CHARACTERISTICS OF HIGH-TEMPERATURE DEUTERIUM PLASMA IN RPI-TYPE DEVICES

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The paper presents results of the spectroscopic and corpuscular measurements of pulsed plasma streams generated within the RPI-IBIS experimental device, which was operated with the pure deuterium puffing. Particular attention was paid to time-integrated and time-resolved measurements of selected spectral lines, i.e. D_α, D_β and D_γ, emitted from deuterium discharges. The measurements made possible an assessment of the basic plasma parameters. The achievement of the local thermal equilibrium (LTE) was investigated. Energies of emitted ions, their total numbers, as well emissions of soft X-rays and fusion-produced neutrons vary considerably with a change of gas conditions.
PACS: 52.70.-m; 52.30.-g

1. INTRODUCTION

Spectroscopic measurements of the pulsed plasma streams deliver important information about dynamics and characteristics of the investigated plasmas. Studies of high-energy ions, which are emitted from plasma discharges, provide also information about dynamics of plasma phenomena and mechanisms of the charged particle acceleration. On the other hand, spectroscopic and corpuscular measurements are of importance for various technological applications of plasma facilities.
The pulsed plasma streams, generated by coaxial multi-rod injectors, so-called RPI- or IONOTRON-type facilities, have been studied at IPJ for many years [1-3]. The studies performed during recent two years shed some new light on the operation of such devices [4-7]. The main aim of this paper was to summarize the recent spectroscopic and corpuscular studies.

2. EXPERIMENTAL SETUP

The recent studies have been performed mainly within the RPI-IBIS facility [5], which was powered from a current pulse generator charged to U_0 = 30 kV, W_0 = 33 kJ. The facility was equipped with a set of diagnostic tools, as shown in Fig. 1.

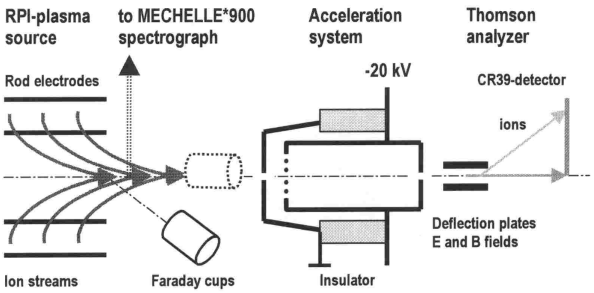

Fig. 1. Scheme of the RPI-electrode system with the basic diagnostic equipment.

During the described experiments the RPI-IBIS device was operated mostly with the pure deuterium puffing. Time-integrated and time-resolved measurements of selected spectral lines, mainly those of deuterium species, were performed with the MECHELLE®900 optical spectrometer equipped with an intensified CCD readout. It made possible optical measurements within the wavelength range from 200 nm to 1100 nm, at an exposition time ranging from 100 ns up to 50 ms.
Time-integrated and time-resolved measurements of ions were carried out by means of Faraday-type collectors and a Thomson-type mass-spectrometer. In order to record low-energy ions the Thomson spectrometer was equipped with an input ion-acceleration system. The time-integrated measurements were performed mainly with the use of solid-state nuclear track detectors of the CR-39 type.

3. SPECTROSCOPIC STUDY 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. Some spectral lines from remnant gases and the electrodes (Mo) were also observed, as shown in Fig. 2.

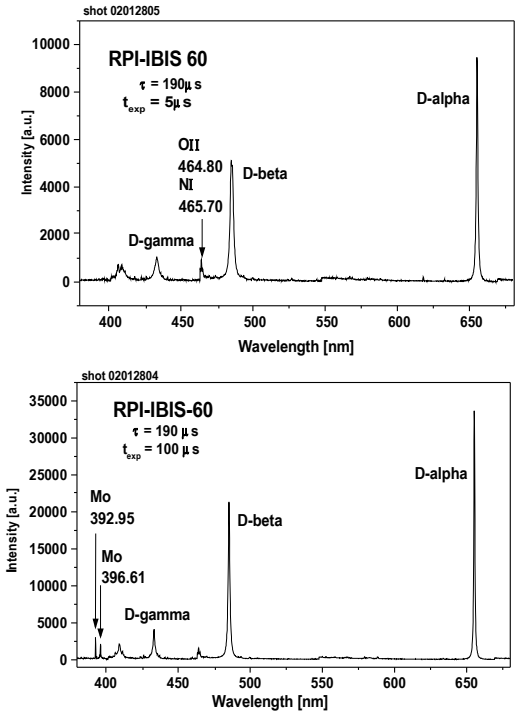

Fig. 2. Optical spectra of the pulsed plasma streams emitted from the IBIS-RPI facility, as recorded for shots at U_0 = 30 kV, W_0 = 33 kJ, D_2-puffing, t = 190 μs, with the spectrometer exposition equal to 5 μs and 100 μs.

A half-period of the discharge current was equal to about 7 μs, and the detection system of the spectrometer was usually opened with a time delay of 3 μs after the beginning of the current pulse, i.e. close to the current peak. In order to embrace the characteristic current peculiarities, several series of the observations were performed with the spectrometer exposition equal to 5 μ s. Other measurements were carried out with the exposition of 100 μs, i.e. practically as time-integrated. On the basis of the spectrum recorded with the 5-μs exposition it was estimated that an average deuterium ion temperature amounted to about 1 keV. It was also found that the impurity lines from the electrode material (Mo) appear during later phases of the discharge.

To study influence of the initial gas conditions, the detailed spectroscopic measurements were performed at different time delays (τ) between the gas puffing and the application of the voltage (current) pulse. FWHM values of selected spectral lines were measured at the different operational conditions, as shown in Fig. 3.

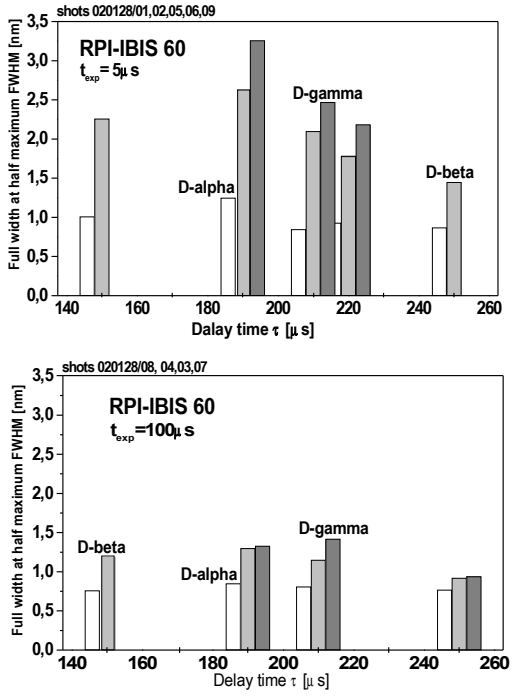

Fig 3. FWHM values as a function of the time delay, as measured for the described experiment with the spectrometer exposition equal to 5 μs and 100 μs.

Those measurements confirmed a strong dependence of the plasma parameters on the initial gas conditions, varied by a change of the delay time (τ). A selection of the optimal operational conditions could be performed on the basis of the observation of the selected spectral lines. The intensity and widening of D_β line was evidently largest at the time delay τ = 190 μs, as shown in Fig. 4. The time delay τ = 190 μs corresponds to the so-called medium operational-mode, when a role of the remnant gases seems to be negligible (see Fig. 4). The finding that the ions from the electrode material appear in later phases of the discharge, is of particular importance for technological applications of the RPI devices.

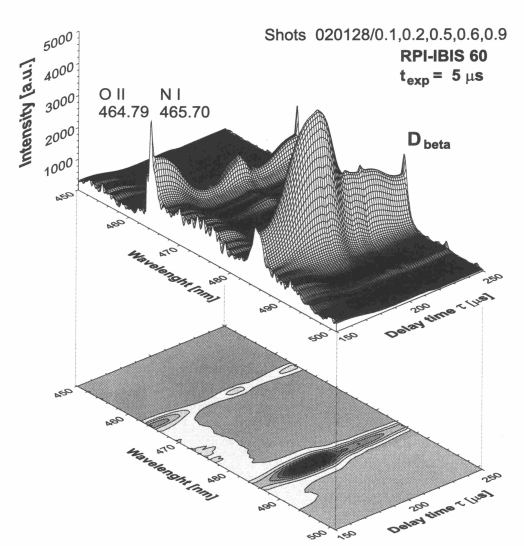

Fig. 4. Intensity of the spectral lines vs. the time delay, as measured for the chosen spectrum part (near D_β line) at the exposition time equal to 5 μs.

4. MASS-AND ENERGY-ANALYSIS OF IONS

Time-integrated measurements of the investigated plasma-ion streams were performed with the Thomson-type spectrometer adjusted along the z-axis. It was equipped with the input ion-acceleration system and CR-39 nuclear-track detectors, as described above. Thomson parabolas, which were visible on the track detectors after their appropriate etching, were analyzed with an optical microscope. To perform an accurate analysis of the ion tracks, the use was made of an automatic system consisted of a CCD camera coupled with a fast PC (Pentium II) equipped with the Image-Pro-Plus software. That analysis enabled a dependence of track diameters on their mass and energy to be found. It determined also the energy distribution of the accelerated primary protons, deuterons and nitrogen ions, as shown in Fig. 5.

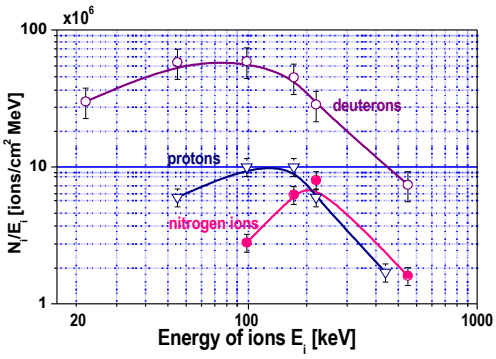

Fig. 5. Energy spectra of deuterons, protons and nitrogen ions, as determined on the basis of measurements performed with the Thomson mass-spectrometer. Bars show the experimental errors.

The protons and nitrogen ions originated evidently from the remnant gases, which were occluded or absorbed in the electrodes used before in experiments with other working gases.

Analyzing ion-spectrum from various shots, which were performed with the deuterium puffing at different time delays (τ), it was possible to determine average energy values and the total numbers of the emitted deuterons, as shown in Fig. 6.

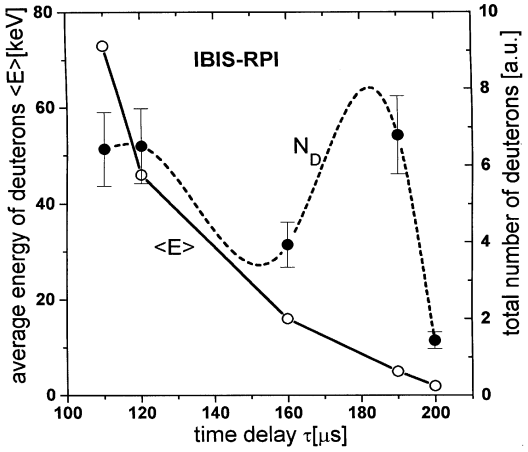

Fig. 6. Average energy values <E> and total numbers of deuterons (N_D) emitted from the deuterium discharges within IBIS-RPI device.

5. MEASUREMENTS OF NUCLEAR FUSION PRODUCTS

During experiments performed with the pure deuterium puffing, the RPI-type facilities can also emit fusion-produced neutrons and protons. In order to determine the optimal operational conditions, the neutron yield measurements have been carried out at different time delay times (τ), as shown in Fig. 7.

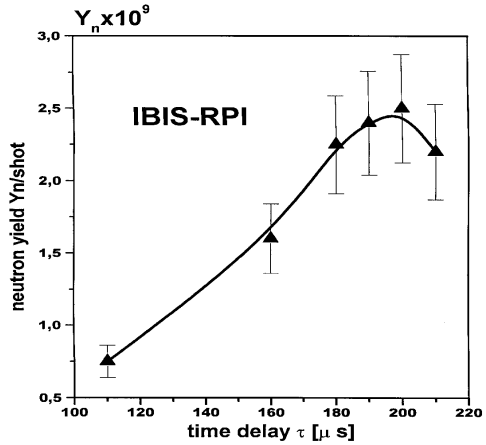

Fig. 7. Average neutron yield <Y_n> from pure deuterium discharges within IBIS-RPI device, as a function of the time delay (τ) between the deuterium puffing and the application of a voltage/current pulse.

The detailed measurements have also shown that the energy spectrum of fusion-produced protons depends considerably on the initial gas conditions within IBIS-RPI facility, as shown in Fig. 8.

6. SUMMARY AND CONCLUSIONS

The results of this work can be summarized as follows:

- The recent spectroscopic studies, as performed within IBIS-RPI device, have confirmed a strong dependence of plasma characteristics on the initial gas conditions (varied by changing a time delay τ).

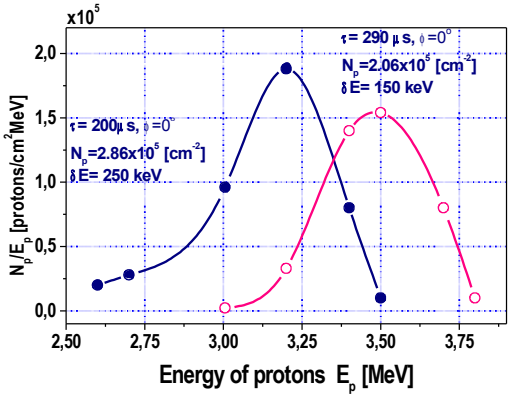

Fig. 8. Typical energy spectra of fusion-reaction protons emitted from IBIS-RPI device operated with the pure deuterium filling.

- A considerable delay in the emission of metal ions, which originate from the electrode material, has been proved. It appeared to be of particular importance for technological applications of RPI-type devices.
- Time-integrated measurements of ions, which were performed with pinhole cameras and the Thomson-type analyzer, have determined a dependence of ion yields and energies on the initial gas conditions.
- Ion measurements have also shown that the average energy value of deuterons varies from about 70 keV down to a few keV with an increase in the delay time τ, while the total number of deuterons is the highest at a delay time τ = 170-190 μs.
- It was confirmed that the RPI-type devices produce also fusion products (fast neutrons and protons), depending on the operational mode.

One might conclude that further spectroscopic studies should be performed with shorter exposition times (e.g. 100-200 ns) during over-voltage pulse and discharge-current peculiarities. In further ion studies particular attention should be to heavy ions emitted from the rod electrodes.

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