Vapour Shielding of Liquid-metal CPS Based Targets Under ELM-like And Disruption Transient Loading

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Motivation
One of the key risks for the DEMO tokamak performance is high energy density transients (disruption and ELM). Capillary porous systems filled with liquid metal (Li, Sn) are considered now as an alternative approach for plasma-facing components of heavily loaded divertor in a fusion reactor. Among the favorable effects for LM divertor approach could be strong vapor shielding of exposed surfaces, which decrease essentially both the resulting surface load and erosion. Different PSI devices are used to analyze the material response to extremely high particle and heat fluxes. This paper presents experimental studies of plasma-surface interactions during powerful QSPA plasma impacts to the Sn CPS structures in conditions, simulating disruption and ELM-like loads.

Experimental facilities, samples and diagnostics

- Plasma energy density 0.1–2.2 MJ/m²
- Plasma load duration 0.1 ms
- External magnetic field 0.8 T
- Diameter of plasma stream 6 cm

CPS based Sn
SS mesh wetted by Sn. Average cell size ~ 190±10 μm. Wire thickness ~ 90 μm
Porous structure made of Sn wire

Spectroscopy studies

- The plasma electron density was estimated using Stark broadening of spectral lines Sn II (3283 Å).
- The shielding layer is thinner without a magnetic field due to the plasma flows around the target.
- Shielding layer size increases in magnetic field. Sn lines are detected at essentially longer distances in magnetic field.
- This dense plasma shield is completely not transparent for the impacting plasma, being considerably larger than the particle free path length.

Measurements of energy density

- Energy density absorbed by the CPS target vs. the energy density in impacting plasma stream and corresponding frames from high-speed camera for varied heat loads.
- Vapour shielding of liquid-metal Sn capillary porous structures under ELM-like and disruption transient loading has been studied in complementary simulation experiments using QSPA-M and QSPA Kh-50 experimental facilities.

Results of numerical simulation

- The thickness of the shielding layer increases in a magnetic field. The spectral lines of Sn were registered only in a very thin plasma layer < 0.5 cm from the surface at B=0, but in the magnetic field of 0.8 T Sn spectrum was recognized at 3 cm from the exposed surface.
- The electron density in plasma shield is 5-10 times higher than in impacting plasma.
- Plasma exposures of Sn CPS target with QSPA plasma load < 0.5 MJ/m² do not trigger the generation of erosion products. For the heat load > 0.5 MJ/m², but < 1 MJ/m² single dust particles traces have been registered. Further increase of heat load leads to the splashing of eroded material. For ELM-like impacts rather weak melt motion was observed on the target surface. A moderate particle splashing is attributed to the heat loads up to 1 MJ/m².
- First comparison of obtained experimental results on vapour shielding of Sn CPS with available data from numerical simulation using the TOKES code demonstrates the qualitative correspondence between the simulated and measured electron density in the plasma shield.

Conclusions

- Only a part of the plasma energy is transferred to the target surface through the shielding plasma layer.
- Vapour shielding of liquid-metal Sn capillary porous structures under ELM-like and disruption transient loading has been studied in complementary simulation experiments using QSPA-M and QSPA Kh-50 experimental facilities.