WP PWIE SPA1 (2022): KIPT
D005: Qualification of current baseline materials under transient (HHF plasma load with QSPA) and steady state loading (PSI-2, JUDITH) (KIPT)

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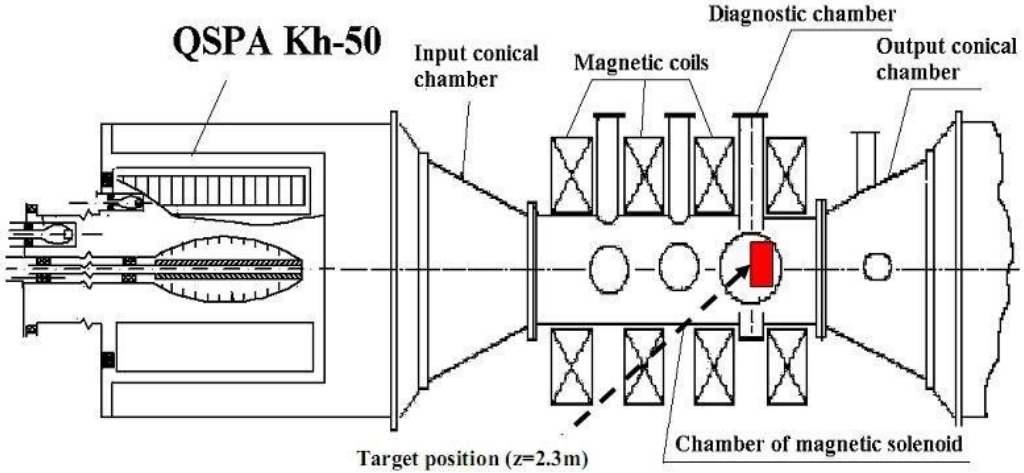
PWIE-SP A.A1.T-T002: Synergistic Load Studies of Plasma-Facing Materials for ITER & DEMO (2022)						
ID	Title	RU	Del. Owner	PM 50 %	QSPA	
					PM 40%	Eq./OGS 40%
PWIE-SP A.A1.T-T002-D005	Qualification of current baseline materials under transient (HHF plasma load with QSPA) and steady state loading (PSI-2, JUDITH) (KIPT)	KIPT	Igor Garkusha	30	13.89	10 days

Tasks planed for 2022:

- ❑ Synergistic effects from sequential PSI-2 and QSPA plasma loads. (FZJ, KIPT)
- ❑ Various combinations of pulsed and steady state loadings (e.g. behavior of QSPA pre-damaged targets in PSI-2, JUIDTH compared with reference samples) (FZJ, KIPT)

SPA1: Experimental facility QSPA Kh-50



Plasma energy density	0.1–2.2 MJ/m^2
Plasma load duration	0.25 ms
Diameter of plasma stream	15 cm

V A Makhlai et al *2020 Phys. Scr. T171, 014047*
V.A. Makhlai et. al. 2021 Phys. Scr. 96, 124043

Maximal energy density up to 30 MJ/m^2

I. E. GARKUSHA et al *2014 Fusion Science And Technology V65, P. 186*

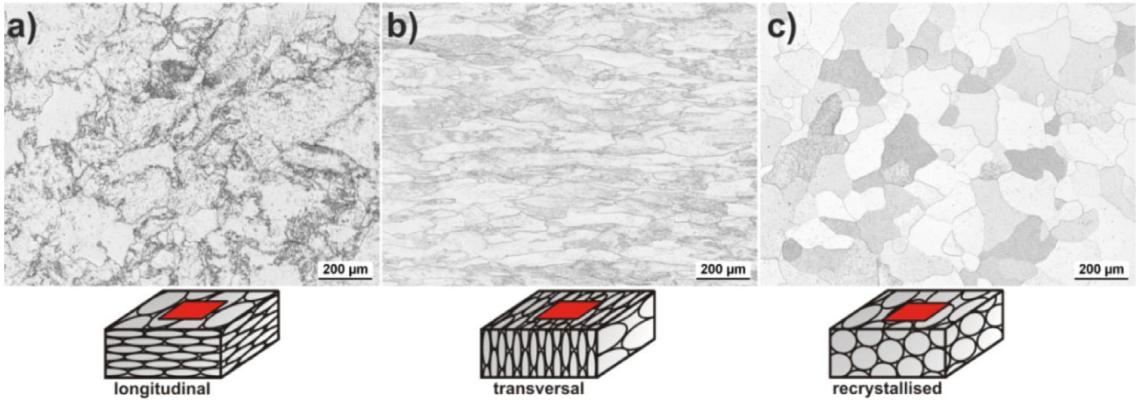
Diagnostics
- Calorimetry
- Optical emission spectroscopy
- High-speed digital camera PCO AG

An optical microscope and Scanning Electron Microscope were used for surface analysis

Parameters	Crack.	Melt.		Evap.
Target Heat Load [MJ/m^2]	0.3	0.6	0.9	1.1
Plasma load duration [ms]	0.25	0.25	0.25	0.25
Surface Heat factor [MW×s$^{1/2}$×m^{-2}]	19	38	57	69.6

12 transversal tungsten samples were provided by Marius Wirtz on the end of august 2021

SPA1: Samples



Tungsten samples were supplied by Plansee AG (Austria), prepared and delivered from Forschungszentrum Julich (Germany). Samples have sizes of 12 ×12 ×5 mm^3.

the longitudinal (L) transversal (T) grain orientation and in the recrystallized (R) state.

Samples were irradiated by **100, 200, 400 plasma pulses**.

Exposures were performed at 2 base temperatures:
room temperature (RT) and
400 °C preheating.

In collaboration with FZJ (M. Wirtz)

SPA1: Qualification of tungsten samples

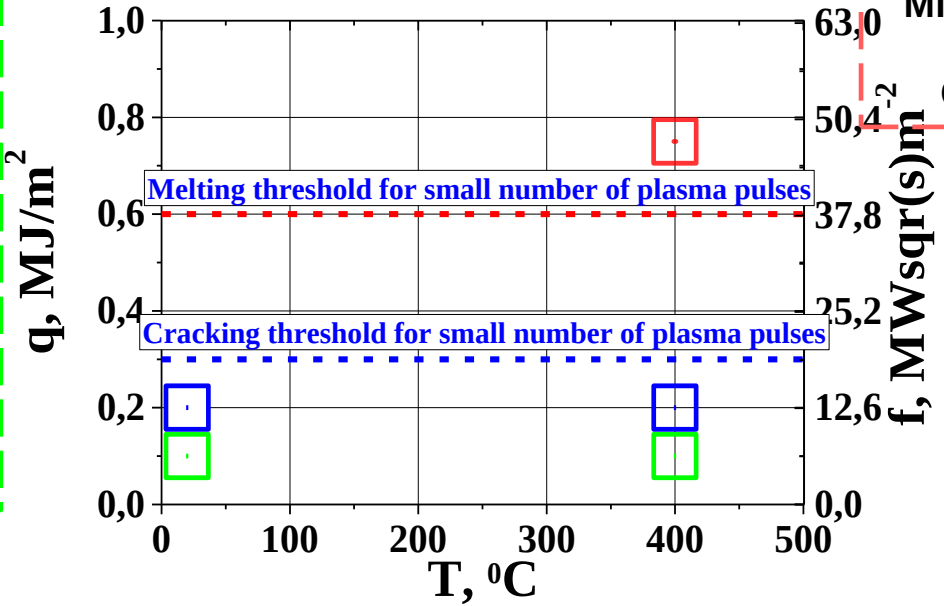
Map of applied plasma heat loadings and brief damage characterization

0,1 MJ/m²
- **100 plasma pulses**

Only L-sample showed single cracks in the bulk
- **200 plasma pulses**

No damages/Surface modifications
- +LHD loading
- **400 plasma pulses**

Cracks on the surface and in the bulk



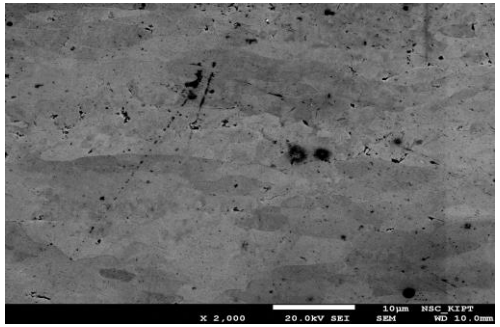
- **0,75 MJ/m²**

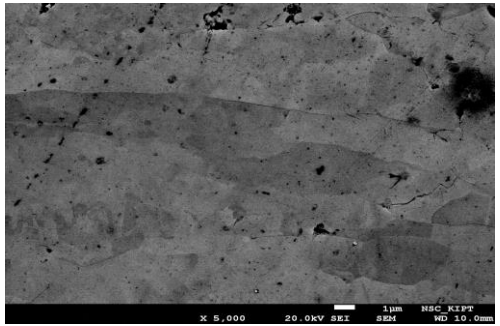
200 plasma pulses
Micro-crack networks/ Resolidified layer, Cracks in the bulk

0,2 MJ/m², 100 plasma pulses; Cracks on the surface and in the bulk

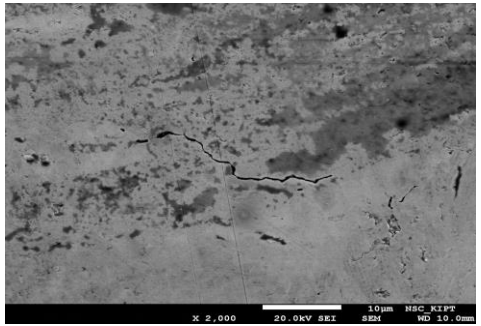
SPA1: SEM for 200 pulses, q=0.1MJ/m^2, T_{base}= RT

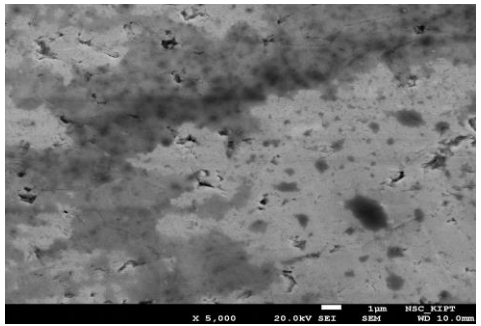
Longitudinal tungsten



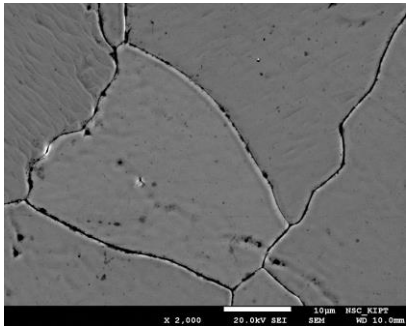


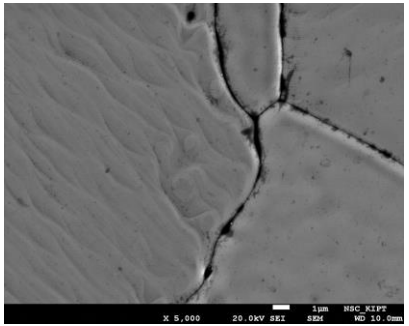
Transversal tungsten





Recrystallized tungsten

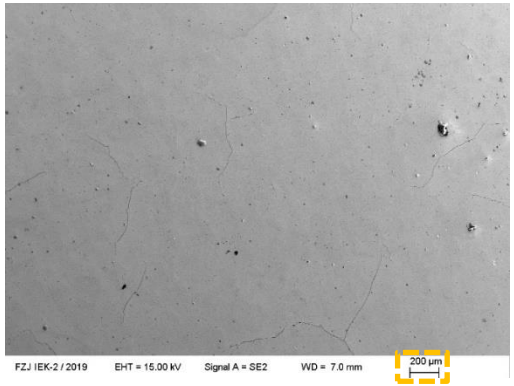




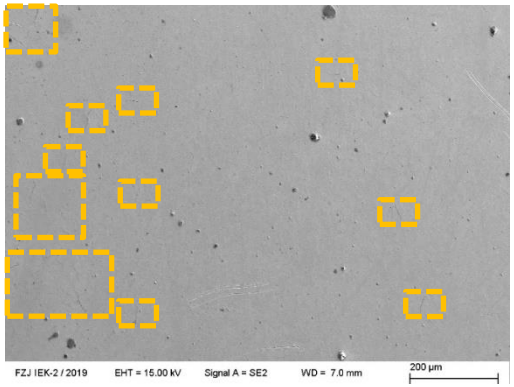
- **Surface modifications**
- **Single fatigue cracks**
- **Porosity**
- **Boundary of grains - R sample**

SPA1: SEM for 400 pulses, q=0.1MJ/m², T_{base}= 400 C

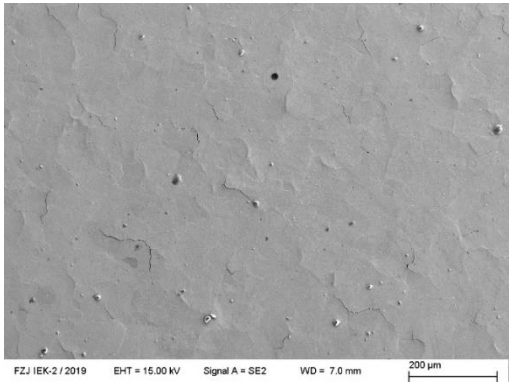
Longitudinal tungsten

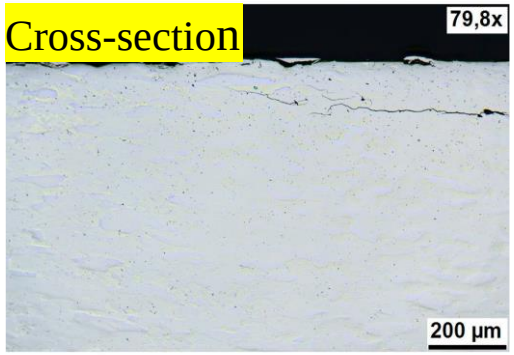


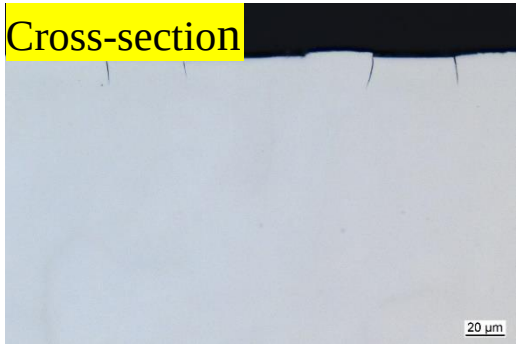
Transversal tungsten

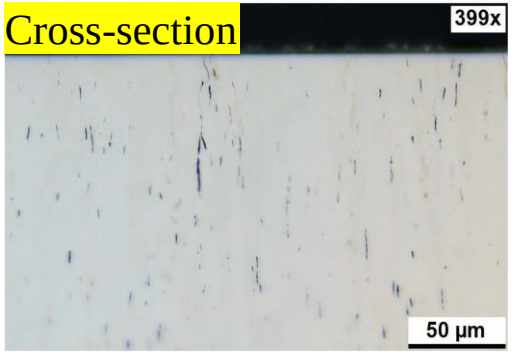


Recrystallized tungsten





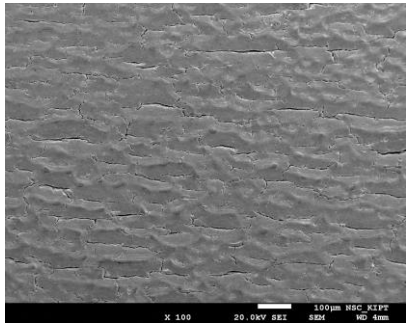


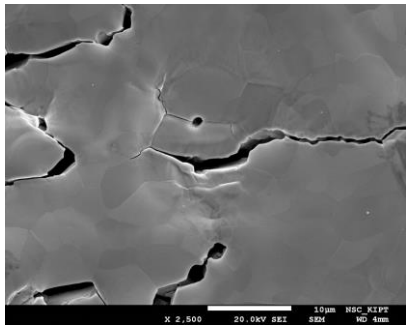


- **Single cracks at T_{base}=400°C**

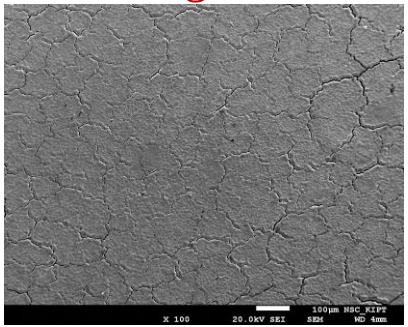
SPA1: SEM for 200 pulses, q=0.75 MJ/m^2,T_{base}=400 C

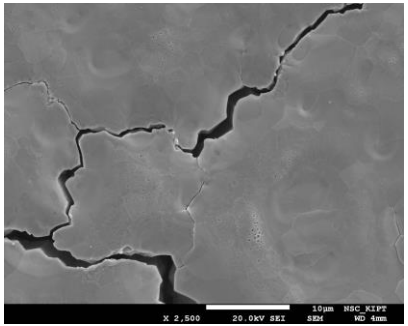
Longitudinal tungsten



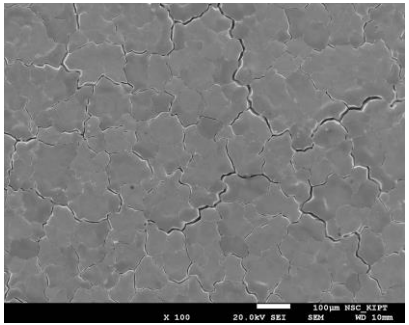


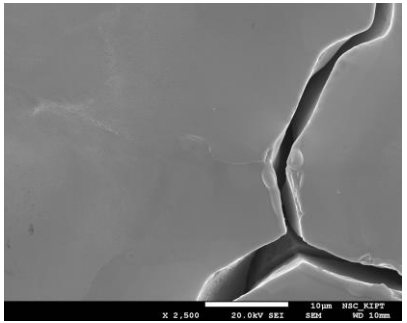
Transversal tungsten





Recrystallized tungsten

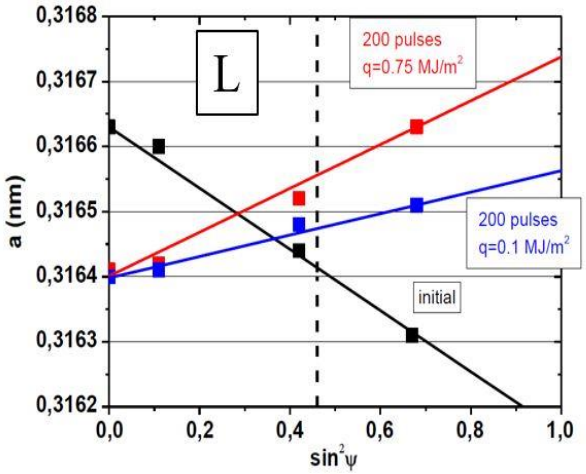


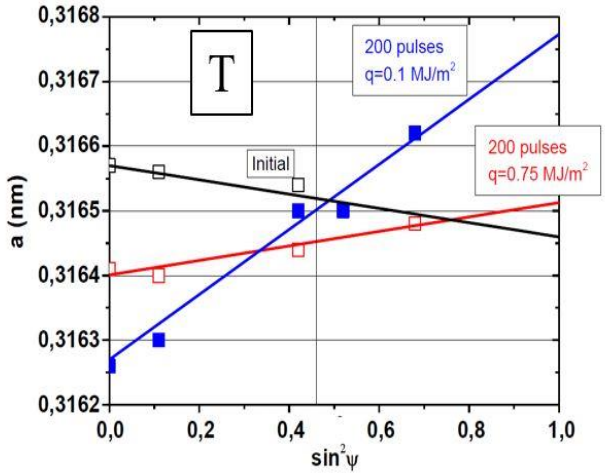


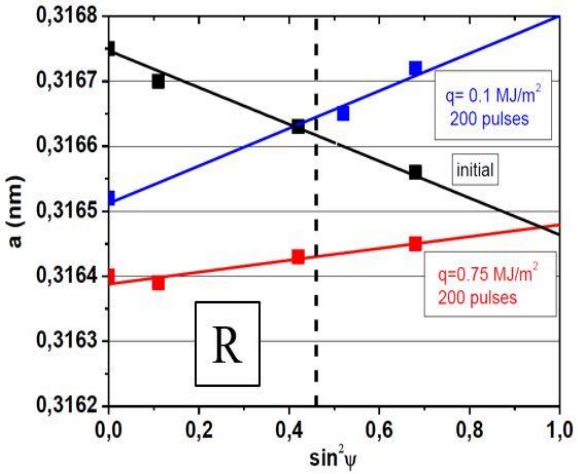
- **Resolidified layer**
- **Micro-crack networks**
- **Corrugated structure**
- **Crack width up to several μm**

Cross-sections will be present later

SPA1: XRD analysis







Initial	L	T	R
Lattice spacing a_o, nm	0.31643	3.1654	0.31662
Asymmetry δB%	+10	+10	+5
Stresses σ, MPa	-409	-108	-228

0.1 MJ/m²	L	T	R
Lattice spacing a_o, nm	0.31648	3.1650	0.31663
Asymmetry δB%	-7	10	-22
Stresses σ, MPa	+144	+443	+225

0.75 MJ/m²	L	T	R
Lattice spacing a_o, nm	0.31655	3.1645	0.31643
Asymmetry δB%	-16	-29	-15
Stresses σ, MPa	+249	+93	+71

Tensile stresses appeared after plasma irradiation. Complexes of vacancies were annealed in course of plasma irradiation. The complexes of interstitial atoms were formed as a result of plasma irradiation.

Summary

- L tungsten showed most essential damage. The deep cracks along the surface could provoke the delamination of material under high cycle loads
- R tungsten showed good resistance. Nevertheless, the nanoscale structures could lead to further crushing of grains, propagation of nanoscale structures in the bulk
- T tungsten demonstrated the best resistance to applied QSPA plasma loads. It might be further tested under different loadings later (incl. different gases mixtures, pulses duration, number of pulses, synergetic loads, etc.)
- Results were presented at EPS 2022 (June 27-July 1, 2022)
- Plasma exposures of other samples are not performed due to the war in Ukraine. Experiments will be shifted to 2023.