TARGET PLASMA FORMATION BY UHF POWER

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Abstract

The properties of plasma injected into open magnetic trap of uniform field from independent UHF source have investigated. Plasma is created in the UHF source at the frequency of 2400 MHz (power input 150 W) in the electron cyclotron resonance (ECR) regime at the pressure of neutral argon $10^{-5}\div10^{-2}$ Torr. It is established that a rather quiescent plasma with controlled density within the range of $2{\cdot}10^{8}\div2{\cdot}10^{12}$ cm^{-3} and temperature $2\div3$ eV is accumulated in the trap. It turned out, that plasma lifetime in the trap is determined by a classical mechanism of particle escape at the expense of collisions, at fixed value of magnetic field in the trap it practically is not changed with the variation of neutral gas pressure and reaches the value $\sim4{\cdot}10^{-3}$ s at the magnetic field strength in the trap equal 1600 Oe.

1. Introduction

Various methods are used to fill the magnetic trap with plasma. From all existing methods UHF contactless methods are used most frequently. As a rule, plasma formation takes place in the trap itself in ECR regime (see e.g. [1-3]). However, this method has various disadvantages. In particular, range of magnetic field changes in the trap is strictly limited by the existence of UHF discharge in the magnetic field; with the change of magnetic field discharge regime and plasma parameters change and the most important is that "hot" region of UHF wave absorption with plasma is in the trap itself, which is often undesirable. Therefore, the application of independent "quiescent" plasma source with controllable parameters, which is far from the trap and from which "target plasma" is injected into it, is of great interest.

For this purpose we have proposed the method of filling the open magnetic trap by plasma injection along the magnetic field from separate stationary UHF source removed from the trap in which the plasma is formed in ECR regime in highly nonuniform magnetic field [4-8].

The present work is devoted to the investigation of the "target plasma" properties in the magnetic trap with homogeneous magnetic field. The investigations are based on the measurements of distribution of plasma charged particles density along the trap, and on density and temperature dependence on the conditions of plasma formation in UHF source and on trap parameters.

2. Experimental set-up

Experiments were carried out on a stationary installation, the diagram of which is presented in Fig. 1. It consists of two main parts: an independent UHF plasma source and open magnetic trap, in which plasma is injected.

In the UHF source plasma is formed in a quarts tube **1** with inner diameter 2.6 cm and length of 10 cm. Stationary UHF power (2400 MHz, 150 W) is supplied to the discharge chamber by standard rectangular waveguide **2** with 7.2×3.4 cm^2 section in which wave TE_{01} is excited. The discharge chamber with the waveguide is located into the stationary magnetic

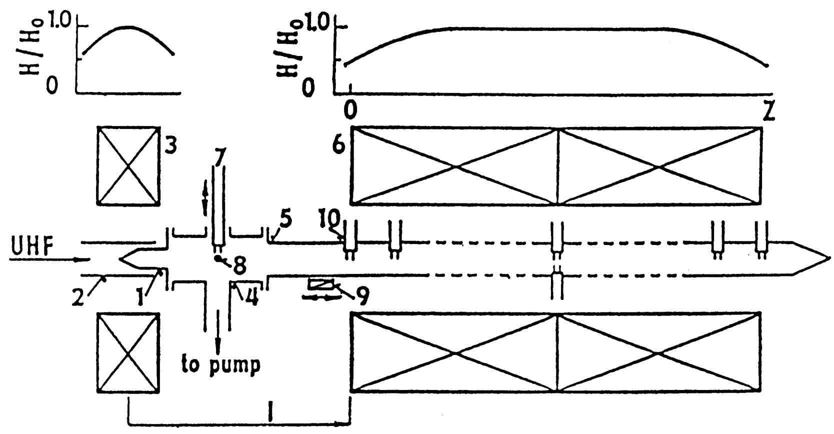

Figure 1. The scheme of experimental set-up

field, created by a short coil **3** with inner diameter of 19.5 cm and length of 15 cm. In the coil strongly nonuniform magnetic field is generated with the maximum value of 2000 Oe in the center of the coil.

The discharge chamber of the UHF plasma source is connected with the cylindrical section **4**, made of stainless steel and being a diagnostical section and low cut-off waveguide for the wave of the UHF source at the same time.

The volume **5** (glass tube with inner diameter of 4 cm and the length of 115 cm), in which plasma injection takes place is coaxially connected with the cylindrical section **4** from the back side of the plasma source discharge chamber. The volume **5** is placed into the stationary magnetic field, created by solenoid **6** with inner diameter of 19.5 cm and the length of 90 cm. By solenoid one can obtain the uniform magnetic field, as well as the field of mirror and multimirror configuration with controllable mirror ratio and the trap with cusp configuration. The maximum field along the axis reaches the value of 5000 Oe. The distance between UHF plasma source and the trap can be varied in the range ℓ=30÷90 cm.

To study plasma characteristics in the trap semiconducting light sensor **9**, moving along the chamber **5**, and double electrical probes **10**, introduced in the chamber axis in 13 sections with 7.5 cm step, were used.

In our experiments, Argon, Helium and Neon were used as working gas. Plasma in the UHF source was created at working gas pressure $10^{-5}\div10^{-2}$ Torr.

3. Plasma particle lifetime in the trap

One of the main characteristics of plasma in trap is lifetime of charged particles. For its determination the special experiments were carried out. We used well-known, so-called plasma "spatial decay" method [9]. The measurements of plasma density and electron temperature along the magnetic trap gave the possibility to determine experimentally the particle lifetime and its dependence on the neutral gas pressure and the magnetic field strength in the trap.

The dependence of reciprocal lifetime $1/\tau_\ell$ on the pressure of neutral gas, when the magnetic field strength in the trap is 400 Oe, is given in Fig. 2.

It turned out, that the lifetime of charged particles determined thus practically does not depend on the pressure of neutral gas and is approximately $3.5{\cdot}10^{-4}$ s (**2**, Fig. 2). This value agrees well for relatively high pressures (p >10^{-3} Torr) with the calculated lifetime of charged

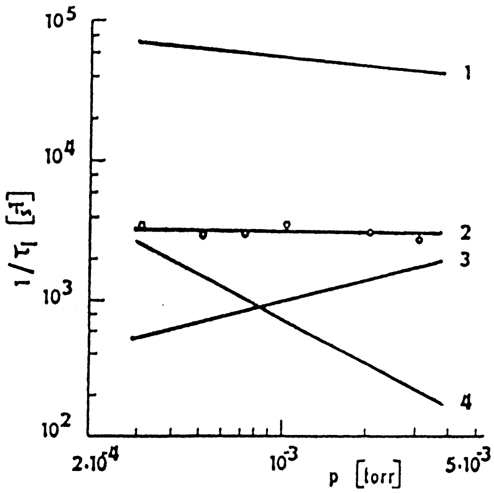

Figure 2. Dependence of reciprocal lifetime on the pressure of neutral gas. 1,3,4 - calculated curves connected with Bohm diffusion (1), transverse ambipolar diffusion (3) and longitudinal ambipolar diffusion (4), 2 - experimental curve.

particles connected with ambipolar diffusion across magnetic field (**3**, Fig. 2)

$$\frac{1}{\tau_{\perp a}} = \frac{D_{\perp a}}{(\Lambda_\perp)^2} = \frac{kT_e(\nu_{ei} + \nu_{ea})}{m_e(\omega_{He})^2(\Lambda_\perp)^2},$$

where $\Lambda_\perp$ is the characteristic transverse diffusion length (a is the chamber radius), k is the Boltzmann constant, T_e is the electron temperature, m_e is the electron mass, $\omega_{He} = eH/m_e c$, e is the electron charge, c is the light velocity, H is the magnetic field strength, ν_{ei} is the collision frequency of electrons with neutral particles (in calculations it was assumed to be equal to $7{\cdot}10^9\ p$ [10]).

At low pressure, when $p < 7{\cdot}10^{-4}$ Torr, experimentally defined value of the particle lifetime is already in good agreement with the calculated lifetime, which is connected with the longitudinal ambipolar diffusion (**4**, Fig. 2)

$$\frac{1}{\tau_{\parallel a}} = \frac{D_{\parallel a}}{(\Lambda_\parallel)^2} = \frac{kT_e}{m_i \nu_{ia}(\Lambda_\parallel)^2},$$

where $\Lambda_\parallel = L/\pi$ is the characteristic longitudinal diffusion length (L is the chamber length), m_i is ion mass and ν_{ia} is the collision frequency of ion with neutral particles. For argon we assume $\nu_{ia} \approx 8{\cdot}10^7\ p$ (at $T_e \approx 2 \div 3$ eV, $T_i \approx 0.3$ eV) [11].

We also define the dependence of the particle reciprocal lifetime on the magnetic field strength at different pressures. The results of the measurements for the high and low pressures are presented on Fig. 3. As one can see from Fig. 3 at high pressures experimental lifetime of particles strongly depends on the magnetic field (curve **2**) and its values are in good agreement with the calculated lifetime, which is connected with the transverse ambipolar diffusion (curve **3**). At the same time at the low pressures particle lifetime practically do not depend on the magnetic field (curve **4**) and its value is in good agreement with the calculated value of lifetime, which is connected with the longitudinal ambipolar diffusion (curve **5**).

We compared our data on the lifetime of charged particles with that of Bohm diffusion (**1**, Figs. 2,3)

$$\frac{1}{\tau_{\perp B}} = \frac{D_{\perp B}}{(\Lambda_\perp)^2} = \frac{ckT_e}{16eH(\Lambda_\perp)^2}.$$

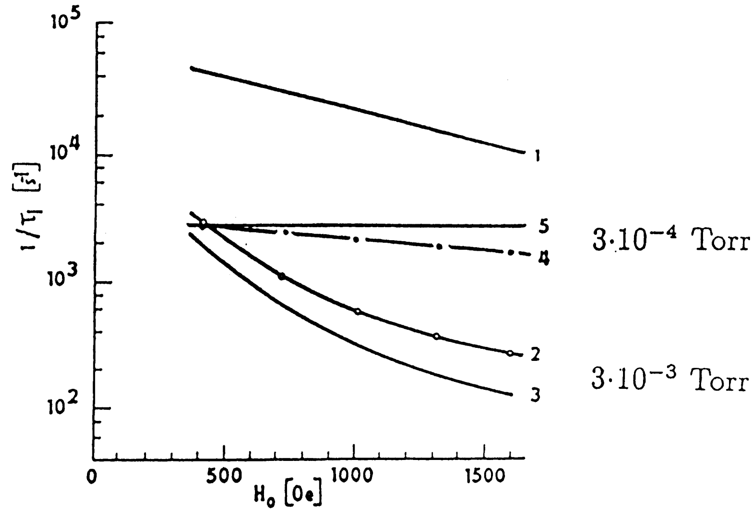

Figure 3. Dependence of reciprocal lifetime on the strength of magnetic field in the trap. 1,3,5 - calculated curves connected wit Bohm diffusion (1), transverse ambipolar diffusion (3) and longitudinal ambipolar diffusion (5), 2,4 - experimental curves.

From Figs. 2,3 it is seen that the rate of particle escape connected with the Bohm diffusion exceeds the experimental value more then of an order of magnitude and obviously it can not be responsible for the particle escape from the trap under our experimental conditions.

4. Conclusion

Let us note the most important results obtained by us experimentally for plasma injection from independent UHF source into open magnetic trap.

1. It is shown experimentally that one can effectively inject plasma from independent UHF source into open magnetic trap. In this case a rather quiescent plasma is accumulated in the trap with controllable density within the range $2{\cdot}10^8 \div 2{\cdot}10^{12}$ cm^{-3} and electron temperature $2 \div 3$ eV.

2. Plasma particle lifetime in the trap is determined by classical mechanisms of particle escape at the expense of collisions, at fixed value of magnetic field in the trap it practically does not change with the variation of neutral gas pressure and reaches the value $\sim 4{\cdot}10^{-3}$ s at the strength of the magnetic field in the trap equal to 1600 Oe.

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