A Hybrid ECR Ion Source for Low Energy Applications

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Introduction

Research in low-energy nuclear physics demands low-energy charged particle beams with lower energy spread and lower emittance. The production of high current beams with lower emittance is an open problem, till now in the field of accelerator physics. As the beam intensities are raised, the space charge effect inside the beam produces a significant level of emittance blow up, thereby significantly degrading the beam qualities. This limits the production of high-intensity beams with lower beam emittance. There are ion sources available like SNICS, RF, etc, which can produce lower emittance beams, however, they are limited by the beam currents. Further, the Electron Cyclotron Resonance (ECR) ion source is the fanciest ion source, producing high current beams with higher charge states. In fact, they are producing larger emittance and energy spread due to higher plasma temperatures[1].

Understanding the requirements of nuclear astrophysics and other low energy applications, a novel ion source design has been developed to meet the demands of high current with lower energy spread and emittance. This has been achieved through a hybrid ion source design having a combined ECR-Glow discharge mode of operation. The ECR modes have been generated with a TEM_{01} class rectangular waveguide design. Further the plasma is confined into a small volume by the externally configured magnetic field. The emittance blow up has been reduced by applying the background gas injection in perpendicular to the beam direction. The details are in the following sections.

Materials and Methods

A hybrid ion source has been designed and fabricated at Nuclear and Radiation Physics division, Department of Physics,University of Calicut. A TEM_{01} type rectangular waveguide, having two harmonics in length and quarter wavelength in the transverse direction has been used as the cavity. The cavity has been designed for the 2.4 GHz characteristic frequency. A 2 KW 2.4 GHz magnetron has been coupled as the inductive load to the cavity. The RF coupling has been established at the position of the first antinodal point of the cavity. A Quartz tube of 2.5 cm internal diameter has been mounted at the second antinodal point of the cavity and used as the gas ionization volume. Two permanent magnets are configured with a 5 cm separation, to provide plasma confinement. This configuration produces a maximum magnetic field of 100 mT at the center of the magnet, and drops to a value near to 5 mT at the mid plane of the plasma cell. This gives an effective confinement for the plasma. The schematic diagram of the setup is illustrated in Figure 1.

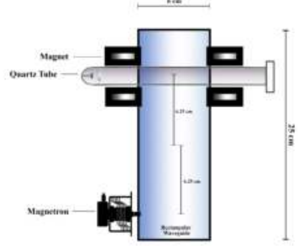

Figure 1: *Schematic diagram of hybrid ion source setup.*

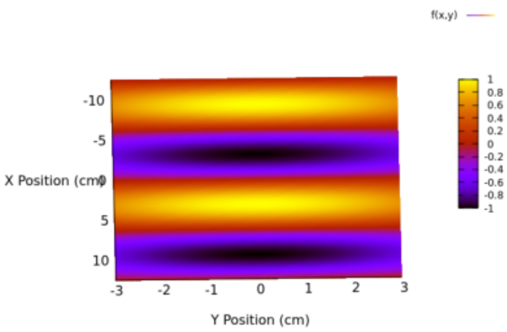

Figure 2: *The superfish simulated field distribution inside the rectangular waveguide.*

An extra glow discharge support has been given to the ECR cell with the help of a 50 kV Tesla type transformer. This helps in the fast ignition of the plasma in the cavity volume. The combined electromagnetic field with external confinement magnetic field excites the ECR type of oscillation in the plasma volume. This produces a multiple electron knocks on the gas particles which increases the ionization efficiency. The ionized gas particles are then extracted with a high potential of 50 kV, given for the glow discharge. This increases the ion extraction efficiency by the formation of the bomb sheath. The extracted ions then pass through the background gas cell, which reduces the space charge effect. The background gas is injected through the firemen's hose geometry which provides an ultrasonic jet for the gas to reduce the beam loss[2].

The 3D field distribution inside the cavity coupled with a 2 kW RF Magnetron has been simulated with the superfish RF cavity design code. The RF injection point and ionization point have been optimized based on the simulations. The simulated field distribution inside the cavity is illustrated in Figure 2. The design is further fabricated in stainless steel with a proper cooling system for temperature handling. The fabricated waveguide-magnetron setup has been appropriately fixed with a sub-mm precision and the magnetron is inductively coupled to the cavity. The magnetic field distribution for plasma confinement has been mapped with Gaussmeter probe. The vacuum level is maintained to 1.5x10^{-6}mbar. The power is optimized by adjusting the attenuator for an effective ionization. The beam parameters were measured in the optimum configurations. The beam profile is measured by firing the beam on a paper screen. The image has been calibrated using a graticule to achieve the measurements. The beam emittance has been estimated using the profile.

Parameter	Value
Beam	^{1}H
Current	1 mA
Energy	50 keV
Cavity Power	1620 W
Reflected Power	380 W
Longitudinal emittance	0.13πmm mrad

Table 1: *Measured ECR operational parameters.*

RESULTS AND DISCUSSION

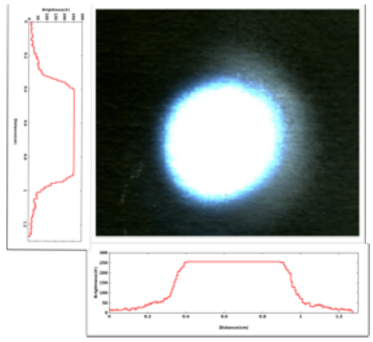

Figure 3: *Measured Beam Profile.*

A rectangular cavity based hybrid Electron Cyclotron Resonance (ECR) ion source is fabricated in-house and the parameters has been studied. A TEM_{01} type rectangular waveguide, with external magnetic field confinement is tested for the ECR mode of operation. The rectangular cavity is providing an effective coupling of RF power to the gas volume. A proton beam current of 1 mA is achieved with 1620 W, under a 23% of reflected power. The measured beam profile is illustrated in figure 3, and the obtained parameters is shown in Table 1. The beam profile measured is symmetric in nature with a FWHM of 0.35 cm at 30 cm from the extraction point. An emittance value of 0.13π mm mrad is achieved.

REFERENCES

[1] G. Voronin et al., NIM. B 161, pp. 1118(2000)

[2] Gokul Das H et al., Proc. 64^{th} DAE Symp. Nucl. Phys. G33. pp. 910-911 (2019)