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Characterization of Liquid Metals as Prospective Divertor Materials Under Transient Plasma Loads

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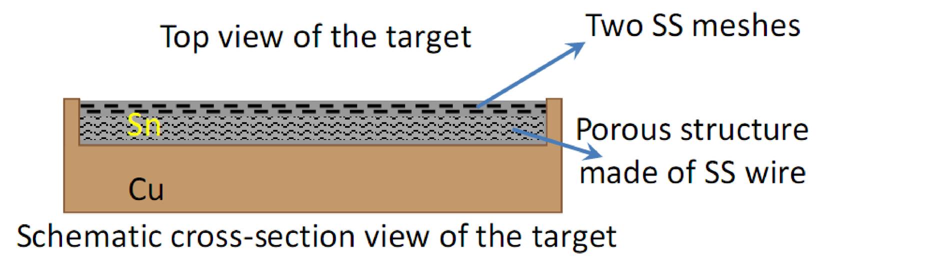
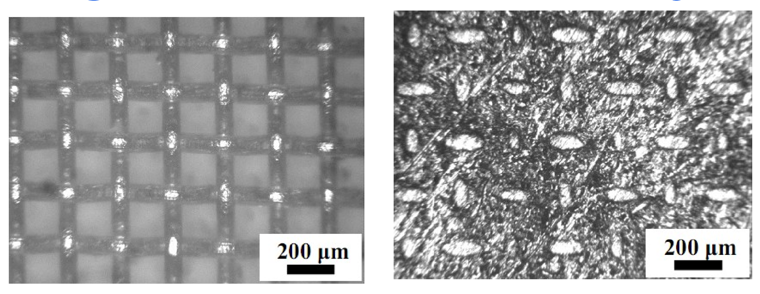
Abstract: Main features of plasma–surface interaction, vapor shield effects and energy transfer to capillary pore systems (CPS) based Sn targets are studied at different heat loads (0.1-2.2 MJ/m^2) within the QSPA Kh-50 and QSPA-M. The plasma density in a front of exposed Sn targets is found to be up to ten times higher than in impacting plasma stream. It leads to the arisen screening effect for the plasma energy transfer to the surface. For small energy loads the transient layer consists of the plasma stream species only, target impurities are appeared when the heat load exceeds the material melting threshold.

Motivation: High power magnetically confined fusion devices have very high heat and particle loads on the plasma facing components. Liquid metals mock-ups were proposed as alternative of full tungsten divertor for DEMO. Extrapolation of the disruptions/ELMs erosion effects obtained at the present-day tokamaks to the transient peak loads of next step fusion devices (ITER and DEMO) remains uncertain. Special investigations on material behavior at the relevant transient loads are thus very important.

CPS based Sn



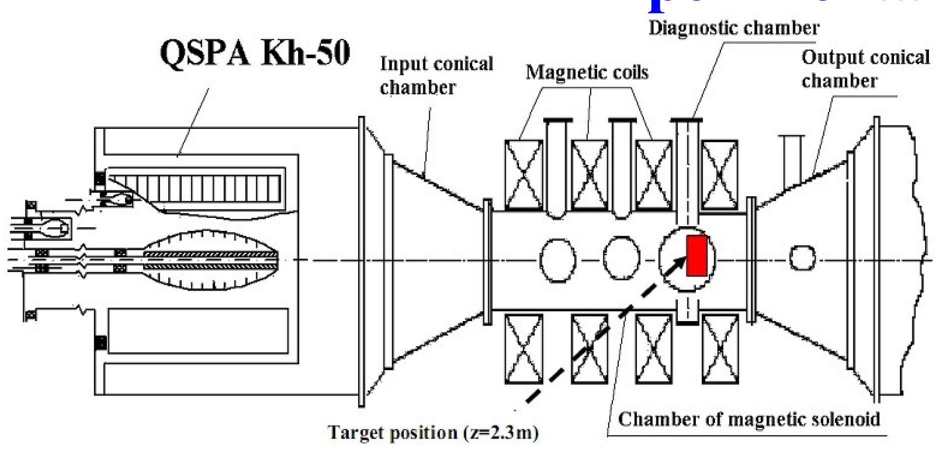
Target is SS mesh wetted by Sn



SS mesh initial view; Average cell size – 150x150 μm; Wire thickness – 90 μm

Diagnostics: Energy density of plasma stream was measured by calorimeter. Particles dynamics monitoring were performed with a high-speed (10 bit CMOS pco.1200 s) digital camera PCO AG. Spectroscopy studies of plasma stream dynamics were carried out also. Surface analysis carried out with optical microscope equipped with CCD camera.

Experimental facilities



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

Tungsten damaging thresholds	Crack.	Melt.	Evapor.
Plasma energy density [MJ/m^2]	0.6	1.3	2.4
Target Heat Load [MJ/m^2]	0.3	0.6	1.1

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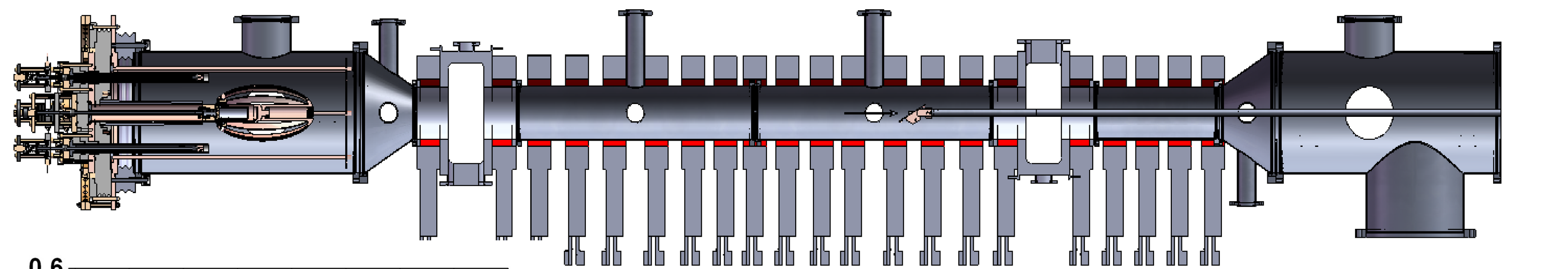
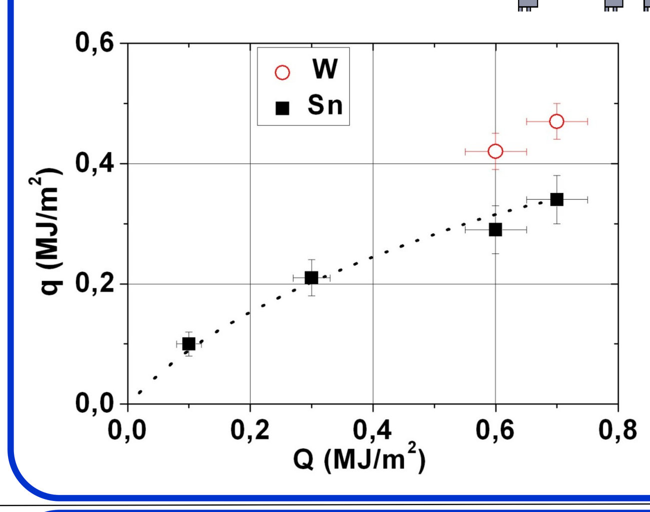
QSPA-M





Heat load to the Sn target surfaces (q) vs. the energy density of impacting plasma stream (Q).

Plasma energy density	0.1-1 MJ/m^2
Plasma load duration	0.1 ms
External magnetic field	0.8 T
Diameter of plasma stream	6 cm

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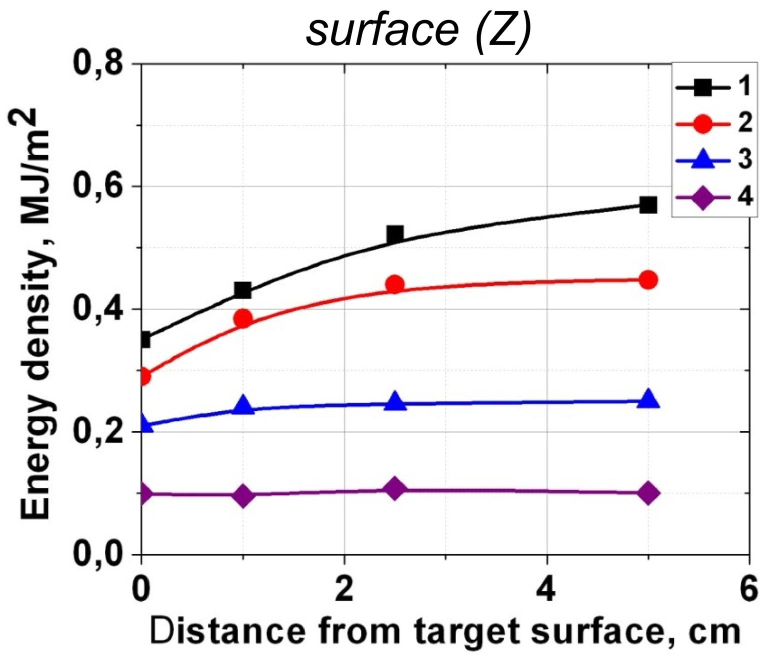
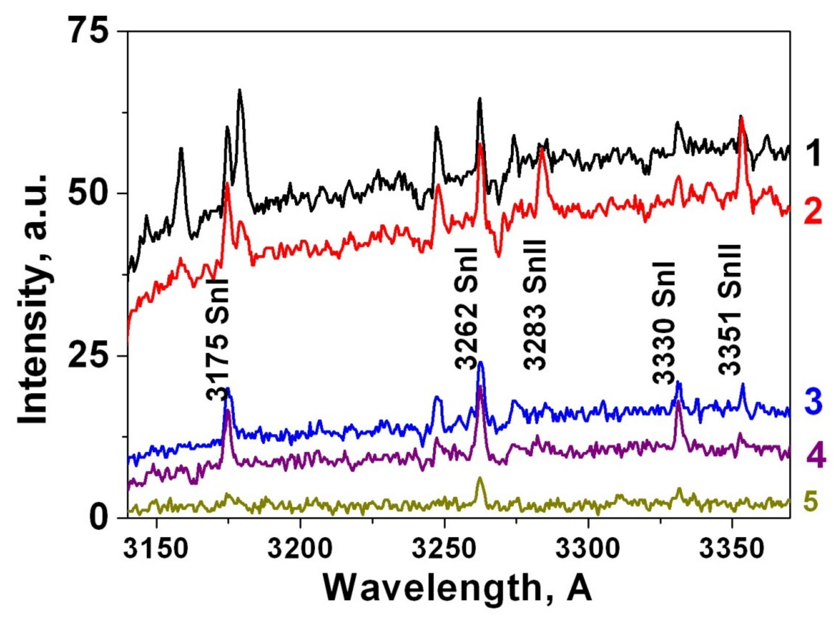
Plasma-surface interaction within QSPA -M

Energy density distributions in shielding layer vs. the distance from the target surface (Z)



Spectral lines obtained near Sn sample at different energy density (Q) of plasma stream



Q= 0.7 MJ/m^2 (1); Q= 0.6 MJ/m^2 (2); Q= 0.3 MJ/m^2 (3); Q= 0.1 MJ/m^2 (4); Q<0.1 MJ/m^2 (5)

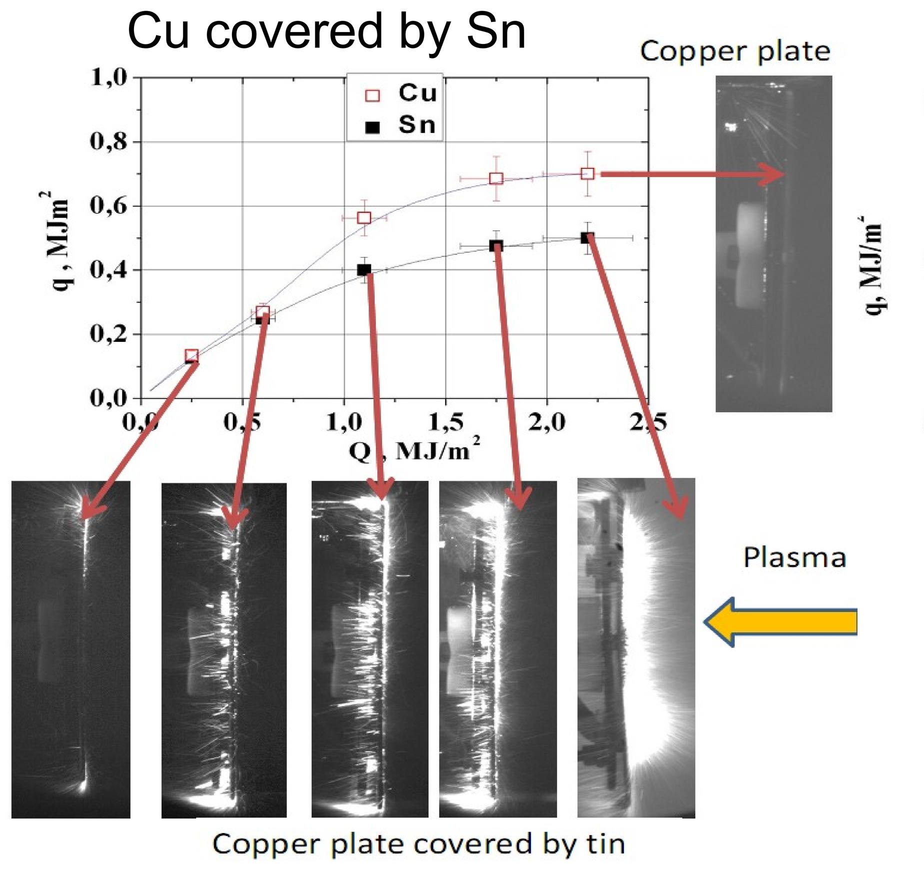
- The energy density increases with an increasing distance from the target surface.
- The absorbed energy is about 50% of the impact plasma energy at Q > 0.5 MJ/m^2.
- Average electron density of $N_e=(1\text{-}3)\times10^{17}$ cm^{-3} near surface was measured from Stark broadening of spectral lines Sn I 3262 Å and Sn II 3283 Å.
- N_e is about 10^{16} cm^{-3} in the free plasma stream

- Spectral lines of Sn I (3175, 3262, 3330 Å) and Sn II (3283, 3351 Å) were identified.
- Plasma shield consisted mostly of Sn neutrals appears at Q~0.1 MJ/m^2.
- Intensive emission of Sn II lines is observed at Q >0.3 MJ/m^2.
- The continuum intensity increase significantly at Q> 0.5 MJ/m^2.

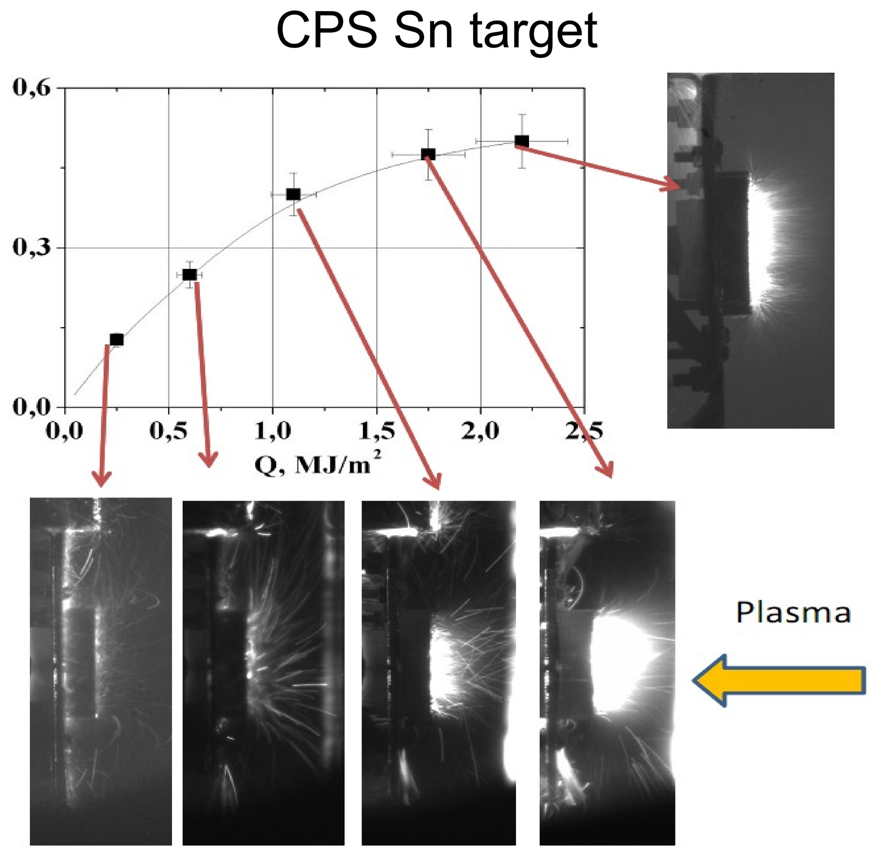
Plasma-surface interaction within QSPA Kh-50

Heat load to the target surfaces (q) and images of particle ejection vs. the energy density of impacting plasma stream (Q)

Cu covered by Sn

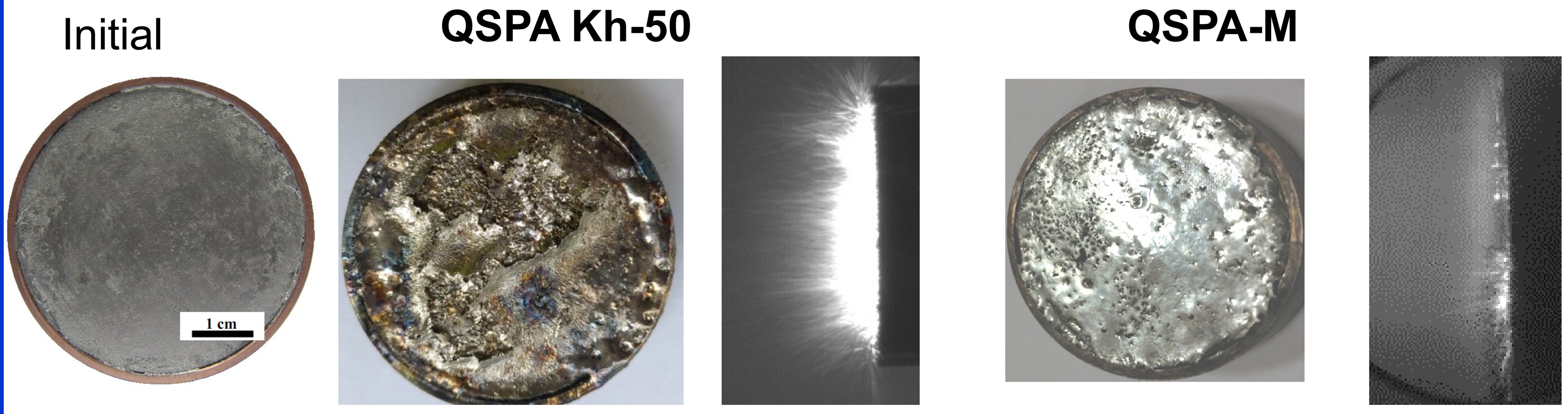


CPS Sn target



- Energy density delivered to the Sn surface is reduced in comparison with Cu.
- Heat load below 0.5 MJ/m^2 does not trigger the generation of erosion products.
- Only several particles traces have been registered at 0.5 MJ/m^2 <Q<1 MJ/m^2
- Further increase of heat load leads to the splashing of eroded material

Erosion of Sn targets irradiated by plasma streams



5 pulses; Q=2.2 MJ/m^2

- Development of instabilities in melted layer
- Pronounced particles splashing
- Delamination of CPS
- Large erosion
- Mass losses: 6.85 mg/cm^2 pulse

10 pulses; Q= 0.7 MJ/m^2

- Weakly melt motion
- Moderate particles splashing
- CPS is not destroyed
- Formation of cavities
- Mass losses: 0.05 mg/cm^2 pulse

CONCLUSIONS

- **Erosion of tin targets has been studied at different heat loads (0.1-2.2 MJ/m^2) within powerful quasi-stationary plasma accelerators QSPA Kh-50 and QSPA-M.**
- **Transient plasma layers formed near surfaces exposed by powerful plasma streams. The plasma density in such layers is found to be up to ten times higher than in impacting plasma stream. It leads to the arisen screening effect for the plasma energy transfer to the surface. Calorimetric measurements of the target heat loads have shown that only about half of plasma stream energy density is delivered to the surface.**
- **For small energy loads the transient layer consists of the plasma stream species only. Target impurities are appeared when the heat load exceeds the material melting threshold.**
- **Further increase of the energy load causes the development of vapor shield. Nevertheless, pronounced erosion of the target is accompanied by separation of droplets/dust from the exposed target surfaces. The delamination of capillary pore systems of target was also observed.**

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