MULTICUSP TRAP WITH CIRCULAR GEOMETRY
FOR CONFINEMENT OF LOW-TEMPERATURE PLASMA

G.I.Dimov[1], I.S.Emelev[2], P.D.Vobly[1], V.V.Kobets [1] and M.A.Tiunov[1]

[1]Budker Institute of Nuclear Physics, Prospect Lavrent'eva 11, 630090, Novosibirsk, Russia
[2]Novosibirsk State University, Pirogova Street 2, 630090, Novosibirsk, Russia

We proposed, manufactured and started the low-temperature plasma multicusp trap, which features fully circular geometry of magnetic field. In such plasma trap the superiority of the electron magnetic confinement over the ion confinement, and also the ion confinement in the electrical potential well are possible.

I. INTRODUCTION

The stationary low-temperature plasma trap is formed by circular magnetic walls with multicusp structure across the rings. The walls are made of permanent NdFeB-magnets with the operating temperature up to 150° C. The magnetic walls are installed tightly on the vacuum thin-walled cylindrical chamber with the following internal dimensions: D=12 cm, H=15 cm.

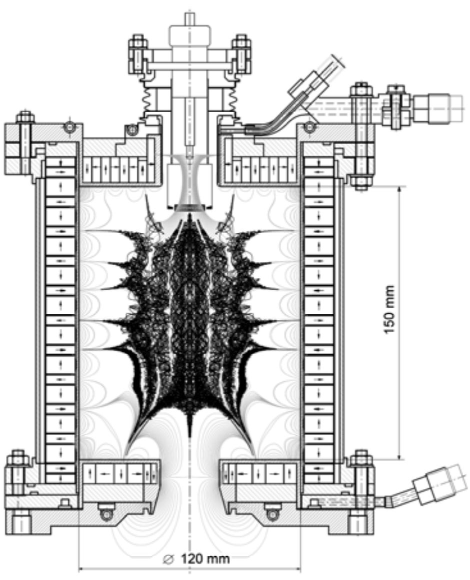

Fig.1. Multicusp trap with circular geometry (longitudinal section) with plasma electron distribution in confinement area.

Direct water cooling of the vacuum chamber was performed, in this case the cylindrical wall of the chamber is cooled by water which is run through spiral canals in the wall. The cooling system allows plasma maintenance in the trap with consumed power up to 4 kW in the stationary conditions.

Fig. 1 presents longitudinal section of the trap. Inside the trap the calculated electron distribution in the plasma confinement area is shown.

II. MAGNETIC FIELD WITH CIRCULAR GEOMETRY

Fig. 2 shows magnetic lines of force in longitudinal section. This Figure also presents the magnetic field distribution along the trap axis.

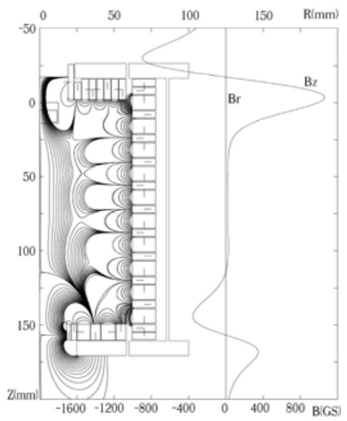

Fig. 2. From the left: Magnetic lines of force in longitudinal section. From the right: Calculated magnetic field along the axis.

The magnetic field geometry was optimized for improved confinement of electrons in the trap. To restrict electron escape to the trap ends, particularly into the hole (in neutralizing target such holes are intended for neutralized beam passage), arrangement and dimensions of circular permanent magnets on the ends were thoroughly selected.

Fig. 3 shows radial distribution of the magnetic field in the middle plane of the trap. Due to the placement of the permanent magnets immediately on the external surface of the vacuum chamber, the magnetic field on the internal surface of the chamber has the value up to 7.0 kG. The magnetic field on the 2.5 cm plasma radius does not exceed 30 G.

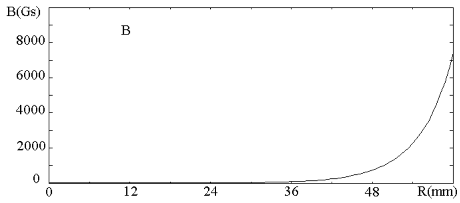

Fig. 3. Radial distribution of magnetic field in middle plane of trap

All calculations of magnetic field and electron motion in this field were made by SAM software [1].

III. PRODUCTION AND CONFINEMENT OF PLASMA

The plasma in the trap is produced due to hydrogen ionization by electrons accelerated in Debye layer from the plate incandescent LaB_6-cathode (pellet with 17 mm diameter), placed normally in the divergent magnetic field (to prevent virtual cathode creation). Such cathode excludes influence of large incandescent currents on the motion of emitted electrons in the adjoining to the cathode plasma.

In such trap with fully circular external magnetic field with zero azimuthal component and due to absence of stationary azimuthal electric field of axisymmetric plasma, the normal to walls stationary plasma drift in crossed fields cannot occur. Owing to this fact and to the plasma natural MHD-stability in the multicusp magnetic field, and also owing to restriction of two-beam instability (single plate cathode in the divergent magnetic field), the plasma electrons are well confined.

In this plasma trap the magnetic electron confinement can exceed ion confinement. As a result the negative potential well can appear, and ions will be confined by the electric field.

IV. RESULTS OF FIRST EXPERIMENTS

First experiments have been performed to obtain and confine plasma in the manufactured circular trap. At the cathode emission current of 18-24 A the hydrogen plasma with rather high electron temperature and density was produced. In such plasma we have not yet manage to perform probe measurements of its parameters even at very large off-duty ratio.

At the cathode emission current of 18 A we could introduce the probe into the plasma to the depth of 3.8 cm from the lower internal surface of the chamber (below in all figures it is accepted that the probe zero position is on this surface). The saw-tooth voltage with the duration of 300 mks is applied to the probe. From Fig. 4 one can see that at the hydrogen pressure of 2 mTorr, in the lower part of the trap the electron temperature reaches 10-11 eV at the plasma density of $\sim 0.8 \times 10^{13}$ cm^{-3}. There are signs of the plasma negative potential in its depth.

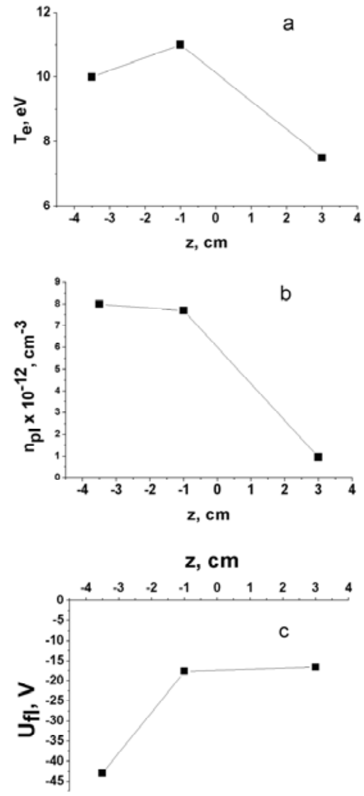

Fig. 4. Measurement results for plasma parameters at I_{dis} = 18 A, p_{gas}= 2 mTorr. a) Electron temperature. b) Plasma density. c) Floating potential.

Further measurements were carried out at 12 A cathode emission current in one-second impulses at 30 off-duty ratio. The probe was upgraded (ceramics was replaced with boron nitride, the molybdenum probe was replaced with the tungsten probe).

Fig. 5 present the results of these measurements at hydrogen pressure p_{gas} = 1.5 mTorr. The precision is not high. Measured electron temperature decreases as the probe gets deeper into the plasma due to the plasma pollution by the substance liberated from the probe. From Fig. 5 one can see that at low pressure of H_2, in the lower part of the trap the electron temperature reaches 20-25 eV. At deep part 7-3.8cm T_e=5-8eV at n=3.7x10^{12}cm^{-3}.

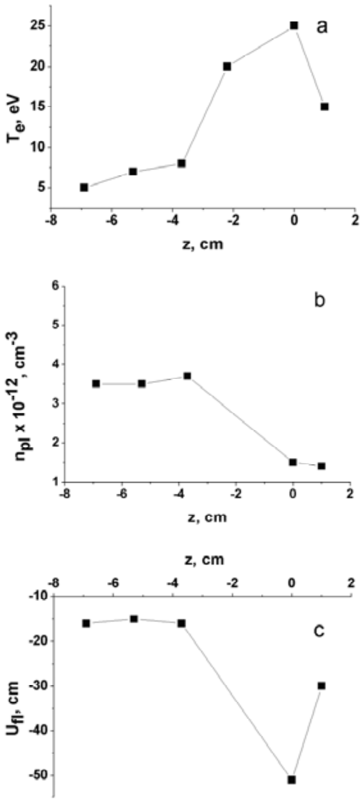

Fig. 5. Measurement results for plasma parameters at I_{dis} = 12 A, p_{gas}= 1.5 mTorr. a) Electron temperature. b) Potential of plasma. c) Floating potential

Fig. 6 present the results of these measurements at hydrogen pressure values p_{gas} = 2 and 3 mTorr. In this cases, the behavior of electron temperature is almost the same: it lowers with the depth from 11.5-8 eV to 5-4 eV at the depth of 7cm. It is quite possible that this relationship is connected with interaction between probe and the plasma. At hydrogen pressures p_{gas} = 2-3 mTorr the plasma density is n =(4.5-5.5)x10^{12} cm^{-3} at the depth of 2-7 cm.

At the current I_{dis} = 18 A we measured the ion current in the plasma jet, outflowing from the end outlet 2.8 cm in diameter, which turned out to be quite small ≈ 0.5 A. It is estimated that the average speed of the plasma outflow from the end outlet V_{fl} ≤ 10^5cm/s corresponds to the measured ion current, and through this outlet only ~ 2% of the plasma outflows.

V. CONCLUSION

Based on circular multicusp trap, a stationary plasma target can be made for neutralizing the hydrogen negative ion beams with the energy of

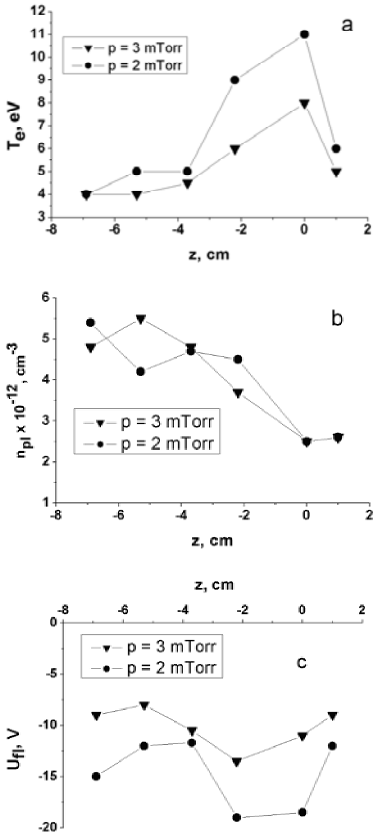

Fig. 6. Measurement results for plasma parameters at I_{dis}= 12 A, p_{gas}= 2 and 3 mtorr. a) Electron temperature. b) Plasma density. c) Floating potential.

~1 MeV and higher [2]. Naturally, such trap must be long and with side cathodes.

The experiments have shown possibility of obtaining plasma with the density of ~ 10^{13}cm^{-3} at high degree of ionization, which means that it is possible to make the stationary neutralizing plasma target with the total length of 1.5-2 m. Also it is important that little plasma outflow from the trap through the inlet and outlet holes for the neutralized beam.

With rather weakened plasma confinement in the outlet canal, the circular trap may serve as the stationary plasma generator, including that with high hydrogen mono ion content.

REFERENCES

1. B. M. FOMEL, M. A. TIUNOV, V. P. YAKOVLEV, “SAM – AN INTERACTIVE CODE FOR EVALUATION OF ELECTRON GUNS”, Preprint Budker INP 96-11, Novosibirsk (1996)
2. G. I. DIMOV, A. A. IVANOV, G.V. ROSLYAKOV, Fizika plasmy 6, p.933 (1980)