

# DEVELOPMENT OF AN ALL PERMANENT MAGNET ECR ION SOURCE FOR LOW AND MEDIUM CHARGE STATE IONS PRODUCTION

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## Abstract

An all permanent magnet Electron Cyclotron Resonance ion source-LAPECR1U (Lanzhou All Permanent magnet ECR ion source no.1 Upgraded), has been built at IMP in 2017 to satisfy the requirements of LEAF (Low Energy intense-highly-charged ion Accelerator Facility) for first two years commissioning. LAPECR1U was designed to be operated at 14.5 GHz to produce intense low and medium charge state ion beams. LAPECR1U features a compact structure, small size, and low cost. A cone-shape iron yoke in injection side and an iron plasma electrode in extraction side were used to enhance the axial magnetic field strength. The typical parameters and the preliminary beam results of the source are given in this paper.

## INTRODUCTION

A Low Energy intense-highly-charged ion Accelerator Facility, LEAF, was launched at IMP in 2015 for researches of irradiation material, highly charged atomic physics, low energy nuclear astrophysics, *et. al.* The layout of LEAF is shown in Fig. 1. It mainly includes ECRIS, LEBT and a RFQ. The 4<sup>th</sup> generation ECR ion source FECR need to provide 2 emA  $U^{34+}$  beam with 45 GHz microwave heating. The design of FECR has been completed and the ion source is under construction. To satisfy the requirement of LEAF platform for first two years commissioning, a substitute ECR ion source, which must be compact structure and low cost, is in demand.

With the development of Lanzhou All Permanent Magnet Electron Cyclotron Resonance ion source (LAPECR) in Institute of Modern Physics (IMP) in the last decades, it has become the cost-optimal machine to produce high intensity and multiple charge state ion beams. LAPECR series are widely used for heavy ion accelerators, atomic physics research [1], and Heavy Ion Medical Machine (HIMM) [2] because of such advantages as compact structure, low cost and small size. We have built an upgraded all permanent magnet ECR ion source No.1, named LAPECR1U to satisfy the requirements of LEAF facility as ion injector for preliminary experiment.

LAPECR1U was designed to be operated at 14.5 GHz with the extraction HV 10-40 kV, and expected to produce intensity low and medium charge state ion beams. Especially, high intensity  $N^{2+}$  ion beam with high

beam quality was expected because of the same  $A/Q$  as  $U^{34+}$ .

LAPECR1U has successfully delivered  $He^+$  and  $N^{2+}$  ion beams for RFQ commissioning. This paper will give the details of the design of LAPECR1U. Then, the preliminary commissioning results of LAPECR1U on LEAF platform were presented.

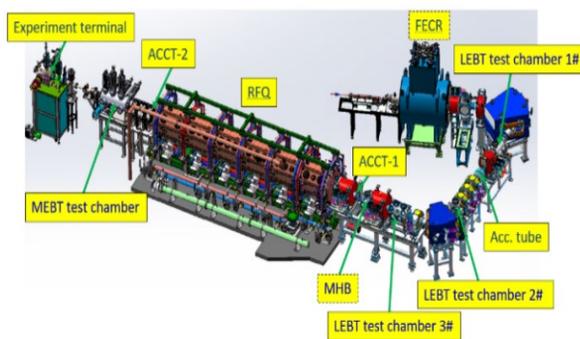


Figure 1: Layout of LEAF.

## THE DESIGN OF LAPECR1U

LAPECR1U, which was designed based on older LAPECR1 [3], is a low and medium charge state ion source that can produce intense  $N^{2+}$  ion beam. In our design, the axial magnetic field is mainly produced by two permanent magnet rings and the radial magnetic field is provided by one hexapole. A 12-segmented axial magnetic ring at injection side provide the injection magnetic field with the peak up to about 0.63 T, and a 12-segmented cone shape magnetic ring at extraction side provide the extraction magnetic field up to 0.67 T. In order to improve the performance and control the size of LAPECR1U, a cone-shape iron yoke in injection side and an iron plasma electrode in extraction side were used to enhance the axial magnetic field strength, and the axial magnetic field can exceed 1.45 T at injection side and 0.72 T at extraction side. The  $B_{\text{mini}}$  field was optimized to 0.38 T by varying the space between injection ring and extraction ring. The radial magnet is a 12-segmented Halbach structure hexapole which provides a 0.94 T radial magnetic field at the inner wall of a 40 mm diameter plasma chamber, which is designed with double-wall structure allowing sufficient low conductivity water cooling. The typical parameters of LAPECR1U are given in Table 1. The schematic of LAPECR1U is shown in Fig. 2.

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Table 1: Key Parameters of LAPECRIU

$B_{inj}$ (T)	0.63(1.45)
$B_{ext}$ (T)	0.67(0.72)
$B_{mini}$ (T)	0.38
Br of chamber surface (T)	0.94
Plasma chamber ID (mm)	40
$R_f$ (GHz)	14.5
HV (kV)	40
$L_{mirror}$ (mm)	78
$L_{ecr}$ (mm)	46
Dimension (mm)	$\Phi 202 \times 210$

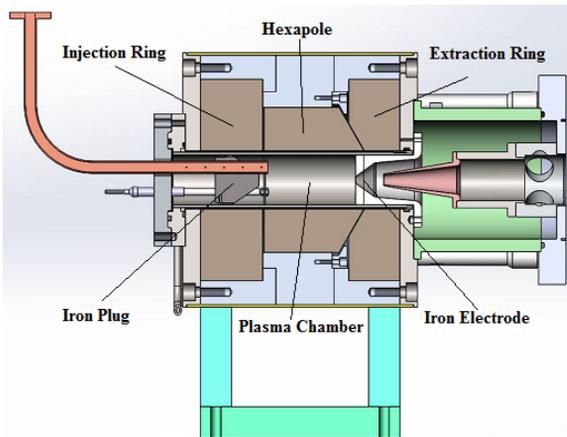


Figure 2: Schematic of LAPECRIU.

As shown in Fig. 2, LAPECRIU possesses more compact structure and higher axial magnetic field strength. Each of magnet rings next to another, and the male cone shape hexapole was cooperated with the inner cone shape extraction ring to compensate the radial field at extraction side. Figure 3 shows the contours map of LAPECRIU in x-z plane, and the total field  $B=0.7$  T contours are well closed inside the plasma chamber. Figure 4 shows the axial magnetic configuration of LAPECRIU ion source.

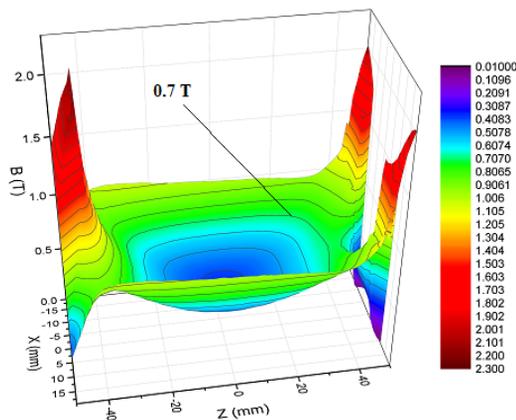


Figure 3: The contours map of LAPECRIU in X-Z plane.

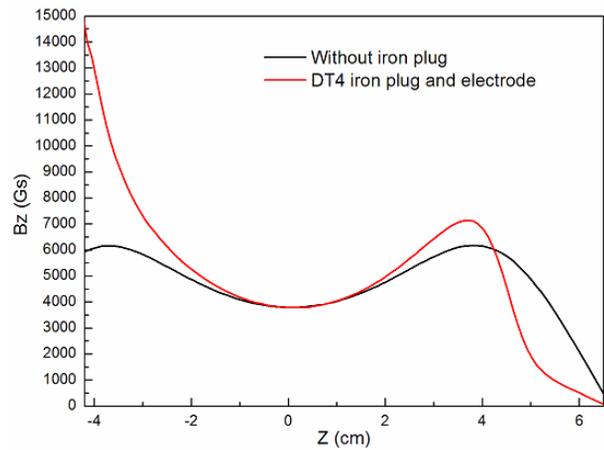


Figure 4: Axial magnetic configuration of LAPECRIU.

As shown in Fig. 4, due to the employment of iron plug and iron electrode, axial fields at injection side and extraction side were enhanced significantly, and the field gradient has increased. This will be beneficial for beam production of higher charge state ions according to the scaling laws.

## PRELIMINARY COMMISSIONING RESULTS

LAPECRIU was installed at LEAF in December, 2017. The first beam was extracted on the end day of January, 2018. Figure 5 gives the photo of the source and Q/A analyser. The Q/A analyser consists of two solenoids and a  $110^\circ$  dipole. Beam diagnostic devices, located at the end of Q/A analyser, include a Faraday cup, X&Y Allison scanners and a beam profile viewer.

The source has passed the 30 kV insulation test without sparking, and it has been working well under 20 kV extraction voltage with the distance between plasma electrode and puller of 22 mm. The pore diameters of plasma electrode and puller were 6 mm and 8 mm respectively. Because of other more important missions of LEAF platform, we have not enough time to optimize the performance of this ion source, the optimization had been operated for only one week. During such a short period, we have tuned the helium ions and nitrogen ions. Microwave power was fed into the ion source from a 14.5 GHz TWT (Traveling-Wave Tube) amplifier. Finally, 5.0 emA of  $He^+$  was measured by faraday cup with -200V biased voltage, when the total drain current was 12.1 emA and microwave power was 200 W. Under the same condition, 1.5 emA of  $He^{2+}$  were obtained under 420 W microwave power, while the total drain current was 7.2 emA.

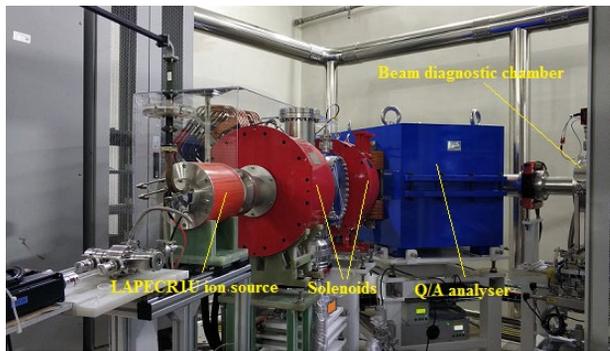


Figure 5: Picture of LAPECRIU and Q/A analyser.

For nitrogen ions beam production, two approaches were taken to optimize the beam intensity. During the first test, only nitrogen gas was fed into the source, 1.7 emA of  $N^{2+}$  was measured by faraday cup under RF power of 190 W. Obviously, it is not difficult to product such lower charge state ions, however, only 56 eμA of  $N^{5+}$  was measured. In order to enhance higher charged state ions production, helium was also fed into the source as supporting gas. Easy to see that the CSD (Charge States Distribution) was shifted to the high charge state ions when supporting gas was used, then 157 eμA of  $N^{5+}$  and 8 eμA of  $N^{6+}$  were obtained at 20 kV extraction voltage and 260 W rf power. Figure 6 shows the spectrum optimized on  $N^{5+}$ . The performance of the source for Helium and Nitrogen ion production was summarized in Table 2.

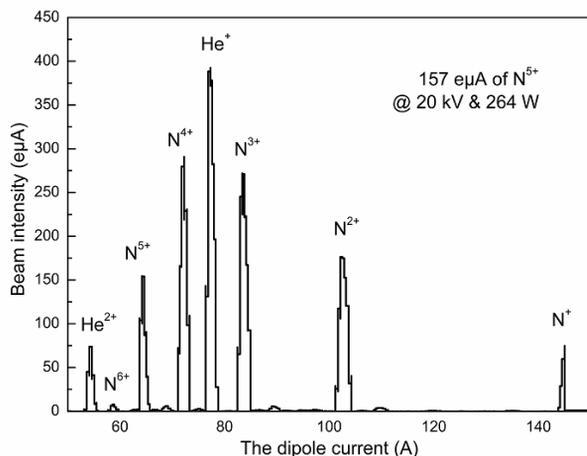


Figure 6: The CSD optimized on  $N^{5+}$  with mixed gas.

Table 2: Summary of Maximum Beam Current for Various Ions and Charge States (eμA)

	1	2	3	4	5	6	7
He	5100	1500					
N	1600	1700	828	424	157	8	

In order to investigate the beam quality of  $N^{2+}$  ion, beam emittances with several beam intensities were measured and plotted. As shown in Fig. 7, beam emittance increases with the intensity. Two reasons should be considered, the one is plasma status depended on source tuning, which decided the plasma meniscus [4]. Another

is aberrations from magnets and space charge effects [5]. Both of two reasons led to the growth of beam emittance. In addition, the measured phase space distribution of  $N^{2+}$  with beam intensity about 1.5 emA was displayed in Fig. 8. Not hard to see that the phase space was seriously distorted with such a stronger beam intensity. It is disadvantages to beam transportation. Fortunately, beam performance at a low intensity is enough to the early stage commissioning. Anyhow, some methods should be taken to optimize the beam quality in the future.

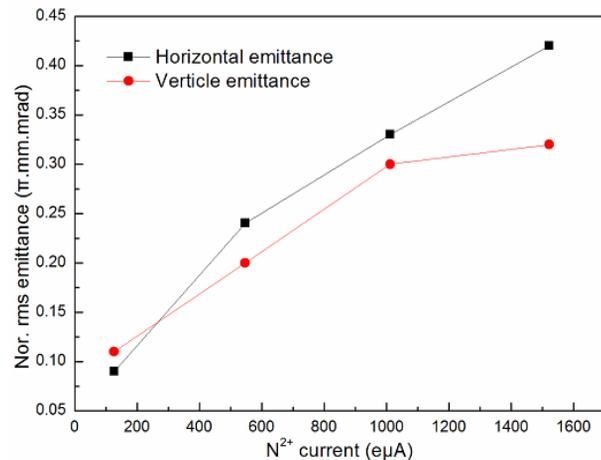


Figure 7:  $N^{2+}$  beam emittance versus beam intensity.

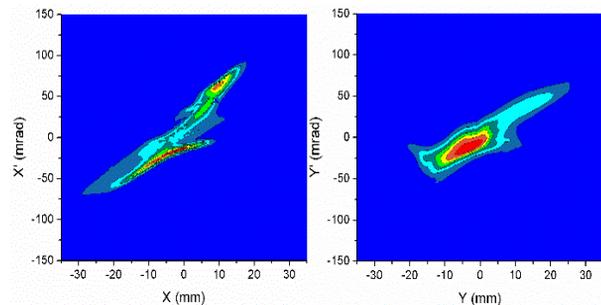


Figure 8: Measured phase space distributions for 1.5 emA  $N^{2+}$  beam.

## CONCLUSIONS

A compact all permanent magnet ECR ion source for low and medium charge state ions has been successfully fabricated at IMP. The preliminary operation results of LAPECRIU for the LEAF platform have been presented in this paper. Performance of the ion source is good enough to meet the requests of LEAF project for preliminary commissioning.

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