Update and Plans KIPT for 2024

Vadym Makhlai

Kharkiv Institute of Physics and Technology
Institute of plasma physics, Kharkiv, Ukraine

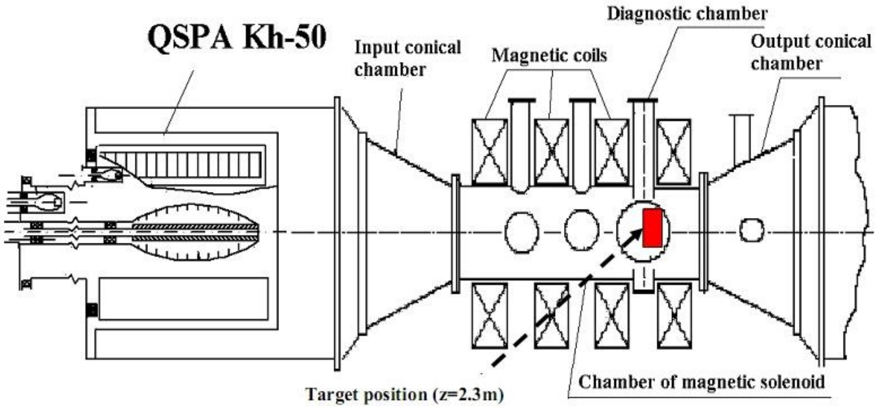
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Introduction/Update on KIPT Status

- QSPA experiments were terminated due to the war in Ukraine.
- The team of technicians and researchers is working onsite to repair buildings, installations, and equipment damaged due to the war
- The roof of the QSPA hall was significantly damaged, actually, a new cover has been installed. The opposite wall of the hall has also been repaired.
- QSPA facilities were mothballed for the winter.

- Nevertheless, the analysis of surface damage of 3D-printed tungsten CPS filled with tin samples continued in 2023 for previously exposed samples.
- The damage of CPS samples was compared with the erosion of 3D-printed tungsten advanced material with a lattice structure.
- The influence of the shielding layer near exposed surfaces on the erosion of irradiated samples was evaluated.

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

Test conditions for CPS	
Energy density in plasma stream, [MJ/m^2]	up to 3
Number of pulses	100
Base temperature, [T °C]	~ 300 °C , ~ RT

Test conditions for AM W	
Energy density in plasma stream, [MJ/m^2]	up to 3
Number of pulses	10
Base temperature, [T °C]	~ 500 °C

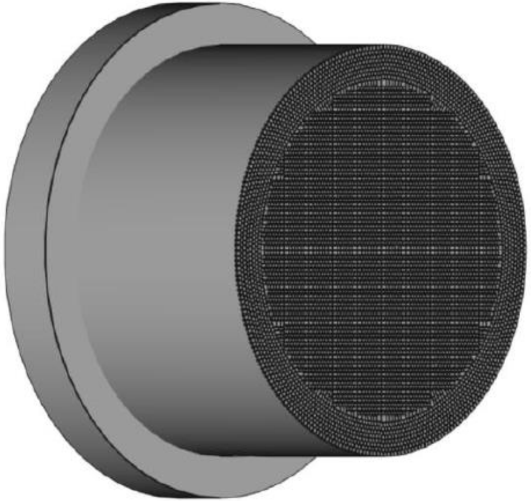
Diagnostics

- Calorimetry
- High-speed digital camera PCO AG
- SEM EDXA

I.E. Garkusha *et al* 2021 *Nucl. Fusion* **61** 116040
S.S. Herashchenko et al. Fus. Eng.& Des. 190 (2023) 113527

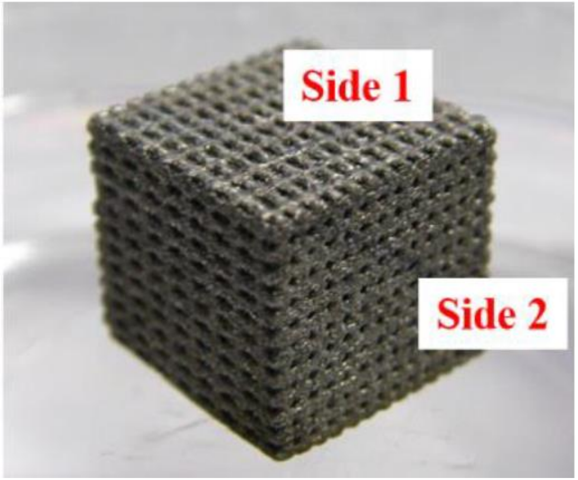
Samples

CPS cylindrical samples filled with tin



CPS cylindrical samples of 25 mm in diameter and 17 mm in height were provided by Peter Rindt, DIFFER.
P. Rindt et al, *Nucl. Fusion* **59** 054001, 2019

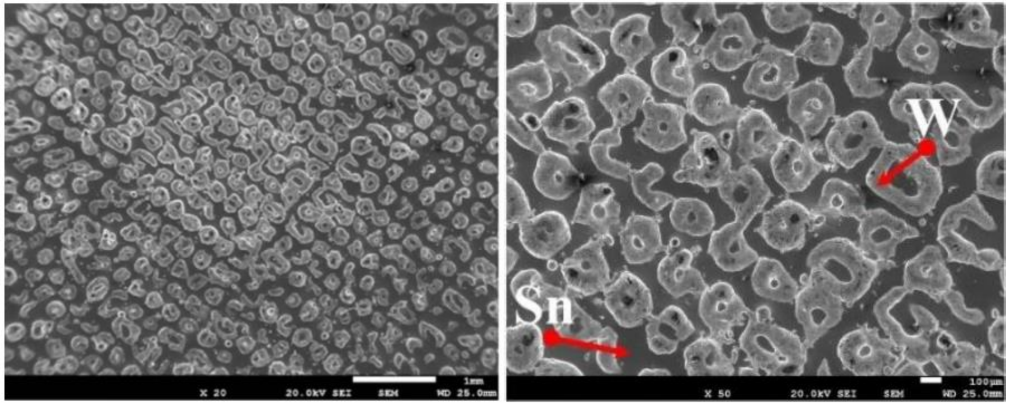
AM W/Ta



Advanced material "build trials" at Fraunhofer Augsburg (directed by IPP Garching) and Renishaw PLC (directed by CCFE) have produced nominal 1 cm cubes of lattice material in W and W-6% Ta at a range of lattice parameters, designed by Uni Tuscia

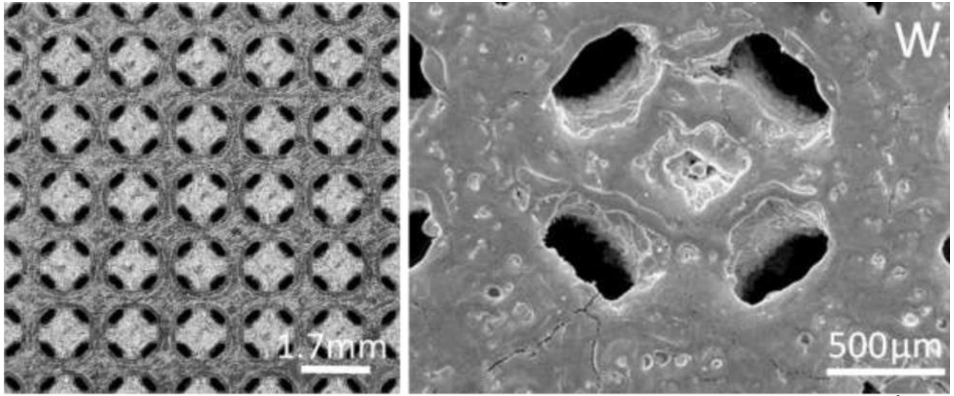
SEM images of the initial surfaces

CPS target



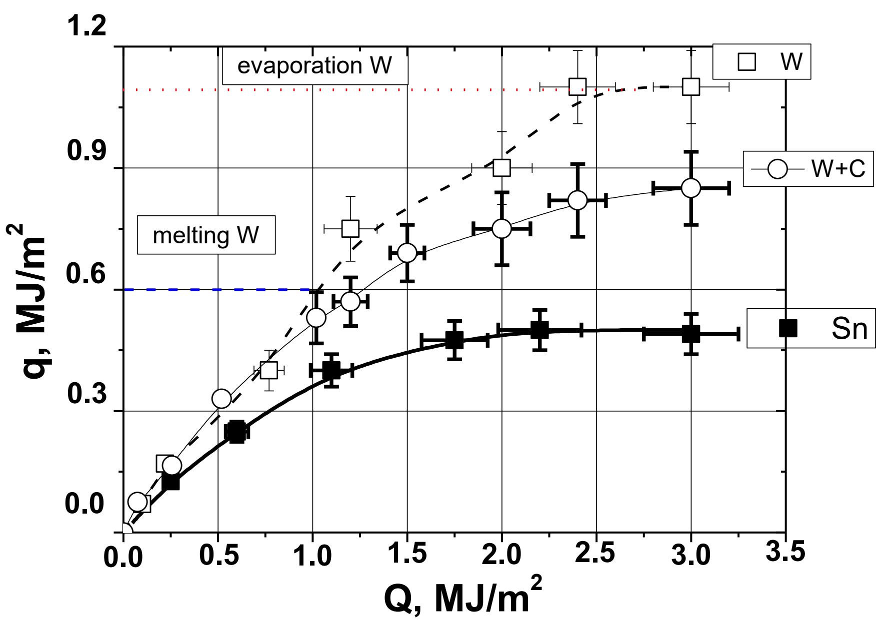
3D-printed tungsten structure filled with tin.

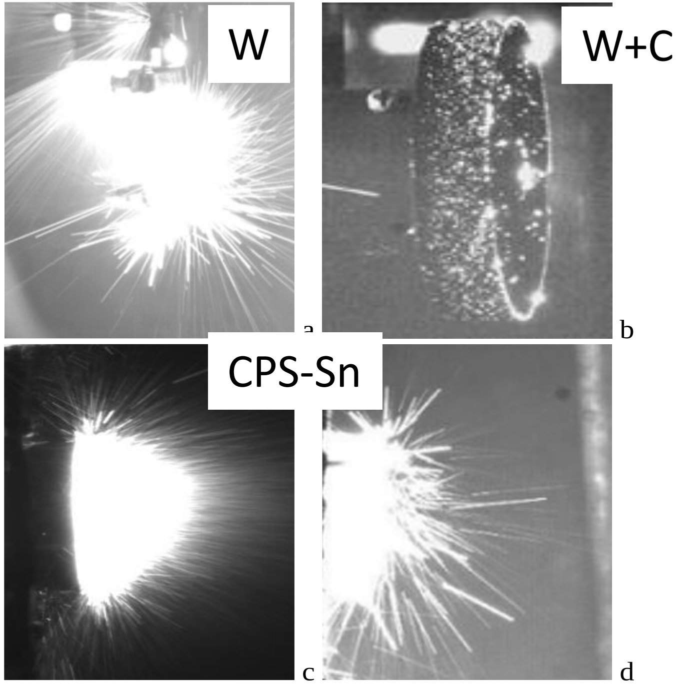
AM W/Ta



- Frontal view of the laser-printed lattice cube.
- The microstructure is characterized by
    - micro-cracks,
    - microvoids
    - pores.

Heat load to the target surfaces vs the energy density of impacting plasma

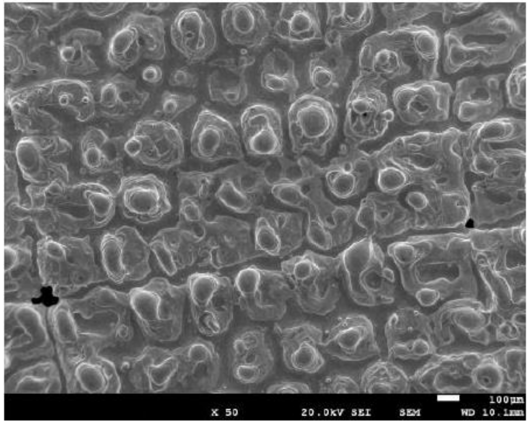




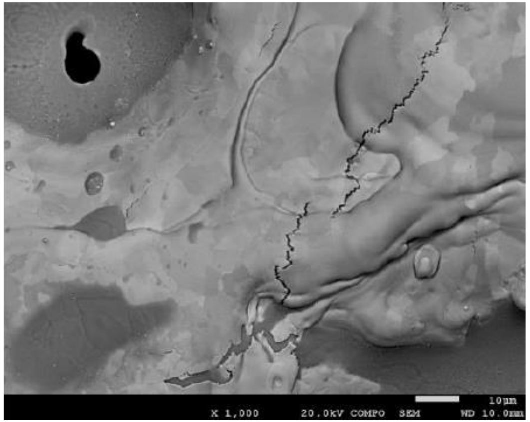
Analysis of plasma-surface interaction features has been performed using QSPA exposures of reference plasma-facing materials. The energy density delivered to the capillary porosity system wetted by tin is half as small as that of a tungsten surface. The lower evaporation threshold of Sn causes a larger shielding effect.

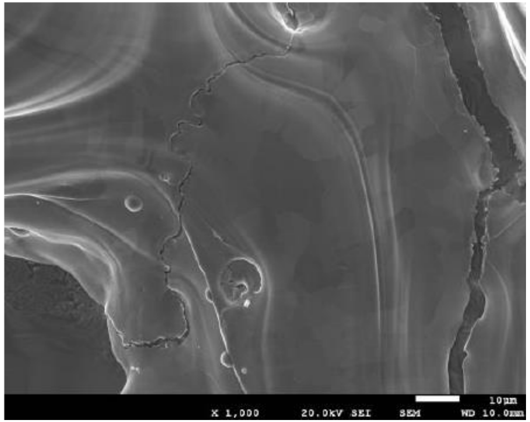
V. Makhlai et. al., Probl. At. Sci. and Tech. 2023, #6, p 101

Erosion of the 3D-printed W target filled by Sn



Surface heat loads above the W melting threshold, T_{base} = 300 °C, 100 pulses

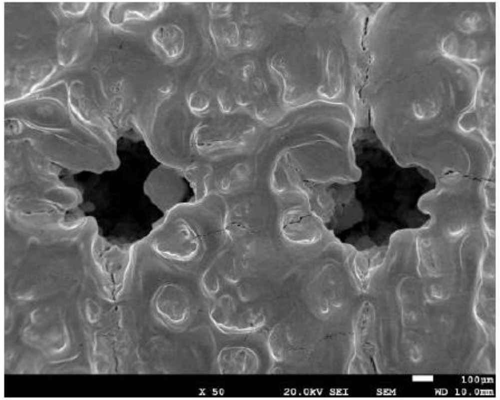




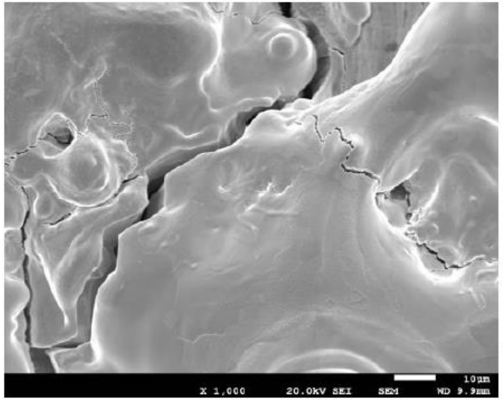
- After 100 pulses, the reduced Sn pool is observed.
- As well as, areas not filled with Sn on the exposed targets.
- Nevertheless, the severe damage of the W base of the CPS targets is not observed during repetitive powerful plasma loads
- Mass loss up to 760 mg/cm^2pulse for CPS target filled by Sn

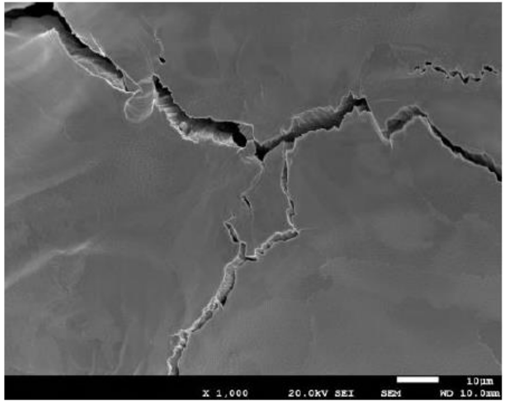
S.S. Herashchenko et al., Fus. Eng. Des. 190 (2023) 113527

Erosion of the 3D-printed AM W target



Surface heat loads above the W melting threshold, T_{base} = 500 °C, 5 pulses





- Cracks, pores, balls are observed on the exposed surfaces
- Intergranular cracks with a width up to several μm
- Re-solidified layer
- Fine cellular structure of the surface layer as a result of QSPA exposures
- Typical cell size of 150…250 nm
- Mass losses reached up to 4 (mg/cm^2) per pulse for AM W/Ta

N. Mantel et al, Nucl. Fusion 62 (2022) 036017

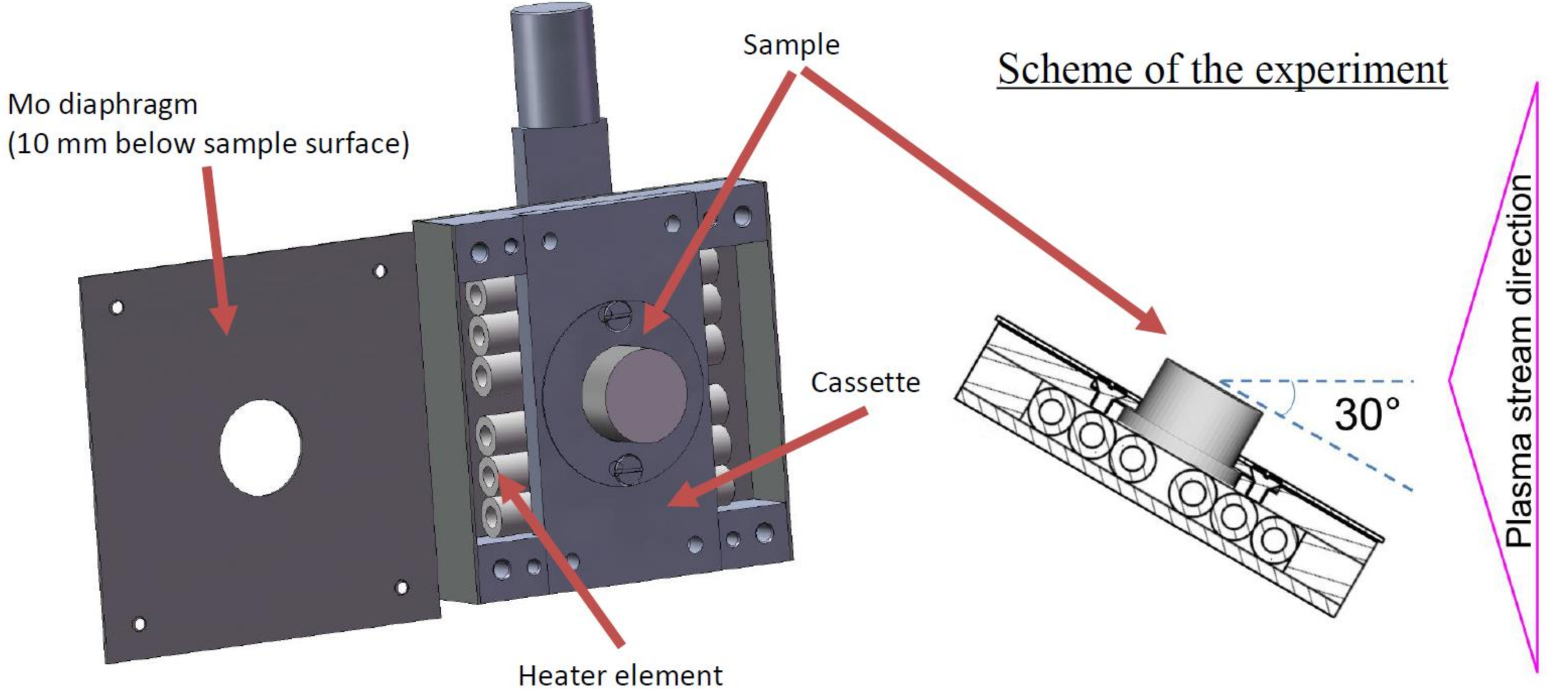
SUMMARY

- Comparative analysis of the damage of 3D-printed tungsten CPS filled by tin samples and 3D W advanced materials was performed.
- The energy density delivered to the capillary porosity system wetted by tin is half as small as that of a tungsten surface due to stronger shielding. As a result, only the beginning of tungsten melting is observed for CPS target, whereas AM W demonstrates pronounced melting of exposed surfaces. The results are published in 2 journal papers in 2023.
- Plasma exposures of both CPS and AM W samples triggered the ejection of droplets/dust from the surface. The mass loss of CPS target is larger then for AM W due to splashing and evaporation of tin.
- Unfortunately, QSPA experiments were affected by the war in Ukraine. Repair works on QSPA are in progress. We plan to restart the experiments in March 2024

Plans for 2024

- We plan to restart the experiments in March 2024.

Preparation of the target holder for plasma irradiation of the 3D-printed CPS W target filled by Sn under inclined plasma exposition is in progress



Plans for 2024

- Works to be performed in 2024 year :
  - Analysis of the damage of the CPS samples exposed at different base temperatures will be continued.
  - Study of mechanisms responsible for the particles ejection (both in liquid and solid state).
  - Collection of solid dust as well as splashed droplets.
  - Characterization of dust/droplets particles ejected from exposed CPS surfaces. Estimation of start-up time of the droplets/dust from the surfaces
- Deliverables:

  Evaluation of damage mechanisms of CPS structure under the transient plasma loads. Characterization of ejected droplets and solid particles.

FAIRNESS

Transparency
Collaboration
Loyalty

OPENNESS

Open doors
Open hearts
Open minds
Open ears

COMMITMENT

Ownership
Critical thinking
Determination
Respect

DIVERSITY

Cooperation
Equal opportunities
Inclusion