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Investigation of plasma–surface interaction at plasma beam facilities

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ABSTRACT

The new Plasma Beam Facility (PBF) has been put into operation for assistance in testing of plasma faced components at Material Science Kazakhstan Tokamak (KTM). PBF includes a powerful electron gun (up to 30 kV, 1 A) and a high vacuum chamber with longitudinal magnetic field coils (up to 0.2 T). The regime of high vacuum electron beam transportation is used for thermal tests with power density at the target surface up to 10 GW/m^2. The beam plasma discharge (BPD) regime with a gas-puff is used for generation of intensive ion fluxes up to $3 \cdot 10^{22}$ m^{-2} s^{-1}. Initial tests of the KTM PBF's capabilities were carried out: various discharge regimes, carbon deposits cleaning, simultaneous thermal and ion impacts on radiation cooled refractory targets. With a water-cooled target the KTM PBF could be used for high heat flux tests of materials (validated by the experiment with W mock-up at the PR-2 PBF).

1. Introduction

Linear simulators with electron beam driven generation of plasma [1–5] have some advantages as devices that allow combining plasma impact with electron beam high heat flux tests. Earlier it was shown that simultaneous exposure of materials to plasma and high heat loads corresponding to transients can increase the surface damage [6–8]. A new Plasma Beam Facility (PBF) has been put into operation for assistance in testing plasma facing components at the Material Science Kazakhstan Tokamak (KTM) [9]. The bakeable vacuum system pumped with turbomolecular and sorption pumps to 10^{-6} Pa allows conducting PSI experiments at low levels of impurities (less than 0.01% of gas feeding). Electron beam fluxes up to 10 GW/m^2 (30 kW of beam power) with scanning system and ion fluxes up to $3 \cdot 10^{22}$ m^{-2} s^{-1} could be achieved in the beam-plasma discharge (BPD).

In this paper some features of the KTM PBF are described, results of initial tests are presented, and possibilities of BPD simulators for PMI investigations are demonstrated.

2. Regimes of the KTM PBF

The KTM PBF (Fig. 1) is a high vacuum installation with an oil-free pumping system. The typical vacuum base pressure is 10^{-6} Pa. The electron gun with an indirect heated tungsten cathode and a separate pumping system make it possible to generate an electron beam with current of 1 A at accelerating voltage up to 30 kV. This beam is transported by a longitudinal magnetic field of $\sim$ 0.1 T with a variable configuration through the electron beam path. This path has a small diaphragm at the entrance, so feeding gas could be ionized, yielding a highly nonequilibrium BPD. So plasma temperature can be defined only in regions without primary electron beam (outside cylindrical or inside circularly scanned beam). The target chamber is equipped with various diagnostics systems, including reciprocating Langmuir probes for plasma temperature and plasma density measurement and a spectrometer with 200–1100 nm wavelength range. The full installation length is 2 m. Various water cooled target systems were designed, but in the first experiments only radiation-cooled targets were used.

Three main plasma parameter regimes could be realized in this machine, depending on the gas feeding (Fig. 2). The first one (I) corresponds to the electron beam transport with a quasi-compensated space charge at a gas pressure less than 0.1 Pa (at the Ar feed-in). By varying the magnetic field configuration the electron beam can be defocused at the target surface to diminish the heat density on the target, or, in contrary, it can be focused into a very small spot. This regime is used for high heat flux tests of materials with maximum thermal loads. The present magnetic configuration provides an electron beam 2 mm in diameter and power density at the target up to 10 GW/m^2.

The second regime (II) is a diffusive BPD regime which starts with an increase of the working gas pressure. This regime is

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convenient for generation of radial ion fluxes and could be effectively used for wall conditioning.

The BPD mode (III) starts at working gas (Ar) pressures above 0.16 Pa, when the partial stabilization of the radial drift at enhanced plasma density takes place. As a result, the plasma density increases by a factor of 2–3 relative to the mode II (up to $n_e \sim 10^{18}\ \mathrm{m}^{-3}$).

Additional possibilities for PSI control in the KTM PBF are available due to the electron beam scanning system. It consists of 3 electromagnetic coils positioned at 120° (or 4 coils with 90° spacing) embraced by a ferromagnetic yoke around the pipe joining the BPD tract and the target chamber. Properly matched coils provide programmed electron beam scanning or its stationary displacement in the vicinity of the beam axis. Fig. 3 shows the rotation circle of the electron beam impact spot on the target surface. The circle diameter can be regulated up to 4 cm. Plasma inside the circle at the axis is free of the primary high power electron beam and has typical density of $10^{18}\ \mathrm{m}^{-3}$. In some experiments the circularly scanned primary electron beam is used for heating of an auxiliary ring cathode in front of the target. With use of a separate power supply (−500 V, 2 A) this cathode emits an additional electron beam into the BPD region and enlarges the plasma density. So, plasma density at the target inside the ring cathode can be sufficiently increased (1.5–2 times up to $\sim 2 \cdot 10^{18}\ \mathrm{m}^{-3}$). For hydrogen and helium plasma similar parameters were achieved. Maximum ion flux of about $3 \cdot 10^{22}\ \mathrm{m}^{-2}\,\mathrm{s}^{-1}$ was achieved with helium plasma, measured with a flat Langmuir probe in front of the target.

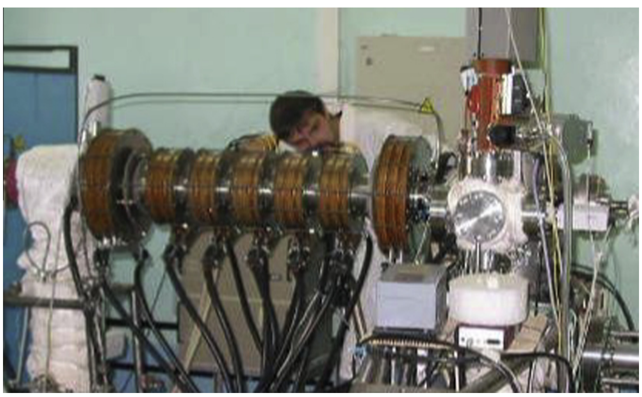

Fig. 1. Photo of KTM plasma beam facility.

3. Experiments on carbon deposits cleaning

The PBD discharge (T_e = 12–15 eV) demonstrates a very high dissociation rate of molecular oxygen into chemically active species which can remove carbon deposits at room temperatures. Fig. 4 represents the starting composition of enriched with oxygen gas mixture measured with a quadrupole analyzer (85% O_2, 10% N_2 and 5% H_2O). It is puffed into the BPD path with carbon deposits on the target chamber surface after operation of the KTM PBF with a carbon MPG8 target. Before BPD is switched on, the molecular oxygen mass 32 is the main component. After BPD is switched on in the mode II one can see that the molecular oxygen disappears due to almost full transforming into volatile CO and CO_2. So, carbon deposits on the walls of the chamber can be effectively scavenged

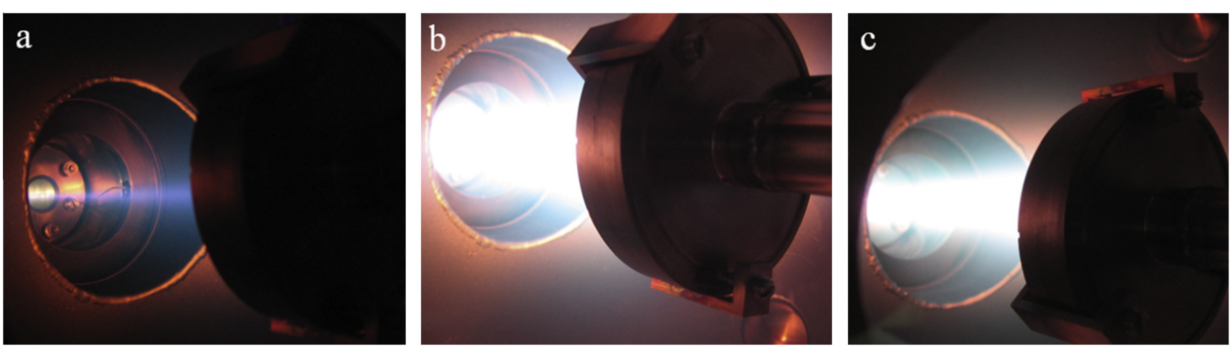

Fig. 2. Picture of main regimes of KTM PBF with Ar feeding: (a) mode I – pressure less than 0.1 Pa, accelerating voltage 6.0 kV, electron beam current 0.10 A, (b) diffusive BPD mode II 0.12 Pa, 6.0 kV, 0.11 A, (c) mode III with stabilized radial drift 0.2 Pa, 6.0 kV, 0.12 A.

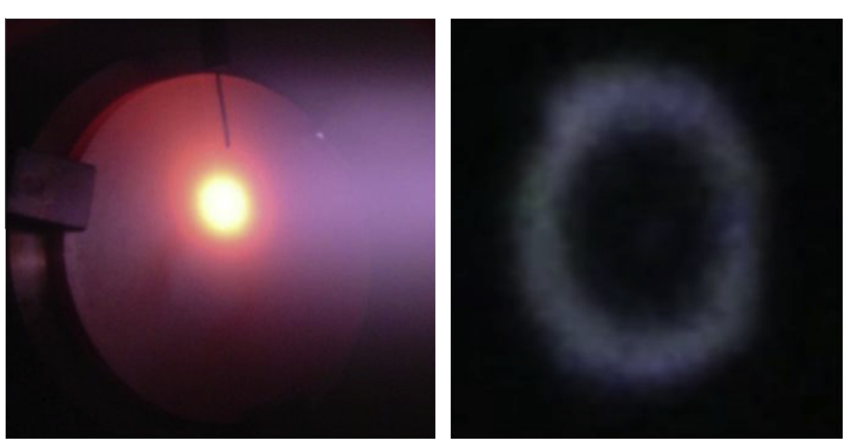

Fig. 3. Electron beam striking the target without and with scanning system switched on.