ELECTRON CYCLOTRON RESONANCE PLASMA DIAGNOSTICS TO STUDY MICROWAVE POWER COUPLING WITH LANGMUIR PROBE

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Abstract

An electron cyclotron resonance plasma source at 2450 MHz has been designed and developed at Raja Ramanna Centre for Advanced Technology (RRCAT), Indore. The plasma for nitrogen, argon and hydrogen gas has been produced. The source microwave power, gas pressure and magnetic field have been varied for the optimization of the plasma. The base vacuum of 2 x 10^{-6} mbar was obtained in the plasma chamber using turbo molecular pump. The gas was feed to the source using fine precision valve and plasma was initiated at the pressure of 10^{-3} to 10^{-5} mbar at 300-1500 watts microwave power. The reflected power was around 120 watts at the full power operation. The quartz window was used as view port. The microwave coupling is studied using Langmuir probe as a diagnostics to optimize the plasma parameters.

INTRODUCTION

The electron cyclotron resonance plasma source at 2450 MHz frequency has been designed and developed for the proton beam extraction at 50 keV beam energy and 30 mA current using three and five electrode geometry [1]. The ECR plasma source with electrode geometry and sector magnet is shown in Fig. 1.

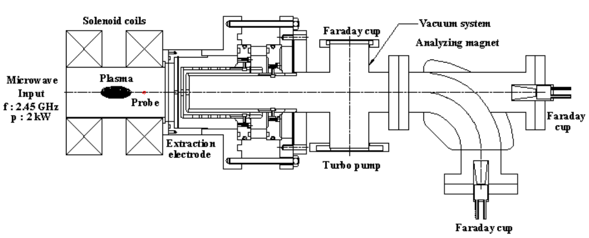

Figure 1: The ECR plasma source with electrode geometry and sector magnet.

The source is at ground potential except the plasma chamber for beam extraction. The microwave line (directional coupler, triple stub tuner, high voltage dc break and microwave vacuum window) components were indigenously developed [2] using rectangular waveguide WR-284. The microwave components, resonant plasma chamber electric field were optimized using Microwave Studio CST software [3]. To built the high efficiency ion source and beam quality, it is very important to know the health of the plasma under the influence of microwave power coupling, gas pressure and magnetic field.

To know the health of the plasma, a Langmuir probe has been developed which is widely accepted as a plasma diagnostics tool [4]. The probe is biased with negative and positive voltage and current flowing through the probe is recorded with respect to the probe bias voltages. The schematic diagram of the Langmuir probe with electrical biasing circuit is shown in Fig. 2.

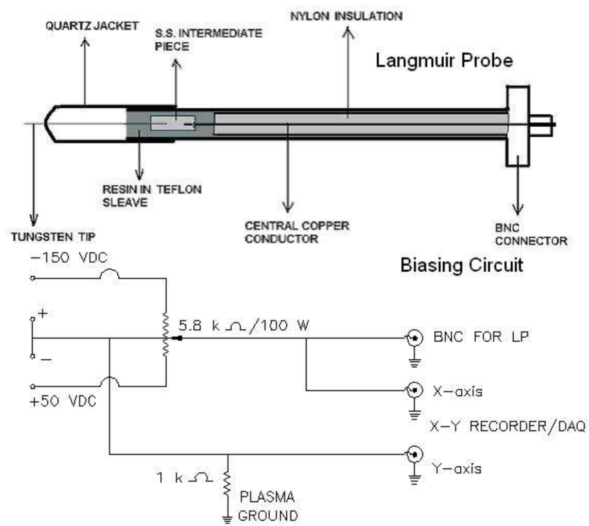

Figure 2: The schematic diagram of the Langmuir probe with biasing circuit.

Thus we get the current-voltage characteristic which is further analyzed to derive the plasma parameters like electron and ion density, electron and ion temperature, plasma potential, floating potential, electron energy distribution function etc. It is being developed with an automated personal computer based data acquisition system for on line determination of fundamental plasma properties.

EXPERIMENTAL SETUP & PLASMA CHARACTERIZATION

The base pressure 2 x 10^{-6} mbar in the plasma chamber was maintained using turbo molecular pump and dry pump as backing pump. The stable discharge was obtained with the little variation of magnetic field as required to have electron cyclotron resonance at gas pressure of 10^{-3} to 10^{-5} mbar with nitrogen, argon and hydrogen gas at the microwave power of 300 watts. The microwave power was varied up to full power of 1.5 kW through which the plasma parameters can be controlled. Through this, a control on the plasma parameters helps to tailor the plasma to obtain the desired beam characteristics. The gas flow was maintained using a mass flow controller and a high precision valve. The gas was fed through the stainless steel tube of quarter inch size and was isolated from the plasma chamber using the high voltage isolator. Langmuir probe is placed axially using five-port flange in a field free region to avoid any instability at the probe tip due to magnetic field. In order to obtain the electron current from the current-voltage data, ion current were subtracted from the total current on a semi log axis. The inverse slope of the curve gives the electron temperature. A typical single probe current-voltage curve for nitrogen plasma is shown in Fig. 3.

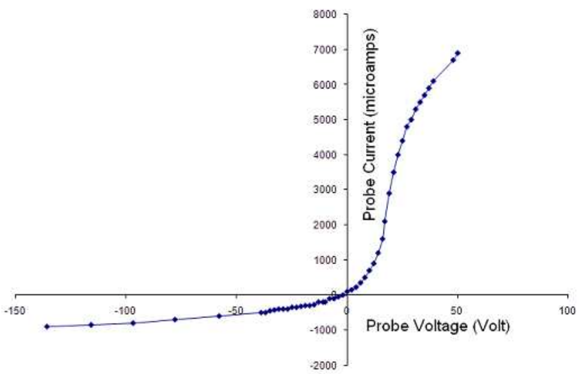

Figure 3: A typical single probe current-voltage curve for nitrogen plasma.

Figure 3 clearly shows the existence of the two-electron temperature inside the plasma and high energy tail appears depleted since the electron contribution to the total current is collected over a narrow voltage range. The measurements were carried out up to the ion and electron saturation current. In the case of electron saturation current just few voltage above the plasma potential to avoid the excess heating of the probe tip to protect it from melting were biased. Extensive research and development have been done to improve and optimize the electron cyclotron resonance sources for a wide range of applications. It has been shown that the most important plasma parameters, depends substantially on the microwave feed method and magnetic field configuration. The maximum field is placed at the microwave window to protect it from damage. The discharge is usually initiated within a few percent of electron cyclotron resonance magnetic field, then little tuning of the magnetic field, stabilized the discharge. Presently current-voltage curve were further analyzed off-line to compute the plasma parameters. The plasma density is about 2-5 x 10^{11} cm^{-3} and lower energy electron temperature 3-10 eV and higher energy electron temperature of 45-70 eV were obtained for the nitrogen case. The electron current, $I_e = I_{e0} \exp [e (V_{probe} - \Phi_p)/T_e]$, where V_{probe} is the probe voltage and Φ_p is the probe potential. The electron temperature T_e is determined from the inverse slope of ln $[dI_e/dV_{probe}]$. The ion current density is determined from the ion saturation current is given by, $I_{is} = 0.61\, e\, n_i\, A \sqrt{[kT_e/2.72\, M]}$, where A is the probe area and M is the mass. The electron energy distribution function was computed from the second derivatives of the Langmuir probe current-voltage curve. Smoothing was necessary to suppress signal noise while computing the derivatives. The plasma characterization using argon and hydrogen gas is in progress.

CONCLUSION

A scheme to characterize the electron cyclotron resonance plasma using Langmuir probes is presented. A simple construction, low cost Langmuir probe is developed. It has tungsten wire of 0.3 mm in diameter and length 5 mm was spot welded on a semi rigid coaxial cable and connected to BNC connectors for electrical biasing. It has been observed that, with increasing the microwave power density of the plasma increases. The effects on plasma density and temperature with the microwave power feed method is studied using the Langmuir probe. This scheme will also be extended for the characterization of the filament based hydrogen negative ion source [5, 6] which is for high current H negative injector linac under development.

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