Development of high current pulsed H^- ion source and ECR ion source for the injector Linac at RRCAT

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Abstract. Development of a high current H^- ion source to serve as an injector for the front end H^- Linac operating at 50 keV energy and 30 mA current has been initiated at Raja Ramanna Centre for Advanced Technology (RRCAT), Indore. A prototype filament driven multi-cusp H^- ion source with three-electrode ion extraction system has been designed, fabricated and undergoing trial runs of operation at ≤10 keV energy to generate ion beam current ≤1 mA. In the first phase of the plan, development of front end linac operating at 3 MeV energy and 30 mA current along with prototype fabrication of DTL and SFDTL structures, is envisaged. We report here on the progress made in the recent past towards development of a prototype filament driven multi-cusp H^- ion source. After completion of physics design of multi-cusp magnetic field using 12 Nd-Fe-B permanent magnets the designed parameters have been verified with the experimental results obtained using a 3D Hall-probe system used for field mapping inside the cylindrical plasma chamber. Placement of tungsten filament is done in the central field free region in triple hair-pin and helical shape. The low temperature, low density plasma generated in the multi-cusp field through filament heating has been characterized using a Langmuir probe technique. The ion beam extraction has been performed using three-electrode extraction geometry. Initial test performed using 5 kV field between plasma electrode and ground electrode has resulted in generation of 0.75 mA of hydrogen ions beam current. Further studies will be carried out after deployment of filter magnets and electron steering magnets to remove co-extracted electrons and test the H^- ion beam. We have attempted to perform generation of stable hydrogen ions beam using microwave generated CW ECR plasma source under solenoid fields in resonance conditions. Hydrogen ions beam of 7.8 mA has been extracted at 25 kV accelerating field using three-electrode flat shape ion extraction geometry. The extraction geometry is being optimized using IGUN code with Pierce geometry angle between the plasma and puller electrodes with suitable gap between the electrodes to deliver high perveance and high brightness ion beam. Efforts will be made to operate ECR ion source as pulsed H- ion source, suitable for injector linac.

Keywords: H- ion source, filament heating, multicusp field, permanent magnets, Hall probe, ion extraction, ECR ion source,Pierce angle geometry, Perveance, Injector, Linac
PACS: 29.25.Ni, 52.25.Os, 52.50.Sw, 52.75Xx

INTRODUCTION

Development of a high current H^- ion source to serve as an injector for the front end H^- Linac operating at 50 keV energy and 30 mA current [1-3] was initiated at Ion Source Laboratory of Proton Linac & Superconducting Cavity Division of RRCAT. A prototype filament driven multi-cusp H^- ion source with three-electrode ion extraction system similar to J-PARC system [4] has been designed, fabricated, assembled (see Fig.1) and presently undergoing trial runs of operation up to 5 kV accelerating field.

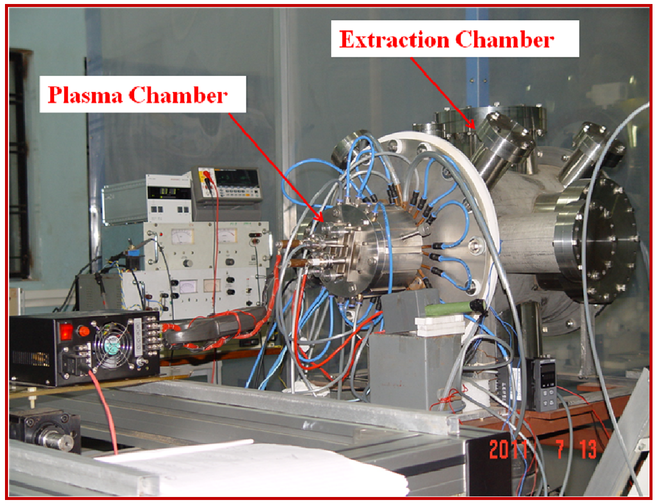

FIGURE 1. Experimental setup of prototype multi-cusp filament based pulsed H^- ion source.

After completion of physics design of multi-cusp magnetic field using 12 Nd-Fe-B permanent magnets, the designed parameters were verified with the experimental results obtained using a 3D Hall-probe system used for field mapping inside the cylindrical plasma chamber [5] . Placement of tungsten filament is done in the central field free region in triple hairpin and helical shape.

Plasma Characterization and Ion extraction

The low temperature, low density plasma generated in the multi-cusp field (See Fig. 2) through filament heating has been characterized using a Langmuir probe technique.

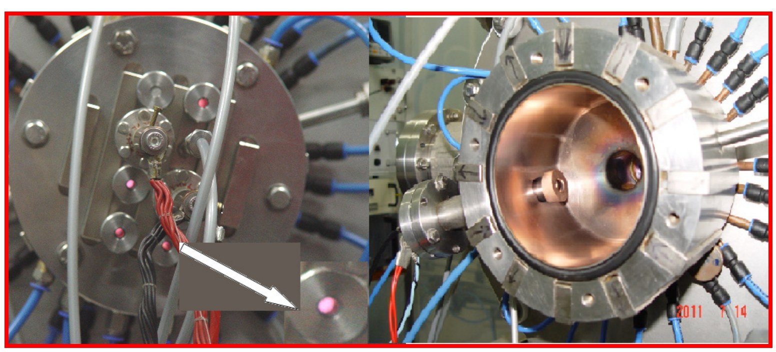

FIGURE2. Hydrogen plasma seen through the quartz glass windows generated inside the multi-cusp plasma chamber and placement of Langmuir probe inside the plasma chamber used for characterization.

The optical emission spectra from the plasma was recorded using an optical spectrometer covering UV to IR range. The spectral line emissions observed in the spectra (See Fig. 3) corresponds to particular ion species present in the plasma. In order to characterize the plasma, Langmuir probe was placed (Fig. 2) inside the plasma chamber and probe tip was biased with positive and negative bias voltages to record the plasma current due to electrons and ions. The plasma characteristics were obtained by analyzing the Langmuir data as shown in the Fig.4 .

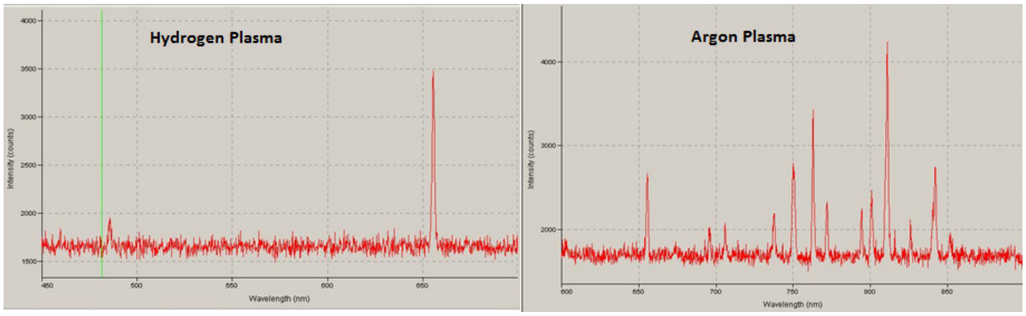

FIGURE3. Hydrogen and Argon ion optical emission spectra recorded from the plasma generated with filament heating and gas discharge.

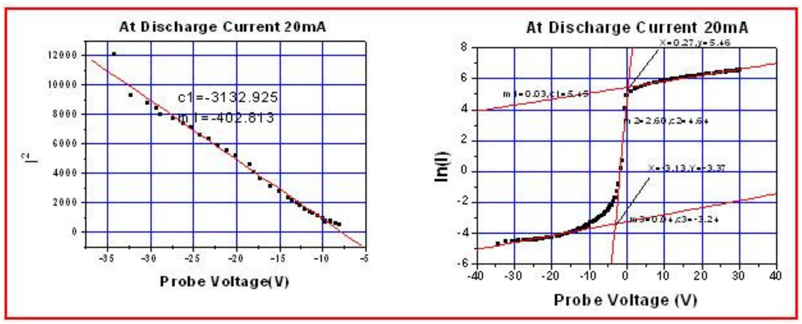

FIGURE4. Plasma characterization using Langmuir probe data.

TABLE 1. Plasma parameters obtained by analyzing the Langmuir probe data

Gas discharge current (mA)	Electron temperature T_e(eV)	Electron density N_e(/cm^2)	Floating potential V_f(Volts))	Plasma potential V_p (Volts))
20	0.383	1.416 x10^{10}	-3.131	0.275
30	0.430	2.648 x10^{10}	-2.86	1.618
40	0.570	2.587 x10^{10}	-3.21	1.494

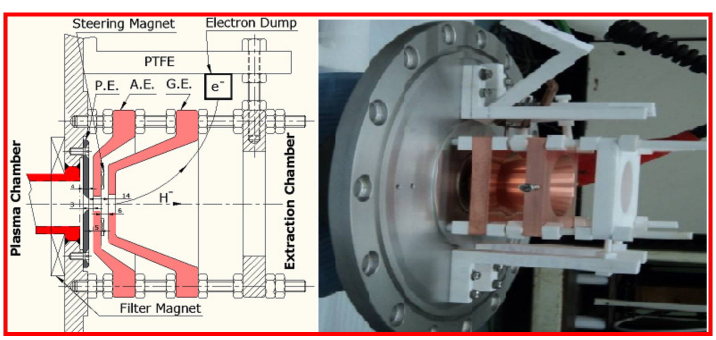

FIGURE5. Three-electrode ion extraction system having plasma electrode (PE), accelerating electrode (AE) and ground electrode (GE) with PTFE insulation.

The ion beam extraction was performed using three-electrode extraction geometry (See Fig.5). Initial test performed up to 5 kV accelerating field between plasma electrode and ground electrode has resulted in generation of 0.75 mA of hydrogen ions current. Further studies will be carried out after deployment of filter magnets and electron steering magnets to remove co-extracted electrons and test the H^- ion beam.

Hydrogen ion beam extraction from ECR ion source

The electron cyclotron resonance ion source (ECRIS) has been developee [5] to serve as an injector to front-end proton linac system. The entire experimental set-up of the ECRIS is shown in Fig. 6. Recently we have performed hydrogen ion beam extraction at 25 kV accelerating field and successfully extracted 7.8 mA of stable hydrogen ions beam current as shown in the Fig. 7. There is a plan to improve the electrode geometry and convert the ECRIS in to a pulsed H^- ion source with significantly higher lifetime similar to the international efforts being made at different places.

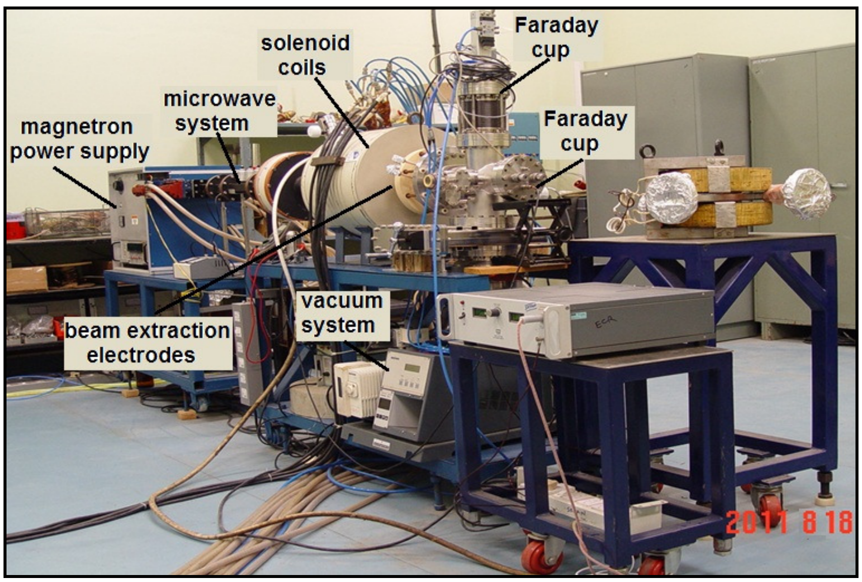

FIGURE 6. Photograph of the complete set-up of electron cyclotron resonance ion source

The measured ion beam current versus accelerating field shows a nearly linear behavior with a slope of 1.6, which closely matches with the slope of 1.5 expected from the Child-Langmuir law ($I \alpha V^{3/2}$) for space charge limited ion current. The nature of the ion beam was determined by properly biasing the Faraday Cup. In the above measurements, the Faraday Cup was at zero potential. By applying a suitable negative bias voltage to the Faraday cup, it was ensured that there was no contribution due to electrons in the measured current.

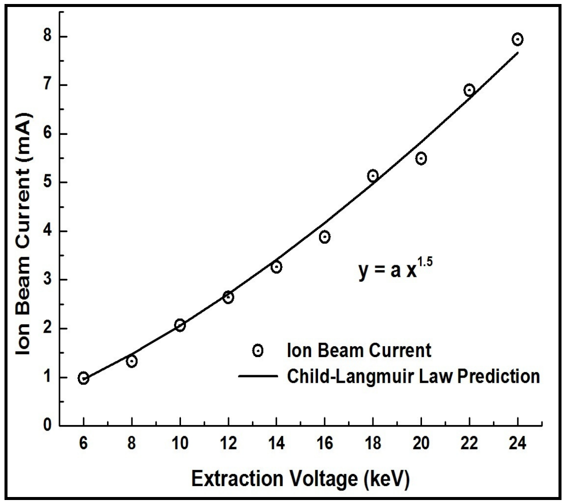

FIGURE 7. The variation of the measured ion beam current with applied extraction voltage of 25 kV.

CONCLUSIONS

Testing of multicusp plasma and ion extraction system of H^- ion source was carried out. The Characterization of hydrogen and argon plasma using the Langmuir probe and optical emission spectroscopy was performed. Hydrogen ions beam current of 0.75 mA was recorded using 5kV accelerating field between the plasma and ground electrode. ECR ion source has been operated up to 25 kV accelerating field and with 600 W, 2.45 GHz microwave power leading to hydrogen ion current of 7.8 mA in cw mode using the flat electrode geometry.

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