STATUS OF THE HIGH CURRENT PERMANENT MAGNET 2.45GHZ ECR ION SOURCE AT PEKING UNIVERSITY*

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Abstract

Several compact 2.45 GHz Electron Cyclotron Resonance Ion Sources (ECRISs) have been developed at Peking University for ion implantation [1], Separated Function Radio Frequency Quadrupole project (SFRFQ)[2] and for the Peking University Neutron Imaging FaciliTY project (PKUNIFTY) [3]. Studies on 2.45 GHz ECR ion sources are concentrated on methods of microwave coupling and microwave window design, magnetic field generation and configuration, as well as the extraction electrodes structure. Investigation also covers the influence of the size of plasma chamber on the discharge efficiency and species factor. Up to now, our sources have produced 25 mA of O^+ ion, 40 mA of He^+ ion, 10 mA of N^+ ion, 100 mA of H^+ ions and 83 mA of D^+ ions, respectively.

INTRODUCTION

In recent years the production of high current beams is a key point for many research projects [4]. The 2.45 GHz electron cyclotron resonance (ECR) ion sources, invented 30 years ago by Sakudo [5] and Ishikawa *et al.* [6] for industrial applications, are the suitable candidates of producing high current and high brightness proton, deuteron, oxygen and other mono-charged light ion beams. The special characteristics of 2.45 GHz ECR sources, such as high ion current density, compact structure, high reliability, ability to operate in both CW and pulsed mode, good reproducibility and low maintenance, make it popular as a High Current Ion Source in the world [7-10].

Research on the 2.45 GHz high current ECR ion source at Peking University (PKU) can trace back to 1980's [10]. Since then, several 2.45 GHz ECR sources were developed for different purposes [1-3]. Fig.1 is a schematic configuration diagram of the PKU ECR ion source developed for Peking University Neutron Imaging FaciliTy (PKUNIFTY) project (PMECR IV, see below). As shown in fig.1, special designed alumina dielectric microwave window is used for the microwave coupling between the rectangle microwave guide and plasma chamber. The axial magnetic field needed by the ECR in the plasma chamber with 2.45 GHz rf wave is provided by three permanent magnet rings, so the source is named PMECR ion source. Its out diameter and its length are 10 cm, and its weight is less than 5 kg. The discharge chamber is a cylinder with diameter about 40 mm and length of 50 mm. For beam extraction, a 45° angle cone-expansion type electrode is used to suppressing the beam divergence. Heretofore, we have got several tens of milliampere of various gas ions, such as H^+, D^+, He^+, N^+ and O^+ [1][11][12][13][14]. Now the PMECR I ion source is routinely delivering ion beams for Separated Function Radio Frequency Quadrupole (SFRFQ) project [2] and the PMECR IV, for PKUNIFTY project [3].

The technical achievements and progresses on methods of magnetic field generation and configuration, source body structure, microwave coupling, and beam extraction electrodes design of PKU 2.45GHz ECR ion source in the past decades will be described in this paper.

MICROWAVE COUPLING METHODS

The microwave system of an ECR ion source is used to generate 2.45 GHz microwave and transport the microwave to the ion source. At PKU, the system is a very simple one with a microwave generator, a magnetron cavity, a circulator or isolator, a tuner, some rectangular waveguide, a high voltage break wave guide (HV break) and a coupling part with source body. The tuner (manual three-stub or automatic stub) is adapted for matching the waveguide to plasma impedance, which enhances the plasma density and finally increases the current density of the extracted beam. The WR340 and WR284 rectangular waveguides were compared during the source running. Results show that using the WR340 rectangular waveguide can save more than 30% microwave power comparing with the WR284 to obtain the same beam current extracted at the same conditions [12].

The microwave coupling part refers to the matching unit to adapt the standard rectangular waveguide to the source body. Ridged waveguide, dielectric microwave window and antennas are the three ways to fulfil the coupling. Most Labs, such as Chalk River National Laboratory, Saclay/CEA [15][8], are using a ridged waveguide to match the microwave line with source body. At PKU, ridged waveguide, dielectric microwave window as well as T-shape antenna were tested at the early stage of ECRIS development [11][1][12]. The presence of antennas is not convenient to the routine operation because of periodical maintenance. Experimental results show that the function of dielectric microwave windows with special design is equivalent to a ridged waveguide for microwave coupling between the microwave line and the discharge plasma. As shown in fig.1, the dielectric microwave window for 2.45GHz ECR ion source at PKU which consists of an alumina block with dielectric constant 9 is special design for microwave coupling. It works as vacuum sealing as well. In the meantime, a piece of thin BN or SiN disk toward the plasma is used to protect the microwave window from the bombarding of electrons. The lifetime of SiN is longer than BN for

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window protection [13], which has been proved by the recent research on the D$^+$ ion source developed for PKUNIFTY project. With dielectric microwave window, the microwave system is more compact compared with using ridged waveguide.

By inserting a HV break in our microwave line, the tuner, the isolator, the microwave cavity and the microwave generator can be operated on ground voltage. It has been proved that this design is very robust and safety.

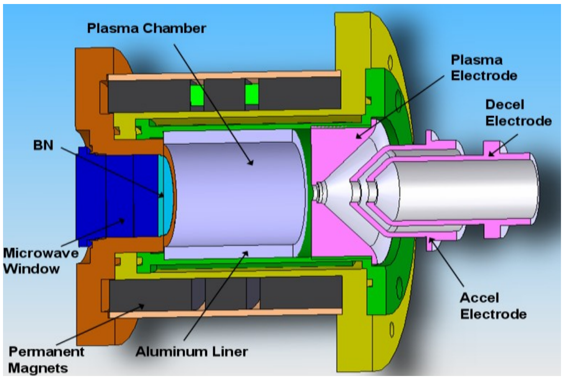

Figure 1: Schematic diagram of 2.45 GHz ECR ion source in PKU.

MAGNETIC FIELD GENERATION AND SOURCE BODY FABRICATION

In microwave discharge ion sources, the magnetic field along the plasma chamber axis is effective on the ionization process because it forces the electrons to circulate around the field lines and increases the ionization probability. Different theoretical approaches exist about plasma ignition in High Current Ion Source operating at 2.45 GHz that depends on the shape and value of the maximum magnetic field with respect to B_{ECR} = 875 Gauss [16].

The axial magnetic configuration can be provided by three ways, which are electromagnetic coils [7][8][16][17], electromagnetic coil plus permanent magnetic rings [1], or permanent magnetic rings only [1][18]. The magnetic field distribution and strength can be adjusted when the electromagnetic coils are used. But in the case of using permanent magnets only, the magnetic field is unchangeable after source assembling.

BEAM FORMATION AND HANDLING

The beam extraction system design is depended on requirements of the accelerator. Special attention should be paid to the electrode design in order to minimize the electric field on the electrode surface, beam divergence angle, beam emittance and the spark risks. The most important parameters in extraction system design are the angle of the conical section of the plasma electrode and the ratio *S* defined as the radius of extraction aperture of plasma electrode over the distance from plasma electrode to the downstream electrode.

So simulation using suitable software is needed in the permanent magnet design, and the special attention should be paid to avoid high stray field at the extraction side, which may result in Penning discharge within the extraction region. The advantages of using permanent magnets are obvious. For example, with permanent magnets the size of the components at high voltage becomes smaller, the power supplies operated on high voltage platform is no longer needed, and the structure of the ion source body is more compact. Also the ion beams produced by PMECR ion source have better stability and reliability in comparison with the solenoid coil system for long term operations [4]. By replacing solenoids and its power supplies with several permanent magnetic rings, the manufacture cost of an ion source drops a lot.

At PKU, the study on the methods of magnetic field generation and magnetic fields configuration for 2.45GHz ECR ion source started at 1990's [1]. We have tested solenoids, solenoid plus permanent magnet rings and only permanent rings. For plasma generation, they did not make any difference. Recently we focused on permanent magnetic rings for our source (PMECR I, II, III and IV) because it is more safety (less components placed at high voltage), compact (smaller source body) and economic.

Unlike the permanent magnetic rings used at CEA/Saclay, that each ring is made of 24 elementary NdFeB magnets assembled in an aluminium shell [18], we use two or three NdFeB permanent magnet rings to form the magnetic field for plasma producing as shown in Fig.1. Fig.2 shows several typical magnetic field configuration curves we have used [12]. The source operated well with all the three magnetic field distributions, and the best one for the source performance is the magnetic field distribution A, which produces two high density plasma regions at both end of the discharge chamber. Further study results indicate that the beam current is very sensitive to the B value at the extraction aperture position, but not sensitive to the magnetic field strength at the microwave window [13].

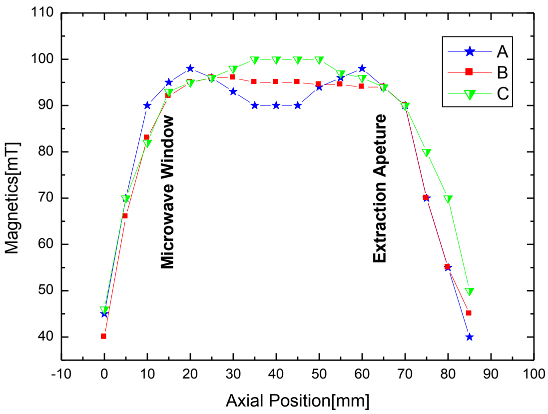

Figure 2: Axial magnetic field profiles of the permanent magnet.

At PKU, studies are focused on a classical three electrode system on test bench and for PKUNIFTY project. Emphases are concentrated on how to decrease beam divergence, suppress emittance growth within LEBT and increase the beam transmission efficiency in LEBT [2, 3, 14]. Study shows that an appropriate angle of the conical section of the plasma electrode and a suitable suppression voltage are important parameters for beam formation and handing. For example, we replaced the original plat electrode with a cone apex angle of 90° for SFRFQ project, the peak oxygen current at RFQ entrance increased from 9 mA to 25 mA [14]. On our LEBT test bench, a set of flat electrodes was used before 2008. The aperture diameter of plasma electrode was 5 mm, and of suppressing electrode and grounded electrode was 8 mm. The acceleration gap and the deceleration gap were 6 mm and 2 mm, respectively, and the suppression voltage was set to 2 kV. In such a case more than 100 mA proton beam could be easily obtained at 50 kV extraction voltage and its normalized rms emittance is about 0.2 π.mm.mrad [12], but its beam half divergence angle was larger than 100 mrad. At the end of 2008, we replaced those plat electrodes with a set of 90° cone - expansion type one, as shown in Fig.1. The emission aperture has a diameter of 6 mm with thickness of 2 mm followed by an expansion cylinder with diameter of 8 mm and thickness of 2 mm. The aperture diameter of the puller electrode and the ground electrode is still 8 mm and their thickness is 3 mm. The acceleration gap and the deceleration gap are 12 mm and 3 mm, respectively. The half divergence angle of the beam reduced to 64 mrad at 2 kV suppression voltage. When the suppression voltage increased to 2.8 kV, the half divergence angle dropped to 35 mrad further, the normalized rms emittance is about 0.13 π.mm.mrad for 100 mA H^+ ion beam at 50 kV, and the beam transmission efficiency on LEBT test bench increased from 75% to 93% [14]. Also a 40 mA He^+ and more than 10 mA N^+ ion beams have been extracted on this test bench with a normalized rms emittance less than 0.2 π.mm.mrad and a half divergence angle less than 40 mrad. The extraction system for PKUNIFTY project is a copy of 90° cone - expansion type [3]. About 83 mA total current deuteron beam has been extracted at 50 kV with half divergence angle less than 70 mrad, and its normalized rms emittance is less than 0.18 mm mrad.

X-ray shielding is another issue outside the acceleration column, especially when operator is on the spot. By embedding the whole accelerator columns into the metal vacuum box above the pump for LEBT test bench and D^+ injector, radiation outside the accelerator columns was reduced to background lever when operated at 50 kV for H^+ ion beam generation [3].

DISCUSSIONS

After the investigation for several decades, a series of compact permanent magnetic 2.45 GHz ECR ion sources has been developed to deliver high current beam for different accelerator projects at PKU. About 25 mA of O^+ ion, 10 mA of N^+ ion, 100 mA of H^+ ions and 83 mA of D^+ ions can be produced with those compact PMECR sources. Recently, 40 mA of He^+ ion beam at 50 kV was also obtained on our LEBT test bench. For all the beams the normalized rms emittance is less than 0.2 π.mm.mrad, the half divergence angle is smaller than 70 mrad. The possible further improvements might be investigated depending on the requirements. Beside higher current and higher brightness, beam divergence is another important parameter for an ion source. Moreover, attentions should be paid to magnetic field shielding and space charge compensation within extraction region. Plasma diagnosis is going to be performed in a new PM ECR source (PMECR V) so that we can understand the behaviour of gas discharge inside the discharge chamber better.

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