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COMPACT ELECTRON CYCLOTRON RESONANCE ION SOURCE BASED ION BEAM GENERATION

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ABSTRACT

A compact 2.45 GHz Electron cyclotron resonance (E.C.R.) based ion source is set up for the production of single and multiple charged ion beams. The sub-system of E.C.R. ion source has microwave system its power supplies, plasma chamber, NdFeB permanent magnets and ion extraction assembly. The gas is ionized inside the cylindrical plasma chamber, which is surrounded by the permanent magnets system. The microwave system consists of 2.45 GHz, 300 watts c-w magnetron and its power supplies for plasma generation. The extraction assembly consists of a spherical extraction aperture and a puller electrode. The source has been operated with hydrogen, deuterium, helium and nitrogen gas. Mono-atomic and multiple charges ions have been extracted from the ion source by controlling the gas pressure and microwave power inside the plasma chamber. Vacuum of the order of 10^{-5} to 10^{-6} mbar is maintained inside the plasma chamber. The ions from the plasma chamber is extracted and focused on negatively biased faraday cup. The deuterium ion beam current has been measured by measuring the voltage across the series resistor and the deuterium ion beam current signal is recorded to see the beam uniformity and stability. Deuterium ion beam current of 1 milli-ampere has been extracted at 7.5 kV extraction voltage.

Key words: *electron cyclotron resonance, NdFeB permanent magnet, magnetron, pierce geometry, helical antenna*

INTRODUCTION

Ion source is important element in the modern day research. Its applications range from providing ion beams of hundreds of Amperes for fusion applications[1], nano-amperes for microprobe trace analysis, broad beams for ion implantation for material research, industrial polymerization, to medical and accelerator applications. The ECR Ion source can produce singly and multiple charged ion beam [2]. The advantage of ECR ion source is that it can produce ions of all elements and it doesn't have filament as compared with penning and duo plasmatron ion source, so a stable ion beam can be produced for longer duration.

E.C.R. ION SOURCE

PRINCIPLE

Electron Cyclotron Resonance (ECR) ion sources are also called hot-plasma ion sources and their operation principle is, when electrons move in a magnetic field they gyrate around the magnetic field lines due to the Lorentz force. The gyration frequency is called the cyclotron frequency $\acute{\omega}_{cyc}$. If microwave radiation of the same frequency ($\acute{\omega}_{hf}$) propagates into such a region, the electrons are resonantly accelerated or decelerated (depending on the phase of their transversal velocity component with respect to the electric field vector) when the electron cyclotron resonance condition is fulfilled:

$$\acute{\omega}_{hf} = \acute{\omega}_{cyc} = (e/m) .B$$

Here, e and m denote the charge and mass of the electron respectively.

The plasma electrons are confined in a superposition of an axial magnetic field component (produced by permanent magnets) and the radial magnetic field of a multiple magnet. This result in a minimum-B-structure because the magnetic field has a minimum in the middle of the structure and from there increases in all directions. Therefore, a closed surface is created where the electron cyclotron resonance condition is fulfilled. Electrons passing through that surface can be accelerated resonantly. Furthermore, a high mirror ratio of the magnetic field leads to long confinement times for the plasma electrons. They can pass the resonance region very often, gain high energies and ionize plasma atoms and ions into high charge states via successive single ionization. The ions in the plasma are not accelerated due to their large mass and remain thermal. Therefore they are not confined by the magnetic field but by the space charge potential of the electrons. This magnetic confinement, however, is not perfect and electrons can leave the plasma, for example in axial direction. Since the plasma tends to stay neutral, ions will follow the electrons. By using suitable extraction geometry and by applying a high voltage, the ions can be extracted from the ion source.

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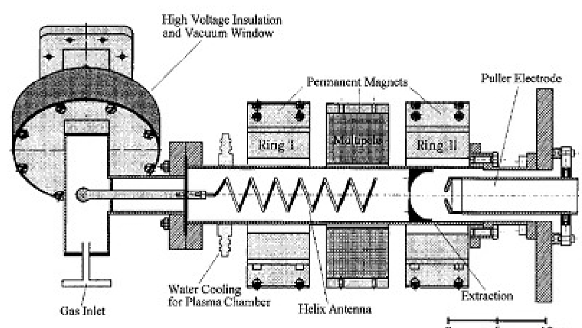

Fig. 1 Schematic overview of ECR Ion source

SYSTEM DESCRIPTION

The ECR ion source [3, 4, 5, 6] is consists of microwave system, plasma chamber, magnets and extraction system. The schematic overview of ECR Ion source is shown in Fig. 1. The plasma is produced inside the plasma chamber which is surrounded by the permanent magnets system. Two ring magnets produce axial magnetic mirror and a hexapole magnet produces radial magnetic field. The microwave system consists of 2.45 GHz magnetron which can deliver 300 Watts power in the continuous mode. The microwave is transported through a rectangular hollow wave guide to power circulator. A three port circulator with the dummy load is used to protect the magnetron from the reflected power. The microwave systems consists further of a combination of a high-voltage and high-vacuum window and a cross bar transition from rectangular wave guide to coaxial line with the gas inlet at the dead end of the transition. The Ion Source set up is shown in Fig. 2 and the specification of ECR Ion source is given in Table - 1.

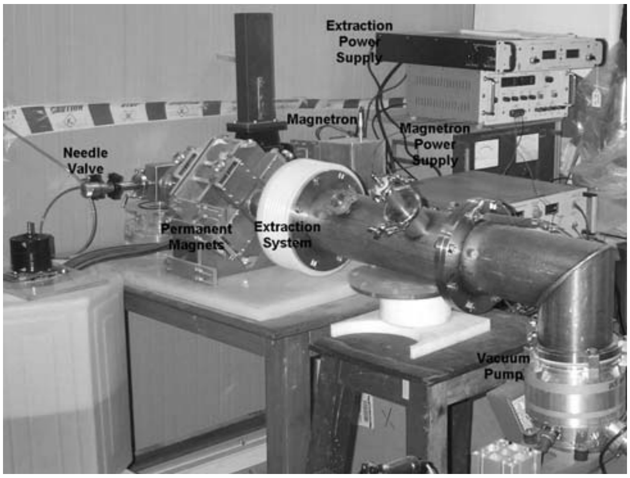

Fig. 2 Ion source setup

Table - 1 Specification of ECR Ion Source

Source type	**Electron–cyclotron – resonance (ECR) Ion source**
Microwave frequency	2.45 GHz
Microwave power	300 watts
Cooling	water cooling, min 2 l/sec
Mounting flange	As required (min NW 63 CF)
Gas feed	NW 10 KF or as required
Dimension	200 mm outside diameter (without microwave system) 400 mm (including HV system and vacuum isolation)
Magnets	2 NdFeB ring magnets, 1 NdFeB Hexapole magnet

MAGNET SYSTEM

The magnet system is consists of 14 permanent magnet made of NdFeB material. The magnets have the dimensions of 65 x 52 x 36.6 mm and the pole magnetic field strength is 0.45T. Six of the 14 magnets form a hexapole magnet, whose inner diameter is 65mm. The hexapole magnet is mounted between two magnet rings made by four magnets each. Two ring magnets produce axial magnetic field and a hexapole magnet produces radial magnetic field. The magnetic field distribution of the axial magnetic field in the midplane of the source is shown in Fig. 3. A maximum magnetic field of 208 mT can be obtained at a mirror ratio of 2.7. The maximum radial magnetic field inside the plasma chamber induced by the hexapole magnet is 0.5 T. Cold water is circulated with 2 liters per minutes across the plasma chamber to remove the direct heat load on permanent magnets.

MICROWAVE SYSTEM

Microwave system of the ion source is consists of 2.45 GHz magnetron, which can deliver a maximum power of 300 watts in the continuous mode. The microwave is transported through a R26 rectangular hollow wave-guide to a three-port power circulator, which will protect the magnetron with the reflected power and the reflected microwave from plasma is absorbed without any reflection in a thick walled dummy load. The microwave systems consist further of a combination of a high-voltage and high- vacuum window and a cross bar transition from rectangular wave guide to coaxial line with the gas inlet at the dead end of the transition. At the end of the coaxial line a slow-wave structure (helical antenna) is connected which will radiate circularly polarized microwaves in axial direction. The dimensions of slow-wave structure depend on the used frequency and have a diameter of 41 mm with the distance of 27 mm between the turns for the helix antenna. After a minimum of four turns it radiates circular polarized microwave in the axial direction. The directivity increases with the number of turns. By using slow wave structure the dimensions of the plasma chamber (60 mm inner diameter and 2.5 mm wall thickness) can be reduced with respect with the smallest circular waveguide for the used frequency. The electrons in the plasma gain energy with the applied microwave power due to the electron-cyclotron-resonance and produce more ions. These ions will be extracted by applying a positive high voltage to the ion source with respect to the puller electrode.

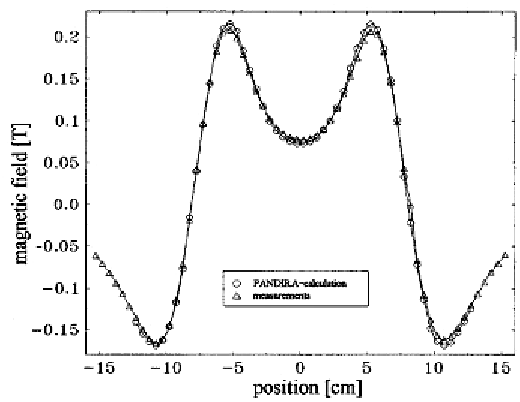

Fig. 3 Magnetic field distribution

EXTRACTION SYSTEM

The extraction system of the ion source is consists of a spherical extraction aperture with 8 mm hole and a puller electrode with 10 mm hole. The ions leave the plasma drifts through the extraction grid and are accelerated away through the immediate high voltage to the puller electrode. The puller electrode can either be operated on ground potential or floating potential. The puller electrode has a pierce geometry, which is a cylindrical pipe limited through a strongly conical tapered shutter, which suppresses the widening of the ion beam caused by the space charge effects. Extraction voltage is applied through a Glassman make 20kV high voltage power supply. All vacuum parts are sealed with rubber O-rings or CF gaskets

E.C.R. ION SOURCE CHARACTERISTICS

The E.C.R. ion source has been operated on a test bench consisting of 80cm beam line. Vacuum of the order of 10^{-5} to 10^{-6} mbar is achieved inside the beam line by 400lps turbo molecular pump. The ion source has been operated with hydrogen, deuterium, helium and nitrogen gas. The deuterium gas was produced by electrolysis of heavy water and the gas flow is regulated by needle valve. The beam current measurements were done for deuterium ions. The deuterium ion beam is extracted and focused on negatively biased faraday cup. The faraday cup is negatively biased 40mm diameter graphite cup placed inside the beam line at a distance of 80 cm from the extraction electrode. The negatively biased graphite cup is grounded with a 2K resistor. The voltage across the resistor is measured with a fluke make multimeter to measure the voltage across the resistor and hence beam current. The voltage signal across the resistor is also measured in the oscilloscope to see the uniformity and the stability of the ion beam (Fig. 4). The maximum extraction voltage of 7.5 kV is applied and the beam current is recorded. Deuterium Ion beam current of 1 mA has been extracted at 7.5 kV (Fig. 5). The beam was stable for longer duration.

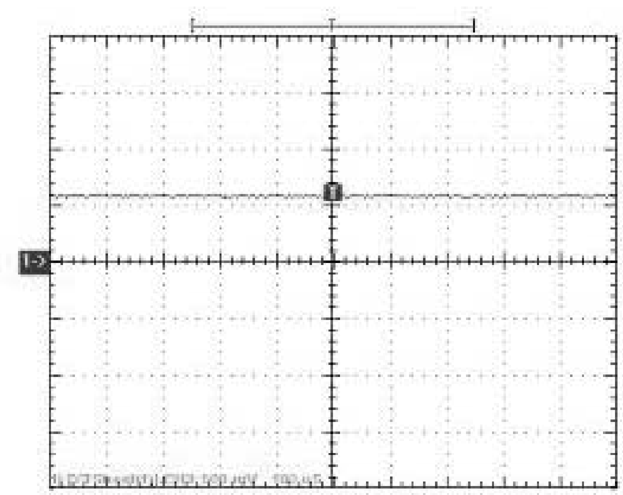

Fig. 4 Beam current measured on oscilloscope

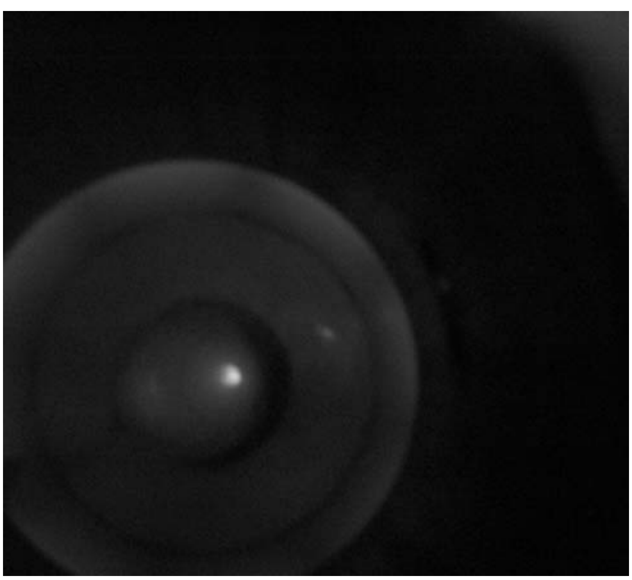

Fig. 5 Deuterium ion beam extraction

CONCLUSION

The electron cyclotron resonance ion source was commissioned and it has been operated with hydrogen, deuterium, helium and nitrogen gas. The ion beam can be focused on material for ion implantation and DPA (Displacement per atom) studies for ion bombardment on materials. The deuterium ion beam current has been measured 1mA at 7.5 kV extraction voltage. The deuterium ion beam will be accelerated and then it will impinges on tritium target and produces neutrons by fusion reaction. System is further being upgraded to produce 5 mA deuterium ion beam current.

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