OVERVIEW OF THE RECENT EXPERIMENTAL STUDIES OF PLASMA-FACING COMPONENTS IRRADIATED WITH DIVERTOR RELEVANT PLASMA

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1. INTRODUCTION

Plasma thermal tests of materials (tungsten, beryllium, graphite, steels, liquid metal components) in modern fusion devices revealed a significant change in the surface structure under the influence of powerful plasma loads [1-10]. The plasma-surface interaction (PSI) in magnetic fusion devices involves several mechanisms including erosion and damage to the surface, melting and recrystallization of surface layers, movement of molten material over the surface, sputtering, evaporation, re-deposition of eroded material on the surface, modification of surface layers on the scales from tens of nanometers to hundreds of micrometers (see, for example, the review [1]). The conditions corresponding to the plasma load in the fusion reactor cannot be fully achieved in modern tokamaks. To identify the dominant PSI mechanisms under prolonged irradiation, steady-state plasma tests of fusion materials are performed in linear plasma devices - divertor simulators and plasma accelerators such as PLM–M, NAGDIS-II, PISCES, MAGNUM-PSI, PR-2, PF-3, QSPA-T, QUSPA-Be and others. The report will provide an overview of recent experimental studies of plasma-facing components in such plasma devices with a comparative analysis of the dominant phenomena critically affecting erosion and surface modification of plasma-facing components in a fusion reactor.

2. REVIEW OF EXPERIMENTAL STUDIES

Tests of ITER grade tungsten in tokamaks (in tokamak T-10, Fig.1, and others) and the QSPA-T plasma gun (see [1,4]) demonstrated the effects of cracking and erosion, including arc erosion with the formation of deep craters, Fig.2. The evolution of surface morphology under high-heat plasma load in fusion devices is dominated by not one elementary process, but by the combined integral effect of many processes. This leads to synergetic effects considered by the theory (see, for example, [2,3]), taking into account the instability of surface growth caused by the stochastic movement of agglomerated particles and clusters. As a result, the structure of such a surface, in addition to the previously known effects of cracking and erosion under high-heat load, also acquires the property of heterogeneous hierarchical granularity, with signs of statistical self-similarity and scale invariance of the surface structure, with high porosity on scales from tens of nanometers to hundreds of micrometers. Recently, materials with a porous surface of the "cauliflower" type [8,9,10] and "fuzz" type with a high specific area [1,5,6] have been found in fusion devices. On tungsten, under steady-state plasma irradiation (see [6,8]), "fuzz"-type surfaces with fibers of 20-50 nanometers in diameter and a layer thickness of approximately 1.6 microns are formed, Fig.3. The results obtained on the formation of nanostructured porous tungsten should be taken into account when analyzing the erosion and modification of tungsten plates faced to plasma in ITER and large tokamaks. Combined tests of tungsten samples with a "fuzz" type structure using an electron beam and a stationary plasma load revealed the stability of such a structure to powerful plasma beam loads.

The effects of the formation of porous surfaces under the action of plasma were observed during tests of capillary-porous systems (CPS) made of liquid metals in tokamak T-10 and in plasma device PLM [9]. CPS made of liquid lithium and tin were tested using steady-state plasma in PLM for ~200 minutes, demonstrating stability under high-heat plasma load. Lithium materials deposited in the T-10 tokamak in experiments with lithium CPS were subsequently irradiated with stationary plasma in PLM to test the evolution of the over-deposited layers under prolonged plasma load. The analysis showed that lithium carbonate-based composites have a modified structure with a hierarchical granularity and a high specific surface area, Fig.4. The topology of such a structure, with a "cauliflower" type shape, is similar to the previously observed morphology of hydrocarbon composites deposited in tokamaks [10].

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Fig.1. Tungsten after plasma testing in tokamak T-10

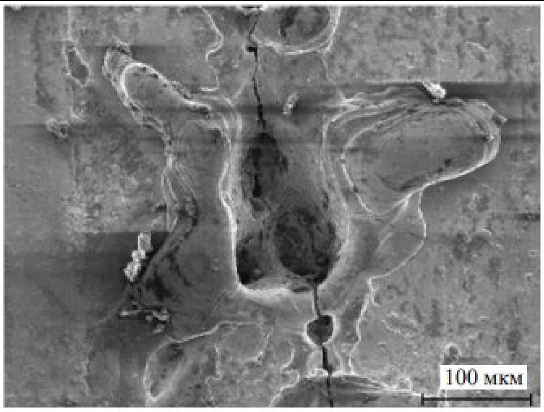

Fig.2. Arc crater on tungsten in tokamak T-10

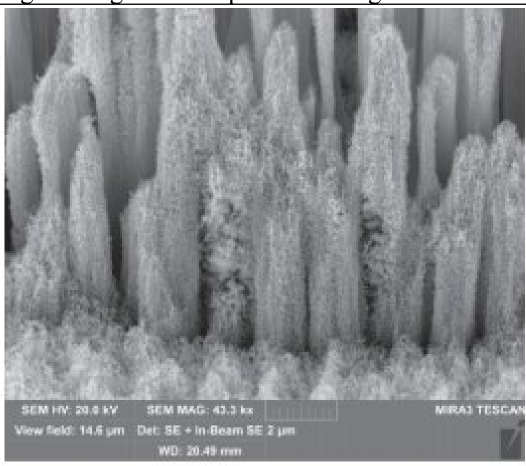

Fig.3. A tungsten sample with a "fuzz" structure after irradiation with helium plasma in PLM

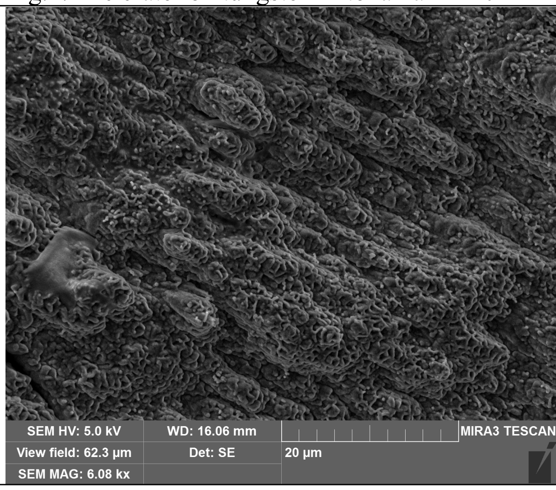

Fig.4. Lithium sample from tokamak T-10 after irradiation with helium plasma in PLM