Study of ITER-like tungsten irradiated at ELM-power density

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Development and testing of plasma facing materials is the most intractable problem for creation a thermonuclear tokamak reactor. The most intense energy is exposed in the divertor unit of the tokamak. It is expected that during ELM-events the energy density will reach 0.2-5 MJ/m^2 in 0.1-1 ms. Tungsten is considered for the plasma-facing material in fusion reactor due to its capability to survive in high-temperature, high neutron irradiation environment. Goal of this work is studding of ITER-like tungsten irradiated with plasma jet at the power densities comparable to transient processes - local instabilities (ELM). In particular task of this work was investigation of the modified tungsten properties after/during such irradiation.

Modelling experiments to check ELM scenario are suggested. In such a scenario plasma gun generating plasma beam with similar to the ELM-event heat load was used. ITER-like tungsten was irradiated to achieve an unstable surface brittle layer after 100 and 1000 cycles of melting and solidifying. The cyclically irradiated tungsten was investigated both in low energy plasma jet and divertor plasma of tokamak to understand what happens if such a layer is exposed to a plasma flux.

With the aim of collecting data on material irradiation by different sources the so-called damage factor is used in transient condition ε = (Energy density)/(Time duration)$^{1/2}$ [1]. For ELM-events in the ITER the damage factor can be in the range ε_{ELM} = 77 - 123 MJm^{-2}s$^{-1/2}$. Melting parameter for tungsten: ε_{melt} = 48 MJm^{-2}s$^{-1/2}$.

Test bench for irradiation of tungsten with plasma jet consists of small and large vacuum chambers, coaxial plasma gun and diagnostic complex [2]. The power density of the jet exceeds the values achievable in tokamaks. Plasma gun increases the rate of data accumulation on tungsten-plasma interaction. The gun produces ~ 100 shots in automatic mode during working day. The gun could generates plasma jet of clean, highly ionised pure

hydrogen plasma with energy density up to 1 MJ/m^2 during 10 μs (100 GW/m^2), with jet density up to 3×10^{22} m^{-3} and jet flow velocity 100 – 200 km/s, $\varepsilon_{gun}\leq300$ MJm^{-2}s$^{-1/2}$ [3]. Two different modes of tungsten irradiation were used. High specific energy density mode was utilized for damage modeling. Low specific energy density mode was utilized in diagnostics of the damaged layer.

Spherical tokamak Globus-M is characterized with R=0.36 m and r=0.24 m, B=0.4 T, I~200 kA, pulse duration up to 100 ms, energy of the confined plasma 1-3 κJ/m^3 [4]. Estimations showed that the energy flow to the divertor region, can reach value few MW/m^2, $\varepsilon_{Globus\text{-}M}$=0.33 MJm^{-2}s$^{-1/2}$. Experiment on interaction of Globus-M plasma with tungsten previously cyclically irradiated by plasma jet and electron beam at the power densities comparable to current disruption or local instabilities are prepared. More details see in [5].

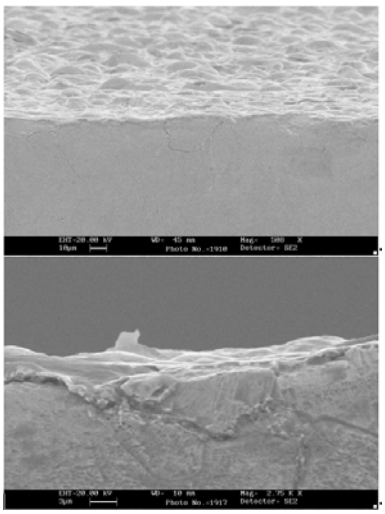

Fig. 1: Microstructure of ITER_D_2EDZJ4 tungsten on a polished cut of sample

The structure of the irradiated surface of ITER_D_2EDZJ4 tungsten proved to be the most resistant to damage (Fig.1). The depth of the molten layer about 1 - 3 μm and the zone of active thermal effects about 15-20 μm in depth was registered. Diffractograms showed very pronounced texture on a plane associated with the processes of melting and crystallization of the surface. Structural analysis do not showed any impurities imbedded into tungsten body.

Significant changes of the structure of the surface layer of PLANSEE Double Forged tungsten under irradiation with 100 and 1000 pulses were observed (Fig. 2). After 100 shots general structure is similar to the structure after 10-20 shots, but more definite large columnar formation perpendicular to the plane surface was performed. The identical pattern of large-scale surface topography produced by multiple pulsed laser irradiations was observed and analyzed in [6].

After 1000 shots (~one ITER shot) character of the surface layer changed dramatically in the direction of its roughening - recrystallized layer was formed.

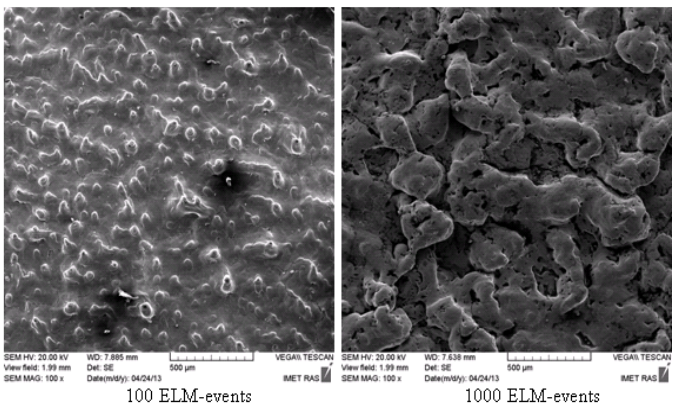

Fig. 2: Microstructure of PLANSEE Double Forged tungsten after cyclical irradiation

Diagnostic irradiation showed deferent emission of the edge plasma from ELM-loaded-tungsten in a low specific energy plasma jet flow (Fig. 3). The highest emission was registered from 1000 ELM-loaded sample. Emission from different samples was equalized with shot number.

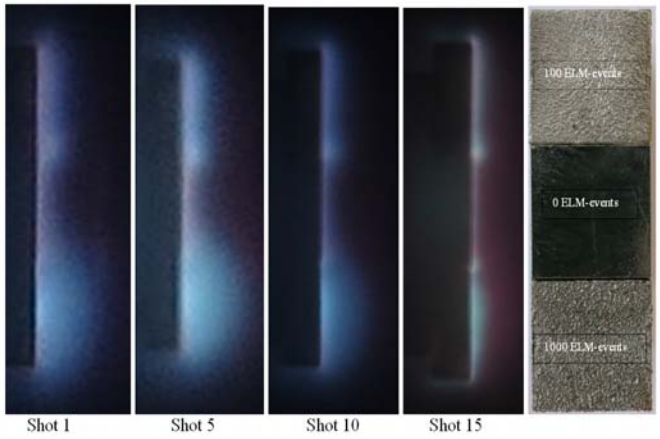

Fig. 3: Emission of the edge plasma near ELM-loaded-tungsten samples in a low energy plasma flow

Several tungsten plates were installed in the Globus-M divertor in order to study material interaction with plasma. Traces on the polished tungsten surfaces were observed after 1295 shots (Fig. 4). Further irradiations of the plates are conducted.

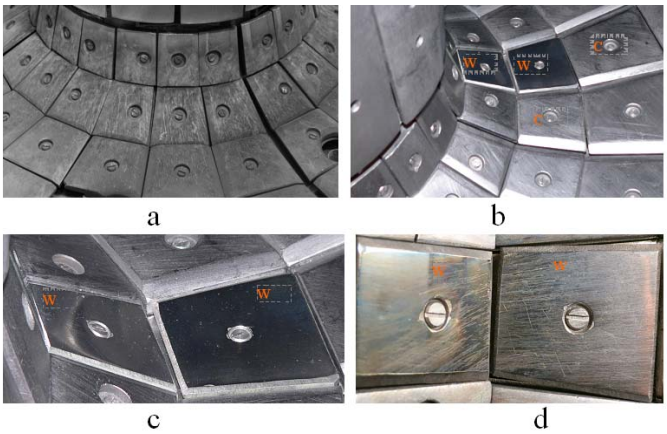

Fig. 4: a - diverter of the tokamak Globus-M, where separatrix contacts with the graphite plates; b - arranging the tokamak with W-specimens for long repetition irradiation; c - polished tungsten plates before irradiation; d-traces on tungsten plates after 1295 shots, 70 ms pulses duration

Experiment on interaction of Globus-M plasma with ITER_D_2EDZJ4 and PLANSEE Double Forged - tungsten, previously cyclically irradiated with plasma jet at the power densities comparable to current disruptions or local instabilities (ELM) are prepared (Fig. 5).

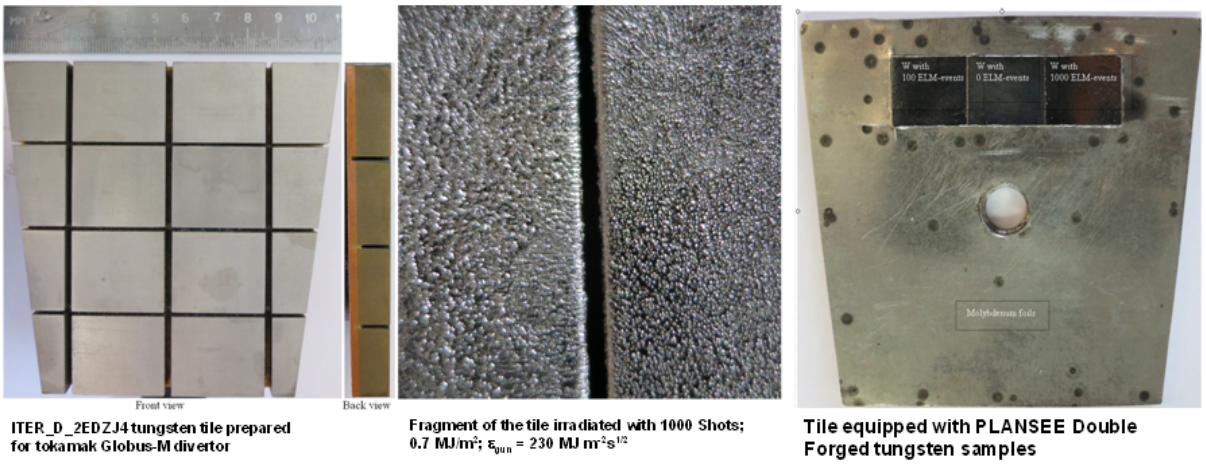

Fig. 5: ITER_D_2EDZJ4 and PLANSEE Double Forged - tungsten tiles prepared for Globus-M divertor

Summary

Study on tungsten-plasma interaction in the Globus-M tokamak and plasma gun test bench are conducted. Irradiation with the energy densities 0.25 - 1 MJ/m^2 offered basic physical and mechanical degradation processes: melting surface, destruction of near-surface layer arising due to thermal stresses, plastic flow and dynamic recrystallization in bulk. The structure of the irradiated surface of ITER_D_2EDZJ4 tungsten proved to be the most resistant to damage. The depth of the molten layer about 1 - 3 μm and the zone of active thermal effects about 15-20 μm was registered. Diffractograms showed very pronounced texture on a plane associated with the processes of melting and crystallization of the surface. Structural analysis do not showed any impurities imbedded into tungsten body.

Significant changes of the structure of the surface layer of PLANSEE Double Forged - tungsten under intense irradiation were observed. After 100 shots the structure in general is similar to the pattern after 10-20 shots, but more pronounced large columnar structure perpendicular to the plane surface was performed. After 1000 shots (~one ITER shot) character of the surface layer changed dramatically. It was roughening - recrystallized layer was formed. Several tungsten plates were installed at the divertor in order to study material interaction with plasma. Traces on the polished tungsten surfaces were observed after 1292 shots. Further irradiations of the plates are carried out. Experiment on interaction of Globus-M plasma with ITER_D_2EDZJ4 and PLANSEE Double Forged - tungsten, previously cyclically irradiated with plasma jet at the power densities comparable to current disruption or local instabilities are prepared.

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