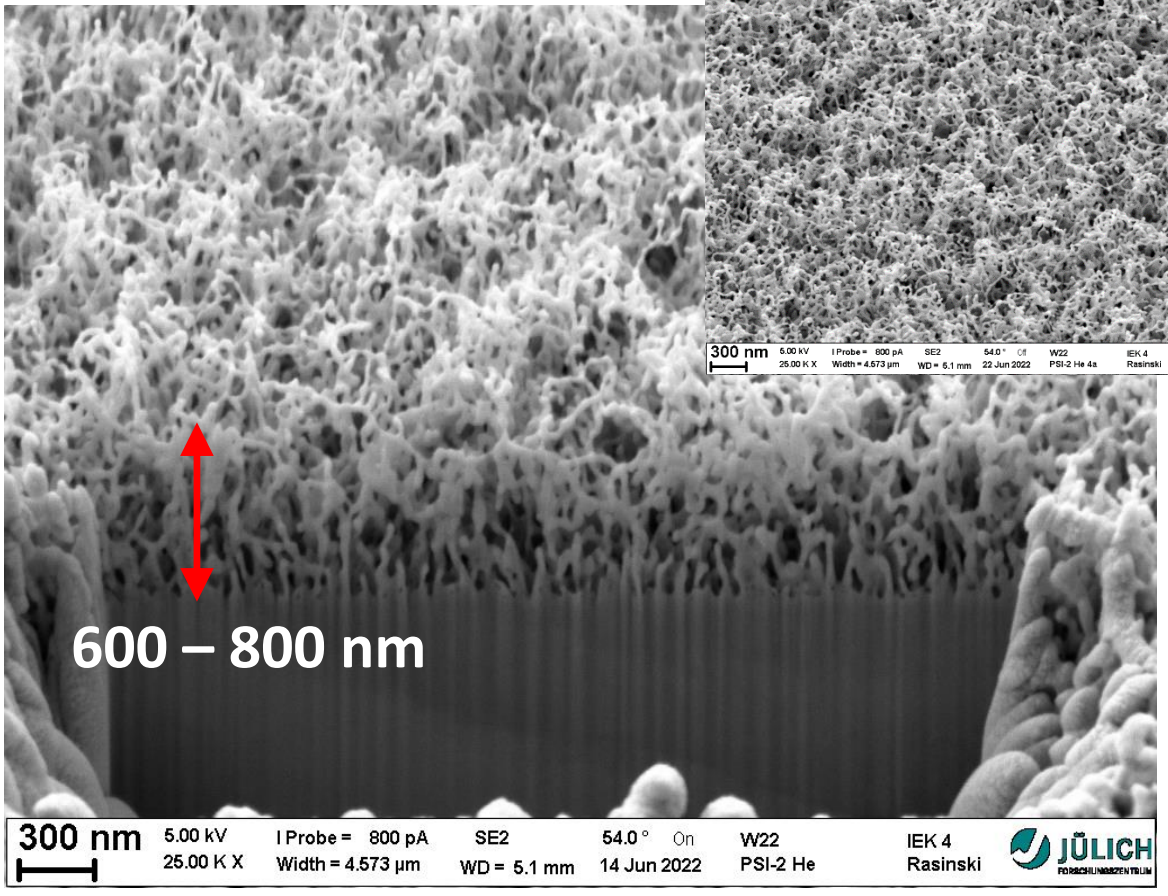
Fluence ~ 1.5×10^{25} m^{-2}

Energy ~ 80 eV





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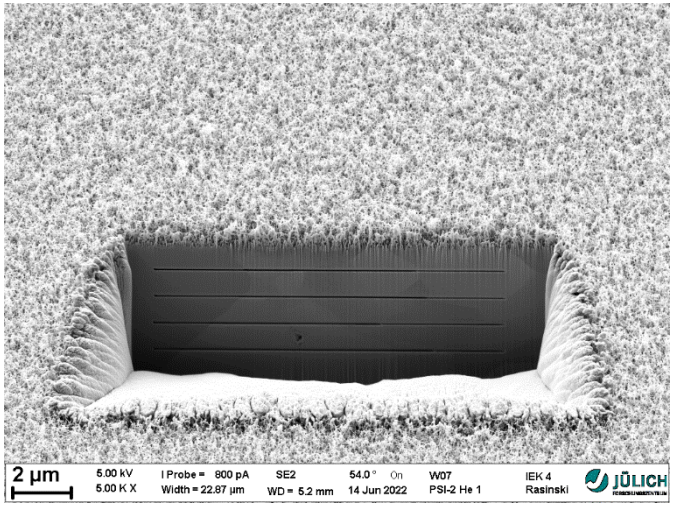
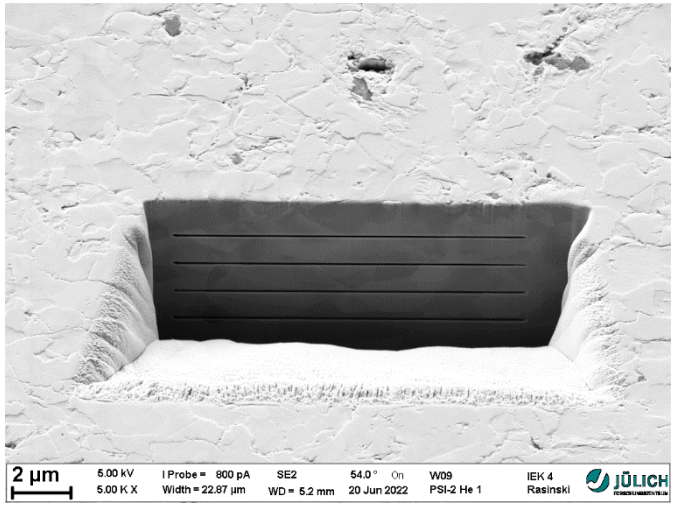
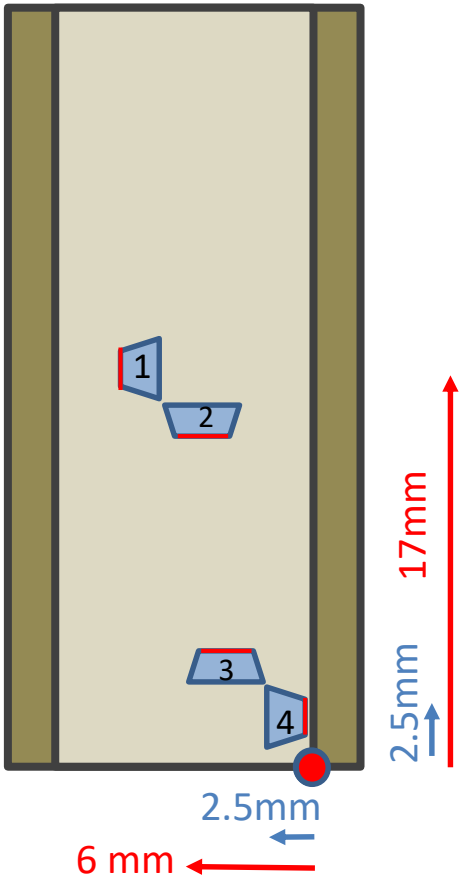


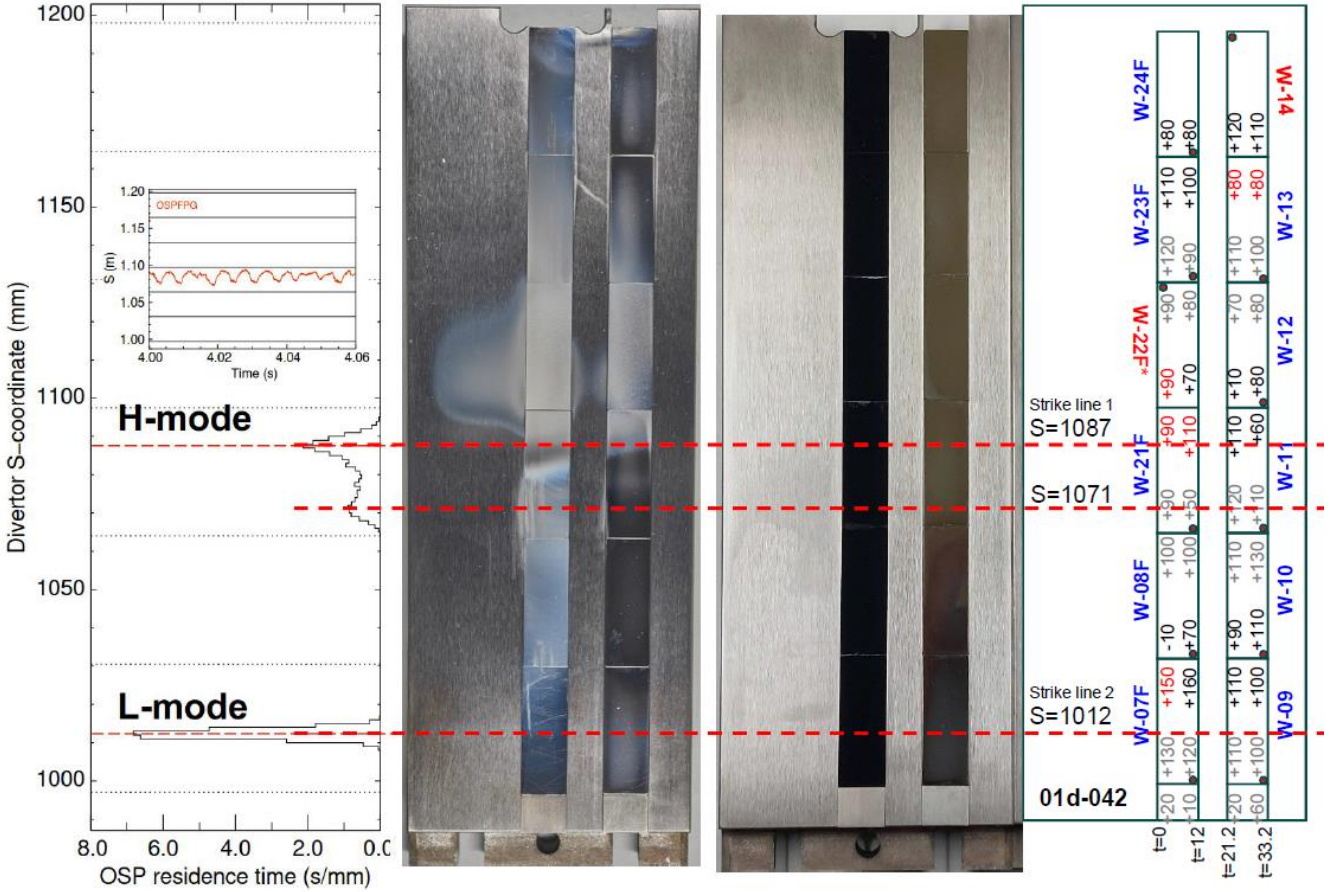




- On each sample **4 FIB cross-sections** with line marking
- **Different position and orientation** of each cross-section for better understanding the influence of plasma direction
- Cross-section examined **after AUG He** campaign to determine the erosion/deposition and fuzz formation

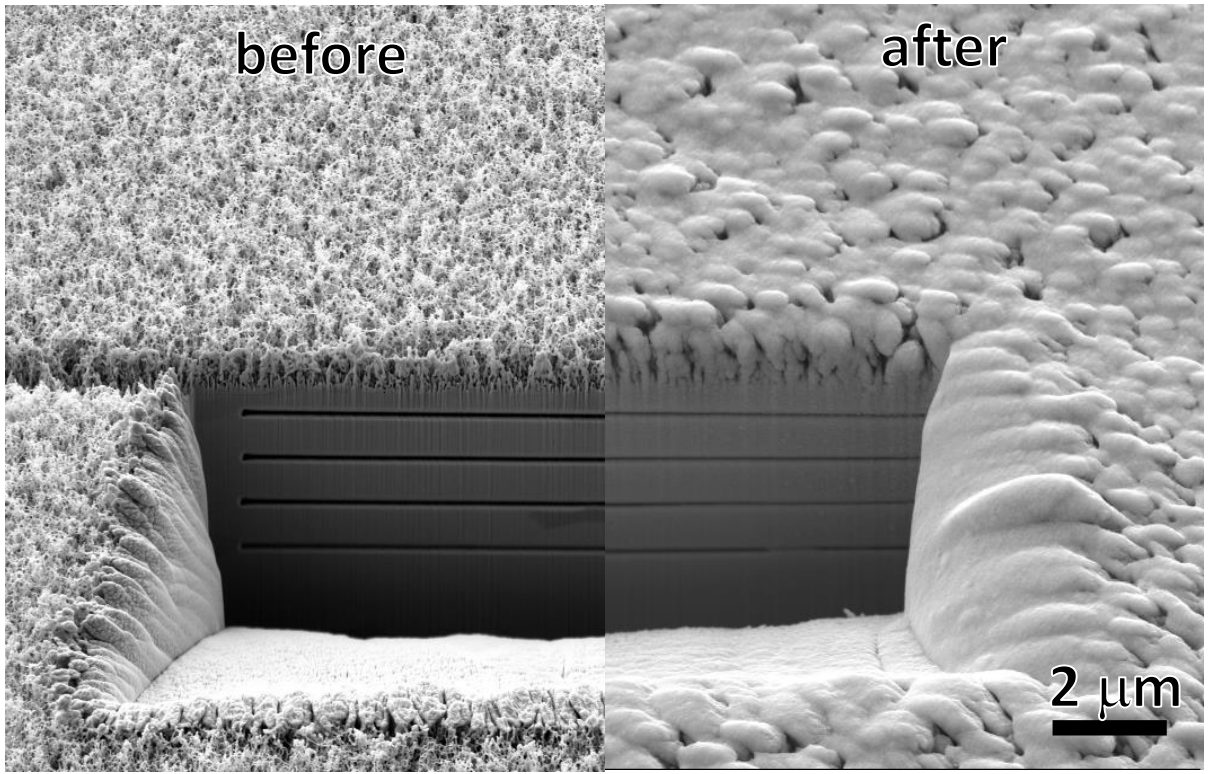
Samples for helium plasma studies on AUG

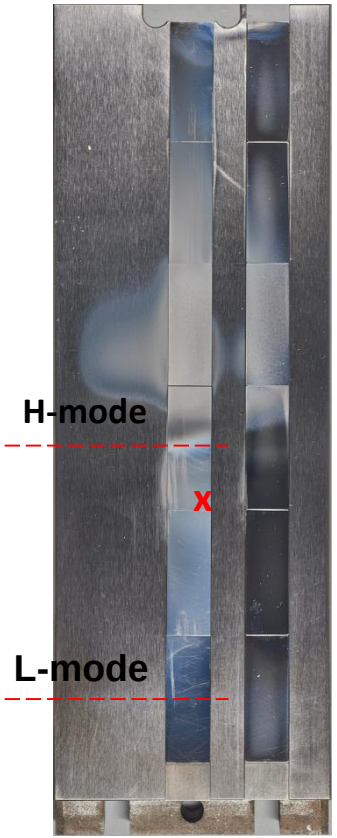
- 8 ok H-mode
- 6 ok L-mode



Samples for helium plasma studies on AUG

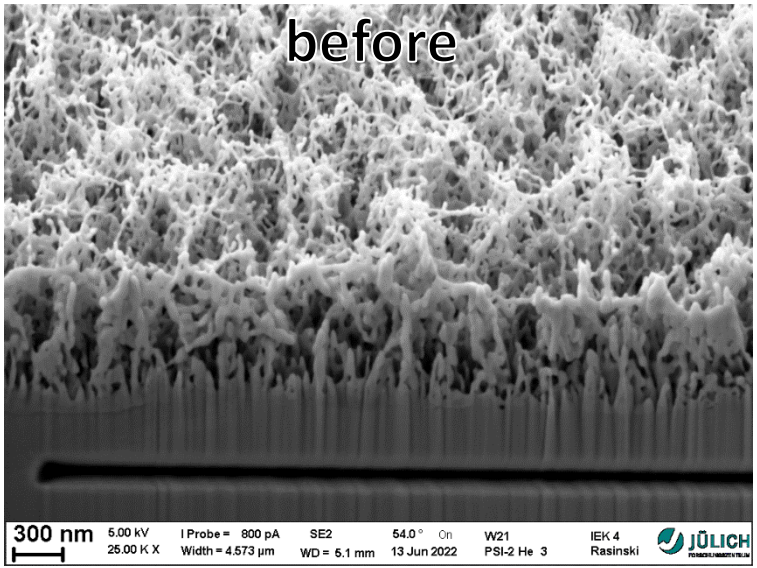
Sample W21 **fuzz**
cross-section 3

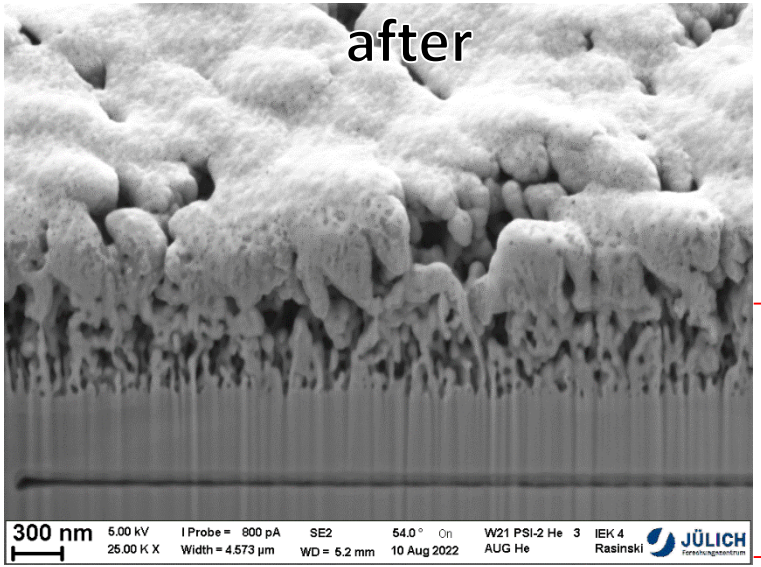


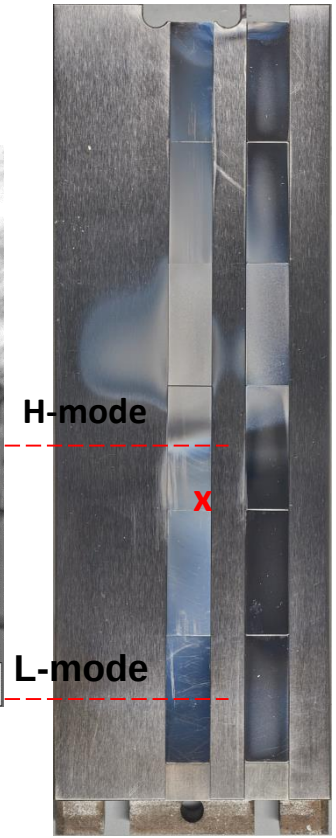


Samples for helium plasma studies on AUG

Sample W21 **fuzz**
cross-section 3



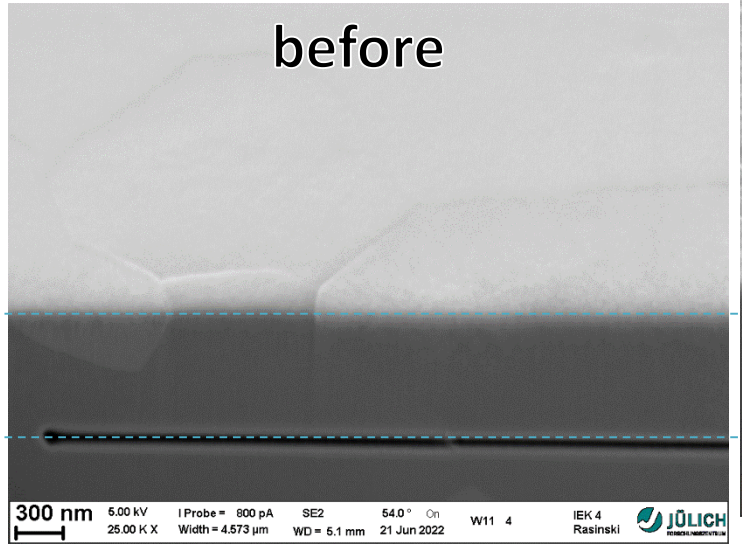


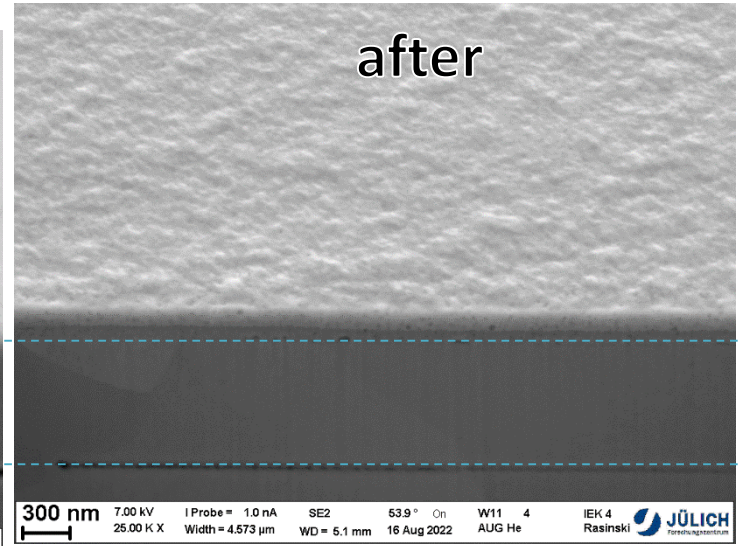


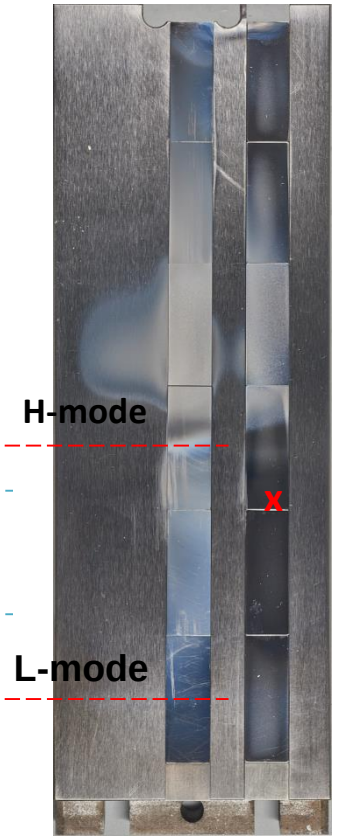
Fuzz structure from PSI-2 preserved
On top deposited layer of about 200 nm

Samples for helium plasma studies on AUG

Sample W11 **polished**
cross-section 3



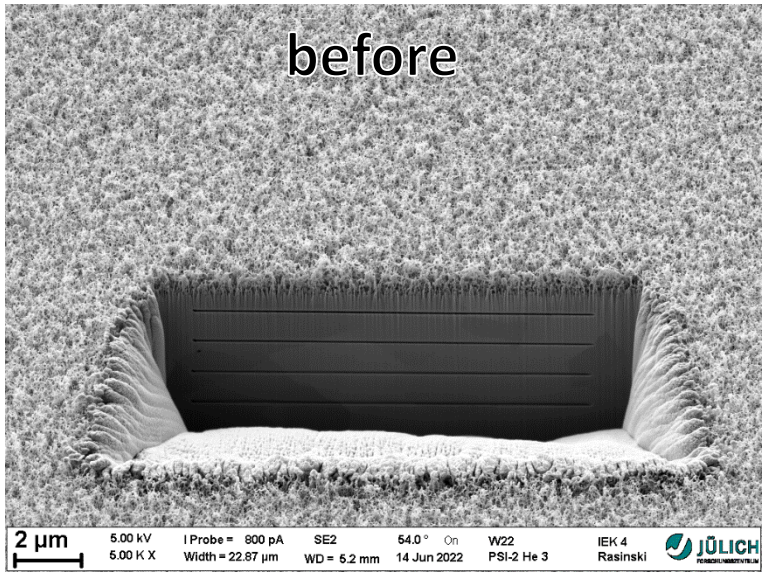


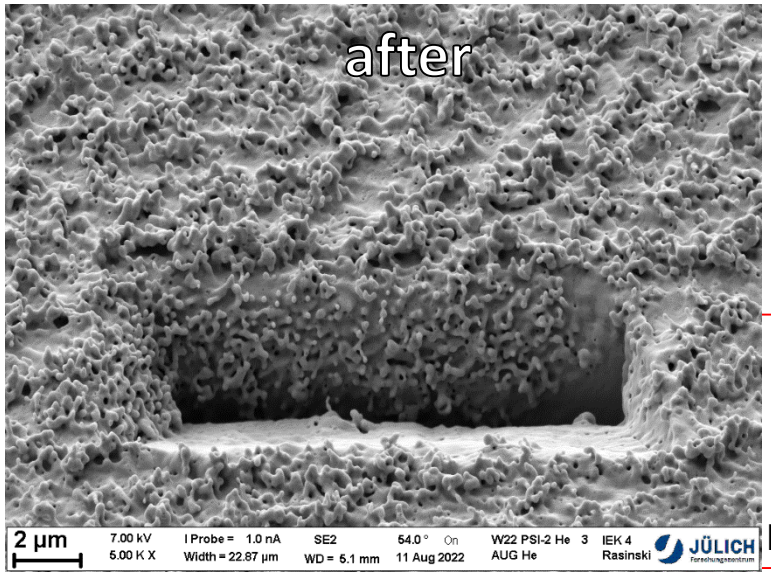


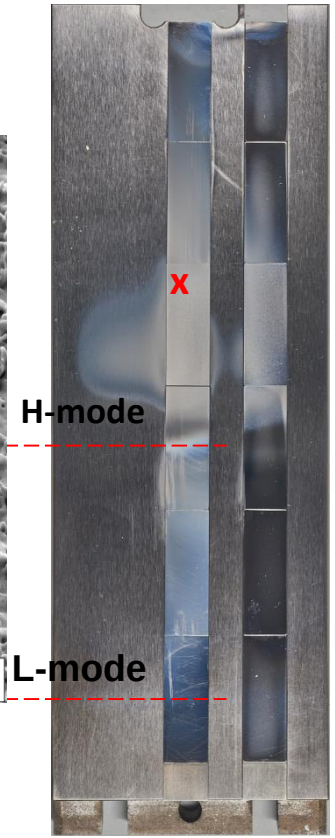
Deposited layer of about 200 nm
Deposition very similar to those on a fuzzy sample

Samples for helium plasma studies on AUG

Sample W22 **fuzz**
cross-section 3

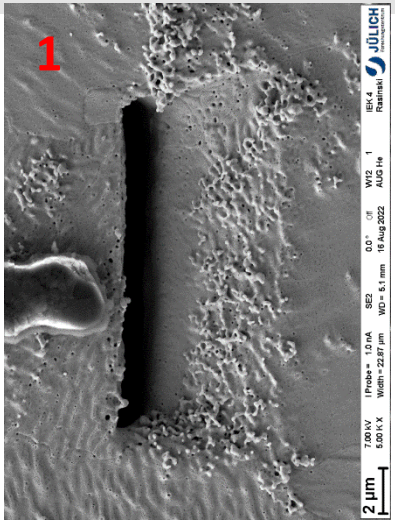


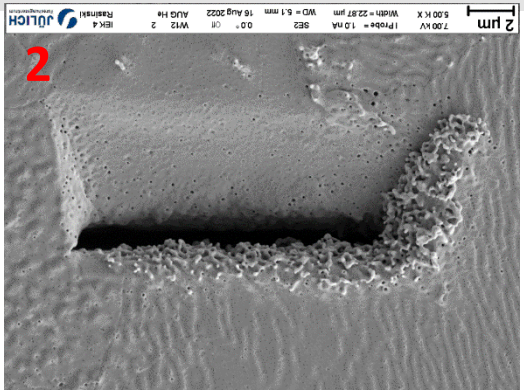


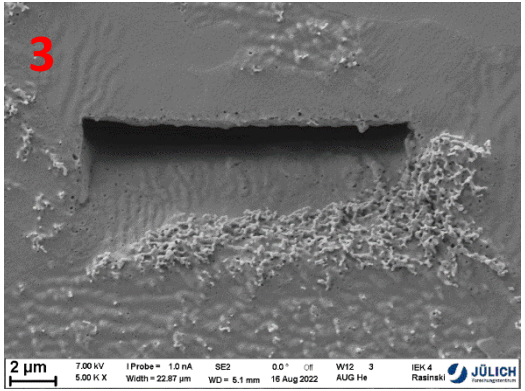


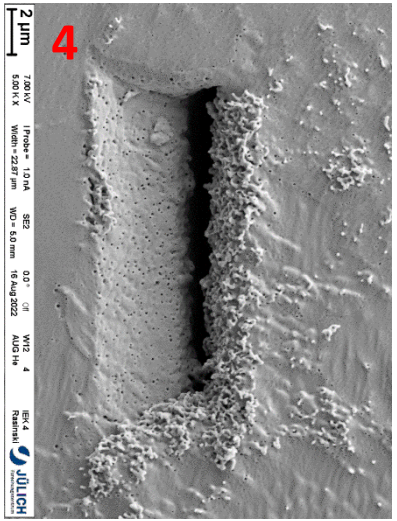
Fuzz formed in PSI-2 removed/modified
New fuzz observed

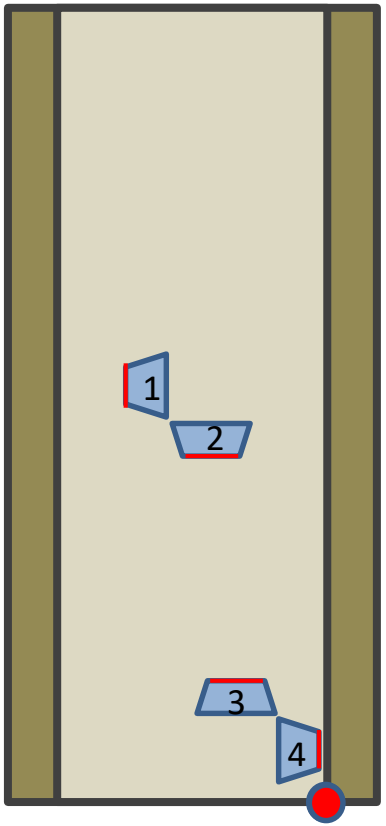
Samples for helium plasma studies on AUG











Sample W12 polished