GASDYNAMIC ECR SOURCES OF MULTICHARGED IONS

V.G. Zorin, A.F. Bokhanov, S.V. Golubev, I.V. Izotov, D.A. Mansfeld, S.V. Razin, A.V. Sidorov, V.A. Skalyga, and A.V. Vodopyanov, Institute of Applied Physics RAS, 46 Ulyanov St., Nizhny Novgorod, Russia.

Abstract

A new type of pulsed sources of multicharged ions(MCI), namely, a gasdynamic ECR source is proposed. Its main difference from the classical ECR ion sources is a different, quasi-gasdynamic regime of plasma confinement in a magnetic trap. Plasma was produced and heated by radiation of a pulsed gyrotrons with the frequencies of 37.5 and 75 GHz in magnetic traps of various configurations. Plasma confinement in quasi-gasdynamic regime under such conditions was studied. It was demonstrated that with such a confinement regime it is possible to generate multicharged ions and create intense (more than 1 A/cm^2) ion fluxes through the trap plugs. Creation of intense plasma fluxes allows one to extract high-current MCI beams of high brightness. Transverse homogeneity of a plasma flux makes it possible to use a multi-aperture extraction system for the formation of broad intense MCI beams. MCI beams with current up to 150mA and normalized emittance lower than 1 π·mm·mrad were produced. Comparison of results of calculations and data of experiments shows that they are in a good agreement, which allows us to predict creation of a new type of ECR source.

INTRODUCTION

The recent experimental and theoretical research carried out at the Institute of Applied Physics (IAP RAS, Nizhniy Novgorod, Russia) resulted in development of a new type of pulsed ECR sources of multicharged ions – gasdynamic ECR ion sources (ReGIS). It will be demonstrated that such sources are capable of generating high-current and high-brightness ion beams with a moderate ion charge.

The ideas underlying development of such sources were borrowed from the field of classical ECR sources of multicharged ions (we will refer to them as to the Geller ECR ion sources (GECRIS)) [1], as well as from investigations of fusion mirror traps (FMT) [2]. The ReGISs differ from the Geller sources by the mechanism of plasma confinement in a magnetic trap. It is the quasi-gasdynamic mechanism [3] similar to that used in FMT. The principal distinction from FMT is strong nonequilibrium of confined plasma (the temperature of the electrons is much higher than the temperature of the ions), which is typical of GECRIS.

REGIS PRINCIPALS

A possibility of realizing two different (classical and quasi-gasdynamic) regimes of confinement of nonequilibrium plasma in open magnetic traps at powerful ECR heating by millimeter wave radiation was demonstrated in [3]. The great majority of modern ECR sources of MCI operates in the regime of classical plasma confinement in a trap. Ion confinement in this case is determined by ambipolar potential distribution in the trap [4]. In a mirror trap, electrons get into a loss cone either as a result of collisions with ions or with each other, or due to quasi-linear diffusion in velocity space due to intense ECR heating [5]. With increasing plasma density the transition from the classical to the quasi-gasdynamic regime of plasma confinement was observed in experiments [3]. The mechanism of plasma confinement in a trap changes for the values of the plasma such that the velocity at which the loss cone is filled in by electrons in velocity space is higher than the velocity of plasma escape from the trap. The loss cone is filled in, the electrons are confined in the trap by ambipolar potential, and plasma losses are determined by gasdynamic ejection of ions. This regime of confinement of nonequilibrium plasma with filled loss cone is called a quasi-gasdynamic regime. The transition to this regime of plasma confinement is inevitable when its density is increased [6]. The plane of plasma parameters divided into characteristic regions for the two regimes of plasma confinement with characteristic regions for classical and gasdynamic ECR ion sources is presented in fig.1.

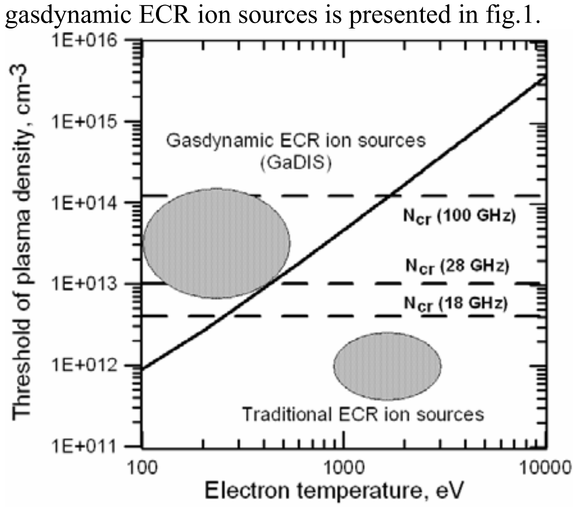

Fig. 1. The border between the two regimes of plasma confinement.

In quasi-gasdynamic regime plasma life time can be roughly determined as $\tau = \dfrac{R \cdot L}{2 \cdot V_s}$, where R is the mirror ratio and L is the length of the trap and V_s is the ion-sound velocity. Thus, in the quasi-gasdynamic regime plasma lifetime is determined only by ion-sound velocity and

geometry of the trap and does not depend on plasma density. Due to this plasma confinement parameter (N_e τ) can be increased by enlargement of the trap size (trap length) and creation of plasma with higher density. For increasing of plasma density it is necessary to apply MW radiation with higher frequency. Effectiveness of both approaches was demonstrated in our experiments.
Deformation of ion charge state distribution due to modifying of the trap length, which lead in accord with (5) to a change in the confinement time, shown in fig.2.

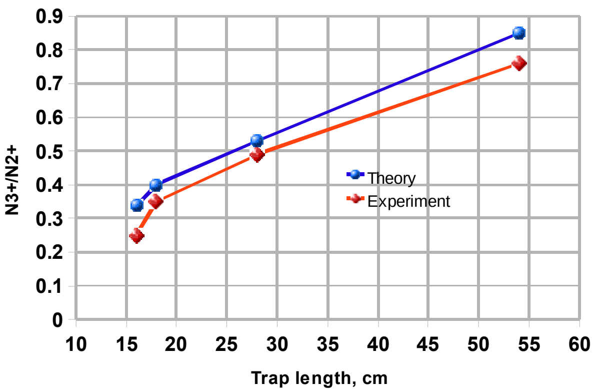

Fig. 2. The ratio of N ions with charge +3 and +2 *versus* the effective trap length (calculation and experiment).

In fig.3 the results of experiments for two frequencies of heating MW radiation (37.5 and 75 GHz) in helium are shown.

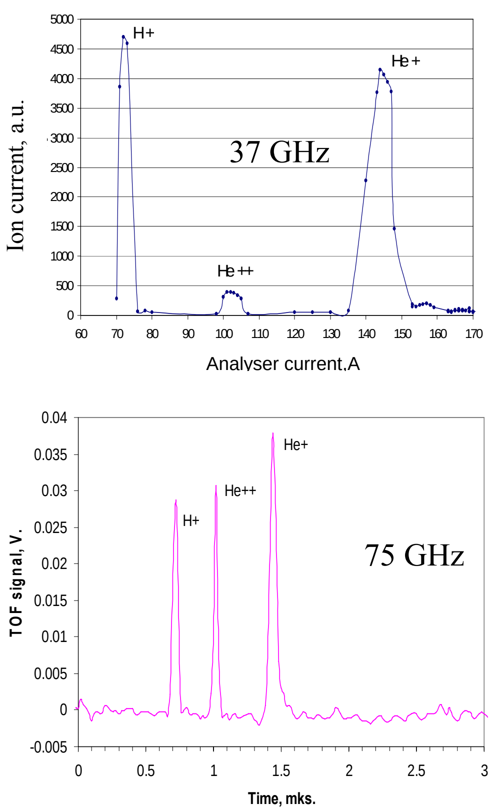

Figure 3. Helium charge state distributions for 37.5 GHz (upper one) and 75 GHz.

ION BEAM CURRENT AND EMITTANCE

The latest experiments were performed with multi-aperture extraction system, which is shown in fig.4.

a)

b)

Fig. 4. 13-aperture extractor (photo). a) General view; the holes in plasma electrode can be seen at foreground. b) Electrodes of the extractor.

The 13-aperture extractor has been optimized; the beam current at the extraction system exit (Faraday cup current) and puller current have been measured as a function of the extraction voltage. The ion beam emittance has been measured at the extracting voltage equal to 30 kV.
The ion beam current (Faraday cup current) of 160 mA has been obtained at 30 kV extracting voltage (fig. 5), 85 kW gyrotron microwave power and 1.6 T magnetic field in trap plugs (with cusp magnetic configuration), puller current being near 100 mA. In these experiments the extractor was placed 21 cm off the magnetic trap plug, distance between electrodes being 9 mm.
The emittance of the obtained ion beam was measured with use of 'pepper-pot' screen and scintillator. Analysis of experimental data has demonstrated that normalized emittance of the beam is equal to 0.9 π·mm·mrad (for 30 kV extracting voltage).

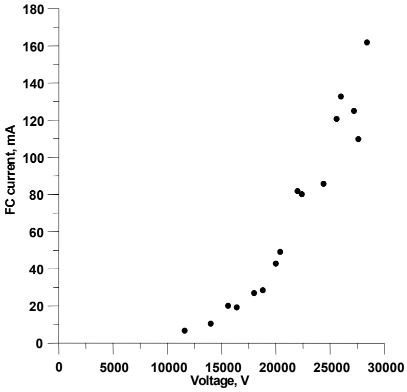

Fig. 5. Ion beam current (Faraday cup current) versus extracting voltage in 13-aperture extractor. Nitrogen is used as working gas.

CHARGE STATE DISTRIBUTION

The primary experiments have been carried out on generation of multi-charged ions of nitrogen with use of modified cusp magnetic trap.

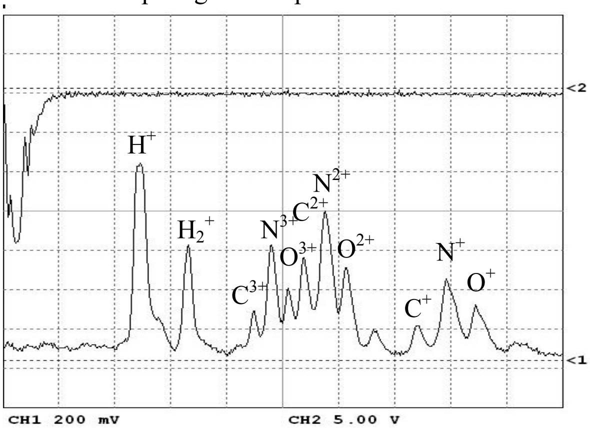

Fig. 6. Mass-charge ion spectrum of nitrogen plasma.

Fig. 6 present mass-charge ion spectra obtained in ECR plasma of nitrogen (the time-of-flight ion analyzer was used in these experiments). Plasma was created in modified cusp magnetic trap with effective length equal to 54 cm, magnetic field in plugs reached 2.3 T, and pulsed power of gyrotron radiation was 85 kW. It can be seen from this figure that nitrogen ion charge state distribution has maximum at + 2 charge (peak corresponding to N^{3+} ions being only 25% less). This indicates more effective generation of multi-charged ions under conditions of the described experiments compared with earlier ones with shorter (L_{eff} = 28 cm) cusp trap[7]. Unfortunately we couldn't avoid large amount of admixtures polluting plasma on this stage due to low repetition rate.

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