STUDY OF DEUTERIUM PLASMA INTERACTION WITH A TUNGSTEN TARGET WITHIN RPI-IBIS FACILITY

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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 pulsed deuterium plasma was produced within the RPI-IBIS (Multi-Rod Plasma Injector) facility at IPJ in Swierk. Measurements were carried out by means of optical spectroscopy and corpuscular diagnostic techniques. Structural changes in the irradiated targets were investigated with a SEM. Before experiments with the W-target there were determined operational conditions, when clean deuterium plasma streams can be generated. For that purpose a so-called "slow or PID (Plasma Ion Deposition) mode" of the RPI-IBIS operation was chosen. Particular attention was paid to the identification of spectral lines from WI and WII species. The obtained results, i.e. optical spectra and other characteristics have demonstrated applicability of the RPI-IBIS facility for research on the interaction of plasma streams with W-targets, e.g. those constituting some internal parts of fusion facilities.
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1. INTRODUCTION

The pulsed plasma streams, generated by coaxial multi-rod injectors (so-called RPI or IONOTRON facilities), have been studied at IPJ-Swierk for many years [1-3]. The studies performed during recent years shed some new light on the operation of such devices [4-7]. Studies of ions emitted from plasma discharges provided important information about dynamics of plasma phenomena and mechanisms of the charged particle emission. Spectroscopic and corpuscular measurements appeared also to be of importance for various applications of those plasma facilities. This paper reports on the recent experimental results.

2. EXPERIMENTAL SET-UP

The described studies have been performed mainly within the RPI-IBIS facility [5], which was powered from a current-pulse generator charged up to U_o = 30 kV, W_o = 33 kJ. The operational mode of the device was varied by changes of a time delay (τ) between the gas puffing and the application of a high-voltage pulse. Coaxial multi-rod electrodes of the RPI-IBIS device and an example of a plasma jet are shown in Fig.1

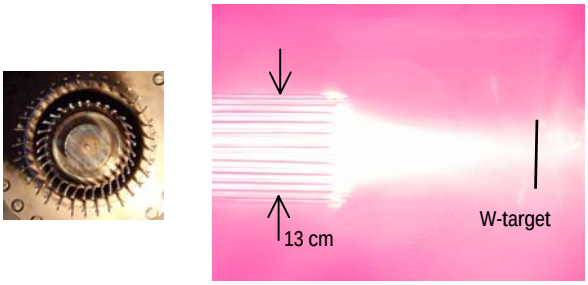

Fig.1. RPI-IBIS electrodes and the VR emission from a plasma jet, as observed behind a red-filter (near D_α)

The most important time-resolved signals from the RPI-IBIS are presented in Fig. 2.

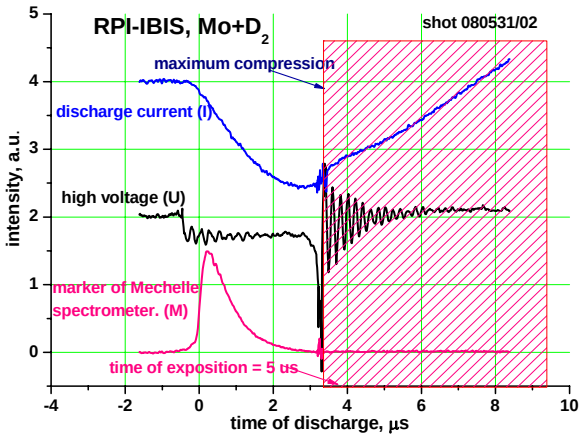

Fig.2. Current and voltage waveforms together with a marker of the optical-spectrometer synchronization

Spectroscopic measurements of tungsten plasma, which was produced during the interaction of a deuterium plasma stream with a tungsten target (placed 20 cm from the electrodes outlet) were performed by means of a Mechelle®900 optical spectrometer. It was able to record optical spectra in the wavelength range from about 300 nm to 1100 nm, at exposition times varied from 100 ns up to 50 ms. The spectrometer detector was a cooled CCD camera coupled with a PC equipped with a spectroscopic software (GRAMS/32 V6.0) [8].

In order to determine the spatial structure of the produced deuterium streams there was applied a miniature ion-pinhole camera equipped with exchangeable nuclear track detectors (NTD) of the PM-355-type. An analysis of the mass- and energy-spectrum was performed by means of a Thomson-type spectrometer using similar NTD.

3. SPECTROSCOPY OF PLASMA-ION STREAMS

During the spectroscopic studies particular attention was paid to observations of the Balmer spectral lines of the working gas, i.e. D_α – 656.10 nm, D_β – 486.029 nm and D_γ – 433.298 nm. Before the insertion of a W-target into the RPI-IBIS chamber, there were determined the operational gas conditions (PID mode), when a clean deuterium plasma stream was generated. To study an influence of the initial gas conditions, the spectroscopic measurements were performed at different time delays (τ) between the gas puffing and application of a voltage (current) pulse. A dependence of the observed spectral lines on τ values is shown in Fig. 3.

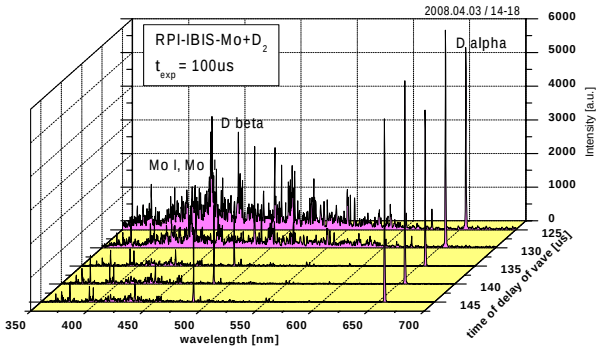

Fig.3. Optical spectra of the pulsed plasma streams emitted from the IBIS-RPI facility, which were recorded at z = 20 cm and exposition of 100 µs, as a function of τ

On the basis of the obtained spectra it was possible to estimate values of the electron density and temperature of the investigated deuterium-plasma streams. At τ = 145 µs, the plasma parameters were estimated to be $N_e \approx 3.5 \cdot 10^{16} cm^{-3}$ and $T_e \approx 1.5$ eV. The described measurements confirmed a strong dependence of the basic plasma parameters on the initial gas conditions, which were varied by changes of τ values. It was observed that for τ larger than 135 µs the RPI-IBIS facility generated very clean deuterium-plasma streams, and such conditions were chosen for experiments with a W-target. The pure W-target (of 50 x 50 mm^2 surface) was placed at a distance z = 20 cm from the electrode outlet. Using the Mechelle®900 optical-spectrometer it was possible to record and identify the W spectral-lines. The recorded spectra showed distinct WI and WII spectral lines, as presented in Figs.4 and 5.

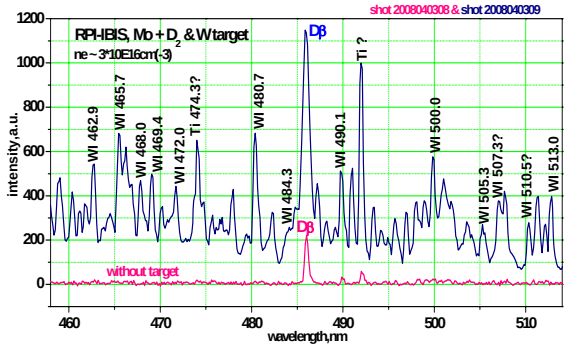

Fig.4. Intensities of the spectral lines near the D_β line, as measured within the RPI-IBIS experiment with and without any target

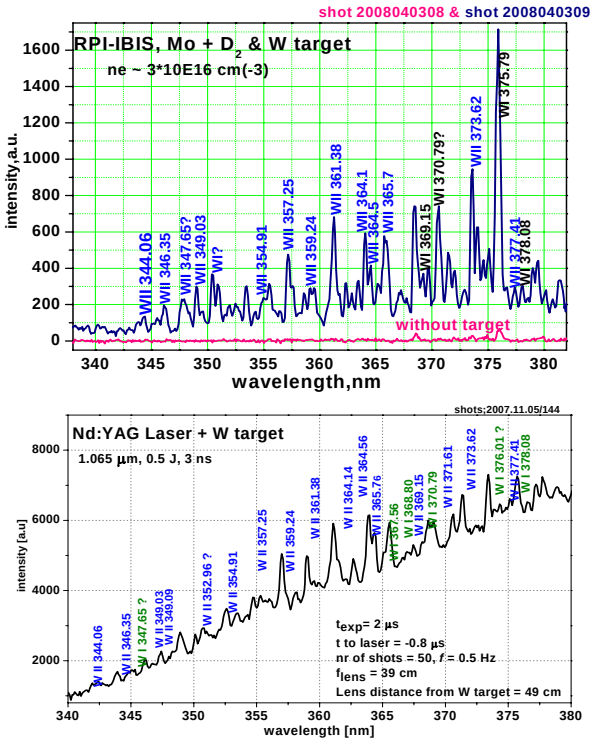

Fig.5. Spectral lines recorded within the RPI-IBIS experiment (with and without W-target) in the chosen spectrum range (340-380 nm). For a comparison, there is shown the spectrum of the laser-produced W-plasma [9]

The plasma electron density was estimated from the observed linear Stark-broadening of Balmer series, particularly from a Lorentz shape of the D_α line [10-11]. In the described experiments, during the optical measurements the exposition time was equal to 15 µs. Therefore, the measured electron density value (N_e) was time-integrated, and it was about 5.7 x 10^{15} cm^{-3} for freely propagating plasma streams, and 3.4 x 10^{16} cm^{-3} - in the experiments with the W-target. That increase in N_e indicated the strong erosion of the investigated target.

4. MASS- AND ENERGY-ANALYSIS OF IONS

In order to collect information about mass- and energy-spectrum of ions, time-integrated measurements of the investigated plasma-ion streams were performed with a Thomson-type spectrometer. The energy distributions of ions, i.e. deuterons are shown in Fig. 6.

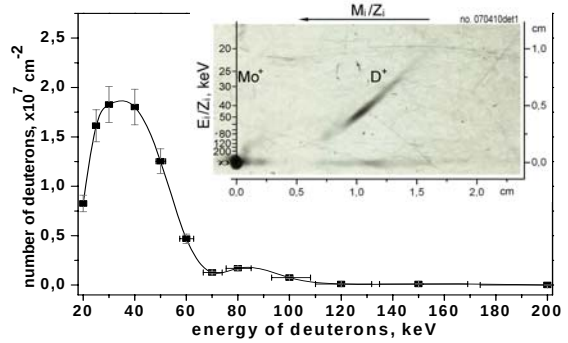

Fig.6. Thomson parabolas recorded on PM-355 detectors irradiated in the RPI-IBIS during deuterium discharges, and the corresponding energy spectrum of deuterons

On the basis of the measured ion-energy spectra, which were obtained from various shots performed with the pure deuterium puffing and different τ values, it was possible to determine the average energy values and total numbers of the emitted deuterons.

Structural changes in the target surfaces, after their irradiation with the described plasma pulses, were also investigated by means of SEM technique. Some examples of the corresponding images are presented in Fig. 7.

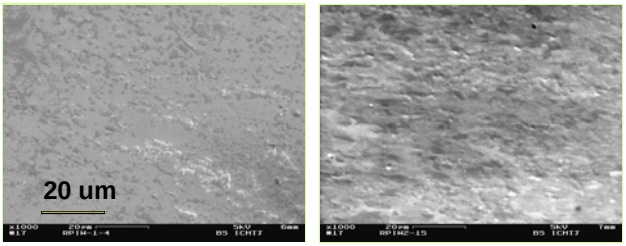

Fig.7. SEM image of the W-target surface; virgin (on the left) and after irradiated (on the right) which was partially destroyed by the pulsed plasma-deuteron stream (5 J/cm^2) within the RPI-IBIS facility

5. SUMMARY AND CONCLUSIONS

The results of this work can be summarized as follows:

- The described experiments, which were performed within the RPI-IBIS facility (equipped with the multi-rod electrodes), showed that the produced pulsed plasma streams can interact with W- targets very strongly.
- The determined operational regime (PID mode) of the RPI-IBIS device ensured the generation of a very clean deuterium-plasma stream. It was observed that with an increase in a τ value the averaged energy of deuterons decreased from about 70 keV to a few keV. The total yield of deuterons was higher at larger τ = 160-190 μs.
- Using a Mechelle®900 optical-spectrometer, it was confirmed that distinct WI and WII lines emitted during the interaction of the deuterium-plasma stream with the W-target, can be recorded and identified.
- The main parameters of plasma, i.e. averaged values of the electron density and electron temperature, were estimated both for a freely propagating plasma stream as well as for its interaction with the pure W-target.

It can be concluded that the RPI-IBIS facility (with the hydrogen- or deuterium-filling) can be used for research on the interaction of plasma streams with W-targets, and such studies might be of interest for technology of future fusion reactors.

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ИЗУЧЕНИЕ ВЗАИМОДЕЙСТВИЯ ДЕЙТЕРИЕВОЙ ПЛАЗМЫ С ВОЛЬФРАМОВОЙ МИШЕНЬЮ НА УСТАНОВКЕ СПИ-ИБИС

Э. Складник-Садовска, К. Малиновский, М. Садовский, К. Чаус, М. Кубковска, М. Ладыгина, Б. Сартовска

Представлены результаты экспериментальных исследований по взаимодействию импульсного плазменно-ионного потока с вольфрамовой мишенью. Импульсные дейтериевые потоки плазмы генерировались внутри СПИ-ИБИС (стержневой плазменный инжектор), который расположен в ИЯП в Шверке. Измерения проводились с помощью оптической спектроскопии и корпускулярной диагностики. Структурные изменения облучаемой мишени исследовались с помощью SEM. Перед экспериментами с вольфрамовой мишенью определялись рабочие условия, когда генерировались чистые дейтериевые плазменные потоки. Для этой цели был выбран так называемый режим "медленной или PID-моды" (плазменного ионного осаждения). Частичное внимание уделялось идентификации спектральных линий WI и WII. Полученные результаты, оптические спектры и другие характеристики, продемонстрировали применимость установки СПИ-ИБИС для исследований взаимодействия плазменных потоков с W-мишенью, которые составляют некоторые внутренние части термоядерного реактора.

ВИВЧЕННЯ ВЗАЄМОДІЇ ДЕЙТЕРІЄВОЇ ПЛАЗМИ З ВОЛЬФРАМОВОЮ МІШЕННЮ НА УСТАНОВЦІ СПІ-ІБІС

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Представлено результати експериментальних досліджень по взаємодії імпульсного плазмово-іонного потоку з вольфрамовою мішенню. Імпульсні дейтерієві потоки плазми генерувались в СПІ-ІБІС (стержневий плазмовий інжектор), який знаходиться в ІЯП у Шверку. Виміри проводились за допомогою оптичної спектроскопії та корпускулярної діагностики. Структурні зміни облучаємої мішені досліджувались за допомогою SEM. Перед експериментами з вольфрамовою мішенню визначались робочі умови, коли генерувались чисті дейтерієві плазмові потоки. Був вибраний так званий режим "повільний або PID-моди" (плазмового іонного осадження). Частична увага приділялась ідентифікації спектральних ліній WI та WII. Отримані результати, оптичні спектри та інші характеристики, продемонстрували можливість застосовувати установку СПІ-ІБІС для досліджень взаємодії плазмових потоків з W-мішенню, які складають деякі внутрішні частини термоядерного реактору.