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DEVELOPMENT OF A TEST BENCH OF 2.45 GHz ECR ION SOURCE FOR RFQ ACCELERATOR

Sudhirsinh Vala†, Ratnesh Kumar, Mitul Abhangi, Rajesh Kumar and Mainak Bandyopadhyay,
Ins-titute for Plasma Research, 382428 Gandhinagar, India
also Homibhabha National Institute, 400094 Mumbai, India

Abstract

The optimization of beam quality at the entrance of a RFQ system requires a test bench for the optimization of the ion source and beam parameters. The aim of this test bench is to produce a 5 mA proton/deuterium beam with rms normalized emittances lower than *0.2 pi.mm.mrad* for the 5 MeV RFQ. This bench consists of an indigenously developed permanent magnet based 2.45GHz ECR ion source with three electrode ion extraction system and a LEBT to match the beam for the injection into the RFQ. The LEBT system has been designed using TRACEWIN© code. The LEBT parameters have been optimized in order to maximize the beam transmission through the RFQ.The ECR ion source test bench has been setup and operated up to 50 kV. The plasma parameters of the ECR ion source have been measured using optical emission spectroscopy system. The electron temperature and electron density are typically 3.6 eV to 1.3 eV and 1- 6 × 10^{19} m^{-3} at chamber pressure in the rang of 10^{-4} torr to 10^{-5} torr respectively. Deuterium ion beam of 9.8 mA is extracted from the test bench.This paper presents the design of the test bench, results of latest extracted ion beam and plasma parameters

INTRODUCTION

Institute for Plasma Research is developing a Radio Frequency Quadruple (RFQ) based 5-MeV accelerator facility for fusion material studies. The 5-MeV RFQ accelerator is mainly consist of an ECR ion source, a Low Energy Beam Transport (LEBT) system and a RFQ [1]. The low-energy transport between the ion source and the RFQ, is probably the utmost complex portion of any linear accelerator. LEBT plays an important role to transport the beam from ion source to RFQ as well as in matching the beam properties at the injection plane of the RFQ i.e., twiss parameters α_{Twiss}, β_{Twiss}, γ_{Twiss} and the emittance ε. The main objective of the development of this ECR Ion Source (ECRIS) test bench is to produce a 5 mA H+/D+ pulse/CW ion beam up to 50 keV energy with rms normalized emittance lower than 0.2 π•mm•mrad, as per the requirements of the RFQ accelerator. This paper presents development of the test bench setup, results of ion beam extraction and plasma parameters and the design of the LEBT system.

† sudhir@ipr.res.in

SETUP OF ECR ION SOURCE TEST BENCH

ECR ion source test bench consists indigenously developed 2.45 GHz ECR ion source followed by three electrode ion extraction system, Einzel lens, vacuum chamber, beam profile monitor, faraday cup and the control system. The photograph of the ECR ion source test bench is shown in Fig.1.

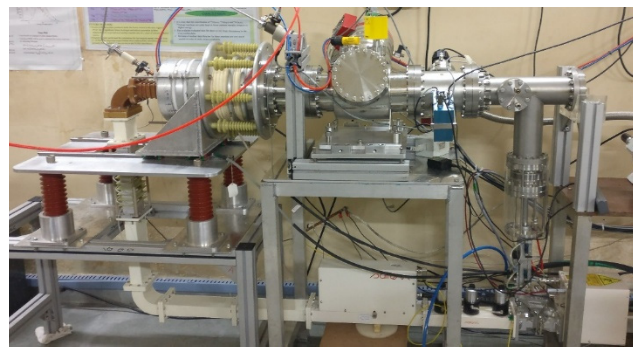

Figure 1: Experimental setup of ECR ion source test bench.

The ECR ion source is floated on a 50 kV high voltage platform. 50 kV HVDC isolation break is present between the ECR ion source and the 2.45 GHz microwave source system. 2.45 GHz microwave is transferred from the microwave source to the plasma chamber of the ECRIS through 3-stub tuner, 50 kV HVDC break, vacuum window, 90 degree bend and a 3-step ridge wave guide. Two 3mm Boron nitride disks are placed at the both end of the circular water cooled plasma chamber. One boron nitride disk at inlet side protects the microwave system from the back streaming electrons from the plasma and also provide the vacuum barrier between the plasma chamber and microwave system. The other disk, near the extraction side, covers the plasma electrode to avoid the high outgassing during plasma discharge [2]. To achieve the resonance magnetic field of 0.0875 T for 2.45 GHz frequency, three axially magnetized permanent NdFeB ring magnets are used. Each ring consists of 24 elementary NdFeB magnet of pre-defined shape and sizes [3-4].

To extract the high quality bright beam from the ECR ion source, a three electrode accel-decel system have been installed. In accel- decel extraction system, first plasma electrode placed at positive 50kV followed by accel electrode at the -2 kV and then decel electrode at ground potential.

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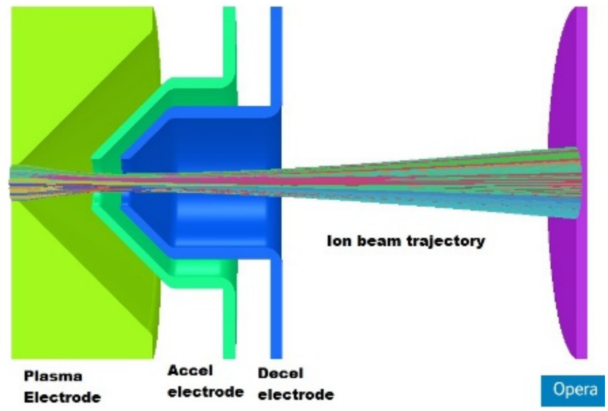

Figure 2: Simulation results of ion beam trajectory of Three Electrode extraction system .

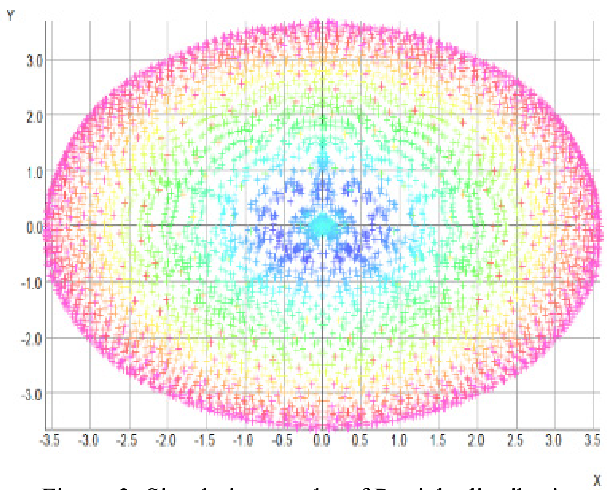

Figure 3: Simulation results of Particle distribution.

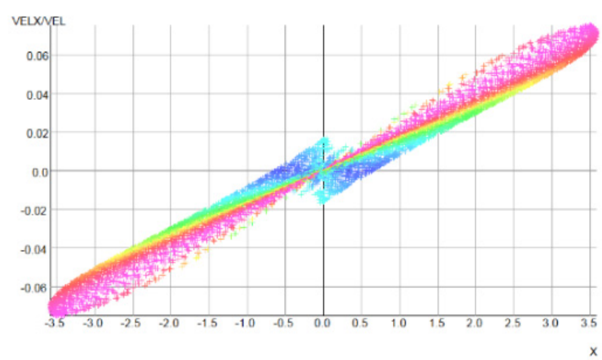

Figure 4: Emittance plot

The extraction aperture of the plasma electrode, accel electrode and decel electrode are 6 mm, 8mm and 8mm respectively. The gap between plasma electrode to accel electrode and accel electrode to decel electrode are 12 mm and 2mm respectively [5-6]. The optimization of electrode size and shape is done with Opera-3D particle trajectory simulation code [7]. The simulated particle trajectory of the extracted deuterium beam and the results of simulated beam profile are shown in Figs. 2 and 3. The calculated normalized emittance of the simulated ion beam is 0.21 pi mm mrad. The Phase plot of the emittance is shown in Fig. 4. To focus the extracted ion beam into the LEBT, three electrode Einzel system has been installed in the test bench. In the Einzel lens, the outer two electrodes are placed at the ground potential and the middle electrode is supplied up to 20 kV positive high voltage [8]. Each electrode is fabricated using ETP copper having same dimension of 63 mm internal diameter and 53 mm in length. Both outer electrodes are separated by 10mm gap from the middle electrode. Beam focusing simulation have been performed with LORENTZ 3EM code and its ion beam trajectory is shown in Fig. 5 [9]. All the electrodes are placed in the stainless steel vacuum chamber with 35 kV high voltage feed through. The photo graph of the Einzel lens assembly is shown in Fig. 6.

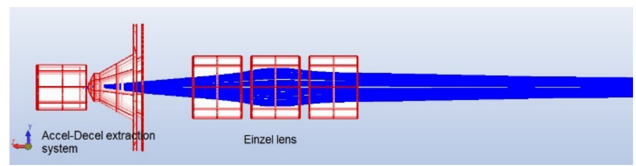

Figure 5: Ion beam trajectory profile using einzel lens.

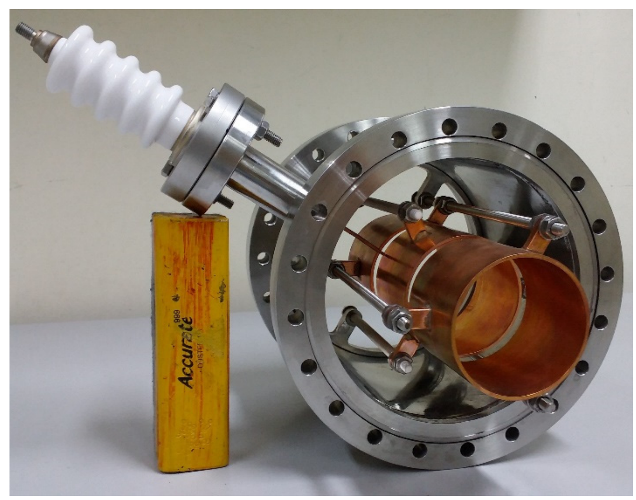

Figure 6: Photographs of Einzel lens assembly.

For the diagnostic of the ion beam parameters, a wire scanner type NEC make beam profile monitor (Model No: BPM-83) and a Pantechnik make faraday cup have been installed in the test bench. One set of turbo molecular pumping system with valves and gauges have been integrated in the test bench to achieve base vacuum of the order of $\sim 10^{-7}$ torr.

Control system of ECR ion source plays an important role in the safe and stable operation of the test bench. The Programmable Logic Control (PLC) based control system is adopted to control the ECRIS. This control system consists of status monitor, status control and device control. The 2.45 GHz microwave source, 50 kV extraction power supply, -3kV accel power supply, 20 kV focusing power supply and mass flow controller have been controlled by 0-10 V analog signal. TMP, Water chiller and hydrogen generator are controlled by digital signal.

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RESULTS AND DISCUSSIONS

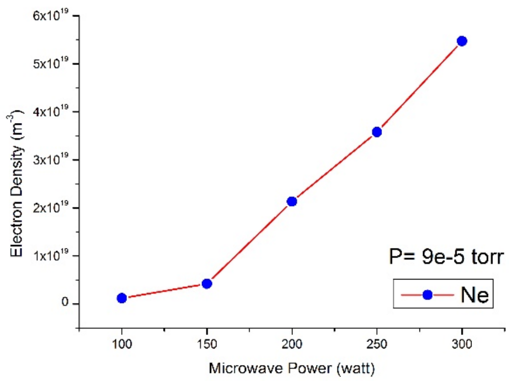

Figure 7: Results of electron density measurement as function of microwave power.

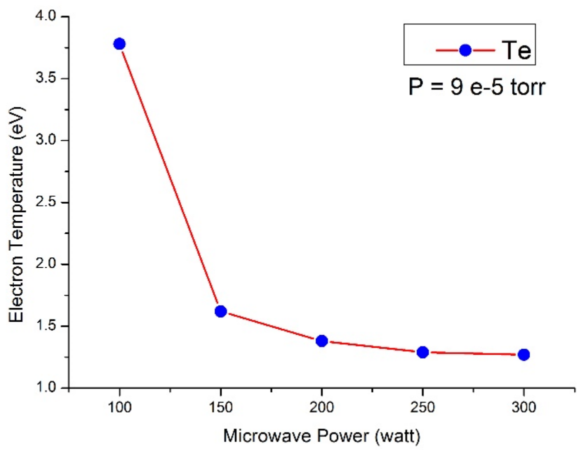

Figure 8: Results of electron temperature measurement as function of microwave power.

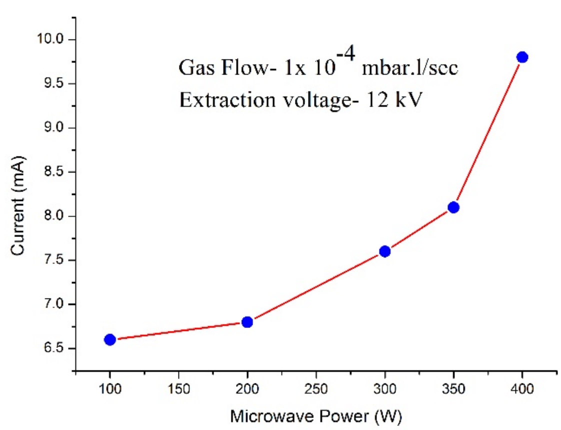

Figure 9: Results of beam current measurement as function of microwave power.

Prior to the fitting of the ion extraction system, the plasma parameters were measured with the optical spectroscopy system [10]. In first set of experiment, the electron density and electron temperature were measured as function of chamber pressure (10^{-4} torr to 10^{-5} torr) and microwave power (100W-300W). The electron temperature and electron density were typically 3.6 eV to 1.3 eV and 1-6 × 10^{19} m^{-3}. Measurements of plasma temperature and density are shown in Figs. 7 and 8. It is found that plasma is over dense.

The ECR ion source has been tuned for extraction of deuterium ion beam. The beam current as a function of microwave power with constant gas flow rate of 1 × 10^{-4} mbar l/s were measured and the results of it is shown in Fig. 9. Maximum 9.8 mA deuterium beam current was extracted at 400 W microwave power and 14 kV extraction voltage. During experiment it is observed that the focusing of ion beam by einzel lens is not effective for high current ion beam. It is decided to replace the einzel lens by a magnetic lens to achieve a better focusing.

DESIGN OF LEBT

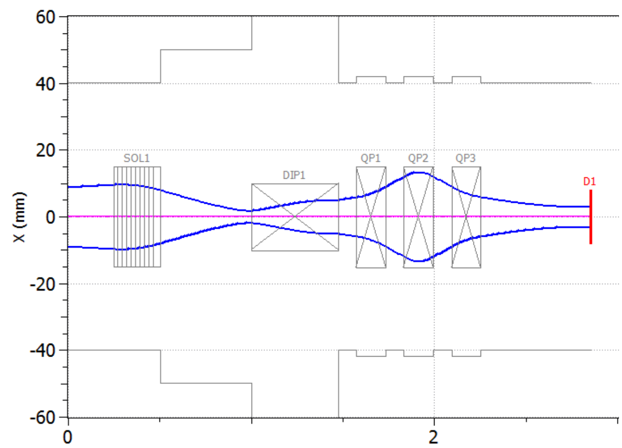

Figure 10: Beam envelop of x-axis for 7 mA ion beam current thorugh LEBT.

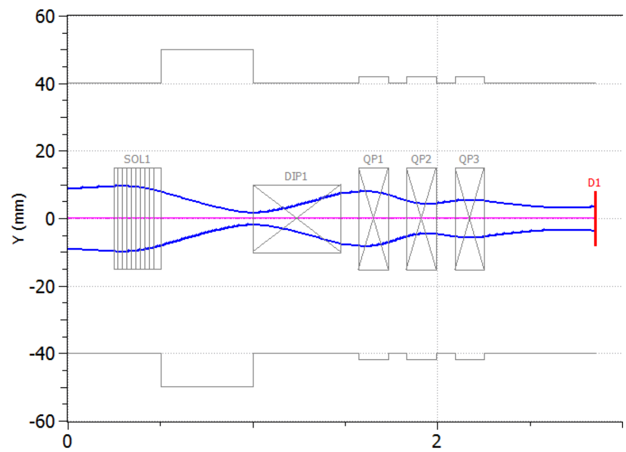

Figure 11: Beam envelop of Y-axis for 7 mA ion beam current thorugh LEBT.

LEBT consists of Magnetic lens (solenoid), Analysing magnet, Quadrupole Magnetic Triplet (QMT) and diagnostics for beam parameters. The conceptual parameters for the beam line components are frozen by analytical calculations. The design of the LEBT has been done using the TRACEWIN code [11]. The LEBT transports the beam

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from the ECR ion source to the entrance of the RFQ. The solenoid focuses the extracted ion beam into the 90 degree analysing magnet, which analyses the ion beam and separates the un-wanted ion species from the ion beam and transports the D^+/H^+ ions. The analysed D^+/H^+ ion beam is again focused into the RFQ by using QMT and then to the beam diagnostics system. The beam diagnostics system includes Beam Profile Monitor (BPM), Emittance scanner and Faraday cup to measure the beam profile, emittance and beam current respectively. The space charge effect has been observed during the simulation and same is optimized during the iteration of the simulation by Space Charge Compensation (SCC). The provision of the SCC is incorporated in the design of LEBT. The optimized beam envelop of x-axis and y-axis for 7 mA ion beam current with 90% SCC are shown in the Figs.10 and 11.

FUTURE PLANS

For the better focusing of the ion beam in to the LEBT, Einzel lens will be replaced with the magnetic lens (Solenoid). Typical length of the solenoid is 255 mm with 0.35 T uniform magnetic field. It is under fabrication and it will be installed soon. To measure the beam emittance at RFQ entrance, dual Allison emittance scanner will be integrated in to the test bench.

SUMMARY

The ECR ion source test bench has been set up and the ECR plasma has been generated using microwave power 100–400 W. The plasma parameters are measured in the ion source using optical spectroscopy method. The measurement of plasma density with different microwave power shows that the plasma is over dense and density of plasma is 500 times than critical density. The extraction system and focusing system have been mounted on ECR ion source test bench and it has been tuned for the beam extraction as function of extraction voltage, microwave power and gas flow rate.

ACKNOWLEDGMENT

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