STUDIES OF ION EMISSION FROM DIFFERENT PLASMA DISCHARGES OF AXIAL SYMMETRY

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Abstract. The paper presents selected results of experimental research on ion streams generated by different plasma devices of axial symmetry, such as RPI (Rod Plasma Injector), and PF (Plasma Focus) facilities. Also presented are measurements of an ion flux generated by a Hall - type plasma injector ISEX designed for space research. Time-integrated and time-resolved measurements of ions are described and discussed.

1. Introduction

Measurements of the energy distribution of ions and their m/Ze ratio, i.e. ion spectra, make possible to determine (after a detailed analysis) basic characteristics of investigated plasma, e.g. its temperature. In order to measure ion spectra within RPI and PF devices operated at IPJ the use was made of mass- and energy - analyzers of the Thomson type [1-2]. Using special measuring techniques, it was also possible to measure waveforms of ion pulses versus time [3-4]. A spatial surface structure of the ion beams was investigated with nuclear tracks detectors (NTDs). The ion spectra and spatial distributions of ion current density were also measured by means of Faraday type collectors [5].

2. Time-integrated and time-resolved measurements within IONOTRON

The detailed experimental studies of ions were carried out within at the IBIS (IONOTRON-type) facility with an energy storage of 51 kJ, at the initial charging voltage U_0 = 35 kV. To measure ion spectra the use was made of a Thomson type analyzer equipped with UV-2 spectral plates or CN-type track detectors. The spectrometer was placed on the z-axis, at a distance of about 2 m from ends of the coaxial multirod electrodes. Typical ion spectra of deuterons, as obtained from the IBIS device for several shots performed at U_0 = 35 kV and

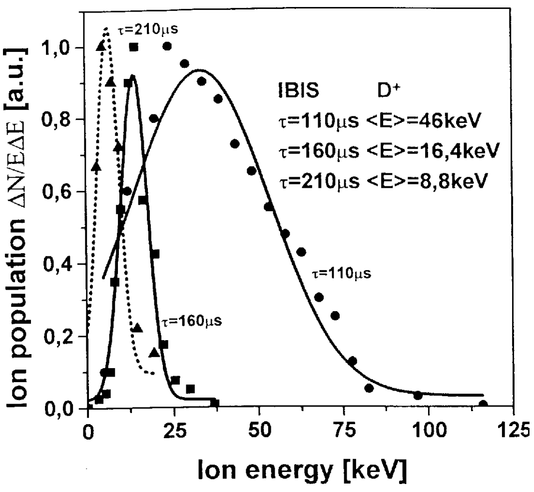

Fig. 1. Energy spectra of deuterons from the IBIS facility (I_{max} = *600 kA*), as obtained for three different modes of the operation.

different ϑ values, have been shown in Fig. 1. It has shown that an average kinetic energy <E> of deuterons decreases with an increase in a time delay τ, e.g. at τ = 110 μs it amounts to 46 keV, and at τ = 210 μs it falls down to 8.8 keV. It should be noted that a neutron yield, Y_N, was several times higher at τ = 210 μs than that observed at τ= 110 μs. In order to get more complete information there were also performed time-resolved ion measurements. The Thomson analyzer was equipped with miniature scintillation detectors protected against visible light by very thin non-transparent Al-filters. Those detectors were placed along the computed parabola upon the rear wall of the analyzer and they were coupled through optical cables with photomultipliers and a fast oscilloscope. An example of the ion parabola and oscillograms, presenting ions signals from a single shot, have been shown in Fig. 2. The places in which the scintillators were placed, have been marked by small circles. In the oscillograms the first small peaks presented time markers (M) from an electronic generator, and the next signals were induced by X-rays and neutrons [1]. The main ion signal on the left oscillogram corresponded to deuterons of an average energy equal to <E> = 9 keV, and that on the right to <E> = 70 keV, respectively. It should be noted that the both ion signals had the same width (about 300 ns) and their amplitudes were very similar. It means that the measured deuterons were emitted under identical local conditions.

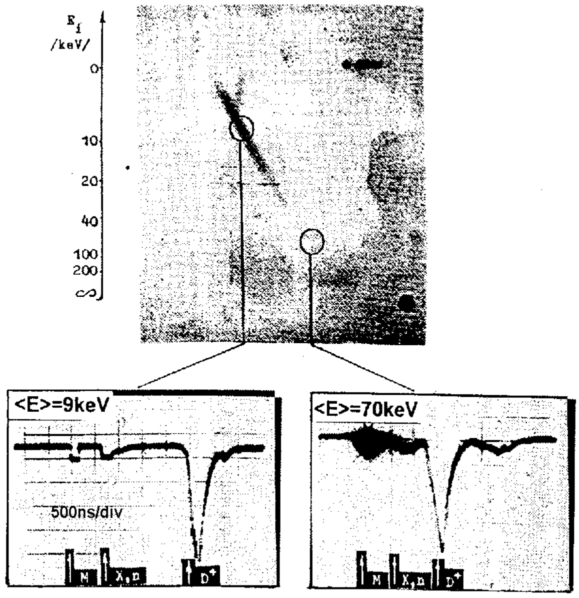

Fig. 2. Typical ion spectra (deuterons) obtained on the UV-2 plate, and appropriate signals from two light pipes mounted in places designated by circle (upper).

3. Visualization of ion beams and time-resolved measurements within PF-360

The PF-360 facility was equipped with a 120-mm-diam. inner electrode and 170-mm-diam. outer one, both 300 mm in length. The main ceramic insulator was 80-mm in length. The facility was operated at 121 kJ/29 kV or 147 kJ/32 kV, with the initial filling of 2 – 8.6 hPa D_2. Time-resolved measurements of the ion emission have been performed by means of an ion pinhole camera equipped with scintillators covered with thin Al-filters. Measured signals were registered by means of a digitizing oscilloscope. Studies of the ion signals from the PF-360 facillity showed that the emission of fast ions varies significantly from shot to shot. A character of the ion emission was complex. The deuteron signals registered at the detection threshold of 1.3 MeV and 1.7 MeV, i.e. with 10 μm and 20 μm Al-filters, correlated well with neutron-induced signals and inter-electrode voltage waveforms, as shown in Fig. 3. The map

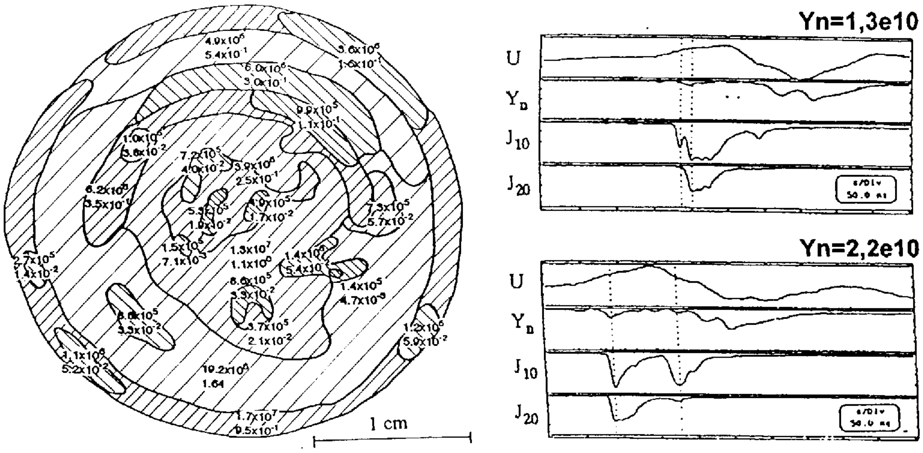

Fig. 3. Map of the ion density distribution (on the left), as obtained within the PF-360 facility, under experimental conditions: E_0 = *36 kJ*, p_0 = *2.6 mbar* D_2, $Y_n = 1.1H10^{10}$. On the right oscillograms registered for two different shots with total energy E_0 = *130 kJ*, which were performed at p_0 = *4.7 hPa* D_2 . Notations: U-voltage, Y_n - hard X-rays and neutrons, J_{10} and J_{20} ion signals with the detection threshold of 1.3 MeV and 1.7 MeV, respectively.

of the deuteron flux density of, as obtained from the NTD film placed within the ion pinhole camera, demonstrated a complex spatial structure of the deuteron beams [2].

The distribution of ion density, as registered at lower total energy E_0 = 36 kJ, showed a structure corresponding to a hollow cylinder with numerous ion microbeams inside it. Considering time-resolved signals, e.g. the upper oscillogram presented in Fig. 3, one can notice a considerable contribution of X-rays to the main ion signal. For a higher neutron yield (e.g. in the lower oscillogram) X-ray and neutron induced signals are well separated from the deuteron peaks.

4. Measurements of energy spectra of ions and their angular distribution within ISEX

The ISEX device is a Hall-type plasma accelerator, which can generate pulse streams of Xe-ions with an average energy of about 400 eV, and the total intensity up to about 1 A [4]. The ion pulses can last 0.1-1 s, and the electric charge compensation at the injector outlet is provided by an external electron emitter. Such plasma accelerators can be used in space research, e.g. to study the collisionless heating of solar wind ions. Laboratory tests of the ISEX device have been carried out within a large vacuum chamber, simulating conditions of future space experiments.

One of the most important characteristics are the Xe-ion energy distributions, which have been measured by means of Faraday-type collectors equipped with additional polarized grids to enable an ion energy analysis to be performed. The ion energy measurements have been performed at a distance of 165 cm from the injector outlet at the z-axis (R = 0) and at a chosen radial distance (R = 40 cm). The ion energy distributions have been shown in Fig. 4.

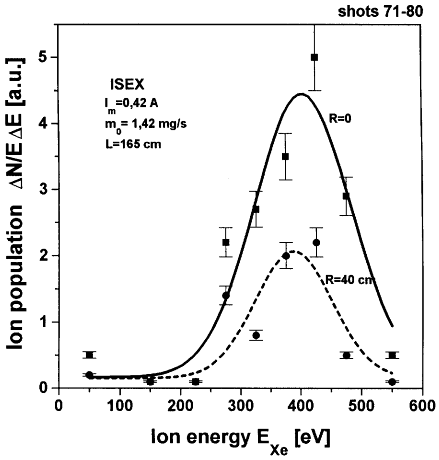

Fig. 4. The ion energy spectra of Xe-ions emitted from the ISEX device, as measured with Faraday cups placed at different angular positions. The distance from ISEX to Faraday collectors was L = 165 cm.

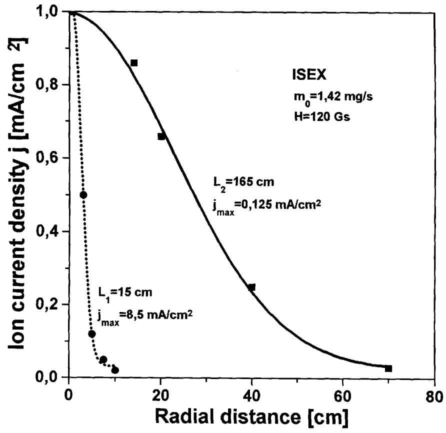

Fig. 5. The angular distribution of Xe-ion flux, as measured at a distance of 165 cm and 15 cm from the ISEX outlet, respectively. The data show a divergence of the generated ion streams.

Other important characteristics of investigated ion streams are angular distributions of the ion current density. On the basis of measurements of the angular distribution of Xe-ion streams from ISEX device, taking into consideration geometry of the experiment, it can concluded that the total ion current at a distance of L = 165 cm from the accelerator outlet was I = 1.15 A, [5] according to requirements for future space experiments.

5. Conclusions

The corpuscular diagnostics techniques described above have been verified and have been shown that they are suitable for investigation of pulsed ion streams generated by various coaxial plasma accelerators (guns) under different experimental conditions.

Acknowledgements

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