Commissioning Test of LAPECR2 Source on the 320kV HV Platform*

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Abstract The high charge state all permanent Electron Cyclotron Resonance Ion Source (ECRIS) LAPECR2 (Lanzhou All Permanent magnet ECR ion source No.2) has been successfully put on the 320kV HV platform at IMP and also has been connected with the successive LEBT system. This source is the largest and heaviest all permanent magnet ECRIS in the world. The maximum mirror field is 1.28T (without iron plug) and the effective plasma chamber volume is as large as Ø67mm×255mm. It was designed to be operated at 14.5GHz and aimed to produce medium charge state and high charge state gaseous and also metallic ion beams. The source has already successfully delivered some intense gaseous ion beams to successive experimental terminals. This paper will give a brief overview of the basic features of this permanent magnet ECRIS. Then commissioning results of this source on the platform, the design of the extraction system together with the successive LEBT system will be presented.

Key words ECR, high charge, beam transmission

1 Introduction

With the prominent development of Electron Cyclotron Resonance (ECR) ion source in the last two decades, it has become the most efficient and indispensable machine to produce intense high charge state ion beams. ECR ion source also proves its obvious importance in the fields such as accelerator development, atomic research, material physics and biology techniques etc. And the availability of low energy, intense, high charge state, high duty factor ion beams from ECR ion source has opened many areas of MCI research that previously inaccessible. Heavy Ion Research Facility in Lanzhou (HIRFL) has been dedicated to the research activities associated with heavy ion for many years. The HIRFL low energy ECR ion source platform and the HIRFL accelerators together with the latest-built HIRFL-CSR[1] (Cooler Storage Rings) will provide the physics researches ion beams covering a large energy range. And to further extend the present energy range available in Institute of Modern Physics (IMP), a 320kV high voltage (HV) platform has been recently built. A multiple charge all permanent magnetic ECR ion source LAPECR2 has been designed, built and installed on the platform to produce intense multiple charge state ion beams for the successive 5 experimental terminals. The goal of this source is to reach the beam intensities equivalent to those of LECR2 source. This source was successfully built and gave the first plasma in 2005. In this

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paper, the general commissioning results of this source on the platform are presented.

2 Conceptual design

LECR2 source is one of the first ECR ion sources that adopted the techniques such as high frequency, high-B mode and large plasma chamber. The final performances of this source were comparably high at that time. To produce the equivalent performance of LECR2, the main parameters of LAPECR2 should be designed close to those of LECR2. With the development of permanent magnet material techniques, it is nowadays possible to design and fabricate an all permanent magnet body to produce very high magnetic field. LAPECR2 source was designed to be operated at 14.5GHz with several key aspects being taken under consideration at the same time, for instance: i. plasma chamber should be as large as possible to feed rf power and to realize better ion confinement; ii. large resonance zone is favored; iii. compromise between the magnetic field and the magnetic body compactness.

The successful design and fabrication of several all permanent magnet ECR ion sources[2, 3] have given some references to the design of LAPECR2 source. Further more, the latest updated empirical scaling laws[4] can be counted as a basic theory in the design. In the other hand, the magnetic field of an all permanent magnet ion source is unchangeable, which is an intrinsic drawback of this kind of source. Reasonable design of the magnetic field configuration of the source will make the source more powerful.

14.5GHz rf power is directly fed into the Ø67mm diameter copper plasma chamber with a liner aluminum film cylinder inside. WR62 flange waveguides are used for rf power feeding. The double wall water cooling structure is adopted in the design of the plasma chamber. One insertion port is also available on the injection tank for macro-oven or inserted rod to produce metallic ion beams. Typical tricks like mixing gas and biased disk are applied to the source design. Vacuum evacuation of the chamber is realized by a 110 l/s and a 360 l/s molecular pump at the injection side and extraction side respectively.

3 Magnetic field

The magnet body was successfully built in IMP. According to the careful measurement of the magnetic field, the magnetic field configuration is close to our design. Fig. 1 gives the comparison of the designed and measured axial magnetic field configurations. The injection magnetic field peak is 1.28T that is too low for the optimum operation at 14.5GHz. But an iron plug insertion at the injection side may help increase the magnetic field. The $B_{\rm min} = 0.42$T, $B_{\rm ext} = 1.07$T and $B_{\rm rad} = 1.2$T results are well up to the optimum magnetic field requirements of a 14.5GHz ECR ion source. And the typical parameters of LAPECR2 source are close to those of LECR2 source[5].

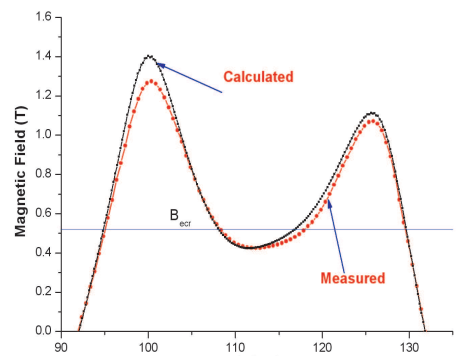

Fig. 1. Measured and calculated results of the magnetic field of LAPECR2.

4 Preliminary commissioning

After the magnetic measurement of LAPECR2 source, it was removed to another building. Then the magnet body was successfully mounted on the HV platform. The installation of the accessory parts to the source was completed at the beginning of 2005. After several tests of high voltage insulation and vacuum pumping of the source, the ion source was ignited in July 2005 at 14.5GHz. Some ion beams were extracted by the 15kV HV and analyzed by the analyzing magnet. 60eμA O^{6+} beam was obtained with the first plasma[5].

Because of the optical design of the ion transmission beam line, the distance between the plasma electrode and the solenoidal coil is very small, and the thus the dimension of the extraction tank is quite limited. On the other hand, the molecular pump should be put as far as possible from the magnet body and the source symmetric axis to avoid the possible damage of the stray magnetic field of the source to the pump. Thus, the effective vacuum evacuation speed of the pump at the extraction side is quite low. These aspects limit the source vacuum. The normal base vacuum of the source is about 1.2×10^{-6}mbar at the injection side and 9.0×10^{-7}mbar at the extraction side.

The ion beam extraction from an all permanent magnet ECR ion source is more complex than a classical ECR ion source. Because of the magnetic structure of the source, the extraction region of an all permanent magnet ECR ion source is quite long, especially for the case of LAPECR2 source. To decrease the strong influence of the extraction magnetic field, the puller electrode of LAPECR2 is put as close as possible to the plasma electrode. In this way the ion beam extraction electric field is increased and the ion beam acceleration distance (very low energy transmission distance) is decreased. But because of the extracted ion beam bombardment on the puller electrode, the vacuum condition at the extraction region becomes worse, normally 2.0×10^{-6}mbar at the extraction side. The poor vacuum and the strong magnetic field at the extraction region make it difficult to increase the extraction HV higher than 22kV because of the Penning discharge. And then 20kV extraction HV is normally applied during the test.

Because the available TWT rf power generator at hand can only provide the maximum output rf power of 280W, a 14.5GHz klystron rf power generator with the maximum rf power output of 450W was connected with the ion source though a HV DC-break. To test the successive beam lines of the HV platform, the analyzed ion beams were let to the experimental terminals during the commissioning. In the preliminary tests, only oxygen beams were tuned for the platform test. According to the test, intense oxygen ion beams were successively extracted from the source. But unfortunately, the aluminum film cylinder liner inside the plasma chamber was burnt because of insufficient cooling. Then a same dimension stainless steel plasma chamber was installed. With about 450W rf power injection more than 0.5emA O^{6+} beam was obtained with the total drain current about 6emA. Because of summer maintenance at IMP, the source had to be stopped. Before that, a two-hour tuning of argon ion beam gave some preliminary results of argon ion beams. More than 300eμA Ar^{8+} was obtained in the test and Fig. 2 presents the spectrum when optimizing the production of Ar^{11+} beam. Obvious nitrogen and carbon ion beam peaks are seen in the spectra illustrated by Fig. 2, which denotes some vacuum leakage and outgassing are in existence. Table 1 gives the preliminary results of LAPECR2 in comparison with those of LECR2. Bad vacuum, outgassing and low ion beam transmission efficiency may account for the lower performance of LAPECR2 than LECR2.

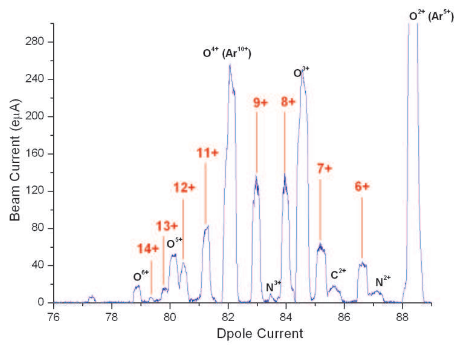

Fig. 2.　Argon CSD for optimizing Ar^{11+} production.

Table 1.　Comparison of the preliminary results of LAPECR2 with the performances of LECR2 (eμA).

Ion	LAPECR2	LECR2
O^{6+}	550	610
O^{7+}	130	140
Ar^{8+}	310	460
Ar^{9+}	200	
Ar^{11+}	105	185
Ar^{12+}	53	105
Ar^{13+}	19	
Ar^{14+}	6	12

5　Beam extraction and transport

Ion beam extraction system is very important for an ion source. High efficiency, good quality ion beam extraction inquires an optimum ion beam extraction system. For classical solenoidal coil type ECR ion source, the extracted ion beams experience a semi-Glaser lens magnetic field, which decays very fast to 0 along the symmetric axis. Thus the influence of the stray magnetic field to the extracted ion beams is not very severe. But as to the case of all permanent magnet ECR ion source, the influence of the stray field to the extracted ion beams is quite severe. Fig. 3 presents the magnetic field configuration at the extraction side of LAPECR2 source. The extraction magnetic field decreases to 0 after a certain distance and then a negative magnetic field peak arises. Then the negative magnetic field slowly decreases to 0 after a very long distance. This special magnetic field configuration has a severe impact on the extracted ion beam transmission, especially for the case of LAPECR2 source (the extraction magnetic field is stronger than the other permanent sources).

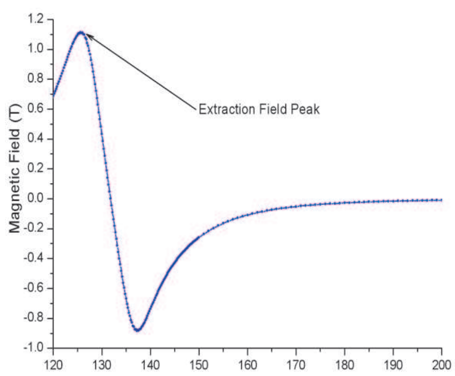

Fig. 3. Extraction side magnetic field configuration.

Figure 4 illustrates the simulation of the ion beam extraction and transmission from LAPECR2 source with PBGUNS code[6]. In the upper plot, ion beam extraction from a classical source with a normal extraction magnetic field configuration is simulated. It denotes that the after the ion beams being extracted, the extracted ion beams firstly focus near the puller and then gradually defocus till the entrance of the analyzing magnet. Although a Glaser lens has been added to help focus the beam, most of the unwanted ion beams and part of the tuned ion beam will be lost during the transmission. The lower plot gives the simulation result of the ion beam extraction and transport from LAPECR2. It illustrates that the extracted ion beams will form a focus near the puller and then the ion beams defocuses a little bit, and after that the ion beams transmit a certain distance in a quasi-parallel mode. Certainly, the space charge effect plays an important role which makes the ion beams diverges by some degree before the entrance of the analyzing magnet. It is predicable that the special extraction magnetic field configuration of an all permanent ECR ion source has strong influence on the extracted ion beam transmission optics.

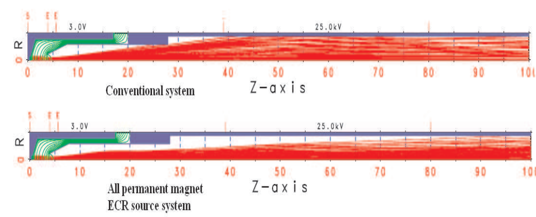

Fig. 4. PBGUNS simulation results of two kinds of magnetic field configuration influences.

The energy range of IMP HV platform is 20—320kV/q. To realize the high efficiency transport of the extracted ion beam from the source to each of the experimental terminals, optimum design of the ion beam transmission optical system is very important. In our principle design (as shown in Fig. 5), ion beams extracted from LAPECR2 transmit to a 120π·mm·mrad acceptance 90° analyzing magnet with the entrance dimension of 70mm×68mm. Then the analyzed ion beam focuses before the Faraday cup. The position of the ion beam extraction hole and the position of the faraday cup form a simple point to point optical image system. A Glaser lens is added for slight adjustment of the ion beam transmission. Fig. 7 presents some simulation results with Trace 3D code. The upper plot illustrates the extracted ion beam transmission situation for a classical source with a normal extraction magnetic field configuration. The lower plot presents the simulation result of the extracted ion beam from LAPECR2. Easy to see that unlike the conventional ECR ion sources, the ion beam extracted from an all permanent ECR ion source can not form a good focus point at the Faraday cup, and only a fat large envelope beam waist can be detected. This result is far different from the original design of the ion beam transmission optical system. And that is why the effect of the successive Einzel lens is very weak.

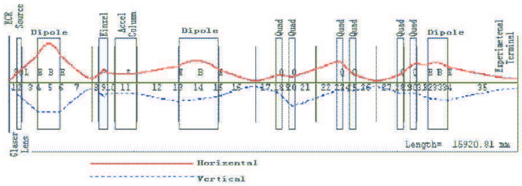

Fig. 5. Beam envelops from LAPECR2 source when the platform is grounded ($20\times q$ keV beam).

According to the preliminary test with O^{6+}, the estimated transmission efficiency between the source and the first Faraday cup is about less than 40%. The transmission efficiency between the first Faraday cup and the second Faraday cup behind the acceleration column is more than 80% when the HV platform is grounded, but the transmission efficiency between the first Faraday cup and the Faraday cup at the experimental terminal is only about 30% — 35%. It means that the successive ion beam transmission suffers a lot from the optical mismatching of ion beam transmission between the platform and the successive beam line. Higher extraction HV and applying the HV platform with HV may help increase the transmission efficiency. Screening of the negative magnetic field with an iron block at the extraction side is another good solution. As for the low transmission efficiency between the source and the first faraday cup, several reasons might result in it, for instance the bad extraction vacuum, the low extraction high voltage, the small acceptance of the analyzing magnet and the beam line misalignment problem.

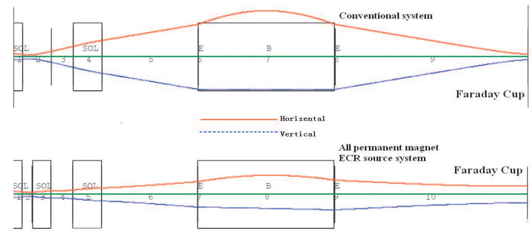

Fig. 6. Trance 3D simulation results of two kinds of magnetic field configuration influences.

6 Conclusion

The all permanent magnet LAPECR2 source at IMP has produced some preliminary results on the 320kV HV platform. Typical beams like 550eμA O^{6+}, 130eμA O^{7+}, 105eμA Ar^{11+} and 6eμA Ar^{14+} have been extracted. The analyzed ion beam was tuned to one of the experimental terminal. Although the poor transmission efficiency, more than 80eμA O^{6+} have been detected at the terminal when the platform is grounded. Nest step work will focus on the enhancement of the transmission efficiency and the improvement of the source vacuum.

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