*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-4.091 (2006)*

Surface structure measurements of deposits from CFC and W divertor armour materials sputtered in ELMs simulated experiment.

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Introduction

ELMs (Edge Localised Modes) and disruptions are a concern for the thermonuclear reactor ITER because they have the potential to produce considerable erosion damage of plasma facing components and reduce significantly the lifetime of divertor target materials. The basic mechanisms of surface erosion during ELMs and disruptions are evaporation, melt layer losses with splashed droplets for metals and brittle destruction for CFC (formation of surface cracking with spallation of detached grains). The largest power loads on the divertor target in ITER are expected during the thermal quench of plasma disruptions and Type I ELMs. Because of their larger number compared to disruptions during ITER operation Type I ELMs are likely to dominate the erosion of PFCs under transients. The erosion of ITER PFCs under ELMs and disruptions is presently modelled by plasma-material damage codes [1], which can evaluate the expected erosion of CFC, W and Be PFCs in ITER under transient loads. These codes are being validated by experiments in which ITER relevant targets are exposed to large energy loads by laser, electron beams and by energetic plasma impact [2]. Although the quantitative agreement between experiments and modelling is improving, the understanding of the erosion, migration and deposition of materials during transient energy loads in ITER is poor at present. The formation of metallic and hydrocarbon dust particles and the growth of porous hydrocarbon films can impose very restrictive limits on the operation of ITER because of their safety implications. Furthermore, small dust particles can be transported injected by SOL plasma flows into the bulk plasma and may contribute significantly to the core plasma impurity concentration. [3]. Deposits with high porosity that may be produced during transient loads in ITER can have a significant amounts of absorbed tritium leading to a considerable retention. Because of this reasons, the ITER project has setup a rigorous safety limit based on the chemical reactivity and radiological hazard of the dust.

Experiment and analysis.

A collaborative research activity on the investigation of deposited films and dust was undertaken in frames of joint EU-RF experiment. CFC and tungsten macrobrush divertor plates were manufactured in EU according to the ITER divertor target specifications. These targets have been exposed to Type I ELM and disruption-like loads at the plasma gun facility QSPA at the TRINITI institute [4]. The diameter QSPA plasma cloud – 5 cm, ion energy ≤ 100 eV, electron temperature ≤ 10 eV, density ≤ 10^{22} cm^{-3}. For W macrobrush melting temperature (3680^0K) run up with 0.38 MJ/m^2, but boiling point (5900^0K) – with 0.67 MJ/m^2. The energy of the ELM-like loads covered a range of 0.5-1.5 MJ/m^2. For all plasma pulses the duration was 0.5 ms. During the experiments, collectors for eroded fragments from the targets produced by the transient loads were installed at a distance of ~ 20 cm from the CFC and W targets (see Fig. 1). The analysis of erosion products was made after series of, typically, ~ 100 shots. Scanning electron and tunnelling microscopes were used as basic diagnostics for films and dust analysis.

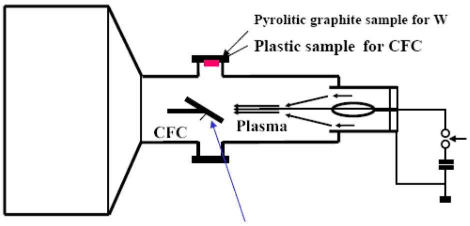

Fig.1 QSPA facility

In the case of experiments with W macrobrush target and power load 1.0 – 1.5 MJ/m^2 a large number of dust particles with spherical shapes and fractal surface structures (cauliflower) have been measured (fig.2). The observed dust particles had typical dimensions of 0.1-5.0 μm were formed by accumulation of small particles, which in turn consisted of particles with even smaller size, etc. Particle size distribution has power-behaved dependence $N \sim r^{-2.2}$ (Fig.3). Surface measurements of 100 nm clusters by STM show that they consist of 20 nm particles. As in the QSPA experiments, small size particles are found to accumulate in a film and particles of greater sizes were deposited on top of the films in the form of elongated clusters. The size of these clusters of agglomerated dust particles was 3 -10 μ and they showed a coral-type structure with fractal surface. At increase in plasma pulse energy up to 1.5 MJ/m^2 on a films surface there were tracks from particles of the extended form, which can be treated as a metal droplet.

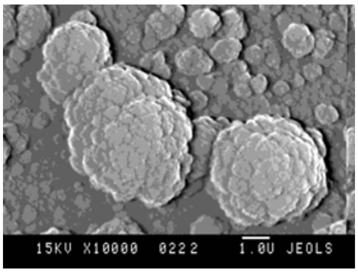

Fig.2 Dust particles after W macrobrush erosion

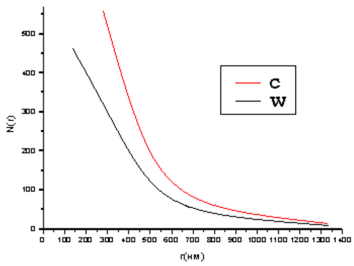

Fig.3 W and CFC particle size distribution

In the case of impact with a CFC target plasma energy load of 0.5 MJ/m^2 only flakes have been found in the measured deposits but the amount of dust particles was negligible small (Fig.4). The deposited films have a complex structure with a large number of porous with diameters of 100 nm and substructures of typical 20 nm scale dimensions. The flakes showed self-organisation of the surfaces up to sub-micron scales. At a plasma pulse energy nearby 1.5 MJ/m^2 the film, on the contrary, consisted only from fractal particles of the spherical form with the sizes from 0.1 up to 2 microns. Distribution of particles in the sizes submits to power-behaved dependence $N \sim r^{-2.3}$ (Fig.3), that also specifies on fractal mechanism of particles formation.

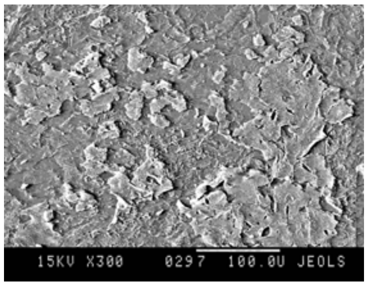

Fig.4 Flakes after CFC macrobrush erosion

Discussion

In the realize experiments evaporation and splashing are estimated as the major mechanisms for W macrobrush erosion and sublimation - for CFC macrobrush during Type I ELM and disruption loads. At a plasma pulse energy near 1.0 - 1.5 MJ/m^2 in both cases the possible mechanism of fractal dust particles and coral-type structures formation are, apparently, primary coagulation from supersaturated vapor with the subsequent agglomeration in larger clusters. CFC macrobrush erosion at 1.5 MJ/m^2 energy load at the same time produce vapor carbon droplets (Fig.5). At smaller energy - 0.5 MJ/m^2 sharply changes structure of deposits, leading to formation "pancake" films structures with a combination of nanovoid and nanocone on the surfaces. For such energy sedimentation (condensation) from the gas phase and growth through hydrocarbon molecules are the likely mechanisms of flakes formation and surface self-organization for CFC case. In all cases, the deposits have a developed surface that may lead to high absorption of deuterium and tritium in a thermonuclear reactor. The distribution law of fractal particles from their size – $N \sim r^{-2.2 \div 2.3}$, indicate a significant role of nanoparticles. The minimum particles size found out makes 20 nanometers.

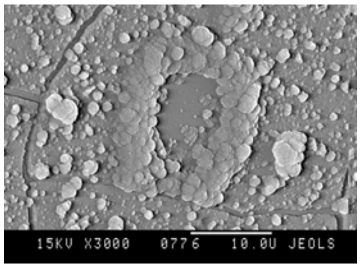

Fig.5 Carbon vapor droplets

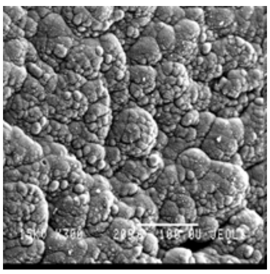

Fig.6 The surface of T-10 flake

Attracts attention similarity of the above-named structures and structures of a dust and films, received in tokamak T-10 [5]. The feature of "H-mode" T-10 regime was in significant power flow on to a small surface of graphite tiles in HFS of a circular limiter with power load nearby 50 MW/m^2. At the same time tiles were heated up to 2000 ^0C, and the basic mechanism of erosion was intensive sublimation of graphite under intensive arcing. Near to this place grew a films, consisting of spherical particles with fractal structures (Fig.5). The same situation with self-organizing of a surface. The surface of T-10 hydrocarbon films is covered by nanocone, marshaled in structures of lattice type. The surface of these films in microscale range consist of fractal structure with fractal dimension $D = 2.15 \div 2.32$.

Conclusion

The found out mechanism of possible formation carbon and tungsten fractal dust with nanoscale size and films formations from them can essentially change conception of energy and particles balance in ITER divertor chamber. For example, constant reproduction of a dust and films with strongly developed surface will lead to a constant deuterium and tritium sorption. Erosion of such structures can essentially differ from standard. The films developed surface can lead to increase in secondary electron emission, and, accordingly, to cooling divertor plasma. Safety requirements at presence of nanoparticles in divertor can lead to change of reactor economy. A surface clearing from deuterium and tritium may become the problem.

Acknowlegments

This workwas supported by the NSh grant 2264.2006.2 and Contract 02.445.11.7471. Discussions with B.N.Kolbasov and M.I.Guseva are acknowledged.

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