PERMANENT MAGNET CUSP FIELD FOR 18 GHz ECR ION SOURCE

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Abstract

A cusp magnetic field (CMF) configuration is robust in achieving more plasma confinement than a traditional minimum-B field. The classical CMF ECR ion source (ECRIS) [1] had a little success because of huge loss of plasma at the cusp (mainly ring cusp) positions owing to insufficient and asymmetric magnetic field. The CMF has been reconfigured here adopting a simple, novel and cost-effective technique to shrink the loss area [2] and to achieve dense plasma to initiate the confinement by quasi-gas-dynamic process.

INTRODUCTION

Geller's group pioneered constructing ECRIS like MAFIOS and its variants in 1970's and later [3, 4, 5]. Traditional ECRIS have some problems like i) the plasma generated is not axially symmetric, ii) the magnet system is complicated for generating axial and radial field, iii) plasma volume is small, iv) injection and extraction regions are congested and v) vulnerable magnet system. It has been attempted to alleviate the problems in an ECRIS by employing CMF configuration which is herein created by permanent magnet (PM). The plasma density n_e is deduced from $n_e \leq \varepsilon_0 m_e \omega_{rf}^2/e^2$ and given in per cc by $n_e \leq 1.11 \times 10^{10} f_{RF}^2$ in practical notation, where the equality sign corresponds to the critical plasma density and the microwave frequency, f_{RF} in GHz. The critical density *vs*. frequency plot is depicted in Fig. 1

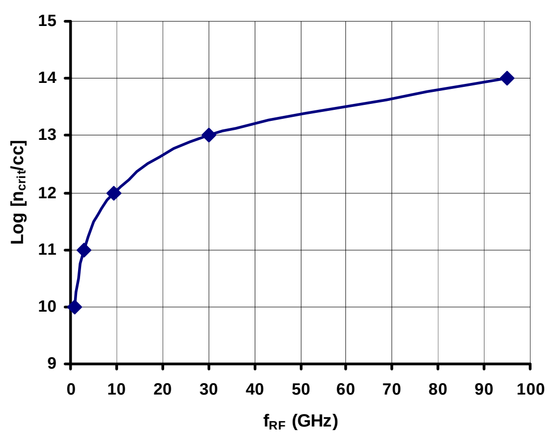

Figure 1: Critical plasma density vs. RF frequency

It is essential to meet the following criteria concerning the magnetic field achieved in the chamber [6]; $B_{max} \geq 2B_{ECR}$, $B_{max} = B_{inj} \geq B_{wall}$, and $B_{ext} << B_{inj}$, where $B_{ECR} = (f_{RF}/2.8)$ kG; B_{max} is the maximum magnetic field at the injection end and B_{ext} is the magnetic field at the extraction end. From empirical scaling laws of ECRIS [4] $<Q_{op}> \propto \text{Log}(B_{max})$ and $I^{Q+} \propto (f^2 n_e V_p)/(A_i^{\alpha} \tau_i)$, where V_p is the plasma volume, A_i and τ_i are the ion mass number and the ion confinement time at the extraction region. The parameter α has value close to 1.

CUSP FIELD FOR 18 GHz USING PM

A cusp is defined as a point of intersection of two arcs or curves at which either the tangents on the curves coincide or are parallel. The FL, PC and RC are field lines, point cusp and ring cusp respectively in Fig. 2. The variation of B_z and B_r along z-axis and R (z=0 radius) are depicted by dashed and dotted curves respectively. The vector potential generated in the CMF configuration is given by $A_\theta(r,z)=(B_0/2z_0)\, rz$, where B_0 is the magnetic field at z_0 on the z-axis. The radial and axial components of the CMF are given by $B_r=-(B_0/2z_0)r$ and $B_z=2(B_0/2z_0)z$ respectively. It constitutes a zero-B field configuration. The plasma pressure, $P_{par} = n_e k_B T_e$, is created mainly by hot electrons, where k_B is the Boltzmann constant. The gravitation-like inward force because of the nature of convex MLF's in the CMF produce a MHD-stable configuration.

The plasma density at 18 GHz or higher frequencies may exceeds 1×10^{12} /cm^3, so the plasma enters into a highly collisional regime. The quasi-gas-dynamic confinement of plasma takes place [7] because of the collisions of the electrons with slow ions on their course of being lost. Then the non-adiabatic motion of electrons at the magnetic centre is insignificant [8].

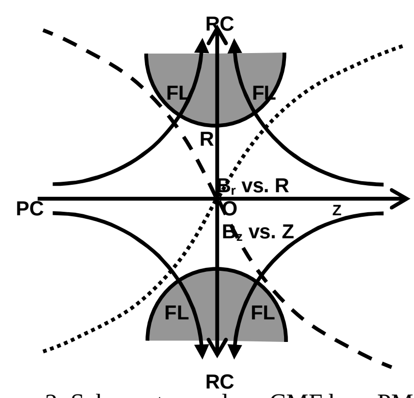

Figure 2: Scheme to produce CMF by a PM ring.

Optimization of the PM geometry and position and plug P (Fig. 3) was done to achieve the maximum field at the cusp positions. Length and diameter of the plasma chamber is 12 cm containing total plasma volume of 1.44 litre. Each of the rectangular blocks represents a ring in cylindrical geometry. The numbered areas have PM's with magnetization angle 20N degree with respect to the radius, where N is the number in the interested area. The CMF so generated is shown in the 3D field plot in Fig. 4. The contribution of the E and P is important and so their placement is very crucial. The plug on the extraction side (say at the RHS in Fig. 3) can be manipulated to reduce the field at the extraction end to widen and open up the loss cone for facilitating extraction of the HCI. The ECR surface of 18 GHz (6.43 kG) in the designed CMF is depicted by the dashed ellipse (oblate spheroid in 3D) in Fig. 3. The ECR surface spheroid (semi-axes a=b=3.82 cm and c=2.23 along x, y and z axes) are large to couple more energy to the electrons crisscrossing the surface.

Nowadays, Nd-Fe-B magnets are used in accelerators and ion sources because of their high remanent field (B_{rem}), coercive force (H_{cor}) and energy product, $(BH)_{max.}$

Table 1: The available Nd-Fe-B strong PM parameters.

Material strength (MGOe)	**B_{rem} (kG)**	**H_{cor} (kOe)**
VACODYM 745HR (50)	14.4	14.0
NEOMAX 5563 (55)	15.0	13.5

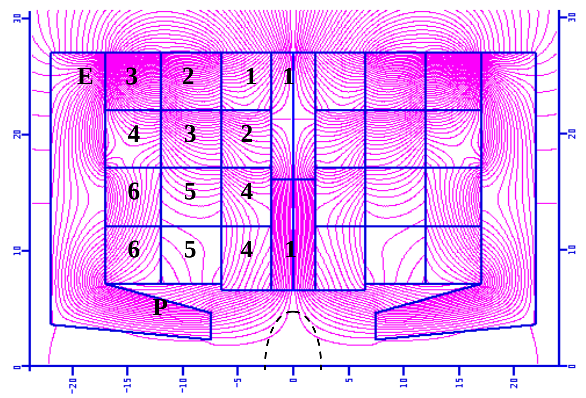

Figure 3: Field structure of 18 GHz cusp ECRIS.

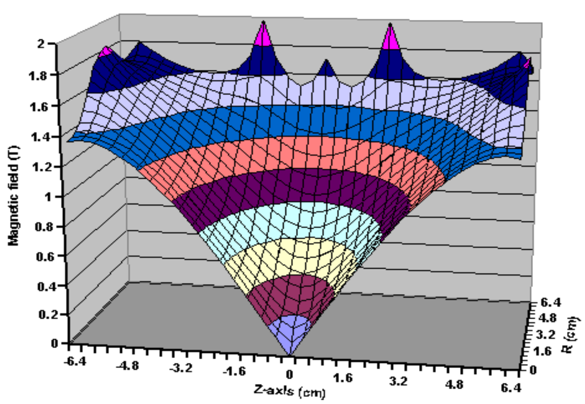

Figure 4: 3D CMF in R-Z plane with shaded strips of width 0.2 T.

BENT MAGNETIC MIRROR

It is seen that the magnitude of the field at the cusp positions is sufficiently high to achieve the high-B mode condition as well as $\pi/4$ angle rotated PC-RC mirror [9]. The mirror ratio , R_m, with respect to the B_{min} on $|z|\approx|r|$ conical plane increases as one goes towards the centre of the field, so the loss cone angle ($\alpha_{apex}= \arcsin(1/\sqrt{R_m})$) narrows down also. The electrons follow the FL's, which form a PC-RC mirror configuration. The electrons get bounced back and crisscross the ECR surface many times to be heated by the microwave to high energy successively. The confinement of these heated electrons is further increased because of the larger perpendicular velocity component ($v_{e\perp}$) than the parallel velocity component ($v_{e\|}$) with respect to the FL followed. These electrons come out of the loss cone area in the velocity space because of the anisotropic velocity components. They interact with the atoms and ions and boost the charge state in stepwise manner. Since the confinement of electrons becomes superb, so the confinement of ions too. This process helps to achieve very high density of contained plasma consisting of the HCI's in the whole large volume of the plasma chamber. It is possible now to extract intense beam of HCI's of desired species according to the current scaling laws. This may require some ingenious design of the extraction system with the combination of additional small PM or coil solenoid to reduce adequately by the reverse magnetic field produced at the position of extraction hole and to focus immediately the extracted beam also. It is also seen that the τ_i in the improved CMF ECRIS is more than in a TMF ECRIS [9] having similar magnetic field.

CONCLUSION

The designed CMF can be operated and used for advanced applications by small laboratories as it is cheap. It has inherent property of MHD stability, so quiescent plasma is contained in such field. Since it does not need any sextupole for radial confinement of plasma, the volume of the plasma chamber increases, which will help in extraction of the intense beam of HCI's. It can be designed for lower RF frequency also. The EM energy can be injected to boost the source operation at several lower RF frequencies simultaneously. Plasma confinement can further be boosted by placing negatively (<-1.0 kV) biased disk and ring at PC and RC positions respectively. A metal-dielectric-disk at PC and ring at RC can act well too

REFERENCES

[1] K. Sudlitz et al. Proc. 12th Intl. Workshop on ECRIS, RIKEN, (1995) p. 217.

[2] M.H. Rashid, Thesis "Studies on Electric … Ion Devices," Jadavpur Univ., Kolkata, 2003.

[3] R. Geller et al, IEEE Tran. Nucl. Sci. **NS-23** 904 (1978); NIM **A 243** 244 (1986).

[4] R. Geller, IEEE Tran. ... **NS-26** 2120 (1979).

[5] R. Geller et al, NIM, **A 184** 293 (1981).

[6] D. Hitz et al, RSI **75** 1403 (2004).

[7] D.D.Ryutov et al, Plas.Phys **28** (1986)191.

[8] S.V.Golubev et al, Tran. Fus...**47** (2005)345.

[9] M.H. Rashid et al, NIM B **262** 95 (2007).