In situ research of tungsten surface modification under thermal shock by a powerful electron beam on the BETA facility

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Tungsten is one of the most possible components of the first wall of fusion devices due to its good thermomechanical properties, resistance to high neutron fluxes and low retention of radioactive tritium. In addition to the constant heat flux to the divertor surface of the ITER tokamak, transient thermal loads can be expected as a result of ELMs type I, which can lead to an increase of erosion of the plasma facing components. Although studies on the resistance of tungsten to thermal shocks are widespread, they are mainly focused on analyzing the results of impact on samples after their extraction from the experimental chamber and give indirect information about processes of materials modification. On the BETA facility (Beam of Electrons for material Test Applications), an in situ approach is applied to study the process of tungsten destruction, which, accompanied with the classical post mortem methods, provide a more complete description of the surface modification dynamics.

Thermal shock to the sample is created by a powerful electron beam source with a plasma cathode and a multi-aperture electron–optical system of the diode type. The electrons are pulled from the plasma of the arc source, accelerated to energy up to 120 keV and transported in a converging magnetic field to the sample surface. The total current absorbed by the target can reach up to 40 A, and the maximum obtained pulse duration is up to 1 ms. The resulting thermal load is well fitted by a normal distribution with a heat flux parameter of 15–300 MJ/m2s0.5 at the maximum and a full width at half-maximum of 10–20 mm depending on the operating mode. Passive and active diagnostics of the surface erosion of the irradiated material are applied on this facility. During the exposure, thermal radiation of tungsten is recorded using fast CCD arrays and a system of avalanche photodiodes. This diagnostics was absolutely calibrated using a ribbon tungsten lamp, which made it possible to obtain a two-dimensional temperature distribution on the sample surface and temporal temperature dynamics in certain areas of the target. Using this technique, local surface overheating was detected, which can be caused by the detachment of material parts as a result of cracks propagation along the irradiated surface. Thus, from the dynamics of the surface temperature after thermal shock, we can make a conclusion about appearance of internal damage in tungsten bulk. In another optical diagnostics, the sample surface is illuminated with a continuous wave laser, the reflected and scattered radiation of which is recorded with spatial and temporal resolution. This technique allows to observe a modification of the target surface at relatively low sample temperatures, at which the thermal radiation is small for detection, for example, at the moment of formation of a large crack network on tungsten. In addition, variation of the intensity of the reflected and scattered radiation can give information about the effects of thermal shock that do not directly affect the local temperature alteration: growth of roughness due to uninform plastic deformation of the grains or tile bending as a result of thermal expansion of the front thin layer.