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On the use of biased movable B_4C-limiter for pumping O_2 and H_2O during discharge cleaning

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Abstract

The movable limiter, the head plate of which is formed with a boron carbide plate hot-pressed in vacuum, is used for studying plasma impurity removal and the possibility of boronization during discharge cleaning in Uragan-3M torsatron. Measurements of current–voltage characteristics, boron and oxygen spectroscopies, residual-gas mass-spectrometry were carried out for different biased and unbiased limiter positions. It is shown that at a negative limiter bias during pulsed discharges cleaning the boron spectral signal from the plasma increases due to arcing. At the same time the oxygen spectral line intensity decreases and it probably means desorbed oxygen and water effective trapping by boronized surfaces and the limiter B_4C-plate, since the main plasma parameters do not change at this moment. The estimations of the limiter application for impurity pumping and solid target boronization shows that the negatively biased movable B_4C-limiter can be used to improve pulsed discharge cleaning in Uragan-3M torsatron.

Keywords: Uragan-3M; Torsatron; Limiter; Biasing; Erosion and particle deposition

1. Introduction

Originally the limiters were used only to suppress plasma–surface interactions and therefore to decrease the amount of the impurity in the plasma. The development of such a thermonuclear device technology has extended the functional sphere of limiters: e.g., pump limiters for effective impurity removal and plasma density control, biased limiter experiments, etc. Recently the local island divertor (some functions of which is similar to pump limiter) with a hot carbon head plate has been proposed as a method drastically shorting the discharge cleaning time required for the wall conditioning to remove main impurities on the surface of plasma facing components [1]. As the Uragan-3M torsatron (U-3M) design did not provide the baking of the plasma facing metallic surfaces, water is the main impurity and it usually takes a few weeks to obtain controllable working discharges. A similar situation can be observed in the Uragan-2M torsatron [2], the baking temperature of which is 100–150°C. Therefore it was of great interest to use the above idea in reference to the U-3M movable B_4C-limiter, which was previously employed [3] to investigate the possibility of solid target boronization and the erosion behavior of head material in biased limiter experiments. In this work the first results of an experimental study of B_4C-limiter use for pumping H_2O and O_2 during pulsed discharge cleaning (PDC) in U-3M are presented.

2. Experiment

To perform experiments, a new version of a movable limiter was designed and installed in the U-3M vacuum chamber. It included a 90 mm · 90 mm · 8 mm head plate, which was made by hot pressing in a vacuum of boron carbide powder (B 78.2%, C 21.5%). The technology and equipment for the making of B_4C bulk tiles were developed in NSC KIPT. The limiter plate material has the following characteristics: density is 2.46 g/cm^3, (B 78.2%,

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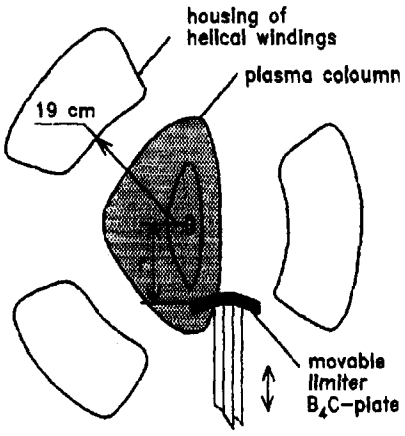

Fig. 1. Schematic drawing of the experiment.

C 21.5%), heat conductivity is ~ 30 W/m · K, and electrical resistivity is $\sim 10^{-2}$ Ω m. Estimation of erosion rates under high power pulsed hydrogen plasma fluxes during 3 μs gave the values from 8×10^{-2} at/ion to 10 at/ion with energy density varying from 5 J/cm^2 · pulse to 30 J/cm^2 · pulse and the H^+ energy varying from 200 eV to 2 keV. The specific rate of outgassing carried out in a special test after 24 h heating at 200°C in vacuum (4×10^{-9} Torr) was $\sim 10^{-11}$ Torr l/s · cm^2. This limiter was installed at the bottom of the U-3M vacuum chamber bellows inlet in such a way that the limiter plate edge could be located at distances from 22 to 12 cm from the plasma column axis. Possibilities were provided to switch on/off negative or positive bias pulses with an amplitude of up to 200 V and duration 1–50 ms.

The schematic sketch of the experiment is given in Fig. 1. It should be noted that, in this configuration, the U-3M movable limiter fulfills the functions of an open pump limiter. There were two channels for boron and oxygen spectral line intensity measurements to investigate boron behavior in plasma. Measurements of current–voltage characteristics, BII and OII spectral line intensities, and residual gas mass-spectrometry in the U-3M vacuum chamber have been made in the PDC with typical parameters: hydrogen pressure $p \approx 1 \cdot 10^{-4}$ Torr, $n_e \approx 2 \cdot 10^{12}$ cm^{-3}, $T_e \approx 10$–15 eV, $B \approx 0.035$ T, plasma pulse duration $\tau = 50$ ms, pulse frequency $f = 0.2$ Hz, total discharge power $W \approx 80$ kW and generator frequency is 5.4 MHz.

3. Results and discussion

As it is seen in Fig. 2 the highest ion current of the limiter plate in the PDC was only 0.2 A even at the nearest distance, $r = 12$ cm of the B_4C-plate from the plasma column axis and a bias up to -90 V. But with a further negative bias increase the arc regime with currents up to 2–10 A developed and controllable BII signals from the plasma in two spectroscopy channels were observed (Fig. 3a). At the same time the oxygen spectral line intensity decreases (Fig. 3d) and this probably points to H_2O and O_2 effective trapping, because the main plasma characteristics (e.g., the CIV line intensity, from which we estimate the plasma temperature), show no changes in this moment. It should be noted that there was no such effect when positive bias up to 200 V was switched on in the limiter.

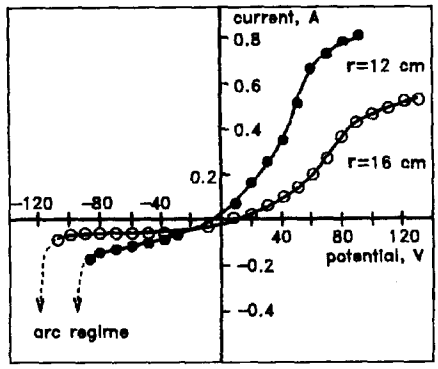

Fig. 2. The limiter current as function of the limiter potential.

The B_4C arcing erosion with the negative limiter bias might be the main reason of oxygen decrease as the result of solid target boronization [4]. Really, if the B_4C erosion coefficient is $\sim 2 \times 10^{-2}$ at/ion [5] and the negative pulsed bias duration is 10 ms then the sputtered number of particles makes up about 10^{17} per pulse. We assume that most of the sputtered boron deposit on the plasma facing surfaces because no boron signs in the U-3M vacuum chamber were observed in mass-spectrometry measurements.

The fresh boron layer partially coating the protective housings effectively absorbs oxygen and prevents it from coming to the plasma from the oxides. It should be noted that it requires about 10^{20} particles to form the monolayer coating on the plasma facing surfaces of the U-3M protective housing of helical windings. So, a few days of PDC

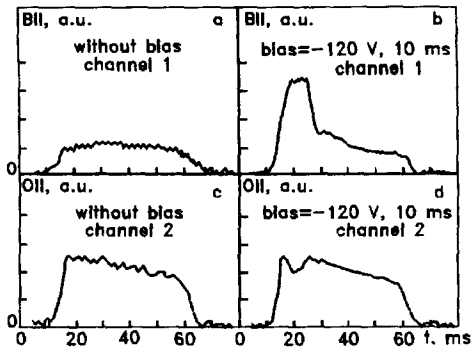

Fig. 3. Time evolution of BII and OII spectral lines intensity: BII intensity without bias (a) and with -120 V bias during 10 ms (b), OII intensity without bias (c), OII intensity with 10 ms -120 V bias (d).

regime would suffice to produce several monolayer coating of boron for the U-3M boronization. Also some number of positive oxygen ions can be trapped by the boron carbide tile [6].

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