INVESTIGATION OF SPACE DEPENDENCE OF PLASMA PARAMETERS IN MULTISLIT ELECTROMAGNETIC TRAP "JUPITER 2M"*

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The experimental researches of a transitive layer structure in the multislit electromagnetic trap "Jupiter 2M" are offered in the article. The dependencies of average plasma density on a magnetic field, energy and current of injected electrons, the spatial distributions of plasma density and volumetric charge potential are measured. The border of superseded magnetic field is determined.
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In electromagnetic traps shell character of plasma confinement is realized. In these traps electrons are confined by a sharp-angle geometry magnetic field and external electrical field, and ions – by electrical field of a volumetric electrons charge. The spatial distribution of magnetic field intensity is characterized by a deep magnetic well - magnetic field at the center of a trap is equal to zero and abruptly grows to periphery. In the central part of a trap, where the magnetic and electric fields are absent, the plasma is in powerless and thermally equilibrium condition. Such system of the combined plasma confinement by electrical and magnetic fields has unique properties allowing tostruggle successfully with plasma instability of a various type [1]. Between this area and boundary magnetic surface is transitive (diffusion) layer, where plasma cooperates with magnetic and electrical fields. The structure of plasma transitive layer - magnetic field plays a determining role during plasma accumulation, heating and confinement. Coefficient of electrons cross diffusion depends on transitive layer structure. With increase of density and temperature plasma supersedes a vacuum magnetic field, condensing diffusion layer and increasing a magnetic field in it, that results in reduction of electrons diffusion losses. The structure of an electrical field determines a share of energy, which ions receive during their acceleration by field of a volumetric electron charge.

In this work dependencies of plasma density and spatial distributions of plasma density and potential of a volumetric electrons charge on magnetic field intensity, injected electrons current and energy are measured for research of transitive layer structure.

Plasma density with application of corpuscular and microwave methods was measured.

Corpuscular method is based on pass of hydrogen neutral atoms beam perpendicularly to force lines of a magnetic field confining plasma on a diagonal of installation. Length of nuclear beam run in plasma is l = 68 cm, and 90 % from it atoms pass through the central area, where the electrical and magnetic fields are absent and plasma density is maximal in the center of a trap. It allows not to take into account spatial distribution of density, as the mistake at definition n and n_{max} does not exceed 5 %. After passage through plasma beam of atoms is registered with the help of photomultiplier tub, fig. 1. Density of plasma in a trap is determined by expression:

$$n_i = - \{ n_0\sigma_{01} l + \ln(N/N_0)\} / \sigma_{10} l. \qquad (1)$$

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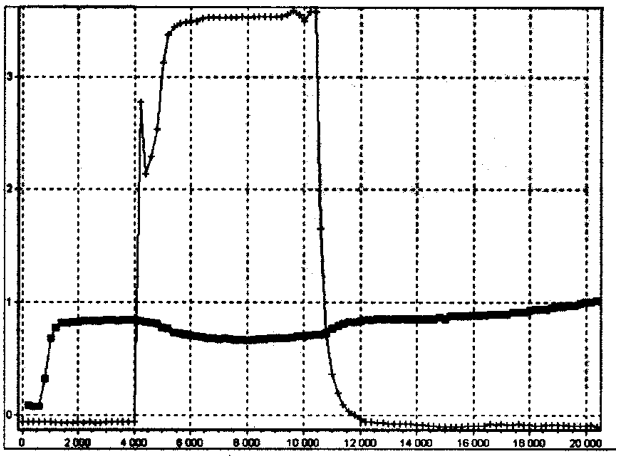

Fig. 1

At constant neutral gas concentration in installation first component does not influence on results of measurements – the unequivocal connection between easing of neutral atoms beam and product nl turns out. In a case, when neutral gas concentration is changed during a pulse of injection, the only value ($n_0\sigma_{01}$ + $n_i\sigma_{10}$) is unequivocally determined and the additional information is necessary for definition of plasma concentration. In the previous experiments [2] it was established, that during a pulse of injection the increasing of neutral gas density in a trap takes place. It connected with it knockout from surfaces, limiting area of plasma accumulation and located near the area of plasma accumulation, (diaphragms, magnetic and electrostatic systems), by charged particles and radiation from plasma. Oscillograms of injection current and neutral gas density change during a pulse of injection are given in fig. 2. In fig. 3 the temporary dependence of plasma density in a trap calculated from oscillograms of easing of hydrogen fast atoms beam (fig. 1) in view of neutral gas density changes during plasma accumulation is submitted.

Measurement of average plasma density by a microwave interferometer is based on change of wave phase, passed through plasma and caused by change of dielectric environment constant, unequivocally connected with change of plasma concentration. Interferometer assembled on the circuit offered by Wharton was applied [3]. Probing of plasma by a microwave radiation with wave length λ = 8 mm on installation "Jupiter 2M" was carried out in a radial direction ander one of thr central magnetic coils. The cross size of plasma in section of probing is L = 22 cm. The frequency of klystron generator was changed by submission of a managing sawtooth voltage with duration 250μs. Oscillogram of linear plasma density change <nl> from time offered on fig. 4.

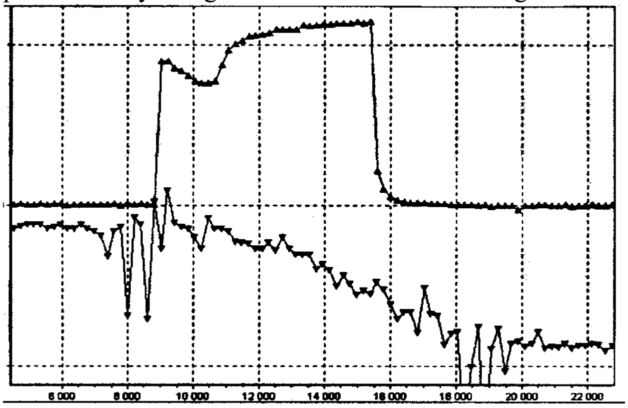

Fig. 2

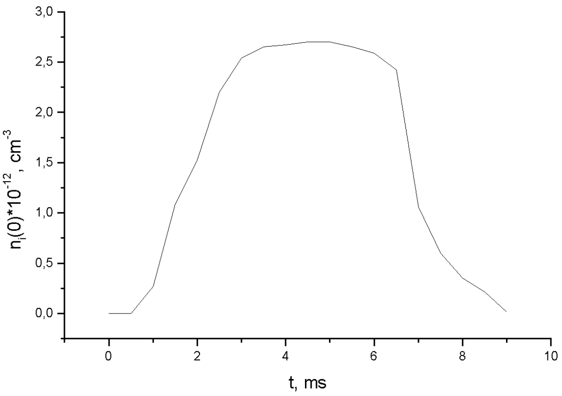

Fig. 3

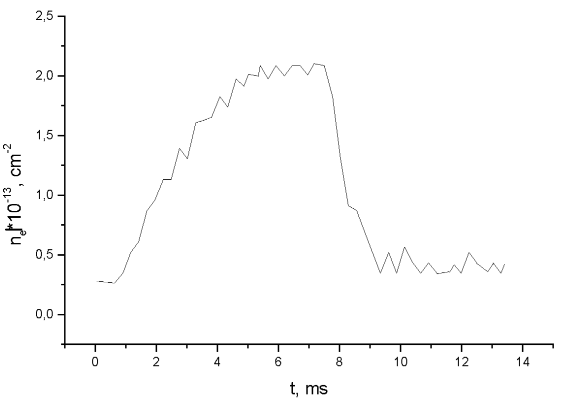

Fig. 4

The shift of a phase caused by change of dielectric permeability in the measuring channel, is connected with plasma concentration by following ratio:

$$\Delta\varphi = 2\pi\{1 - (1 - n/n_{кр})^{1/2}\}l/\lambda \qquad (2)$$

At n/nкр < < 1, that is carried out in conditions of our experiments, we shall receive

$$nl = 2.8 * 10^{13}\,\Delta\varphi/2\pi \ \text{cm}^{-2} \qquad (3)$$

This ratio allows to determine value <nl> average on section. The spatial distributions of plasma density measured by a single Langmuir probe were used for definition of plasma density in the central part of a trap. Average value l for oscillogram on fig. 4, calculated from radial density distribution is 14 cm and plasma density in the central part of a trap at the end of an injection pulse thus is equal $1.45*10^{12}$ cm^{-3}. It is visible from fig. 3 and 4, that the temporary dependences of plasma density measured by methods of corpuscular and microwave diagnostics are similar and in absolute values differ no more, than on 50 %.

The dependences of plasma density at the center of a trap from value of magnetic field intensity in a ring magnetic slit at different energy of injected electrons are given in fig. 5. From these dependences it is visible, that plasma density at the center of a trap grows with increase of magnetic field intensity and energy of injected electrons. Plasma density grows with increase of injected electrons current too.

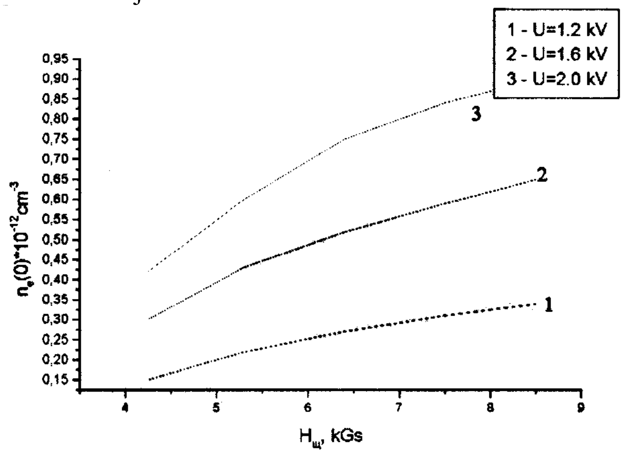

Fig. 5

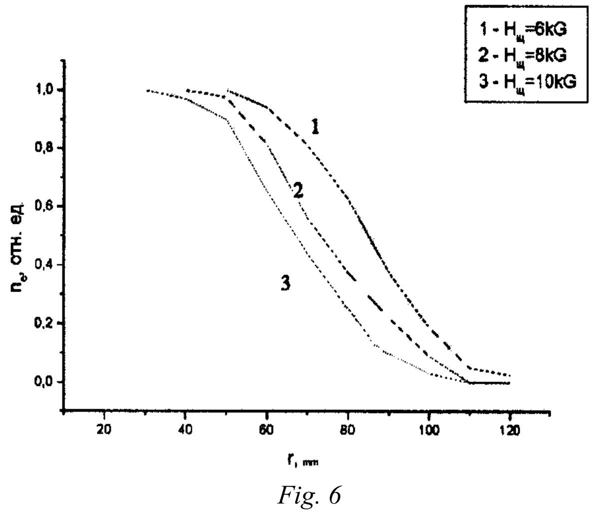

Fig. 6

The spatial distributions of plasma density are measured at various values of magnetic field intensity (see fig. 6). The distributions of plasma density were determined by ions current of saturation of a single Langmuir probe. Plasma density in the central part of a trap was normalized by results of density measurements by a microwave interferometer or by easing a hydrogen atoms beam. It is visible from figure, that the spatial distribution of density has a plateau in the field of a weak magnetic field, so in the central part of a trap plasma core is formed with constant density with a diameter ~10 cm and length ~ 80 cm. With increase of magnetic field intensity the structure of density is deformed inside and the core sizes are decreased. With growth of a current and energy of injection the core sizes are increased.

Plasma potential was measured by a single Langmuir probe in a floating mode, fig 7. It is visible from figure that the electrical field is concentrated in a narrow transitive layer, and at the center of a trap the electrical field is absent. The value of plasma potential is increased with growth of magnetic field intensity and plasma parameters, but the structure of potential thus practically does not change.

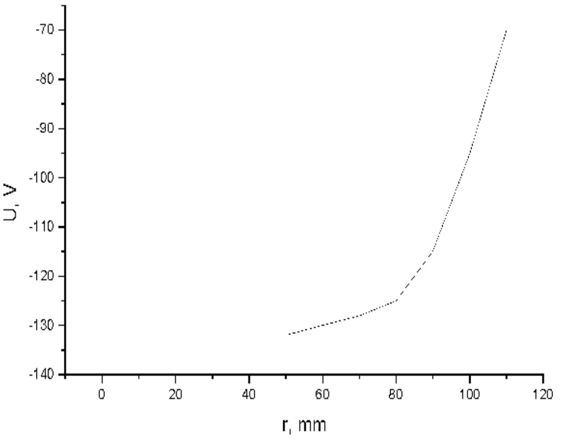

Fig. 7

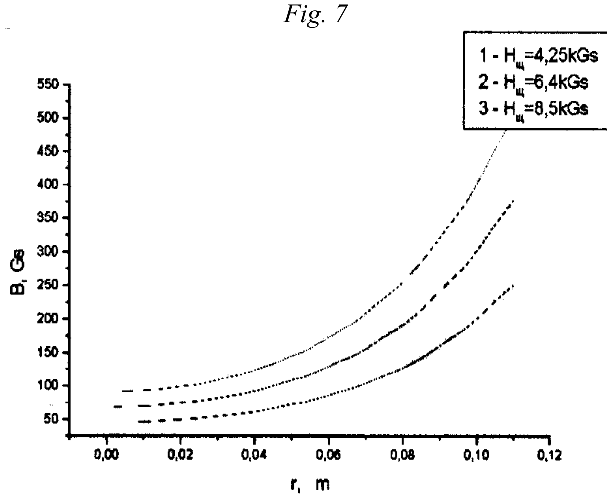

Fig. 8

In fig. 8 the radial distributions of magnetic field intensity under the coil in the central part of a trap for various values of magnetic field intensity in a ring magnetic slit are offered. The magnetic field intensity in section between coils on an axis is equal to zero. It is visible, that magnetic field intensity at the center of a trap approximately a hundred times is less than magnetic field intensity in a ring magnetic slit and in 5 times less than intensity of a field on a boundary force line and is less than 100 Gs.

It is known, that plasma supersedes a magnetic field from occupied volume, if its pressure exceeds pressure of a magnetic field. The border of the superseded magnetic field can be determined from the equation:

$$nk(T_e + T_i) = H^2 /8\pi \quad (4)$$

In conditions of the described experiments plasma with parameters $n_e = n_i = (0.2 - 2)*10^{12}$ cm^{-3}, $T_e = 15$ eV, $T_i = 30$ eV is received. For such parameters the area of the superseded magnetic field is limited by magnetic force lines with magnetic field intensity H = (20 - 70) Gs. Such value of magnetic field intensity in conditions of our experiments is achieved in the central area of a trap by a diameter ~ 10 cm and length ~ 80 cm. The changes of the sizes of constant plasma density area depending on a magnetic field, current and energy of injection, observable on spatial distributions, are caused by magnetic field replacement from the central area of a trap. Increase of a diameter of this area with constant plasma density with growth of a current and energy of injection is caused by increase of plasma pressure, and compression at increase of magnetic field intensity, fig. 6, - by growth of magnetic pressure.

In the field of the superseded magnetic field plasma is in powerless and thermally equilibrium condition. The peripheral part of plasma volume between area of the superseded magnetic field and boundary magnetic surface represents a transitive layer or a diffusion zone. As it is visible from the submitted figures, the gradients of plasma density, magnetic field intensity, electrical field is concentrated in this layer. In this layer plasma cooperates with a confining magnetic and electrical field, which character plays a determining role during plasma accumulation, heating and confinement in an electromagnetic trap.

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ДОСЛІДЖЕННЯ ПРОСТОРОВИХ РОЗПОДІЛЕННЬ ПАРАМЕТРІВ ПЛАЗМИ В БАГАТОЩІЛИННІЙ ЕЛЕКТРОМАГНІТНІЙ ПАСТЦІ "ЮПІТЕР 2М"

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В роботі представлені експериментальні дослідження структури перехідного шару в багатощілинній електромагнітній пастці "Юпітер 2М". Виміряні залежності середньої густини плазми від напруженості магнітного поля, енергії та струму інжектованих електронів, радіальні профілі густини плазми і потенціалу об'ємного заряду, визначена межа витісненого магнітного поля.

ИССЛЕДОВАНИЕ ПРОСТРАНСТВЕННЫХ РАСПРЕДЕЛЕНИЙ ПАРАМЕТРОВ ПЛАЗМЫ В МНОГОЩЕЛЕВОЙ ЭЛЕКТРОМАГНИТНОЙ ЛОВУШКЕ «ЮПИТЕР 2М»

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В работе представлены экспериментальные исследования структуры переходного слоя в многощелевой электромагнитной ловушке «Юпитер 2М». Измерены зависимости средней плотности плазмы от

напряженности магнитного поля, энергии и тока инжектированных электронов, радиальные профили плотности плазмы и потенциала объемного заряда, определена граница вытесненного магнитного поля.