Studies of Deuterium-Plasma Interaction with a Tungsten Target at Different Energy Fluxes

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The paper presents results of experimental research on the interaction of a pulsed plasma-ion stream with a tungsten (W) target. The deuterium plasma streams were produced within the RPI-IBIS facility at NCBJ in Swierk. Measurements were carried out by means of optical spectroscopy and corpuscular diagnostic methods. Structural changes in the irradiated targets were investigated with a SEM technique. Particular attention was paid to the identification of spectral lines from WI and WII species and their intensities observed at different values of the plasma flux density.

Research on interactions of pulsed plasma streams with solid materials, and in particular with tungsten (W) targets, is of primary importance for technology of large fusion facilities. Such studies have been carried out at different labs, including the NCBJ (former IPJ) in Swierk. Poland [1-2]. Since the preliminary studies were performed at a constant plasma flux density, recent research has been concentrated on measurements carried out at different plasma flux densities. The described studies were performed in the RPI-IBIS (Multi-Rod Plasma Injector) facility [3] equipped with cylindrical electrodes composed of thin molibdenum (Mo) wires. Discharges were initiated with a chosen time delay (τ) after the injection of pure deuterium (D_2) and were powered from a current-pulse generator charged initially to U_o = 28.5 kV, W_o = 33 kJ. Investigated targets were placed at the discharge axis, at a distance of 20-30 cm from the electrodes ends. It made it possible to irradiate these targets with an intense plasma-ion stream, as shown in Fig. 1.

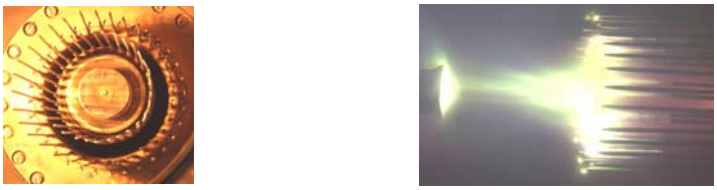

Fig.1. End-on view of the RPI-IBIS electrodes (left) and the side-on picture of the visible radiation from a deuterium-plasma stream interacting with the W-target (right).

The operational mode of the RPI-IBIS plasma injector was varied mainly by changes of the time delay τ value. At constant charging voltage U_0 = 28.5 kV and the injected deuterium pressure (1.5 at), discharge characteristics and the plasma energy flux density were changed by disconnecting of some condenser sections, as shown in Fig. 2.

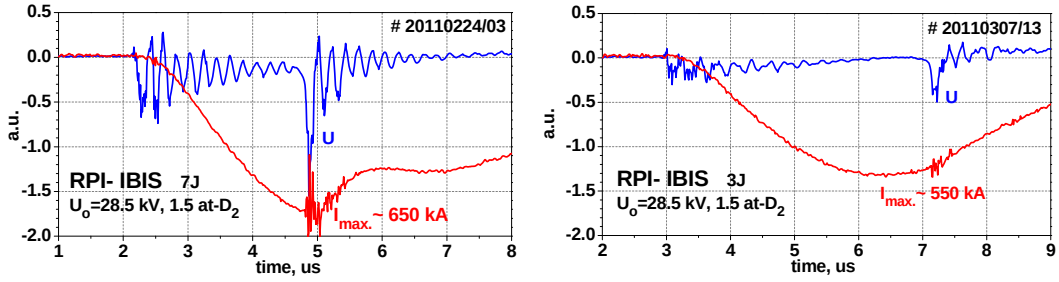

Fig. 2. Current- and voltage-waveforms recorded at plasma flux density equal to 7 J/ cm^2 and 3 J /cm^2.

Ion measurements performed earlier with a Thomson analyzer proved that the amount of impurity ions (e.g. Mo^+ from the wire electrodes) in the RPI-IBIS disharges was very low, and the deuteron

energy spectrum extended from a few keV to about 70 keV, with its maximum at about 40 keV [4]. The period of the plasma stream emission was equal to about 0.5 μs. Recent spectroscopic measurements of plasma, which was produced during the interaction of a deuterium plasma stream with the W-target (4x4 cm^2, 1 mm in thickness) placed 20 cm from the electrodes outlet, have been performed with a Mechelle®900 optical spectrometer. Some examples of the optical spectra, as recorded for free plasma streams (i.e. without any target) at different conditions (τ = 170-200 μs), are shown in Fig. 3. The choice of the RPI-IBIS mode, which ensured the emission of pure deuterium-plasma streams (with a small amount of impurities), enabled to study plasma-target interactions. Examples of the optical spectra taken side-on in front of the W-target at energy flux density varied from 3 J/cm^2 to 7 J/cm^2, and the high power density (1-5 MW/cm^2), are also shown in Fig. 3.

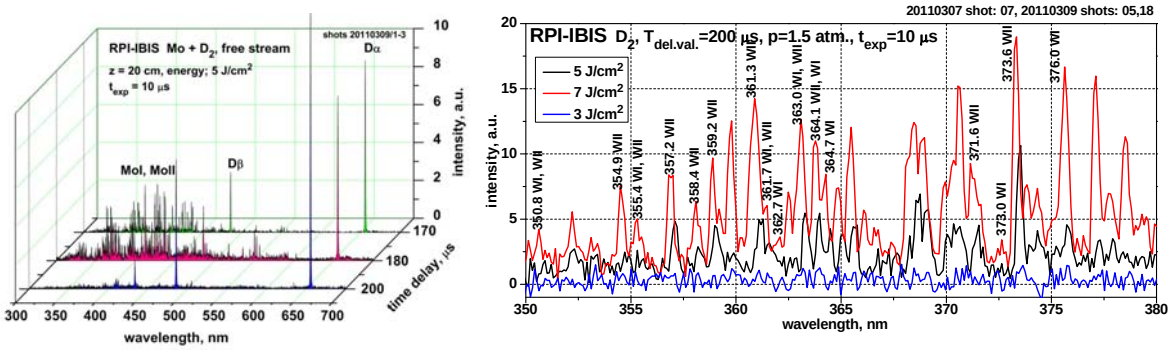

Fig. 3. Optical spectra of free plasma streams in RPI-IBIS at different τ values (left) and a part of the spectrum of plasma produced from the W-target at different flux densities (right).

It was shown that the spectra of free plasma streams contained the deuterium Balmer lines, and the most clean deuterium plasma was obtained at τ = 200 μs. The plasma electron density (N_e) was estimated from the linear Stark-broadening of the D_α line. For free-propagating plasma streams the N_e value integrated over the exposition time (10 μs) amounted to about 5.7 x 10^{15} cm^{-3}. In experiments with the W-target there were recorded many WI- and WII-lines identified by means of the NIST database [5]. A quantitative analysis of these lines was not performed because of their overcovering. In order to learn about erosion of the W-target surface, after the irradiation by the described plasma pulses it was investigated by means of an optical microscope and SEM technique, as shown in Fig. 4.

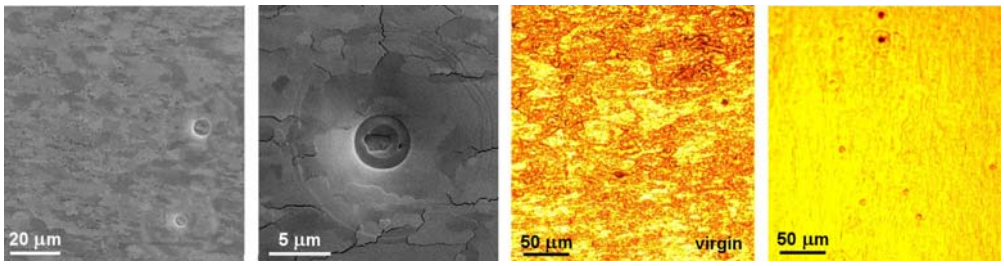

Fig. 4 SEM (left) and optical microscope (right) images of the W-target surface before (virgin) and after its irradiation by the pulsed deuterium-plasma stream (7J/cm^2) in the RPI-IBIS facility.

The main results can be summarized as follows: 1. The RPI-IBIS facility can be applied for research on the interaction of plasma streams with W-targets; 2. Parameters of the pulsed plasma streams can be varied by the choice of the operational mode; 3. The erosion of the irradiated W-target was observed for plasma streams of the energy flux density > 3 J/cm^2; 4. This erosion was found to be about 10 times stronger at the energy flux density of 5 J/cm^2, and about 20 times - at 7 J/cm^2.

References

[1] E. Skladnik-Sadowska, et al., *Probl. Atomic Sci. & Technol.* **6**, *Ser. Plasma Phys.* **12** (2006) 135.
[2] E. Skladnik-Sadowska, et al., *Probl. Atomic Sci. & Technol.* **6**, *Ser. Plasma Phys.* **14** (2008) 95.
[3] J. Baranowski, K. Czaus, M.J. Sadowski et al., *Czech. J. Phys.* **50,** *Suppl.* **S3** (2000) 101.
[4] M.J. Sadowski, K. Czaus, K. Malinowski, et al., *Rev. Sci. Instrum.* **80** (2009) 053504.
[5] NIST database, http://physics.nist.gov