Role of arc formation in overheating of tungsten limiter in the T-10 tokamak at high heat loads expected in the ITER tokamak

V P Budaev1,2,4, S A Grashin1, A V Karpov1 and L N Khimchenko3

1 National Research University "MPEI", Moscow, Russia
2 NRC Kurchatov Institute, Moscow, Russia
3 Institution "Project Center ITER", Moscow, Russia
4 E-mail: budaev@mail.ru

Abstract. Arc erosion of tungsten plates, which occurred after they were tested at the T-10 tokamak in shots with high-power ECR heating, was observed and analyzed. In the T-10 tokamak, the regimes with nonambipolar energy flow onto the tungsten limiter plates were obtained. In such shots, the tungsten plates at the inner contour of the limiter were heated up to a temperature above 2000 °C. Apparently, the nonambipolar energy flow onto the metal surface, which is caused by the effect of sparks and arcs, can be responsible for the surface overheating. The nonambipolar energy flow appears as a result of the explosive electron emission occurring in the course of spark formation which increases the electron flux from the surface into plasma by an order of magnitude.

1. Introduction
Extremely high heat load is expected to attack the tungsten divertor plates of the ITER tokamak during both the steady state operation and transient events such as disruptions and ELMs (see [1]). In fusion facilities, at very high heat load onto the material surface, several large-scale effects affect the plasma-surface interaction, namely, the surface erosion, redeposition of eroded materials, melting and melt motion over the surface, and inhomogeneous solidification resulting in the occurrence of a more complicated stochastic surface structure and collective feedback effects. Arcs and sparks can be easily ignited under conditions existing in plasma above the material rough surface and melt and they can cause the overheating of the material surface.

It is expected that nonambipolar flow toward the surface will occur due to arcs and sparks formation which will result in the enhanced heating of plasma facing materials (PFMs) due to very high heat load [2]. The ekton mechanism [3–5] of the cathode spot operation implies the occurrence of the intense electron emission due to the pulse-periodic bursts of explosive electron emission [3, 4]. Unlike the standard thermionic emission, such mechanism can considerably increase the electron emission and; as a result, the effect of sparks and arcs lead to the surface overheating and melting.

In the experiments on ECR plasma heating at the T-10 tokamak where the ITER-grade tungsten PFMs were used, such conditions of high-power plasma load were formed. In such shots, the tungsten plates at the inner contour of the limiter were overheated, which results in the surface melting.
2. Arcs and sparks observed on the tungsten surface

The ITER-grade tungsten plates were tested at the T-10 tokamak in shots with high-power ECR heating. Regimes with nonambipolar energy flow onto the tungsten limiter plates were obtained [1]. In such shots, the tungsten plates at the inner contour of the limiter were overheated up to a temperature above 2000 °C. Thermal load on the surface amounted to more than 50 MW/m², which is comparable to that expected in the ITER divertor. After a series of ~400 shots, melting, cracking (including deep cracks), sparking and arcing were observed on the surface of the ITER-grade tungsten plates (Figure 1).

Apparently, the observed overheating of the surface is a result of a nonambipolar flow occurring due to the effect of arcs and sparks on the tungsten tiles [2].

Arcs and sparks can be easily ignited under conditions existing in plasma above the rough surface and melt (Figures 2 and 3) and they can cause overheating of the material surface.

Figure 1. Arc erosion of tungsten tiles at the inner contour of the circular limiter in the T-10 tokamak.

Figure 2. SEM micrographs of arc craters on the melted tungsten surface after the exposure to plasma in the T-10 tokamak.

The nonambipolar energy flow onto the metal surface is caused by the effect of sparks and arcs leading to surface overheating [2].

Unlike the standard thermionic emission, the explosive electron emission which occurs in the course of sparking can increase the flux of electrons into the plasma by an order of magnitude. It can change the balances of energy and particles in the edge plasma of a tokamak reactor and lead to a considerable overheating and melting of the divertor plates and, accordingly, to their cracking and enhanced erosion.
Figure 3. SEM micrographs of sparking on the tungsten surface after the exposure to plasma in the T-10 tokamak.

Figure 4. (a) SEM micrograph of an arc spot on the tungsten surface (the third type of cathode spot) and (b) zoomed image of the spot.

The arc current can be estimated: for the 20 µm-diameter (Figure 3) and a large-scale 100 µm-diameter (Figure 4) craters, the estimated arc currents are approximately ~10 and ~100 A, respectively.

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