Preliminary Results of the Updated LECR2 Source-LECR2M*

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Abstract The Latest developed LECR2M (Lanzhou ECR No. 2 Modified) source is the updated one of LECR2 (Lanzhou ECR No. 2) source at IMP. It has been assembled on the low energy ion beam experimental platform to produce MCI beams for atomic physics and material physics experimental research. In our updating program, the structure of injection and extraction components has been modified to make the source structure more simple and effective. The hexapole magnet has also been replaced by a new hexapole magnet with higher radial field and larger inner diameter. With this updating, stronger magnetic field confinement of the ECR plasma is possible and better base vacuum condition is also achieved. LECR2M was designed to be operated at 14.5GHz. During the preliminary test, 1.3emA O^{6+} beam was extracted with the injected rf power of 1.1kW. The source has been used to deliver intense MCI beams for different experiments. After some discussion of the main features of this newly updated source, some of the typical commissioning test results of LECR2M will be presented.

Key words ECR, high charge, NdFeB

1 Introduction

LECR2 (Lanzhou Electron Cyclotron Resonance ion source No. 2) source is one of the first ECR ion sources in the world that adopted the high-B, large volume plasma chamber techniques[1]. This 14.5GHz ECR ion source was designed based on the concept of the CAPRICE[2] and GANIL ECR4[3]. The typical performances of the source LECR2 were quite good at that time. It was with LECR2 source, metallic ion beams were delivered for the first time to the accelerators with the micro-oven or MIVOC methods, which greatly enhanced the performance and efficiency of HIRFL (Heavy Ion Research Facility in Lanzhou) accelerators[4]. LECR2 had been used for HIRFL accelerators for more than 7 years since 1998. In summer 2005, a higher performance ECR ion source LECR3[5] was removed to the basement to take the place of LECR2 to provide more intense multiple charge state ion beams for HIRFL accelerators. Then it was possible to do some updating modifications on LECR2. The updating project of LECR2 takes into account all the latest developments on ECR ion source techniques and tricks to enhance the performance of the updated source-LECR2M. The detail of the updating project and the preliminary test results of LECR2M are presented in the following content.

2 Conceptual design of LECR2M

Since the successful building of the first multiple charge state ECR ion source in France, the physi-

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cists on ECR ion source have made many remarkable achievements in the past several decades. Although the working mechanism of ECR ion source is still at a semi-empirical state, the state of arts of high performance high charge state ion source has some basic requirements that should be satisfied: i. an optimum 3D confinement magnetic field configuration according to the B_{ecr} the source determines; ii. some flexibilities should be left for the optimization of B_{min}; iii. winthin the permission of the source mechanic structure, the larger the plasma chamber, the better the possible performances; iv. all the special techniques to enhance the production of high charge state ions should be adopted; v. good enough vacuum conditions at both the injection side and also the extraction side, and good enough plasma pumping rate.

2.1 Magnetic field of LECR2M

LECR2M is aiming to produce more intense high charge state ion beams than LECR2. The 3D magnetic field confinement that LECR2 source can provide is insufficient when it is operated at 14.5GHz. Both the injection and radial magnetic field should be increased by some degree according to the requirement of scaling laws[6]. We are intending to use the same solenoidal coils and also the iron yokes from LECR2, so some tricks should be applied to increase the injection magnetic field. The B_{min} of LECR2 is typically 0.38T that is lower than the optimum value of 0.42T, which can be increased by the modification of the surrounding iron yokes. The plasma chamber inner diameter of LECR2 is only Ø70mm. To enlarge the plasma chamber volume and at the same time increase the radial magnetic field confinement, a new hexapole magnet with larger radial magnetic field and inner bore diameter should be adopted to provide radial magnetic field confinement to the ECR plasma.

2.2 Other aspects

Rectangular waveguide direct feeding method of rf power has been applied in many laboratories for many years. Good plasma stability and better rf power coupling efficiency to the ECR plasma have been observed, especially in the case of higher rf power feeding. Considering these facts, and also for the simplicity and easy-handling of the injection side of the source, the rf injection method is designed as the rectangular waveguide direct feeding one instead of the original coaxial feeding method used on LECR2.

Mechanical design of the injection and extraction sides of the source takes into consideration of good vacuum evacuation. The injection tank and the extraction region are designed to set aside large enough space to maximum vacuum pumping rate. The ion beam extraction region is designed as close as possible to the Galser lens to maximize the plasma pumping rate and what is more important to minimize the transmission distance of extracted mixing ion beams and thus to lower the influence of space charge effect to the ion beam.

3 Magnetic field configuration

By adding an iron plug at the injection side, the injection magnetic field can be effectively increased. At full excitation of the injection solenoidal coil, the injection magnetic field can be as high as 2.5T. Special mechanical design was done on the hexapole magnet outer iron shield. The central part of the shield is made of aluminum while the both ends are made of iron. An iron ring is designed to be installed at a large radius at the same axial position of the aluminum shield part. By removing or adding the iron ring, the B_{min} can be altered between two values, i.e. 0.48T and 0.41T. The axial magnet field distributions under different conditions of LECR2M are given in Fig. 1. For the design of the hexapole magnet, the traditional Halbach structure[7] is adopted. With a 36-segmented structure, the hexapole magnet can provide a maximum of 1.15T radial magnetic field at the inner wall of a Ø76mm inner diameter, doubled-wall water-cooling structure plasma chamber. The sketch plot of LECR2M is presented in Fig. 2. Additionally, it can be predicable that the magnet field configuration of LECR2M without the extra iron ring is suitable for the operation of the source at 18GHz with B_{inj}=2.5T, B_{min}=0.54T, B_{ext}=1.2T and B_{rad}=1.15T. The extraction magnetic field can be increased by the adoption of an iron puller. As a comparison, Table 1 gives the main parameters of LECR2M and LECR2.

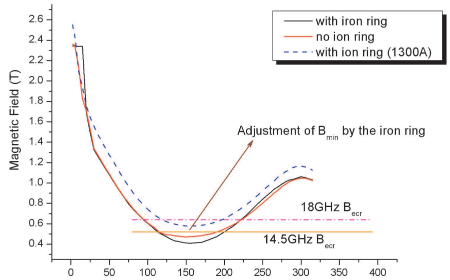

Fig. 1. Axial magnetic field distributions of LECR2M.

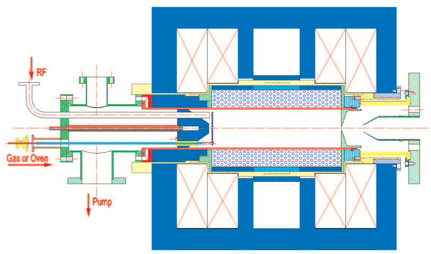

Fig. 2. Schematic structure plot of LECR2M.

Table 1. Comparison of the typical parameters of LECR2M with LECR2.

parameters	LECR2M	LECR2
axial field/T	2.5, 1.2	1.5, 1.0
$B_{\rm rad}$/T	1.15	1.0
hexapole material	N45M	N42
RF frequency/GHz	14.5—18	14.5
RF injection + mode	rectangular wave guide	coaxial
plasma chamber ID/mm	76	70
$L_{\rm mirror}$/mm	285	300
ECR Length/mm	90	90
$B_{\rm min}$/T	0.42	0.39

4 Preliminary test

The installation of LECR2M was completed at the end of August 2005. Then the source was mounted on the test bench of former LECR3 source. After about two weeks of vacuum evacuation and plasma conditioning, a very good vacuum condition was obtained: 1.0×10^{-7}mbar at the injection side and 6.0×10^{-8}mbar at the extraction side (base vacuum). Oxygen was the first gaseous element tested on the source. By the injection of maximum 1.1kW 14.5GHz rf power into the plasma chamber, very promising results were obtained. 1.4emA O^{6+} beam was detected on the Faraday cup applied with a -150V biased voltage. By some optimization, 310eμA O^{7+} was also obtained at the rf power of 0.76kW. Fig. 3 gives the curve of obtained O^{6+} beam intensity versus injected rf power. It is demonstrated in the plot that the beam intensity of O^{6+} does not saturate at $P_{\rm w}$=1.1kW. By increasing the rf power, more intense ion beam can be obtained.

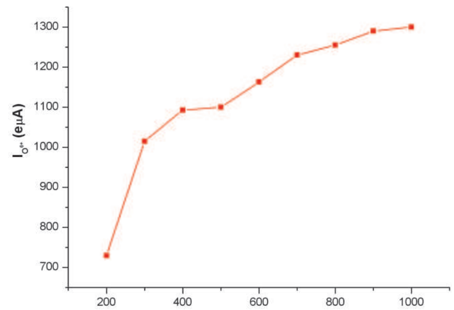

Fig. 3. O^{6+} beam intensity vs. injected rf power.

Table 2. Typical results of LECR2M in comparison with LECR2 and LECR3.

Ion	LECR2M	LECR2	LECR3
O^{6+}	1400 (1.1kW)	610	780
O^{7+}	310 (760W)	140	235
Ar^{8+}	540 (400W)	460	1100
Ar^{11+}		185	240
Ar^{12+}	53 (600W)	105	140
Ar^{13+}	33 (600W)		
Ar^{14+}	26 (600W)	12	30
Ar^{16+}	2.5 (600W)		8

To explore the performances of LECR2M, argon ion beam production was tested. Unluckily the rf power generator failed to output large rf power. The maximum output was limited to about 600W. With such a rf power heating of the plasma, only very preliminary results could be obtained. Table 2 lists the typical results obtained from LECR2M in comparison with LECR2 and LECR3[8]. Despite of the insufficient rf power, the performances of LECR2M are quite promising in comparison with LECR2, especially for the higher charge state ion beam production. It demonstrates again that optimum magnetic field confinement and larger plasma chamber are favorable for the production of high charge state ions.

5 Ion beams for experiments

After about one month's tuning of the source, LECR2M was used to provide multiple charge state ion beams for atomic physics research and material study experiments. The updating project of LECR2M is further verified to be successful in these experiments when the source delivered intense and stable high quality multiple charge state ion beams to the experimental terminals. For instance, despite of the severe contamination of SF_6 gas to the plasma chamber, very stable and intense sulfur and fluorine were still produced by the source.

Metallic ion beam production was also tested on LECR2M to provide some experimental data for the LECR3 source, which was in service to the accelerators. The tested metallic elements are iron, nickel, magnesium and lead. By using MIVOC[9] and micro-oven methods, very promising results of metallic ion beams were obtained even though the available rf power generator was a maximum output 300W 14.5GHz TWT tube. For the production of nickel ion beams with MIVOC method, the extracted ion beams are quite stable in long-term operation, but the beam intensities are quite low. It is possibly because of the insufficient rf power and the natural abundance nickel component we had used. Fig. 4 gives one of the spectra when optimizing the production of $^{58}Ni^{15+}$. Iron ion beam production results are better when tuning with $Fe(C_5H_5)_2$ compound. Typical results of 48eμA Fe^{12+}, 25eμA Fe^{13+} and 6eμA Fe^{15+} are obtained. Fig. 5 presents one spectrum when optimizing Fe^{13+} production. For lead ion beam production with a micro-oven, it seems to be obvious that more rf power is needed when optimizing the production of the high charge state ion beams of such a heavy element. Finally, 15eμA Pb^{27+}, 2.5eμA Pb^{32+} and 0.6eμA Pb^{34+} were produced with a feeding rf power of 280W. Fig. 6 gives the CSD spectrum when tuning on Pb^{27+}. Strong nitrogen ion beam peaks exist in the CSD spectrum because of insufficient plasma conditioning and some slight vacuum leakage.

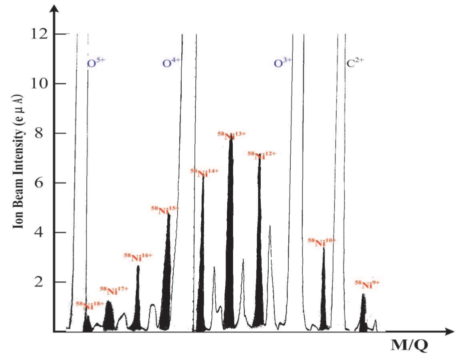

Fig. 4. CSD spectrum tuning on $^{58}Ni^{15+}$.

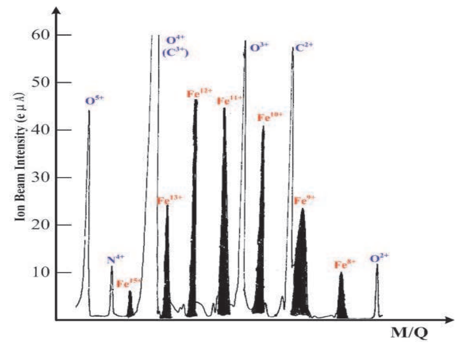

Fig. 5. CSD spectrum when optimizing on Fe^{13+}.

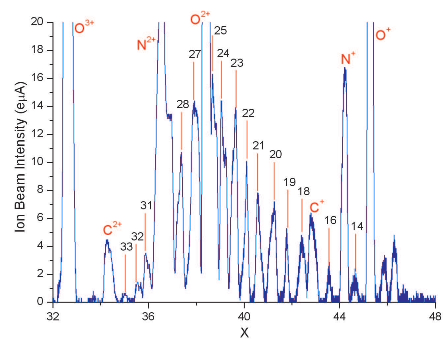

Fig. 6. CSD spectrum when testing Pb^{27+} production.

6 Conclusion

An updating project of the former LECR2 ion source has been successfully accomplished at IMP. The preliminary results are quite promising, for instance 1.4emA O^{6+}, 0.31emA O^{7+}, 26eμA Ar^{14+}, 48eμA Fe^{12+} and 25eμA Fe^{13+}. Because of being lack of high rf power output 14.5GHz generator, the preliminary tests could not produce better results. But comparing the obtained preliminary results at such a low rf power with those of LECR2, the prominent improvement is demonstrated, which owes much to better 3D magnetic field confinement, larger plasma volume and some key techniques adopted.

Some future tests of the source with higher 14.5GHz rf power or at 18GHz are necessary to have better results of the gaseous ion beams as well as some heavy metallic ion beams. Additionally, some special emphasis should be put on the enhancement of the transmission efficiency of the extracted ion beams, which was analyzed to be quite low during the preliminary tests.

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