DESIGN AND DEVELOPMENT OF HIGH INTENSITY ECR PROTON SOURCE FOR LEHIPA

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Abstract

Electron cyclotron resonance (ECR) proton source at 50 keV, 50 mA has been designed and developed for the low energy high intensity proton accelerator LEHIPA. Plasma characterization of this source has been performed. ECR plasma was generated with 400 - 1100 W of microwave power at 2.45 GHz, with hydrogen as working gas. Plasma density and temperature was studied under various operating conditions, such as microwave power and gas pressure and the typical hydrogen plasma density and electron temperature measured were 7 x 10^{11} cm^{-3}, and 6 eV respectively. The total ion beam current of 42 mA was extracted, with three-electrode extraction geometry, at 40 keV of beam energy. The extracted ion current was studied as a function of microwave power and gas pressure. The optimization of the source is under progress to meet the requirement of long time operation. The required rms normalized emittance of this source is less than 0.2 ð mm-mrad. The simulated value of normalized emittance is well within this limit and will be measured shortly. This paper presents the study of plasma parameters, first beam results, and the status of the ECR proton source.

Keywords: Ion source, Beam extraction

Introduction

The high beam power (MW) proton accelerators of GeV energy are now being built in several countries for ADS applications. As a first step towards this goal in India, a 20 MeV, 30 mA proton accelerators LEHIPA [1] (Low Energy High Intensity Proton Accelerator) is under development at BARC. LEHIPA consists of H^+ ion source at 50 keV will be accelerated to 3 MeV by Radio Frequency Quadrupole (RFQ) and to 20 MeV by an Alvarez type DTL.

High intensity cw ECR proton source with good beam quality and high reliability is the essential requirement of LEHIPA. A desirable property of such source is that the proton fraction of the extracted beam be as high as possible so as to avoid the need for selection of the desired ion i.e. to enable direct injection into RFQ accelerating structure.

A microwave based ECR proton source has been designed and indigenously developed for LEHIPA [2-4]. The key components of ECR proton source are plasma chamber, vacuum system, microwave system, solenoid magnets, plasma diagnostics devices, beam extraction electrodes, and beam measuring devices. Detailed description and measured results of this source are presented in this article.

Source development

The schematic of ECR proton source is shown in Fig. 1. The source parameters are presented in Table I.

Microwave system

The microwave system in Fig.1 has been designed using WR-284 waveguide section. The microwave system was sourced by a variable power magnetron (2 kW) at a frequency of 2.45 GHz. A circulator was used to protect

Table 1: Source requirement and status

Parameters	Required	Status
Beam energy	50 keV	40 keV
Beam Current	50 mA	42 mA
Discharge Power	< 2 kW	0.5 – 1.1 kW
Frequency	2.45 GHz	2.45 GHz
Axial Magnetic Field	875 – 1000 G	875 – 1000 G
Duty Factor (%)	100 (dc)	100 (dc)
Gas flow rate	< 2 sccm	0.4 - 1.3 sccm
Gas	Hydrogen	Hydrogen
Proton Fraction	> 80 %	To be measured
Beam Emittance	< 0.2 mm-mrad	To be measured

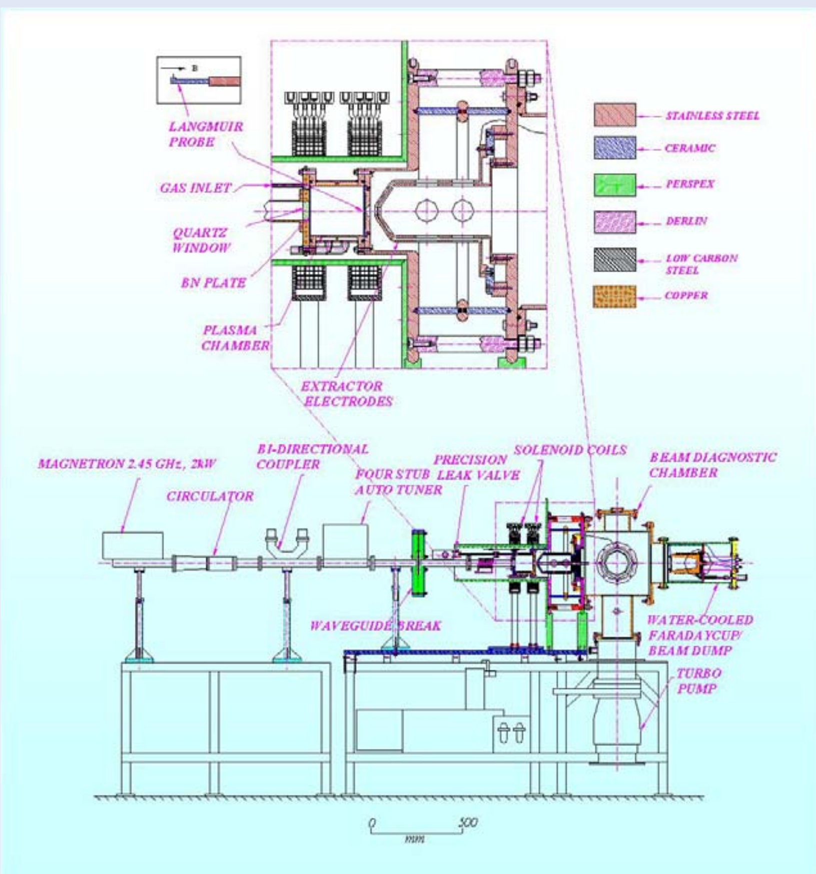

Fig. 1: Schematic of ECR proton source

the magnetron from load (plasma) reflection. The four stub auto tuner was used for waveguide to plasma impedance matching.

The microwave power was monitor using a directional coupler with diode detector and a calibrated analog meter. A ridge waveguide developed in house was used for (1) optimizing the coupling between the microwave generator and the plasma chamber that realizes a progressive match between the impedance of waveguide and impedance of plasma chamber and (2) concentrating the electric field at the chamber axis to maximize the resonance. The quartz window provides vacuum isolation to plasma chamber. The waveguide break was used for the isolation of the microwave system to the plasma chamber that is floated at high potential.

Magnetic field

The magnetic field required to satisfy ECR resonance condition is $B = 2 \pi f m / e$, where f = microwave frequency in (Hz), m = mass of the electron (kg), and e = electronic charge (C). The resonant magnetic field corresponding to microwave frequency of 2.45 GHz is 875 G. The magnetic field in the plasma chamber was simulated using POISSON. The solenoid coils placed around the plasma chamber produces the necessary magnetic field for ECR resonance condition. The measured and simulated magnetic field

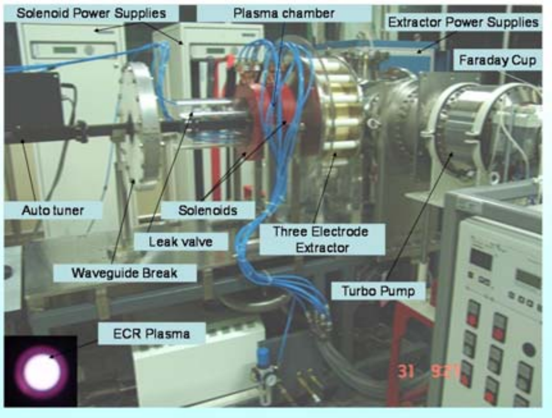

Fig. 2: ECR proton source on test stand

distribution along the axis of the source was found to be in close agreement.

Plasma chamber and vacuum system

The plasma chamber performs two roles: it couples microwave power to plasma and it contains plasma. The dimensions of the plasma chamber are 90 mm in diameter and 100 mm in length and it is used to accommodate the solenoid coils and extraction geometry. Gas breakdown and formation of plasma has been observed in this chamber for microwave power ~ 300 W in the presence of ECR field of 875 G and gas pressure of 10^{-4} -10^{-3} mbar. The plasma chamber and the associated vacuum systems are fabricated using stainless steel 304L. The vacuum chamber has four ports. These ports are used for connection to pump, to plasma chamber, view port, pressure gauge and Faraday cup. All the vacuum components are electro-polished and helium leak tested. The leak rate was better than 5 x 10^{-10} mbar l/s. The ultimate vacuum requirement is less than 1 x 10^{-6} mbar. Turbo molecular pump, with the hydrogen pumping capacity of 2000 l/s, and a dry roughing pump was selected by considering gas throughput (≈ 2 x 10^{-3} mbar l/s) to maintain a pressure of the order of 10^{-4} - 10^{-3} mbar in plasma chamber, 10^{-6} - 10^{-5} mbar in extractor chamber, and to get hydrocarbon free clean vacuum. A gas dosing system consisting of a high purity gas cylinder, a pressure regulator, precision leak valve and a flow controller was installed.

Beam extraction electrode geometry

The three electrode extraction geometry (acceleration – deceleration) for 50 mA / 50 keV beam energy was designed and fabricated to extract the proton ion beam from the source. The parameters of the extraction geometry viz. electrode apertures, electrode gaps and electrode shapes were optimized to reduce beam divergence and emittance using beam trajectory simulation software PBGUNS. The space charge effect of the beam is incorporated in the code. A five electrode extractor is also under fabrication.

Beam characterizations

A beam line has been designed and under development to measure proton beam emittance and proton fraction. The beam line consists of two solenoid magnets, x-y steering magnets, analyzing magnet and emittance measurement unit. The beam line has been designed using TRANSPORT and GPT software. The profile of the beam is measured using CCD cameras. An emittance measurement unit is under development using two slits and a collector. The proton fraction is measured using an analyzing magnet and a Faraday cup.

Results and discussions

Plasma characterization

The experiment was aimed at verification of high density plasma production with the variation of microwave power, gas pressure and to vary the magnetic field to match the ECR conditions in the plasma chamber. The results are obtained with Langmuir probe at different microwave power and gas pressure. As the microwave power is increased from 400 W to 1100 W there is increase ionization leading to increase in plasma density from 4.2 x 10^{11} cm^{-3} to 7.2 x 10^{11} cm^{-3} and decrease in electron temperature from 6 eV to 2.5 eV. This phenomenon is related to the dependence of the electron temperature on the mean free path between collisions of charged species. As the density increases, the mean free path decreases between collisional events. Therefore, an electron looses more of its energy on average in high-density plasma than in low density plasma. Similar trends have been observed at other flow rates.

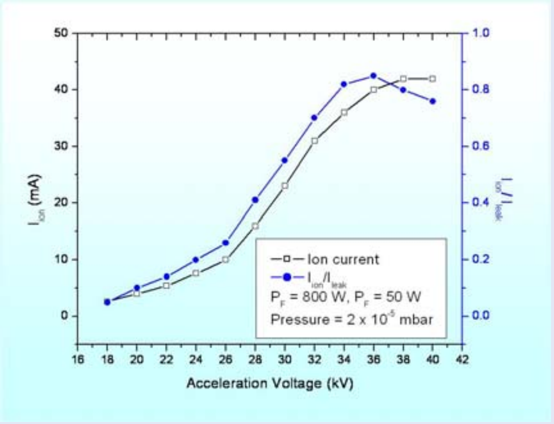

Fig. 3: The ion current and the ratio of ion current to the power supply's leakage current as a function of acceleration voltage.

Beam extraction

The ion extraction experiment was conducted when the ECR plasma was established. The plasma electrode was kept at + 50 kV and the suppressor electrode at – 2 kV. The total measured ion current is plotted versus acceleration voltage as shown in Fig. 3. Also plotted in the figure is the ratio of the measured ion current and the measured power supply leakage current. A Faraday cup with secondary emission electron suppression was used to measure the total ion current. It was observed that the ion current increases more or less linearly with the increase in extractor voltage. The saturation point of the extracted ion current is where the leak current has reached a minimum i.e., at 36 kV in Fig. 3. The extracted ion current was studied as a function of microwave power at various gas pressures. In the pressure range studied i.e., 8 x 10^{-6} mbar to 1.8 x 10^{-5} mbar, the beam current was found to increase linearly with gas pressure.

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