CONTROL OF THE PLASMA TRANSVERSAL LOSSES, CAUSED BY MHD INSTABILITIES, IN OPEN MIRROR MAGNETIC TRAP OF THE ECRIS: RECENT EXPERIMENTS ON SMIS 37 SETUP

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Abstract
This work is a continuation of the experiments described in [1, 2] and aimed at the investigation of the new conceptions of MHD stabilization of plasma in open axisymmetric traps, specifically, it is aimed at the investigation of the shear flow influence on the transport control in open mirror traps. As in previous experiments, shear flow was created by limiter-electrode with bias potential according to the vacuum chamber. Plasma density structure in radial and azimuthal directions was studied. Mode structure of the perturbations was investigated. Substantial sharp shift of the plasma density maximum to the system axis with bias potential growth was demonstrated. It was shown, that the value of the bias potential that corresponds to the plasma density profile shift grows with the magnetic field growth that can be interpreted as the electron temperature growth.

INTRODUCTION

Creation of the new generation of the ECR ion sources now is connected with an increase in the heating radiation frequency up to 56 GHz. In this case, the required value of the magnetic field in the trap can reach a value of 5 Tesla. The minimum B magnetic field configuration, which is traditional for the ECR ion sources, in the case of high values of the magnetic field is quite complicated, and now its creation requires a lot of efforts, whereas creation of a strong magnetic field in the axisymmetric magnetic trap is not a problem. That is why the stabilization of MHD perturbations in axisymmetric magnetic traps seems to be perspective. The advance in plasma stabilization using the shear flows achieved on the GDT (GasDynamic Trap, described in details in [3]) setup allows one to assume the same result in the case of the non-equilibrium plasma of the ECR ion sources. The essence of the method developed in Budker Institute consists in creation of a differential rotation zone at the periphery of the plasma column. It is obtained by the creation of the special (step-like) form of the radial profile of the plasma potential, which is achieved by using a system of special electrodes: radial limiters and bit-slice plasma receivers placed in the plasma expansion zone after the magnetic trap plug. This method now allows one to confine the plasma with $\beta \sim 0.6$ in the GDT in the stationary regime with a negligible level of the transverse losses.

In papers [1-2] mentioned method was for the first time tested for the plasma of the ECR discharge created by 37.5 GHz radiation (SMIS 37 setup, see Fig.1) in an axisymmetric magnetic mirror trap of multicharged ion source. A limiter with bias potential was set inside the vacuum chamber for plasma rotation. The limiter construction and the optimal value of the potential were chosen according to the results of the preliminary theoretical analysis. The increase in the limiter's potential up to the values of 70–100 V leads to a substantial (by approximately 3.5–4 times) increase in the entire amount of the ions leaving the trap through the magnetic plugs during one working pulse. That is the result of the increase in the plasma density and, probably, in the electron temperature in the trap. So, the confinement became better, which was interpreted as substantial suppression of the transverse losses. Measurements of ion spectra showed that the increase in the ion current couldn't be a result of additional flux of contaminations from chamber walls. Investigation of the time dependences of the ion current in the plasma decay regime demonstrated the decay time increase from 60 μs to 110 μs for the regime with improved confinement. This work is a continuation of the previous researches [1-2] and aimed on the further investigation of the shear flow influence on the transport control in open mirror traps of the ECR ion sources.

SMIS 37 EXPERIMENTAL FACILITY

The experimental investigations presented here were carried out on the SMIS 37 setup, which was described in details in [4]. The scheme of the setup is shown in Fig. 1. A gyrotron with the 100 kW power at 37.5 GHz, pulse duration up to 1.2 ms, and linear polarization of the radiation was used as an RF heating source. The plasma was confined in an axisymmetric open mirror trap. The pulsed magnetic field was created by two groups of solenoids. The duration of a current pulse with its form being close to a half-period of the sinusoid was 14 ms; the change in the value of the magnetic field during an RF pulse was less than 3%. The distance between the plugs was about 35 cm, and the mirror ratio was close to 5. The value of the magnetic-field intensity was 1.5-1.9 T at the

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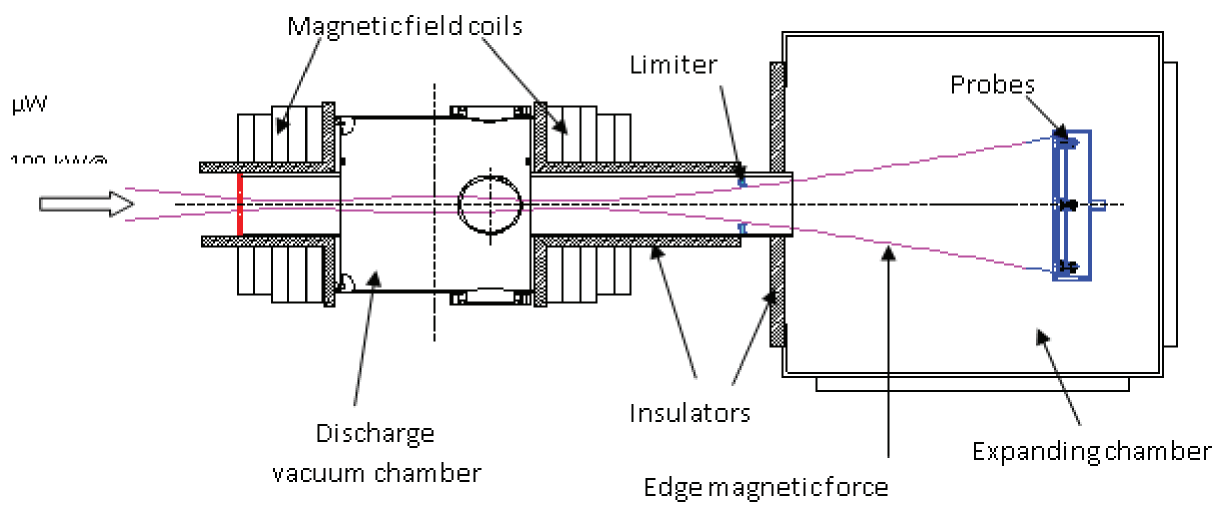

Figure 1: SMIS 37 experimental setup.

plug in most experiments. The gas (at the most part of the experiments we used helium) was injected to the vacuum chamber through a quartz pipe soldered at the center of the RF inlet quartz window.

The typical plasma parameters were as follows: an electron density of $10^{12}\div10^{13}$ cm^{-3}, an electron temperature of 50÷100 eV, and a plasma chord radius of ~ 1 cm. Under such conditions, the frequency of electron-ion collisions is rather high, the loss cone is filled with electrons, and quasi-gas-dynamic confinement is realized with a confinement time of about a few tens of microseconds.

An electrode limiter designed for the control of the electrical-potential profile was set in the vacuum chamber (Fig. 1). The negative electrical bias potential applied to the limiter with value ranged from 0÷200 V.

Plasma created into the trap spread into the expanding chamber where 8 electrical probes, intended for spatial distribution of the ion flux from the plug research, were placed. Position of the probes system is shown on the Fig. 1. Probes were operated in the ion current saturation regime. One of them was placed into the center of the system, three – along the radius and another 4 – along the azimuth at the maximum radius position at the points of 22.5^0, 45^0, 90^0, and 180^0 as it shown on the Fig. 2.

There were the steel mask-disk in front of the probes with 12 mm holes and the glass disk with same holes. Each of the probes was provided with measuring line and analog-to-digital converter (ADC) channel for pulse form registration.

The studying the spatio-temporal dynamics of the discharge optical radiation was made by streak camera.

RESULTS

Radial Profile Dynamics

The main purpose of the experiments was to investigate the structure of the plasma flux from the trap along the system axis under the conditions of the regime with improved confinement. The structure of the flux was studying by use the system of Langmuir probes placed into the expanding chamber (see. Fig.1).

Probes 1 – 4 placed along the radial coordinate (on the Fig. 2 they placed along the horizontal line) allowed one to investigate the dynamics of the plasma flux radial profile. The change of the shape of this profile with the change of the value of the bias potential on the limiter is shown on the Fig. 3 (the value of the magnetic field at the plug in this case was 1.7 T).

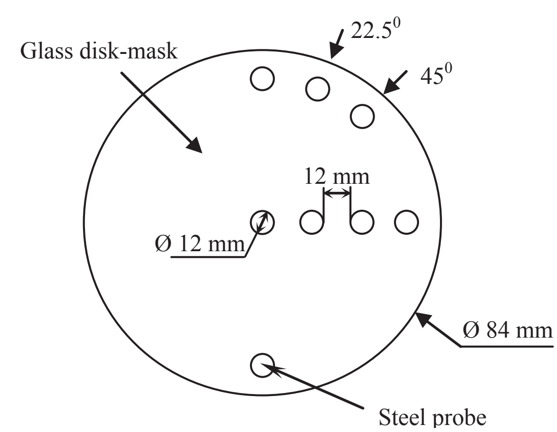

Figure 2: Scheme of the probes positioning in the probe's system.

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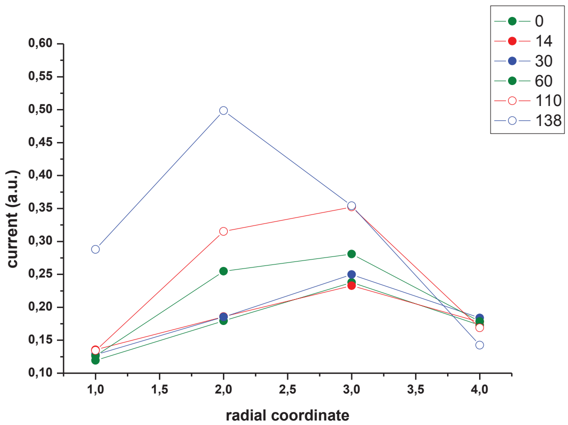

Figure 3: Dependence of the plasma flux radial profile on the value of the biased potential for the value of the magnetic field at the plug of 1.7 T. Radial coordinate 1 corresponds to the 1st probe, 2 – for second, etc.

As one can see at the value of the voltage more then 110 V there is the substantial shift of the profile maximum from the 3rd probe to the second. At the same time the increase of the total current to the probes was observed as it had been at the previous experiments (see [1-2]). For the lower value of the magnetic field at the plug (1.5 T) we observed the same situation but the shift was noticed at the lower value of the biased potential at the limiter (see Figure 4).

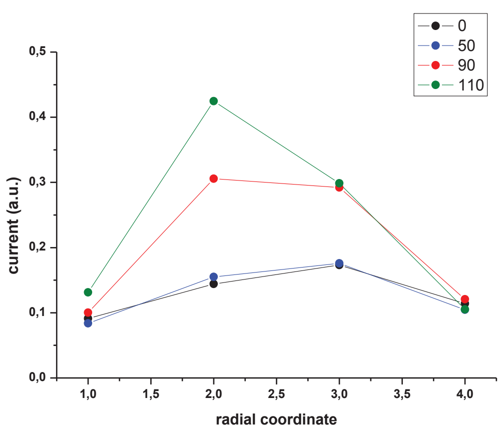

Figure 4: Dependence of the plasma flux radial profile on the value of the biased potential for the value of the magnetic field at the plug of 1.5 T. For this case the shift of the profile maximum observed at the value of the voltage close to the 90 V.

When the value of the magnetic field at the plug was even less (1.3 T, it have to be noted, that this value is lower then the resonance one for the 37.5 GHz, 1.34 T) the shift was observed at the 50 V. Moreover in this case it was possible to shift the profile maximum closer to center (1st probe) at the potential value of about 170 V.

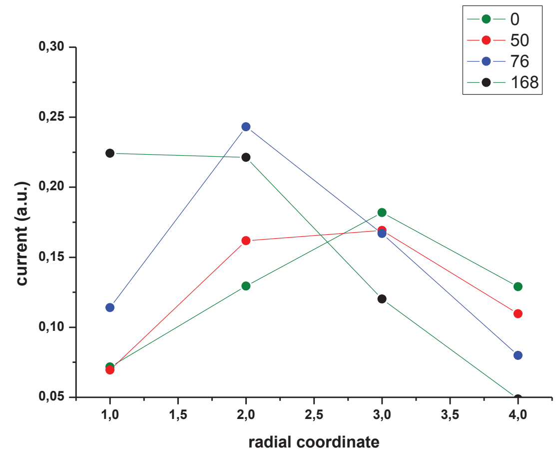

Figure 5: Dependence of the plasma flux radial profile on the value of the biased potential for the value of the magnetic field at the plug of 1.3 T.

We associate observed shift of the profile maximum from the periphery to the center with the switch to the regime with improved confinement (regime with transversal losses suppression). The fact, that even in the case of better confinement, the maximum of the density profile in spite of the shift is still not at axis of system we explain by the presence of the high azimuthal modes in the spatial structure of the plasma flux. The presence of the higher azimuthal modes (m=2, 3) in case of the ECR ion source was demonstrated in previous papers [1-2, 5] theoretically and experimentally and can be explained by the low value of the ion temperature ($T_i \ll T_e$) in ECRIS plasma.

As it was shown in paper [6] theoretically, the switch to the regime with improved confinement occurs at the value of bias potential proportional to the electron temperature. Specifically, for the SMIS 37 facility parameters (for helium plasma) $\varphi \sim 1.2 \cdot T_e$. And as it was shown above experimentally, the value of the bias potential, which corresponds to the switch to the regime with improved confinement, grows with the value of the magnetic field. That fact from the one hand could serve as the additional proof of the fact that in ECR ion sources electron temperature grows with the value of the magnetic field. On the other hand, if you accept the fact the temperature increases with increasing magnetic field as given, it may serve as a confirmation of the fact that the threshold value of bias potential grows with the electron temperature.

Spatio-Temporal Dynamics of the Discharge Optical Radiation

Studying of the spatio-temporal dynamics of the discharge optical radiation was made by streak camera. This camera was placed in front of the optical flange of the discharge vacuum chamber. treak camera images for the different values of the bias potential on the limiter (0 V, 120 V, and 180 V) are shown on the figures 6-8.

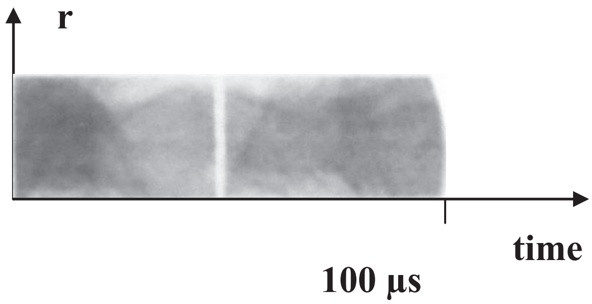

Figure 6: Streak camera image for the limiter potential of 0 V.

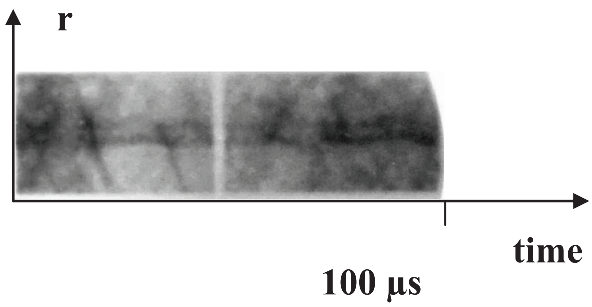

Figure 7: Streak camera image for the limiter potential of 120 V.

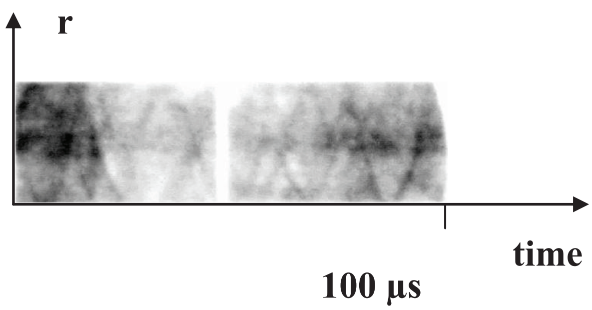

Figure 8: Streak camera image for the limiter potential of 180 V.

The value of the magnetic field at the plug was of about 1.7 T. At the high values of the potential (more then the threshold one) it is noticeable the creation of the plasma core (due to the shift of the plasma density maximum to the center) and the creation of the rotating layer, which is noticeable by its helical trajectory. When the rotation velocity is higher (compare 120 V case and 180 V), the pitch of the helix becomes shorter that confirms our expectations that the greater potential drop will result in a greater rotation speed.

CONCLUSION

The experimental results presented in this paper along with the results had been obtained earlier [1, 2, 5] demonstrated that the effective control of the transversal losses in non-equilibrium plasma of ECR discharge is possible by using shear flows, driven by biasing limiter. We suppose that these results may be useful in developing a new generation of ECR ion sources based on axisymmetric open magnetic traps.

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