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DEVELOPMENT OF DIAGNOSTIC TECHNIQUES FOR STUDIES OF PULSED PLASMA-ION STREAMS

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The paper reports on development and application of different measuring techniques for time-integrated and time-resolved studies of pulsed plasma-ion streams emitted from Rod-Plasma-Injector (RPI) devices, Plasma-Focus facilities and Z-Pinch discharges.

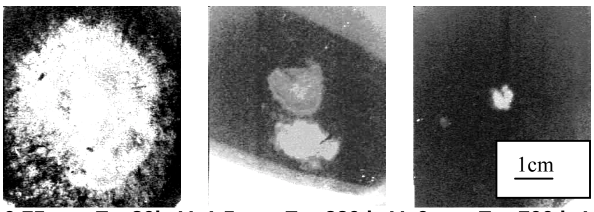
1. Introduction

Studies of high-energy ions emitted from plasma regions provide some information about dynamics of plasma phenomena and mechanisms of the particle acceleration. On the other hand, the ion emission studies are of importance also for various technological applications of plasma facilities. Pulsed plasma streams, generated by coaxial multi-rod injectors (RPI) of the IONOTRON type, have been studied at the IPJ for many years [1-2]. The paper presents different plasma diagnostics techniques developed and used at the IPJ. Also presented are space- and time-resolved measurements of the plasma radiation from the IONOTRON [3] and from different PF facilities.

The main aim of this paper was to describe progress achieved in plasma diagnostics at IPJ, and to present diagnostic methods which can be applied for studies plasma-ion pulses from other sources, e.g., Z-Pinch discharges, laser plasma experiments, etc.

2. Time-integrated study of high-energy ions

In order to perform time-integrated measurements of pulsed plasma-ion streams there were designed different supports and ion-pinhole cameras equipped with solid-state nuclear track detectors (SSNTDs). In particular the use was made of the CN, CR-39, and PM-355 detectors in dependence on experimental conditions and characteristics of investigated ions. To register ion streams emitted along the discharge axis, there were used movable planar supports, which could be placed at different distances from the electrode outlet or a plasma source. In order to perform a rough energy analysis of high-energy (> 80 keV) ions, the SSNTDs were covered with strips of absorption filters made of different metal foils (*Fig.1*).



0.75 µm, E_D>80keV. 1.5 µm, E_D >220 keV. 6 µm, E_D >700 keV

Fig. 1. Ion images registered by means of track detectors of the CN-LR115-type with different Al absorption filters. The results were obtained from 3 successive PF-shots performed under identical experimental conditions. PACO device were operated at p_0 = 2.0 mbar D_2, U_0 = 30 kV, I_{max} = 280 kA. [4]

In order to determine an angular distribution of the emitted ions there were used several SSNTDs samples placed at different angles to the z-axis or a special semicircular support with SSNTDs strips. To eliminate ions of lower energies there were also applied appropriate absorption foil-filters (*Fig.2.*).

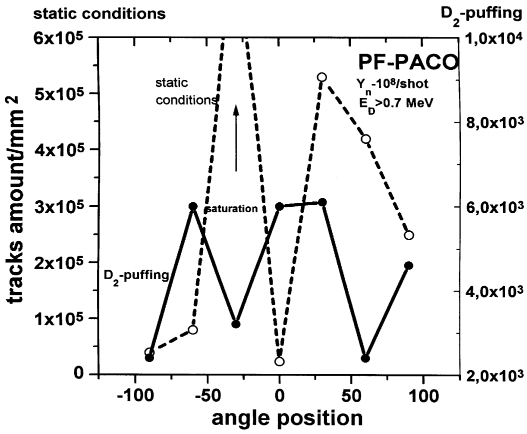


Fig.2. Comparison of angular distributions of deuterons with energies E_D > 0.7 MeV, as obtained at the static gas conditions (broken lines) and under the dynamic initial gas conditions (solid lines) [5]

3. Time-integrated measurements of low-energy ions

In cases when it was required to measure low-energy (< 30 keV) ions there was applied a special pre-acceleration system consisted of appropriately polarized grids (*Fig.3.*).

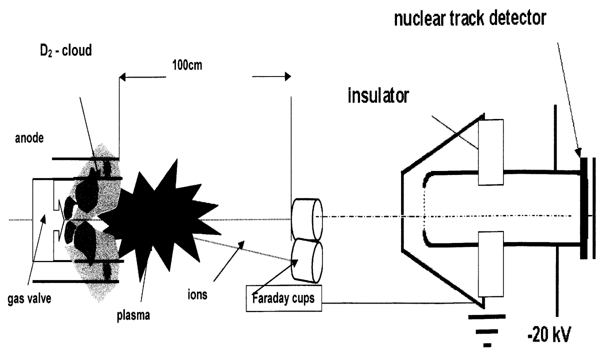


Fig.3. Schematic of RPI and ion acceleration system

That field could accelerate (or stop) ions without disturbing a spatial shape of the investigated plasma-ion stream. That accelerating system enabled an energy spectrum of the investigated ions to be shifted up by a chosen value, e.g. 20 keV. It made possible to register ions of energies lower than the registration energy threshold of the applied SSNTDs (*Figs.4 and 5)*.

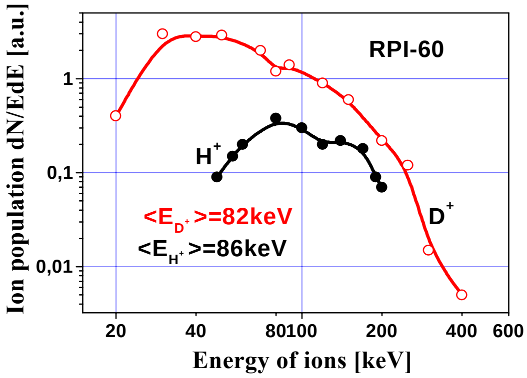


Fig.4. Energy spectra of deuterons and protons, which were determined on the basis of Thomson parabolas registered upon CR-39 detectors [6]

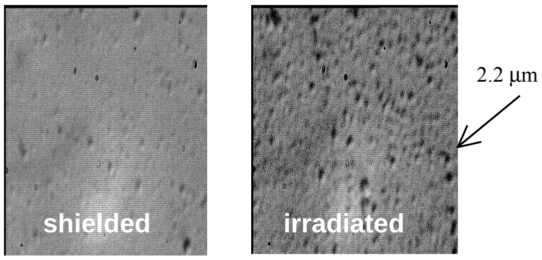


Fig.5. Images of the ion tracks, as obtained from Micro-Capillary discharges (with average energy of ions equal to about 15 keV), which were registered with CN-LR115A detectors using the additional accelerating system [7]

4. Mass-and energy-analysis of ions

An accurate mass- and energy-analysis of ions was performed by means of Thomson-type mass-spectrometers adopted for plasma diagnostics. They were equipped with special input systems of the skimmer type, which made possible a differential pumping. The input system was kept under good vacuum conditions ($p < 10^{-5}$ Tr). Those input systems, together with the spectrometers, could be adjusted along chosen observation axes. Ion Thomson parabolas (*Fig.6.*), as registered upon SSNTDs after their appropriate etching, were analyzed with an optical microscope. It demonstrated that primary deuterons and impurity (or admixture) ions could be accelerated within PF discharges to very high E/Z ratio ranging to about 2.7 MeV. To facilitate and accelerate the optical analysis of ion tracks (micro-craters), the microscope was equipped with a CCD camera coupled with a special interface and a fast (Pentium II) computer with an Image-Pro Plus software (Fig.7).

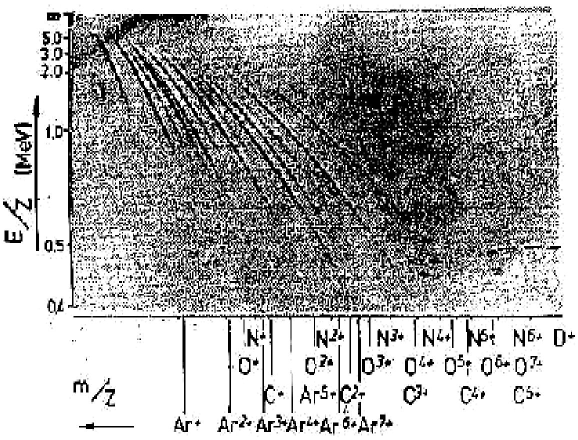


Fig.6. Typical mass- and energy-spectrum (Thomson parabolas) of fast ions emitted along the z-axis from single 60- kJ PF shots with deuterium filling [8]

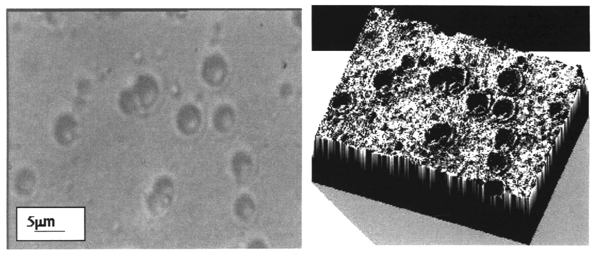


Fig.7. Image of tracks (micro-craters) produced by deuterons of energy equal to about 200 keV (on the left), and a corresponding 3-D micro-crater image (on the right), which was obtained by means of a computer analyzing system [6]

5. Time-resolved measurements of ions

In order to perform time-resolved measurements of ion pulses there were designed and applied different Faraday-type collectors. To make possible the selection of ions above a chosen energy level, the use was made of additional polarized grids. To facilitate time-of-flight (TOF) measurements there was designed a special double Faraday-type probe, in which the first collector had a ring shape, and the TOF basis was a distance to the second conical collector (*Figs. 8 and 9*).

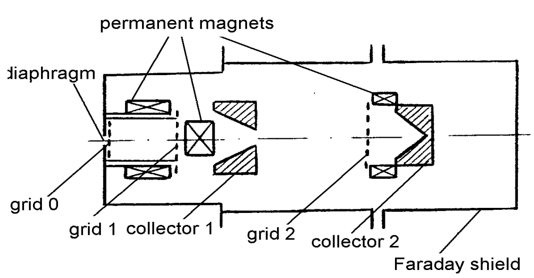


Fig.8. Schematic of the double FC collector [9]

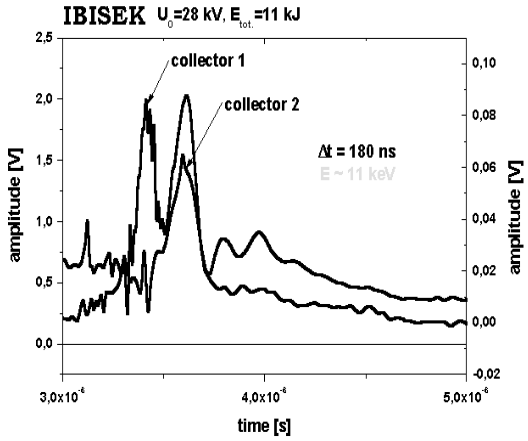


Fig.9. Discharge current waveform and ion signals from the double FC collector, as obtained at the N_2 filling [9]

6. Spectroscopic study of plasma-ion streams

To improve plasma-ion diagnostics there were also applied spectroscopic techniques. Within a frame of the scientific collaboration with the Ukrainian team, there were used optical VR and UV spectrometers for time-integrated spectral measurements (*Fig.10*).

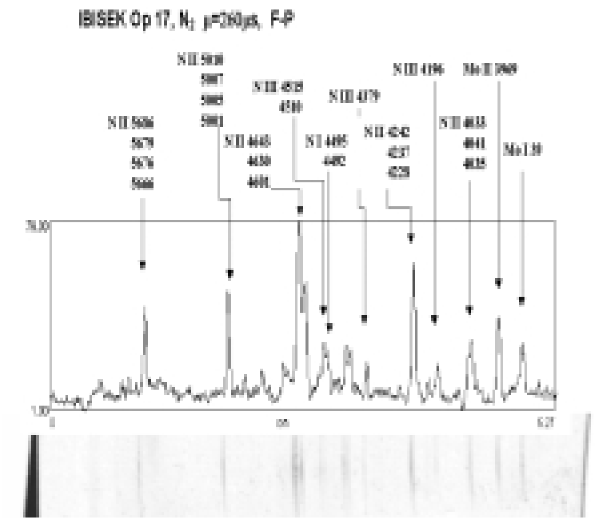


Fig.10 Spectrum of plasma emitted from RPI-IBISEK device at E_0 = 12 kJ, U_0 =28 kV, N_2 filling, τ = 260 μs. The densitometric profile was measured along the symmetry axis on a copy of the original film

For spectrum- and time-resolved studies there were applied monochromator-photomultiplier sets. Particular attention was paid to heavy impurity ions, which originate mainly from electrode surfaces (*Fig.11*).

7. Summary and conclusions

The results of this work can be summarized as follows:

- Different diagnostic techniques for studies ions have been developed at the IPJ in Swierk. They have successfully been applied for investigation of the RPI- and PF-type.

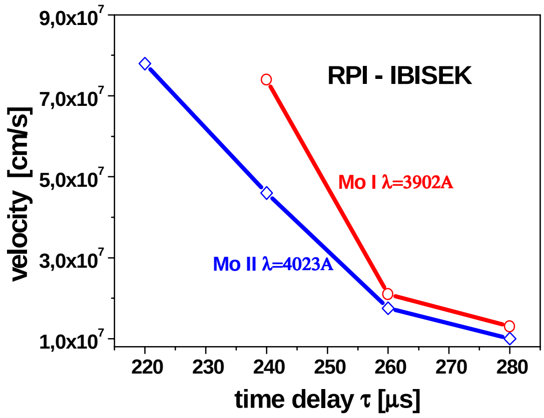


Fig.11. Velocity of the MoI neutrals and MoII ions as a function a time delay (τ) value, as measured within the IBISEK facility [10]

- Time-integrated measurements of ion beams are carried out with pinhole cameras and Thomson-analyzers equipped with CN- or CR-detectors.
- To study ion and electron pulses the use is made of magnetic analyzers equipped with appropriate films or scintillation detectors.
- To improve spatial- and temporal-resolution of the studies of corpuscular beams, further development of diagnostic methods is needed, e.g. the use of microchannel amplifiers of a new generation.

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