Investigation of tungsten interaction with high kinetic energy plasmas

A.V.Voronin[1], A.V. Ankudinov[1], V.K.Gusev[1], Ya. A. Gerasimenko[2], E.V. Demina[4],

A.N. Novokhatsky[1], Yu.V. Petrov[1], N.V. Sakharov[1], Yu.V. Sudenkov[3]

[1] A.F.Ioffe Physical-Technical Institute, Russian Academy of Sciences, St. Petersburg, Russia

[2] St. Petersburg State Polytechnical University, St. Petersburg, Russia

[3] St. Petersburg State University, St. Petersburg, Russia

[4]A.A. Baikov Institute of Metallurgy and Material Science RAS, Moscow Russia

Selection of the materials for the first wall is the most intractable problem for creation a thermonuclear tokamak reactor. In terms of power density the loads are the following: normal operation 5 MW/m^2; ELM-mode 30 GW/m^2; disruption-phase 100 GW/m^2. Tungsten is one of the basic coatings for plasma facing components of fusion reactors, mainly because of its high melting point and high threshold for sputtering. Principal difficulty is that no one existing tokamak can create transient energy densities sufficient to melt tungsten. However, there is uncertainty in the behaviour of the discharge during ignition and burning process in a tokamak with tungsten wall. Unlike graphite, tungsten elements of protection can melt and have little ability to "shaping" plasma. As a result plasma heavy impurity contamination can be increased.

Goal of this work is developing a data base for interaction of ITER-like tungsten with high energy density plasma flows capable for material melting. Experiments are concentrating on study of melted layer dynamics, damaged W properties and effects of W melting. Results of investigation of the modified tungsten properties after high energy plasma irradiation are reported. The work is based on two plasma sources - the original gun device and spherical tokamak Globus-M. Comparable investigations of tungsten irradiation with plasma flows generated both by the gun and the Globus-M plasma are performed. Study of plasma interaction with tungsten, at the tokamak Globus-M and at the gun test bench can help the first wall creation for the tokamak ITER.

a b

Fig. 1: Arranging the tokamak Globus-M with W-specimens for long repetition irradiation

Relatively compact spherical Globus-M tokamak has a high power density flow to the wall from plasma column: R=0.36 м and r=0.24 м, energy of the confined plasma 1-3 кJ/m^3. Estimations showed that the energy flow to the divertor region, can reach value few MW/m^2. Preliminary experiments showed that in the diverter, where separatrix contacts with the graphite tiles, deposited energy density of plasma flow probably could be high enough for tungsten melting (Fig.1a). 3 tungsten plates were installed at the divertor region (Fig.1b) of the tokamak Globus-M for long repetition irradiation.

Also we use an approach based on plasma gun which is powerful enough for simulation of the thermal loads on tungsten close to the ITER conditions. The plasma gun could generates plasma jet of clean, highly ionised pure hydrogen plasma with energy density ~1 MJ/m^2 during ≤15 μs, with jet density 3×10^{22} m–^{3}, total number of the accelerated particles (1–5)x10^{19} and jet flow velocity 100–200 km/s [1]. Advantages of the gun are the high kinetic energy and clean hydrogen plasma jet. Stored energy of the gun capacitors is about 2 kJ. Many specimens may be irradiated per one day. Power density of the plasma gun can exceed 100 GW/m^2. Damage factor F=(Power density)x(Pulse duration)$^{1/2}$produced by the gun is similar to ELM- event in a tokamak: F(ELM)=30GW/m^{2}x(100μs)$^{1/2}$ =F(Gun)=100GW/m^{2}x(10μs)$^{1/2}$ =300 MWm $^{-2}$s $^{1/2}$. The damage factor achieving with plasma jet is higher than the melting parameter for tungsten 48 MWm^{-2}s$^{1/2}$ [2].

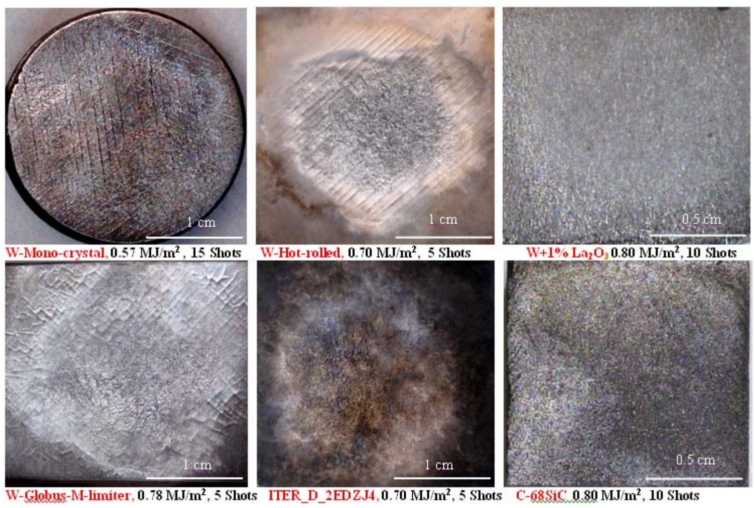

Fig. 2: Several types of material irradiated with plasma gun

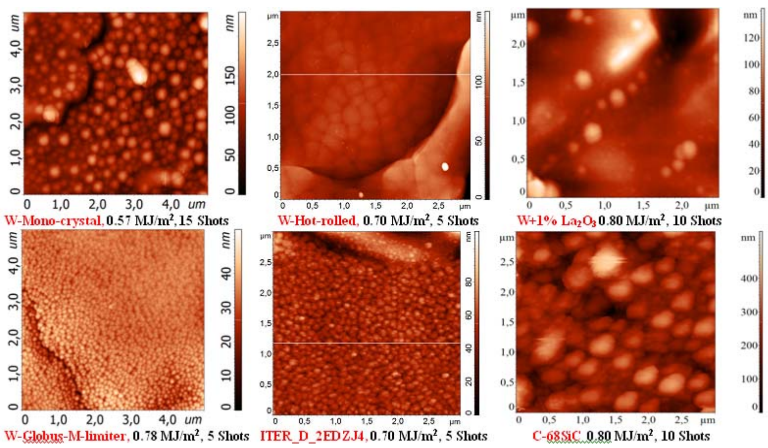

Fig. 3: AFM tomography of different materials irradiated wit plasma gun

Several types of material were irradiated with plasma gun (Fig.2). Pictures of the irradiated surfaces show that

W–ITER_D_2EDZJ4, W+1% La_2O_3, C-68SiC have no sign of cracking of the surface. But W-Hot-rolled, W-Crystal and W-Globus-M-limiter are cracked. Traces of cracking are probably a consequence of technological rolling of the material. AFM tomography observed irradiated sample at different treatment scenarios (Fig.3). One can see that the depth of damaged layer for: W-Mono-crystal ~200 nm, W-Globus-M-limiter ~50 nm, W-Hot-rolled ~150 nm, W+1% La_2O_3~120 nm, C-68SiC ~400 nm, W-ITER_D_2EDZJ4 ~ 50 nm. The structure of the material has a regularity of the characteristic particle size of 100 nm. In the non irradiated specimen such a structure can not be found.

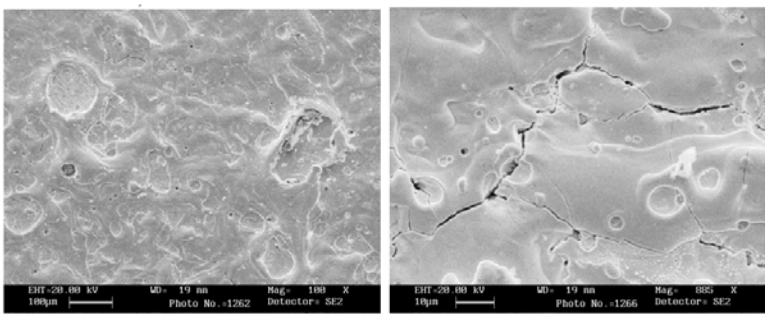

Fig. 4: Scanning electron microscope (SEM) pictures of the ITER_D_2EDZJ4 tungsten irradiated with plasma gun

Scanning electron microscope (SEM) observed the surface of the ITER_D_2EDZJ4 tungsten irradiated with plasma gun (Fig.4). ITER_D_2EDZJ4 tungsten was made by Russian POLEMA JSC. The grain structure has perpendicular orientation to the irradiated surface. The surface has structural defects such as craters and microcracks in 10-100 µm range. Surfaces of W-Globus-M limiters after plasma gun irradiation at different conditions were studied (Fig.5). The most damaged specimens are at

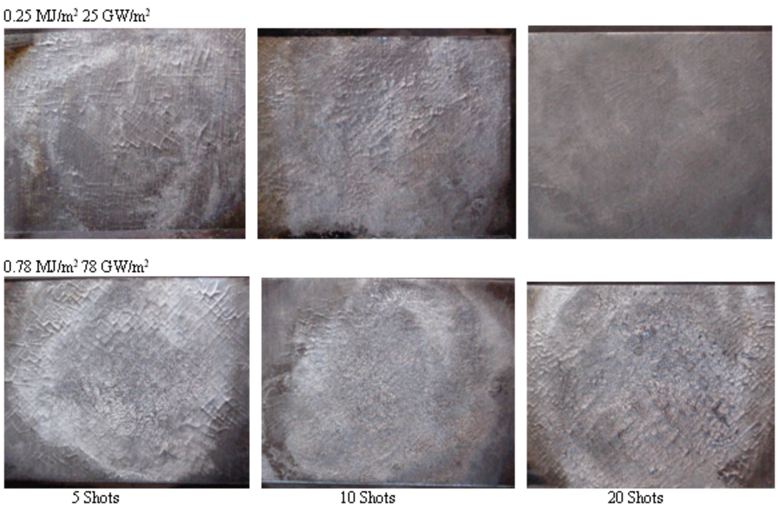

Fig. 5: Surfaces of W-Globus-M limiters after plasma gun irradiation at different conditions

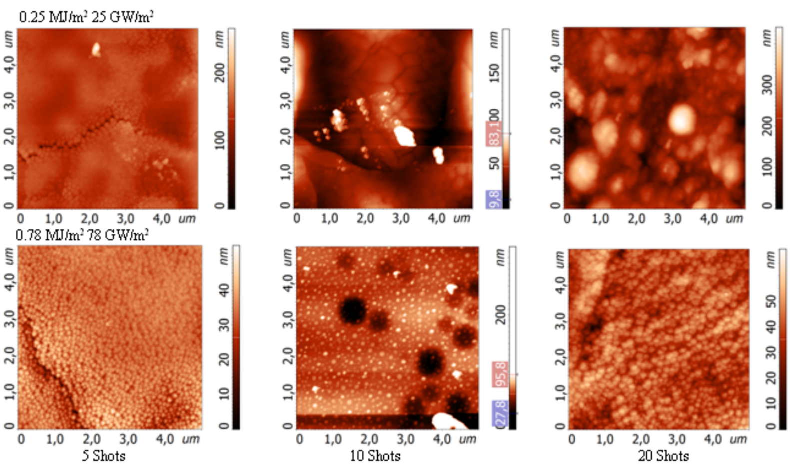

Fig. 6: AFM tomography of W-Globus-M limiters after plasma gun irradiation

high energy density. At low energy and many shots the lowest macro-damage was observed. AFM tomography of W-Globus-M limiters after plasma gun irradiation was examined (Fig.6). Fine regular structure of the material surface at energy density 0.78 MJ/m^2 was observed. Polished cut W-Globus-M limiter after plasma jet irradiation was analysed (Fig.7). The W-Globus-M limiter grain structure has parallel orientation to the irradiated surface. Regular structure with period 30 μm at depth 50 μm was observed. Full depth of regular structure was about 400 μm. Probably this phenomenon as a result of thermal impact of the energy into the specimen.

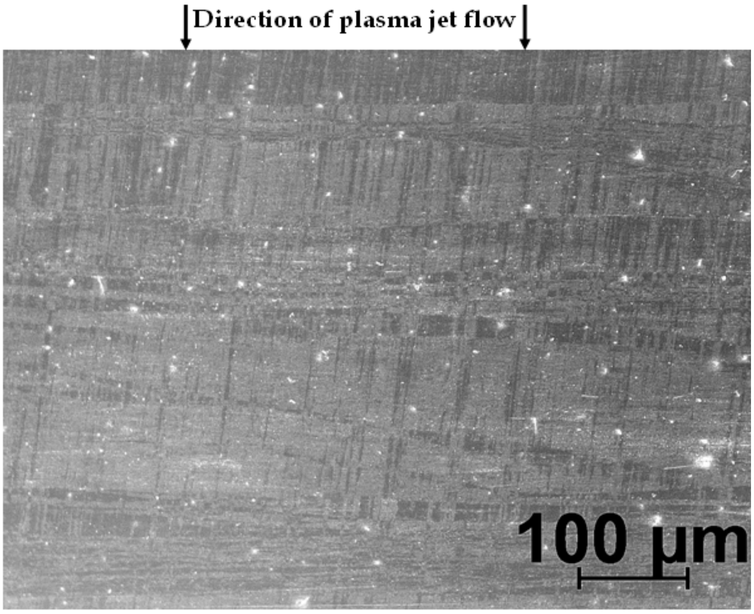

Fig. 7: Polished cut of W-Globus-M limiter after plasma jet irradiation

Conclusions

Preliminary analysis of plasma interaction with wall of tokamak Globus-M was performed. Significant changes in the surface of the graphite plates in the divertor were found. Several tungsten plates were installed instead of the graphite plates in order to study material interaction with plasma. Several types of tungsten were irradiated by the plasma jet with different energy densities. Tungsten ITER_D_2EDZJ4 is the most resistant to the damage. Melting of the material to a depth of several micrometers was observed. Fine regular structure ~ 100 μm of the material at energy density 0.78 MJ/m^2 and at any number of shots was developed.

The work is supported by the IAEA Research Contracts No: 16939, 16960, RFBR grant 11-08-00813-a, RF Ministry of Education and Science contracts; No. 16.518.11.7003; No. 16.552.11.7002, No. 11.G34.31.0041.

[1]. A.V. Voronin et al, Nukleonika **53** (2008) 103.

[2]. R. A. Pitts, ITER divertor strategies: physics basis. Strategy Workshop, Cadarache, 5 September (2011).