Plasma Parameter Measurement in High Current ECR Ion Source

P. Roychowdhury[a], H. Kewlani[a], L. Mishra[a], S. Gharat[a], D. S. Patil[b] and D. P. Chakravarthy[a]

[a]Accelerator and Pulse Power Division
[b]Laser and Plasma Technology Division
Bhabha Atomic Research Centre
Mumbai- 400085

Abstract. The high power proton accelerators are being developed worldwide for ADS applications. A high current electron cyclotron resonance (ECR) proton ion source at 50 keV, 50 mA has been designed and developed for the low energy high intensity proton accelerator LEHIPA. The key components of the ECR proton ion source are plasma chamber, vacuum system, microwave system, solenoid magnets, plasma diagnostics devices, beam extraction electrodes, and beam measuring devices. The ion source has been operated with 400 - 1100 W of microwave power at 2.45 GHz, with hydrogen as working gas. The ECR plasma parameter of the ion source has been measured using a single Langmuir probe. The cylindrical Langmuir probe is constructed from tungsten wire of 0.5 mm diameter and 1mm length and encapsulated with alumina tube. An automated Langmuir probe circuit has been developed in housed to capture the I - V characteristics of the probe using a triangular voltage pulse of - 120 V to + 50 V in ms duration. The plasma parameters i.e., plasma density, plasma electron temperature, floating potential, plasma potential and EEDF were then deduced from the measured I - V characteristics. The typical hydrogen plasma density and electron temperature measured were in the range 10^{11} - 10^{12} cm^{-3}, and 1 - 10 eV respectively. The variation of plasma parameters with microwave power, gas pressure and the radial location of the probe have been studied. The details of plasma parameter measurement and operation of the ion source is presented.

Keywords: ECR plasma, Langmuir probe, ECR ion source
PACS: 52.50, 52.55, 52.70, 52.80

INTRODUCTION

An ECR proton ion source has been developed for the Low Energy High Intensity Proton Accelerator (LEHIPA). The ion beam current of 42 mA (unanalyzed) has been extracted at 40 keV of beam energy. The three electrode extraction geometry has been used for ion extraction. For reliable, stable and long time operations of the ion source it is mandatory to monitor forward and reflected microwave power, gas pressure, magnetic field and the beam parameters. As the extracted ion beam current depends on the plasma parameters, it is important to measure these parameters. Electric probes have been in use for many decades for the measurement of plasma parameters. A single langmuir probe was used to measure the ECR plasma parameters. An automated langmuir probe circuit has been developed for this purpose to get I – V characteristics of the probe in ms duration. The interpretation of probe data from I – V characteristics is complicated in the presence of magnetic field. In the setup, the probe is positioned perpendicular to the magnetic field so that the ion collection is not affected by the magnetic field and the ion saturation current is used for deducing the plasma density. The electron temperature is deduced from the transition region of the I – V characteristics. The plasma parameters were studied as a function of microwave power, gas pressure, magnetic field and radial location of the probe.

EXPERMENTAL SETUP

The schematic of the ECR plasma ion source set up is shown in Fig. 1. The microwave system has been designed using WR-284 waveguide section. The microwave system is sourced by a variable power magnetron (2 kW) at a frequency 2.45 GHz. A circulator was used to protect 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 digital rf power meter. A ridge waveguide developed in house was used for optimizing the coupling between the microwave generator and the plasma chamber.

In the ion source, 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 solenoid coils placed around the plasma chamber produces the necessary magnetic field for the ECR resonance condition.

The ultimate vacuum requirement of the ion source is better than 1×10^{-6} mbar. Turbo molecular pump, with hydrogen gas pumping capacity of 2000 l/s, and a dry roughing pump in Fig. 1 was used to evacuate the plasma chamber and the diagnostics chamber. The gas dosing system in the ion source consists of a high purity gas cylinder, a pressure regulator, precision leak valve and a flow meter that is used to introduce working gas in the plasma chamber.

FIGURE 1. Schematic of ECR plasma ion source set up to measure plasma parameters

PLASMA PARAMETER MEASUREMENT

A cylindrical langmuir probe of 0.5 mm diameter and 1 mm length made of tungsten has been used to measure the plasma parameters. The probe is enclosed

FIGURE 2. Langmuir probe used for plasma parameter measurement

by an alumina tube and installed on a SS tube. The probe is movable along the radial direction in the plasma chamber as in Fig. 1. The probe is shown in Fig. 2.

PROBE CIRCUIT

The probe circuit used in the experiment is shown in Fig. 3. Voltage sweep 110 V /110 ms generated using microcontroller and Kepko OpAm; which is applied to the Langmuir probe. Langmuir probe is inserted inside the plasma chamber as discussed above. Langmuir probe voltage sweep is applied to the tungsten tip and the Langmuir probe ground is connected to plasma chamber. Langmuir probe current in pulsed mode is detected using current shunt of 10 kΩ. With the current shunt, the circuit can sense current up to 1 mA. Shunt resister is connected in signal path to avoid stray capacitance effect which is present in ground path. To avoid the line frequency pickups, shielding and isolation is provided to the shunt resister. Applied voltage sweep to Langmuir probe and voltage across shunt resister is observed using digital oscilloscope.

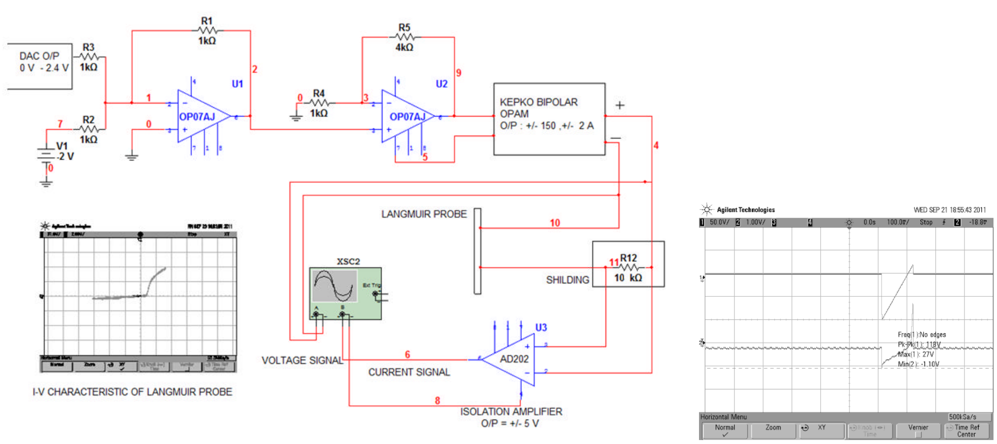
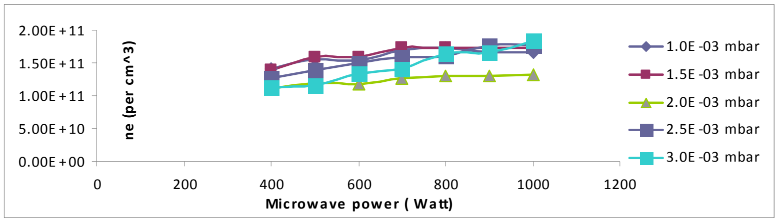
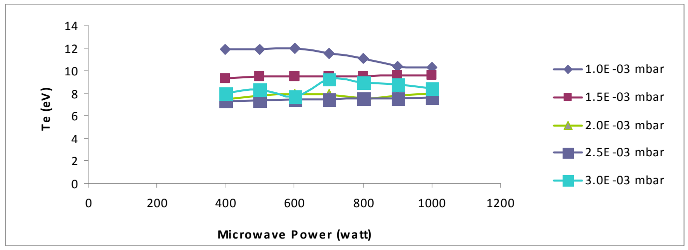


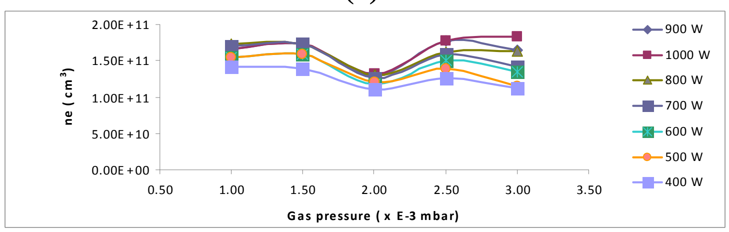
FIGURE 3. Probe circuit and probe characteristics recorded on oscilloscope



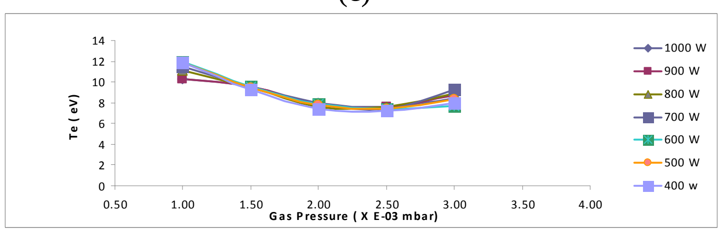
(a)



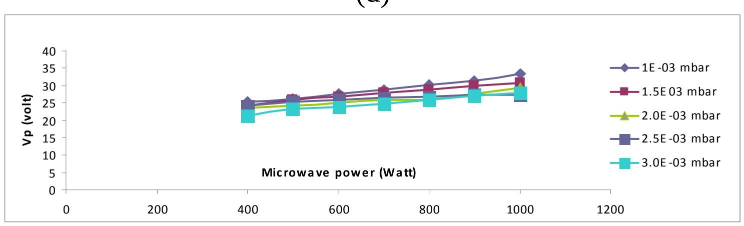
(b)



(c)



(d)



(e)

FIGURE 4. Plot of plasma density and electron temperatures with microwave power (a,b) and gas pressure (c,d). (e) Plot of plasma potential with microwave power.

RESULTS AND DISCUSSIONS

The variation of plasma parameters i.e., plasma density, electron temperature, plasma potential measured for different values of microwave power, gas pressure and magnetic field are shown in Fig. 4. Detail analysis of the data will be published separately.

ACKNOWLEDGMENTS

The authors wish to thank Dr. L. M. Gantayet, Director, BTDG, BARC for his keen interest and support for this work.