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PERFORMANCE OF LI- AND SN-FILLED CPS TARGETS UNDER TRANSIENT PLASMA LOADS IN QSPA

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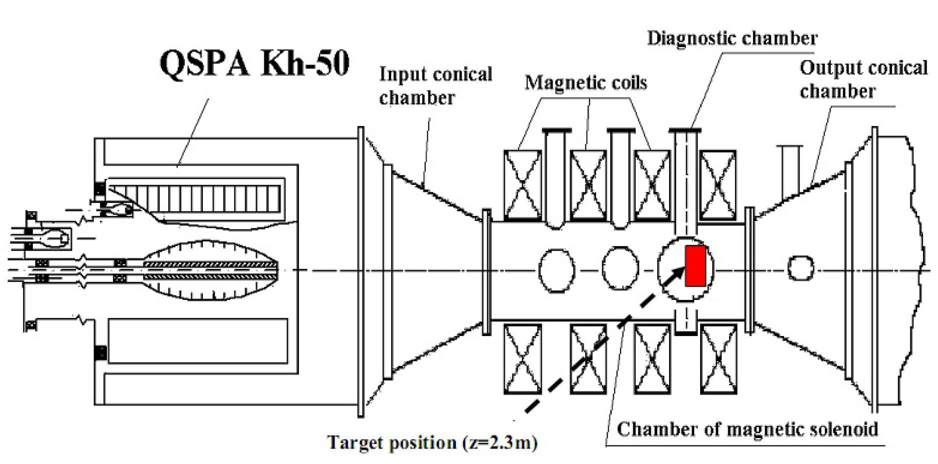
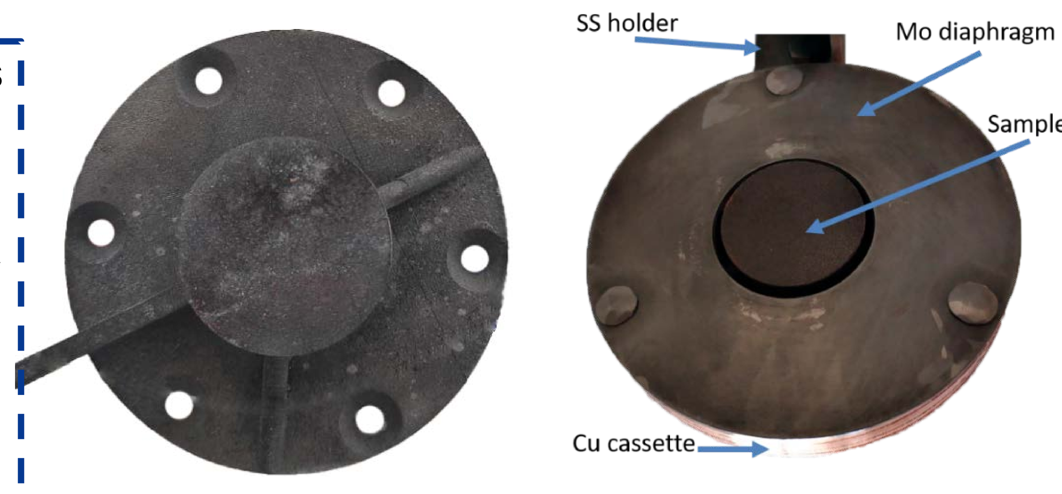
Motivation: The divertor in a tokamak faces extremely high heat and particle loads during transient events like ELMs and disruptions. Besides solid tungsten, liquid metals such as lithium and tin are being studied as alternative materials due to their self-healing properties and vapor-shielding effect. However, challenges like droplet ejection and plasma contamination still require detailed experimental and modeling research for DEMO applications.

Experimental facilities and targets



- Targets used in the experiments were selective laser melting (SLM) tungsten (W) CPSs filled with Li *(provided by DIFFER)*.
- The clamping ring has a density of 92 % of solid W.
- The central part, the Li reservoir, has a density of 82% and a **30 mm diameter**, with a **thickness of 8.5 mm**.
- The mass of Li in the central part of the CPS is about 0.5 g
- The average pore size is (23 ± 3) μm.
- Li filling procedure made in an Ar glove box

The details: M. Morbey et al, Nucl. Fusion 2025, *https://doi.org/10.1088/1741-4326/ae004e*



The CPS target and the design of holder used in the experiment

Energy density [MJ×m^{-2}]	**(0.5…30)**
Pulse duration [ms]	**0.25**
Magnetic field [T]	0.54 (β ≈ 0.3…0.4)
Plasma pressure [MPa]	(0.3…1.8)
Particle flux [ions×(m^{-2}s^{-1})]	up to 10^{27}
Average plasma density [cm^{-3}]	(0.2…5) 10^{16}
Maximal energy of particles [keV]	(0.2…0.9)
Diameter of the plasma stream [cm]	18 cm

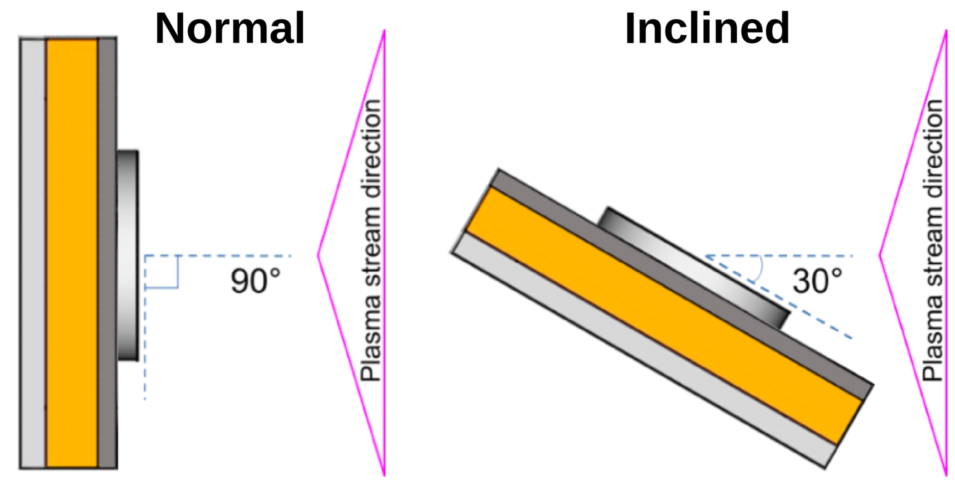
Test conditions

The main experimental series consisted of about **50 QSPA plasma impacts** with an energy density of **~ 3 MJ/m²** and a pulse duration of **0.25 ms** for each target.

The initial temperature of the sample (Tbase) before plasma exposure remained at room temperature (Tbase=RT).

The surface of one target was oriented normal to the plasma stream, while the other was oriented at an angle of 30°

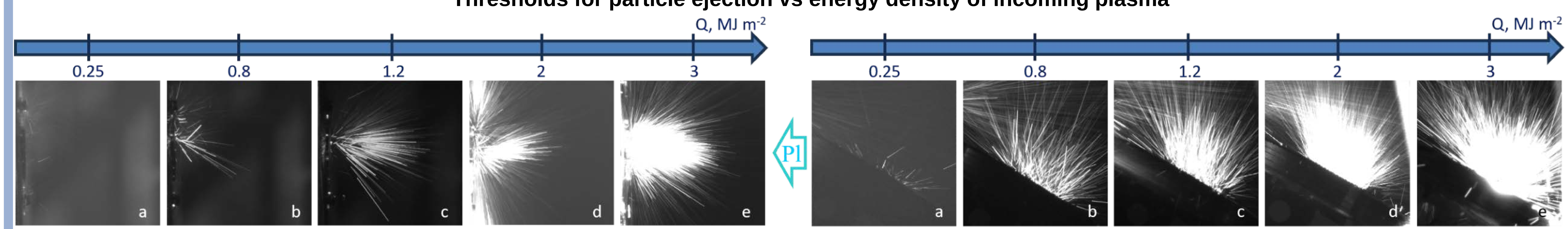
A high-speed digital camera PCO AG (10bit CMOS pco.1200 s) was employed for observing PSI and the ejections of erosion products.



The schematic view of the plasma exposure in the QSPA facility.

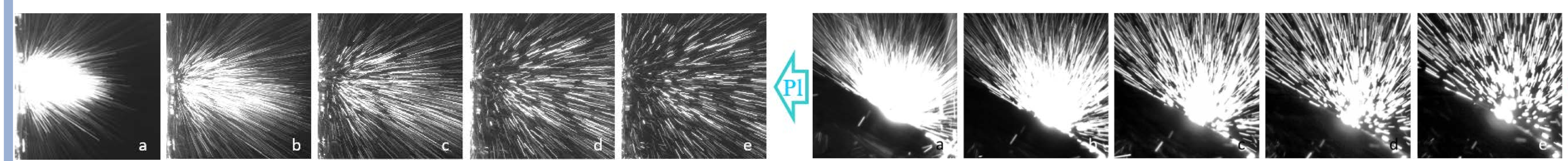
Results of experiments

Thresholds for particle ejection vs energy density of incoming plasma

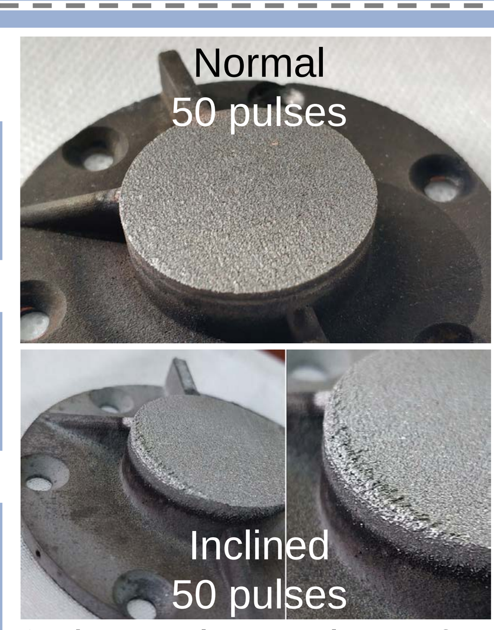


Energy density of incoming plasma and corresponding images of PSI (a – 0.25 MJ m^{-2}, b – 0.8 MJ m^{-2}, c – 1.2 MJ m^{-2}, d – 2 MJ m^{-2}, e – 3 MJ m^{-2}).
The images correspond to 1.2-2.4 ms after the start of the PSI ($t_{exposure}$=1.2 ms).

Images of PSI with Li- CPS targets



Images of PSI after a plasma impact on the CPS targets (with an incoming plasma energy density of 3 MJ m^{-2}).
The images correspond to 1.2-2.4 ms (a); 2.4-3.6 ms (b); 3.6-4.8 ms (c); 4.8-6 ms (d); 6-7.2 ms (e) after the start of the PSI ($t_{exposure}$=1.2 ms)



❖The total mass loss of the targets in both cases did not exceed the initial lithium content.

❖The value of mass losses obtained for the inclined Li-CPS target (0.7 **mg cm^{-2} per pulse**) was higher than that obtained for normally exposed target (0.1 **mg cm^{-2} per pulse**), possibly due to the damage of the leading edge.

SUMMARY

➢ **The erosion of a selective laser melting (SLM) tungsten (W) Capillary Porous Structure (CPS) filled with Li was studied under both normal and oblique high-power plasma exposure in the QSPA. The main experimental series consisted of about 50 QSPA plasma impacts with an energy density of ~ 3 MJ/m² and a pulse duration of 0.25 ms for each target.**

➢ **The thresholds for particle ejection were analyzed under the conditions of a gradually increasing energy density in the incident plasma stream. The experiment showed that the plasma impacts with energy densities below 1.2 MJ m^{-2} caused only a small number of particles to be ejected from the target surface. At higher plasma loads, the number of ejected particles increased significantly. The velocities of the ejected particles ranged from 1 to 33 m/s, which is almost twice as high as the corresponding values obtained in the Sn-CPS experiments [1,2]. The collection and analysis of erosion products will be addressed in subsequent experiments.**

➢ **Mass loss measurements indicated that the exposed CPS remained Li-filled during subsequent exposures. Surface analysis of a normally irradiated Li-CPS target did not reveal any visible changes in the W substrate. In contrast, for the Li-CPS target exposed to inclined transient plasma, damage to the leading edge was observed. The damage to the leading edge is a crucial factor contributing to the resilience of the exposed target. Similar effects were previously observed in experiments with oblique irradiation of castellated W and Sn-CPS targets [1,2], where damage occurred due to the formation of a non-uniform shielding layer on the target surface.**

➢ **Further experiments and detailed studies in QSPA with liquid-metal-filled CPS targets are needed to assess component performance and resilience in fusion reactor conditions.**

[1]. S.S. Herashchenko et al., Fusion Eng. Des. 2023, https://doi.org/10.1016/j.fusengdes.2023.113527
[2]. S.S. Herashchenko et al., Probl. Atom. Sci. Tech. 2024, https://doi.org/10.46813/2024-154-082

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