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NEGATIVE HYDROGEN ION MICROWAVE (ECR) SOURCE

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ABSTRACT

There is a possibility of changing the injection into the PSB from proton to H^- charge exchange and a high intensity (>50mA, 500 sec. and 1 pulse per sec.) H^- source would be required for such an application. In this report, the possibility of obtaining high current H^- ion beam using ECR technique is investigated and the design study of a prototype microwave ion source is presented.

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1. Introduction

The development of H^- ion sources lie in the two major areas (i) in fusion plasmas for neutral beam injection and (ii) in accelerators for charge-exchange injection. In accelerators, an injector linac accelerates H^- particles which are subsequently stripped to protons in the ring to be filled. This allows considerable flexibility in the injection process below the space charge limit. The beam brightness may be increased by large factors, while at the space charge limit there is better control of the final beam distribution. The injection of proton by stripping electrons from H^- ions was first carried out at Novosibirsk[1]. Following their success charge exchange H^- injection has become the preferred scheme for many high intensity proton machines and has been adopted in BNL, KEK, and DESY.

Two methods are used to produce H^- ions, volume production and surface plasma interactions. In volume production, energetic electrons from the source plasma excite the H_2 molecules to an electronically excited state $H_2 + e^-(f)$ -----> H_2^* . After radiative decay, ground state H_2 molecules are formed which are vibrationally excited. H^- formation then proceeds by dissociative attachment of vibrationally excited H_2 molecules by slow electrons $H_2^* + e^-(s)$ -------> $H^- + H$ In surface type sources, H^- ions are produced by double electron capture by H^+ at the surface.

In pure volume sources only the dissociative attachment process is assumed to occur where-as in surface conversion sources, the H^- ions are produced at low work function converter surfaces. To improve the possibility that H^- ions(and not electrons) will leave the converter, cesium is added to the source to partially cover it, lower its work function and thereby maximize the H^- yield. Cesium also ionizes easily to produce electrons and ions in the plasma improving the source stability. But, the use of cesium in the source plasma can lead to contamination of the pre injector and erosion of electrodes.

The H^- ions generated by volume production processes have lower beam emittance and thus are useful for the generation of high brightness beam. Most of the volume type H^- sources are multi cusp sources based on filament discharges[2,3]. The plasma is usually contained in a cylindrical chamber surrounded by permanent magnet multipoles that form cusps to confine the electrons. The rear, or production region, of the chamber contain filaments biased to create electrons of sufficient energy to excite hydrogen molecules to high vibrational states. The second region, separated from the first by a magnetic field, is located near the extraction aperture. This field prevents energetic electrons from entering the second region and destroying the H^- ions once produced. Also here, the collision of slow electrons with excited hydrogen molecules produces H^- ions. At the extraction aperture another magnetic dipole allows the H^- ions to pass whilst deflecting electrons.

To achieve high current densities, volume H^- sources require a high discharge power and thus the life of the filament cathode is normally short. Recently, radio-frequency driven plasmas have been studied and developed at Lawrence Berkeley Laboratory[4]. To meet the beam brightness and long and reliable operational requirement the tungsten filament is replaced by an antenna and the plasma is generated by a 2 MHz induction discharge. The source operates at a pressure of 12 m. Torr and 50kW of RF power. An H^- ion current of 39 mA was obtained through a 5.6 mm diameter aperture.

In this connection, microwave ion source has considerable potential for obtaining higher current H^- ion beams. In a microwave produced plasma, the plasma parameters can be well controlled by the experimental parameters. Gas consumption is very low compared to other types of sources. Non filamentary ion sources have distinct advantages over conventional ion sources such as (i) higher beam current, (ii)longer life time, (iii)low beam emittance and (iv) less energy spread. Invariably, all the microwave ion sources are built using ISM band(2.45GHz) magnetron RF source. Thus, the cost of the source is reduced and the source is compact. Since, these sources are built for implanter applications, they are in general compatible with operation in high voltage platform. Also, in microwave ion sources, a high density plasma is obtained by operating at low gas pressure (10^{-4} - 10^{-3} Torr).

Microwave sources have been developed at various laboratories for different applications and their important parameters are presented in Table.1. It is seen from the table that the maximum ion beam current density obtained is ~ 200mA/cm^2 (beam diameter : 0.8mm) and the maximum beam current obtained is ~ 200mA (beam diameter : 40mm). Recently, there has been interest in developing such a source for obtaining negative ion beam. A surface plasma negative heavy ion source with ECR discharge and cesium secondary has been developed at KEK[11]. The ECR plasma was generated by a 2.45GHz magnetron. In preliminary experiments, the beam current of 7mA for Cu^- was obtained in pulsed mode operation. A volume type ion source for producing H^- ions from ECR plasmas was first investigated by Hellblom[12], and more recently Douglar[13], gave an H^- ion beam with a current density of $17mA/cm^{-2}$ from ECR plasma produced in a dipole magnetic field configuration. In this report, the design and fabrication details of a prototype volume microwave ion source for obtaining high current H^- ion beam are presented

2. Details of the proposed Microwave Ion Source

The desired H^- ion beam parameters are : peak current : 50mA; beam diameter : 20 mm; pulse width : 1 m sec and repetition rate : 1 Hz. The source should be made compatible for the operation on a 100 kV high voltage platform and the total power consumption should preferably be less than 3 kW so that it could be used on a standard pre-injector platform. The important components of the microwave ion source are plasma chamber, microwave system, electromagnet and power supply, permanent magnet, beam extraction and diagnostics. The source will also need vacuum pumps, gas flow system and power supplies.

The plasma chamber has two functions namely (i) it couples microwave into the plasma and (ii) it contains the plasma. Various configurations have been used for the plasma chamber, these include cylindrical waveguide, rectangular waveguide, coaxial line, double ridged waveguide, slotted line antenna, cavity and disc type antenna. In the present study for the volume production of plasma, cylindrical waveguide is the best choice. Although, the plasma parameters of the discharges produced using coaxial line and slotted line antenna are higher than the cylindrical waveguide, and considering the sputtering on the antenna surface (these structures are close to the plasma), then a cylindrical waveguide is the best choice. The inner diameter of the plasma chamber was chosen such that it supports TE_{11} mode at 2.45GHz. At one end of the plasma chamber, a rectangular waveguide couples microwave and at the other end, electrodes are connected for ion extraction.

The microwave system consists of a magnetron based microwave power pack and a waveguide transmission line. The parameters of the power pack would be frequency:2.45GHz; power:100-1000W; pulse width:2msec.(fixed); repetition rate:2Hz; output:WR-340 waveguide with rectangular flange; tube:magnetron (Industrial type). Since, waveguide coupling provides better stability than the coaxial coupling[14,15] waveguide is used for coupling microwave into the plasma chamber.

Also, the power dissipation in a waveguide system is less. The various components involved in the transmission line are shown in block diagram Fig.1. Circulator and water load are used to isolate the Magnetron source from any reflection from the load side. The forward and reflected powers are monitored using a dual directional coupler. A triple layer window (formed by Quartz, Alumina and Boron nitride)[16] would be used for the vacuum isolation. Since the inner diameter of the cylindrical waveguide is 90mm, WR-284 waveguide coupling is preferred. So at the end a waveguide transition (WR-340 to WR-284) is connected.

The magnetic field is the combination of cusp field produced by NdFeB permanent magnet and axial field produced by solenoid coils. The two regions of the plasma are separated by a dipole magnet formed by permanent magnet. The specification of the permanent magnets are: size : 5 x 5 x 2.5mm; B : 1.05 Tesla. The solenoid coil is made out of 1 x 2 mm copper strips (rating : 10A; number of turns:1500). Water is used for cooling the coil and the cooling coils are placed between two sets of windings. It is designed that at the operating current of 9.3A, 875 gauss is obtained at the axis.

The assembly of the microwave ion source is presented in Fig.2. The source chamber is divided into two regions. The first region contains broad range of electron energies produced by ECR discharge. Here energetic electrons and wall collisions create high molecular vibrational states. The second region is separated from the first by a magnetic filter so only low energy electrons can pass together with molecular hydrogen in various states and in the second region, H^- ions are created. In order to extract H^- ions with minimum electrons a magnetic filter is again used.

3. Estimation of Extraction of H^- ion current

In steady state, the vibrational excitation to high levels (v=6-14) of hydrogen molecules can be written as

$$n[H_2(v)] = n(H_2)\, n_{th} < v_{th}\, \sigma_v > D\, \gamma / v[H_2(v)]$$

where $n(H_2)$ and $n[H_2(v)]$ are densities of molecules in the ground and excited states, n_{th} and v_{th} are the density and velocity of thermal electrons, $\sigma(v)$ is the cross section of excitation to level v as a result of collisions with cold electrons[17], D is the chamber size and γ is the number of wall collisions of $H_2(v)$ before de-excitation which is assumed to be 10. $v[H_2(v)]$ is the velocity of the excited molecules.

Secondary electrons are produced by hot electron and in addition it can be supplied by gas mixing and external injection. The secondary electron density may be written as

$$n_s = n_h v_h \delta \tau / 2 \quad + \quad f$$

where n_h and v_h are the density and drift velocity of hot electrons, δ is an electron Larmor period, f is the term correspond to the density of cold electron from other sources(gas mixing, filament). The production rate of H^- ions in the extraction region is given by

$$dn(H^-)/dt \quad = \quad \sum_{v=6}^{v=16} \{ n_s\, n[H_2(v)]\, v_s\, \sigma_d(v) \}$$

where v_s is a secondary electron velocity and σ_d is the cross section of the dissociative attachment process[18]. The total extracted H^- ion current can be written as

$$J = e\, \Omega \;\; dn(H^-)/dt$$

where Ω is the volume out of which ions are extracted.

From our calculations, it is observed that the extracted current is controlled by the plasma parameters. The extracted current with and without the external supply of slow electrons is shown in Fig.3. It is seen that adding slow electrons to the source chamber helps to enhance the extracted current by a factor of 2.

4. Optimization Techniques

In the experimental part, H^- ion current would be optimized by employing the following three techniques. (i)In microwave discharge plasmas, the plasma parameters (electron density, temperature and plasma potential) can be changed by varying the experimental parameters namely gas pressure, microwave power and magnetic field. To maximize the H^- ion production, high energy electrons are required in the first chamber where as in the second chamber low energy electrons are needed. By measuring the plasma parameters using an axial Langmuir probe, favorable plasma conditions can be set. (ii)The H^- ion production can be enhanced by adding xenon (or argon) to the first plasma chamber[19]. The positive xenon ions can cross the filter much more easily than the hydrogen ions. These massive xenon ions bring cold electrons into the extraction chamber and they are effective in enhancing the formation of H^- ions. However, there is an optimum xenon gas pressure, above which the discharge becomes too enriched with xenon ions and the H^- output decreases. (iii) Injection of low energy (< 1eV) electrons in the extraction chamber to increase the H^- ion current[20].

The presence of axial magnetic field produced by the solenoid coil may disturb the dipole magnetic field (filter). This will reduce the effectiveness of hot electron suppression. It is to be noted that the cusp magnetic field configuration have several ECR zones in the azimuthal direction. So, the ECR plasma can be produced in the absence of axial magnetic field . Such technique has already been used for producing large diameter plasma for CVD application.

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Table.1 Parameters of Microwave Ion Sources developed at different places

Microwave coupling device	Plasma Parameters	Beam Parameters	Microwave Power	Ref. No.
Cylindrical wave guide	hydrogen	75 mA $\phi \sim 4$ mm	1 kW	5 Chalk River Lab. Japan
Coaxial line	argon $n_e \sim 7x10^{12} cm^{-3}$ $T_e \sim 12eV$	200mA $\phi \sim 40$mm	1kW	6 Hitachi Lab Japan
Cylidrical waveguide	oxygen	160 mA $\phi \sim 30$ mm	1 kW	7 NTT LSI lab. Japan
Double ridged waveguide	hydrogen	40mA 2x40 mm^2	1kW	8 Hitachi Lab. Japan
Slotted line antenna	argon $n_e \sim 7x10^{12} cm^{-3}$ $T_e \sim 12eV$	20mA $\phi \sim 10$mm	1kW	9 CAT, India
Disc type antenna	argon	2mA $\phi \sim 2$mm	30W	10 Kyoto Univ. Japan

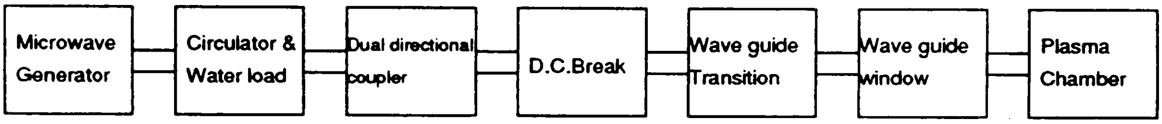

Fig.1 Block diagram of Microwave feed structure

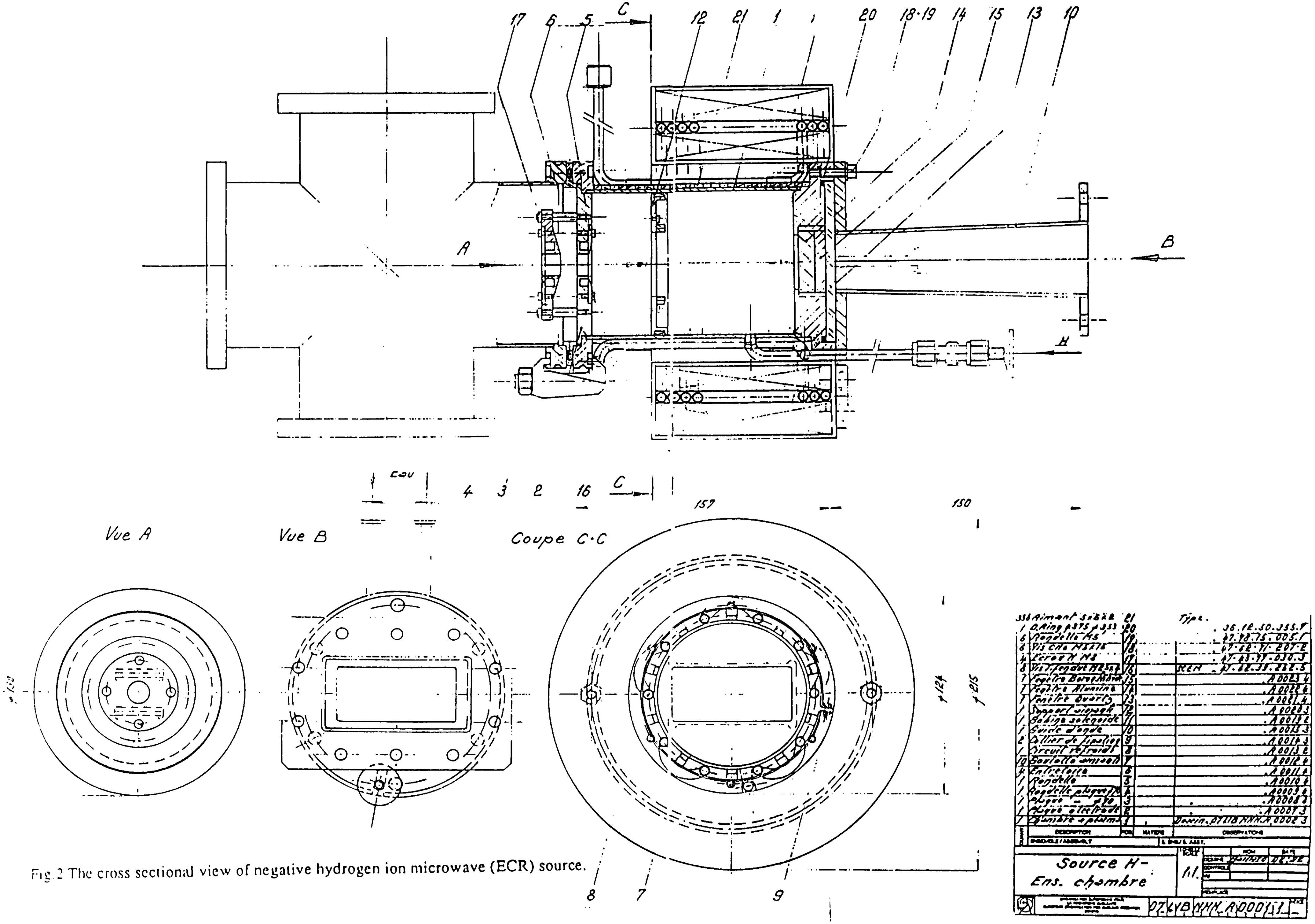

Fig.2 The cross sectional view of negative hydrogen ion microwave (ECR) source.

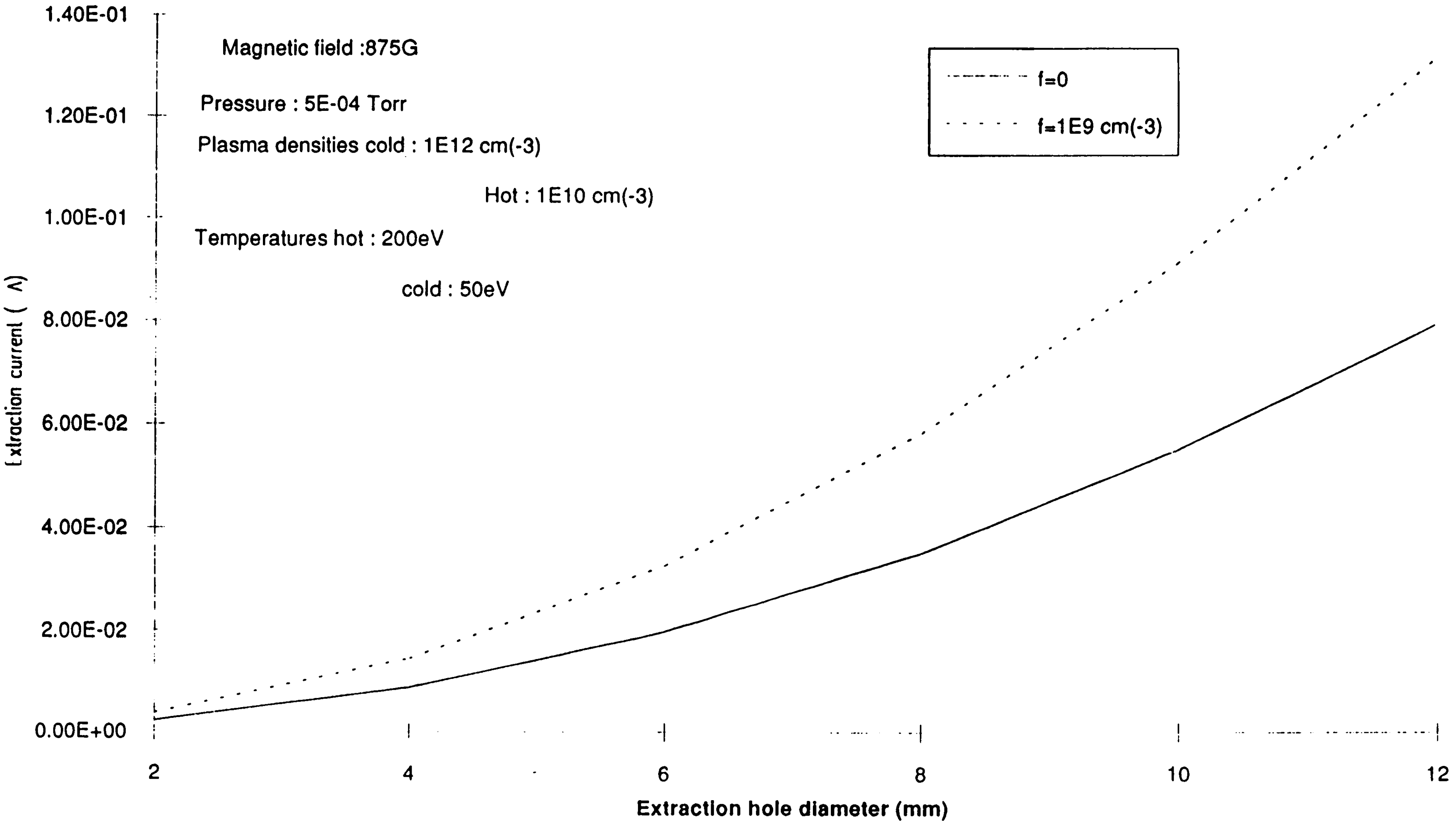

Fig.3 Extraction current with and without external supply of electrons

ANNEXURE

ITEMS TO BE FABRICATED

Name of the Items	CERN drawing numbers
Waveguide Transition	07 LIB NHH-A00153, 07 LIB NHH-A00163 07 LIB NHH-A00173, 07 LIB NHH-A00183
Solenoid coil	07 LIB NHH-A00192
Extraction grids	07 LIB NHH-A0073, 07 LIB NHH-A0083
Fixtures for magnets	07 LIB NHH-A00143, 07 LIB NHH-A00203
Cooling tubes	07 LIB NHH-A00132
Plasma chamber	07 LIB NHH-A00023, 07 LIB NHH-A00033 07 LIB NHH-A00043

MAJOR ITEMS TO BE PROCURED
MAGNETRON POWER PACK(AS PER THE SPECIFICATION GIVEN IN SECTION 2.
VACUUM PUMPING SYSTEM
LINE VOLTAGE STABILIZER WITH RATING 10kW
WATER COOLING PLANT WITH CAPACITY 400W AND OPERATING TEMPERATURE 20°C
POWER SUPPLY FOR SOLENOID COILS
POWER SUPPLY FOR ION BEAM EXTRACTION
WAVEGUIDE COMPONENTS (DUAL DIRECTIONAL COUPLER, CIRCULATOR, WATER LOAD AND D.C.BREAK.
NdFeB OR SmCo PERMANENT MAGNETS