Protection by B_4C Coating under Irradiation of Plasma Pulses

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Abstract: The influence of QSPA-T pulse plasma irradiation on stochiometric B_4C and nonstochiometric boron-carbide coating was investigated. The duration of the rectangular plasma pulses was 0.5 ms with 5-10 min interval between pulses. The peak power density in the middle of plasma flux was 1 GW/m^2. The coating was deposited on the fine grain graphite MPG-8. The structure and surface relief of coating, concentration of porous and microcracks did not change after 50 pulses even at the areas irradiated by plasma with 1 GW/m^2 power density. The evidence of coating destruction was not detected. The coating kept stochiometric structure B_4C.

I. Introduction

Plural experiments in the modeling devices and tokamaks showed that crystalline boron carbide coating can successfully meet requirements to the plasma facing component including ITER. The main features of the crystalline boron carbide coating B_4C deposited on the MPG-8 and RGT graphites, in particular, low erosion characteristics, hydrogen retention capacity, resistibility under high energy loads and etc. were showed under electron and ion beams irradiation in the Sandia National Laboratories (at heat loads 1.1-1.3 GW/m^2), in the PLADIS plasma gun facility in the University of New Mexico [1], in the DIII-D tokamak divertor plasma [2], under real conditions in the T-10 and T-11M tokamaks (Russia) and etc. In all experiments boron carbide coating kept integrity, chemical composition and material structure, any surface destruction wasn't observed. However, it should be noted that to present day was not systematic examination of the ultrahigh power density plasma influence on the crystalline boron carbide coatings and applicable life tests of a coating up to complete degradation under plasma irradiation in extreme conditions. Now detailed information about crystalline boron carbide coating behavior at interaction with high power density plasma fluxes is needed to make definite conclusion about possibility of its application as the removable protecting coating of the tungsten divertor tiles for ITER.

II. Experimental technique

Experiments on plasma flux irradiation of the B_4C coating were carried out in the QSPA-T facility that is a one-step coaxial high-current plasma accelerator with its own magnetic field. Acceleration of plasma occurs between two coaxial electrodes, to electrodes is applied electrical voltage from the power source and plasma generating gas is continuously fed in the gap between electrodes. At constant gas supply the plasma flux duration is determined by lifetime of the electrode voltage. QSPA-T facility is generally used for life test operation of heat-shielding materials, as well as for examination of the mechanisms and erosion products. Tested specimens are placed at the distance of 60 cm from the accelerator electrodes. Irradiation was carried out at normal incidence of the plasma flux under the general scheme shown in Fig. 1. The target of 10 mm thickness was made from two monoblocks of the

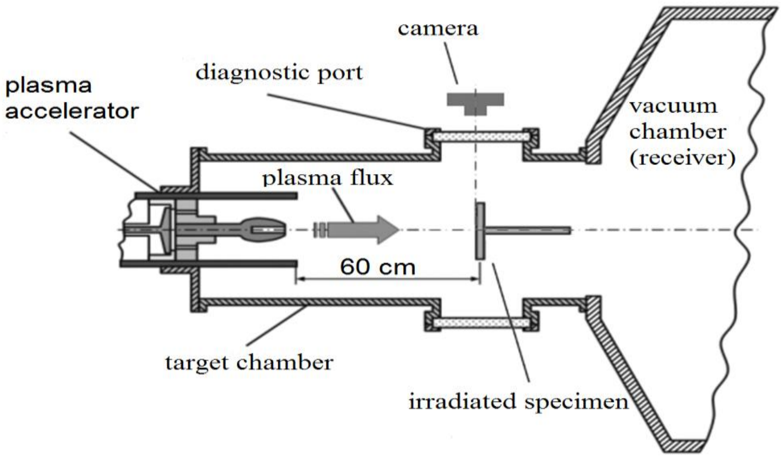


Fig. 1. General scheme of target irradiation

MPG-8 graphite with crystalline boron carbide B_4C coating produced by the CVD method. Because during life tests of the protective coatings irradiated by high power plasma flux, the material erosion increases almost linearly with the plasma influence duration [3], the program of work is planned for sequential series of exposures by hydrogen plasma stream up to complete removal of a coating. The duration of the rectangular plasma pulses was 0.5 ms with 5 - 10 min interval between pulses. The energy density at the target surface on the flux axis was 0.5 MJ/m^2 per pulse and decreases with distance according to the Gauss law. Thus, the irradiation power density on the stream axis 0.5MJ/m^2/0.5ms = 1 GW/m^2 corresponded approximately to the average estimated power of ELMs in ITER [4]. Fig. 2 shows the distribution profile of the heat load (energy density) on the target surface. Pulsed irradiation was performed in three series (total of 3, 15 and 50 pulses). Analysis of the coating surface

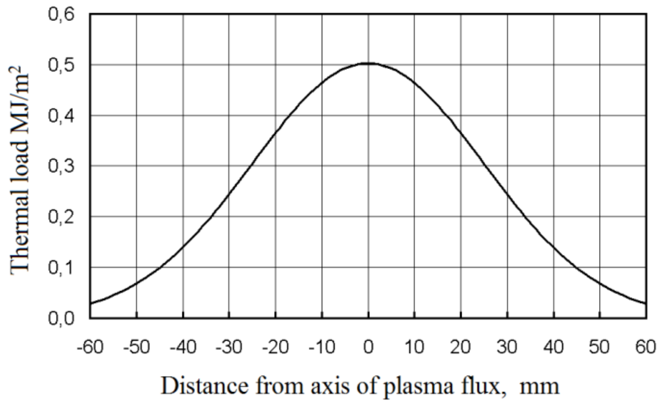


Fig. 2. The distribution of energy density on the plasma flux profile

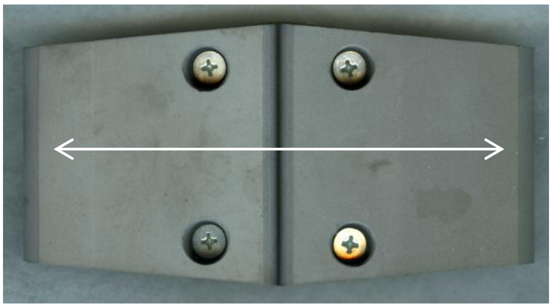
and chemical composition was carried out by scanning electron microscopy and X-ray energy-dispersive spectrometry.

III. Results of irradiation in QSPA-T

The boron carbide coating structure before irradiation composed of two layes: the lower uniform dense layer 8-12 μm and the porous upper layer of 12-32 μm thickness, consisting of randomly oriented 3-15 μm micro crystals. The thickness of the coating varies from 20 to 40 μm on different parts of the surface. The appearance of a target before and after irradiation is presented in Fig. 3. After 3 pulses of irradiation the uniform dense layer of stochiometric B_4C, consisting of micro crystals merged in blocks 40-100 μm, was formed on the coating surface (Fig. 4a). Porosity between micro crystals is minimized. The boundaries between blocks in some cases are cracks up to 1 μm of width. The structure, relief of coating, middle dimensions of micro crystals and concentration of the porous and cracks between blocks did not change (Fig. 4 b, c) after irradiation by 15 and 50 impulses. This effect shows that coating melting does not occur, and all structure forming is a result of the diffusion process activation at increased temperature. Thus, plasma irradiation during 50 pulses of power density up to 1 GW/m^2 does not result in the coating destruction. Surface erosion occurs only through sputtering.

IV. Conclusion

The irradiation of the crystalline boron carbide coating by 50 plasma pulses with high power density in the QSPA-T facility was performed. It is shown that the coating keep its integrity, the chemical composition and stoichiometric structure B_4C after plasma flux irradiation power with power density up to 1 GW/m^2.

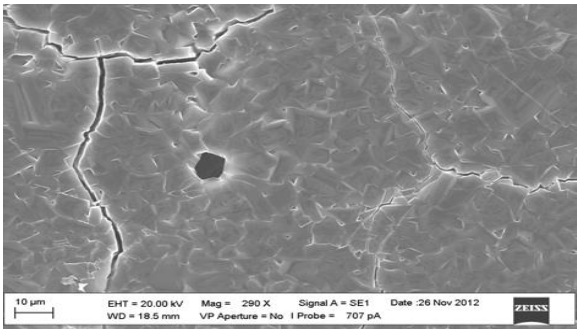


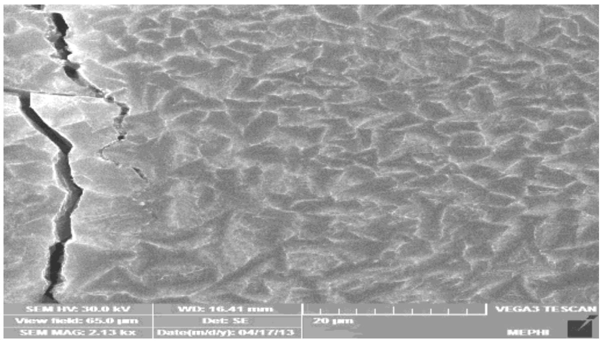
a **b**

c

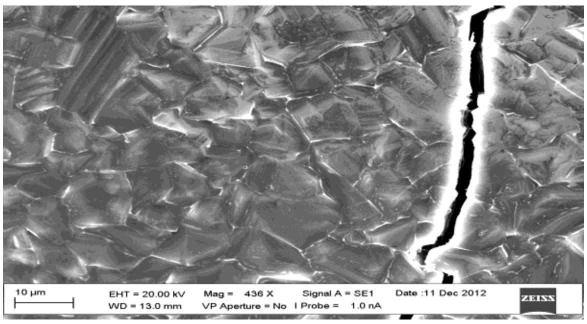
Fig. 3. The appearance of a target before and after irradiation

a – before, b – after N=3 pulses at loading in the centre Q=0,5 MJ/m^2; c - N=15 at Q = 0,5 MJ/m^2





a **c**



b

Fig. 4. Continuous layer of the stochiometric coating B_4C under irradiation in the QSPA-T

(a - after 3, b - 15 and c - 50 impulses of power density 1 GW/m^2)

References

1. O.I.Buzhinskij, I.V.Opimach, V.A.Barsuk et al. J.Nucl.Mater. 220-222 (1995) 922-925

2. D.G. Whyte, R. Bastasz, J.N. Brooks et al. J. Nucl. Mater. 266-269 (1999) 67-73]

3. N.I. Arkhipov, V.P. Bakhtin, S.G. Vasenin et al. Plasma physics. vol. 27, №3 (2001), 243-249

4. Th..Loewenhoff, A. Durger, J. Linke et al. Phys. Scr. T145 (2011) 014057