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SPECTROSCOPIC MEASUREMENTS OF NITROGEN COMPRESSION PLASMA FLOW ELECTRON DENSITY AND TEMPERATURE

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Abstract. Magnetoplasma compressor with a semi-transparent electrode system that operates in the ion current transfer regime is studied. The thermodynamic parameters of the discharge and the compression plasma flow generated in N_2 + 5% H_2 mixture at 500 Pa pressure with input energy 4.9 kJ have been measured. Special construction of the accelerator electrode system enable the electrode shielding by the self-magnetic field resulting in protection from the erosion. Fully predominant N II spectrum is observed in the compression plasma flow during quasistationary phase. The plasma flow velocity and electron temperature maximum values are measured close to 35 km/s and 4 eV, respectively. It was found that electron density values are close to $2 \cdot 10^{16}$ cm^{-3} during discharge quasistationary phase.

1. INTRODUCTION

A quasistationary plasma accelerators are sources of supersonic compression plasma flows in which the duration of the stable state is much longer (~100-1000 μs) then the flight time of the plasma in the acceleration channel (~1 μs) [1]. In these plasma accelerators an ion current transport in the accelerating system occures through the transparent anode [2]. Heavy electrode erosion, which is characteristics of traditional pulsed plasma accelerators, is avoid in the quasistationary plasma systems.

Magnetoplasma compressor (MPC) is the source of quasistationary compression plasma flows (CPF) [1-4]. The importance of research connected with the MPC is in enabling the study of fundamental processes in plasma flows and, also, in application of such systems and their plasma flows in different plasma technologies such as plasma solid surface modification, plasma deposition of the materials to the sample surfaces etc. Plasma flow parameters optimization with nitrogen as working gas is very important because this plasma accelerating system was used for solid surface modification [5].

2. EXPERIMENTAL SETUP

The MPC used in this experiment was described elsewhere [3,4,6]. In this experiment, CPF parameters have been measured in N_2 + 5% H_2 mixture in the regime of residual gas at 500 Pa pressure. Hydrogen is added because of spectroscopy electrone density measurement. The electrode system is connected through an ignitron with 800 μF capacitor banks at 3.5 kV. Time and space developments of CPF and plasma flow velocity were determined using the photographs obtained by IMACON 790 high speed camera. The electron density and temperature time dependences are obtained from side-on observations. The profiles of spectral lines were obtained by Jobin Yvon HR 320S spectrometer equipped with PI·MAX 1024×256 UV CCD camera gated at 2 μs exposure time and synchronized with the discharge. Spectroscopy measurements of H_β and N II lines radiation from MPC plasma have been performed at eight positions along z axis starting from the outlet of the cathode with 1 cm separation up to 8 cm distance. It gives a possibility to obtain a set of the line profiles, from Balmer beta up to Balmer alpha line in one shot at each positions from the cathode and at each time in order to obtained electron densities and temperatures. Line profiles are scanned from 20 up to 60 μs with 10 μs separation at each position. Calibration of spectroscopy system was made by standard of spectral irradiance (FEL F-000 lamp).

3. EXPERIMENTAL RESULTS AND DISSCUSION

Plasma flow electron density and temperature are measured using spectroscopy methods. Plasma reproducibility was found to be within ±10%. The estimated experimental errors of plasma electron density and temperature measurements are within ±10% and ±15%, respectively. When MPC working with pure nitrogen at 500 Pa pressure, highly predominant spectrum in the CPF radiation is N II spectrum. The axial and temporal distributions of the electron temperature are given in Fig. 1.

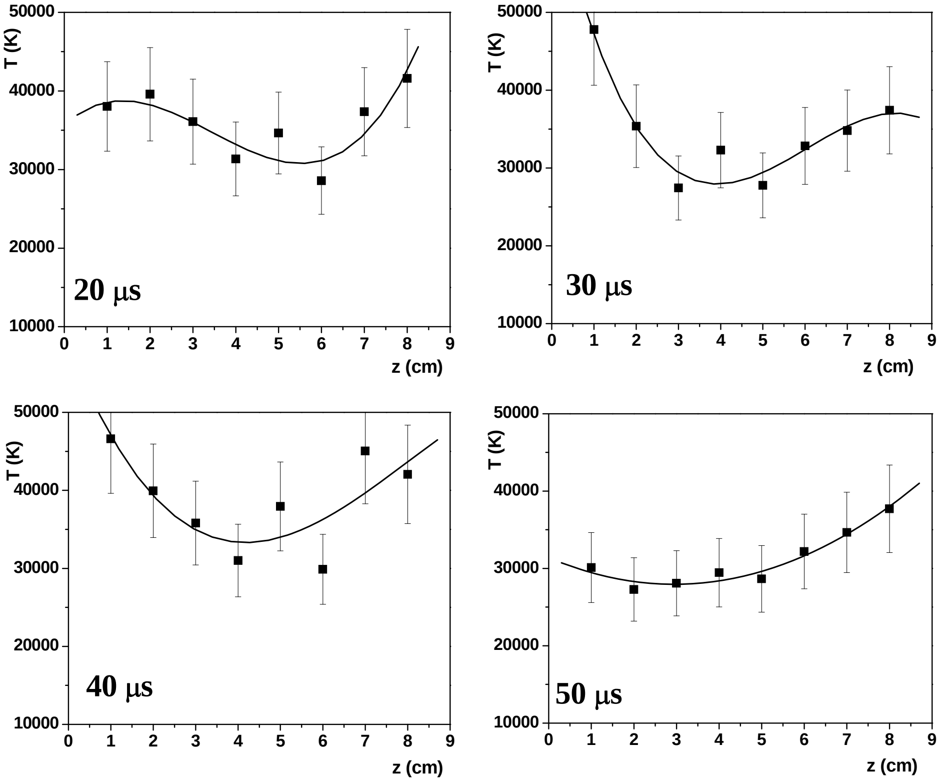

Fig 1. Electron temperature axial and temporal dependences in N_2 + 5%H_2 at 500 Pa pressure.

The electron temperature was measured using a method based on the relative intensity measurements of N II spectral lines, i. e. Boltzman plot. The measurement has been done using the following ten N II spectral lines: 471.8 nm, 478.8 nm, 480.3 nm, 489.5 nm, 504.5 nm, 566.7 nm, 571.1 nm, 589.3 nm, 594.2 nm and 634.7 nm. It was found that during quasistationary phase in the CPF region the average temperature is 35.000 K, what is in good agreement with the results obtained in previous experiments [7,8]. From Fig. 1 one can conclude that two regions can be observed along z axis. One, starting from the top of the cathode up to 3-4 cm, is compression plasma flow. Further from 4 cm is zone of thermalization, because CPF kinetic energy is transformed to thermal energy.

The axial and temporal electron density distributions of the CPF are obtained from the Stark halfwidth of Balmer beta line profiles comparison with theoretically calculated ones [9] and presented in Fig. 2. The profiles were obtained in the single shot.

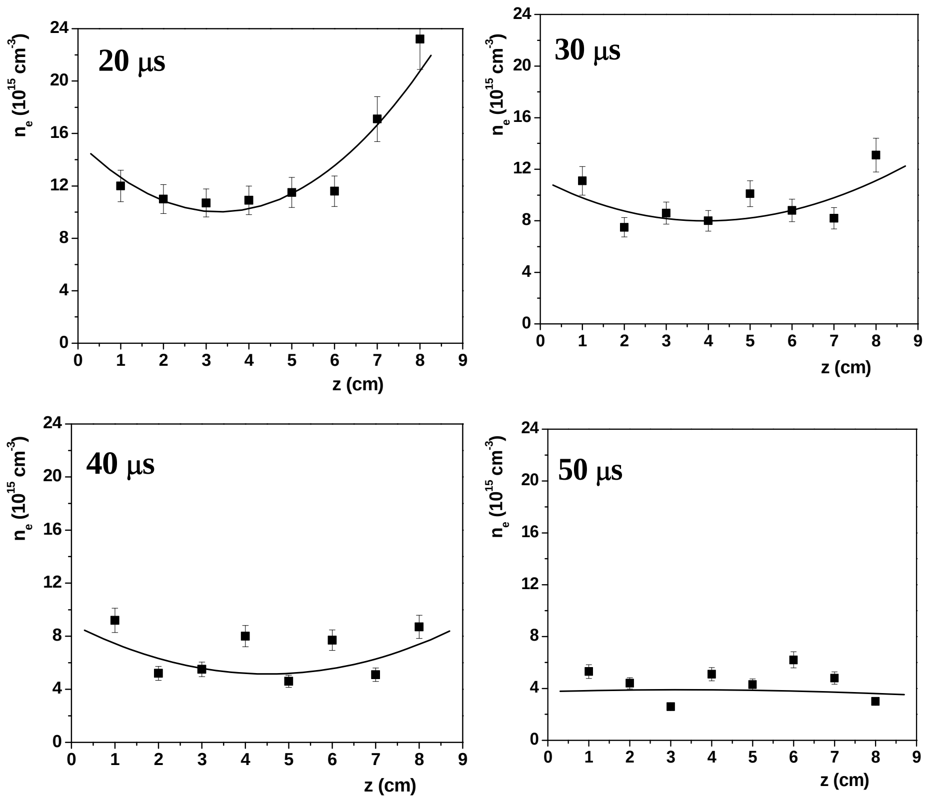

Fig. 2. Electron density axial and temporal dependences in N_2 + 5% H_2 at 500 Pa pressure.

Electron density has maximum at 20 μs and is approximately constant ~10^{16} cm^{-3} within the region up to 4 cm along the z axis with origin at the top of the cathode. For distances larger then 6 cm the higher electron density can be explained by the action of shock wave on the ionization of working gas.

The discharge evolution of MPC was registered by high speed camera. It has been found that the CPF length and diameter in these experimental conditions are about 4 cm and 1 cm, respectively [3]. Plasma flow velocity determined in nitrogen is found to be 35 km/s.

By comparing the obtained electron temperature (Fig. 1) and the electron density axial distribution in time (Fig. 2) one can come to the following conclusions: (i) both distributions have maximum 10-20 μs after the discharge beginning, gradually decreasing later on; and (ii) two regions are observed, one from the top of the cathode up to 3-4 cm along z axis is zone of compression plasma flow and, second, region beyond 4 cm is zone of termalization. During CPF decay, 60-70 μs after the discharge beginning, plasma parameters in this zone are higher than those in CPF.

The advantages of MPC, as compared to other types of accelerators, are high stability of a generated quasistationary compression plasma flows in nitrogen, size and plasma parameters, as well as the discharge time duration sufficient for practical applications (up to 100 μs). During quasistationary phase the continual ionization processes are taking part in working gas introduced into the interelectrode region. The ionized gas (plasma) is steadily accelerated and permanently compressed and within CPF region only this, accelerated, plasma exists. During this phase the plasma flow parameters are slowly changing in time within certain volume. It is a consequence of an ion-drift acceleration of magnetized plasma realised using specially shaped accelerating channel [2].

Beside that, the operation in the ion current transfer mode with the minimization of the electrodes erosion represents an additional and very important advantage of the MPC in comparison with the classical ones. An especially designed electrode system has self magnetic field shielding and it causes a reduction of the electrodes erosion. Also, in order to obtain as pure as possible plasma flow by MPC the ion separation per M/q has to be acheived and therefore the cathode top is shaped as a divertor. If particular ion leave the cathode the high pressure zone (~10 kPa) of the plasma flow push it back into divertor. As a consequence, highly predominant N II spectrum is observed in the CPF during quasistationary phase. Therefore, MPC described here is a favorable one for performing of plasma surface treatment of different materials and for the other plasma technologies.

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