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LECR5 DEVELOPMENT AND STATUS REPORT

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Abstract

LECR5 (Lanzhou Electron Cyclotron Resonance ion source No. 5) is an 18 GHz room temperature ECR ion source featuring Ø80 mm ID (Internal Diameter) plasma chamber and high magnetic fields. It has been successfully constructed at IMP recently and has been fully commissioned to meet the requirements of SESRI (Space Environment Simulation and Research Infrastructure) project. According to the test results, LECR5 can meet the requirements of SESRI with sufficient beam intensities within the required the transverse emittances. As LECR5 is designed to be optimal for the operation at 18 GHz, we have explored the source performance at 18 GHz with a maximum microwave power around 2 kW. Recent source test indicates, LECR5 can produce not only high intensity ion beams such as 2.12 emA O^{6+}, 121 eμA of Ar^{14+}, 73 eμA of Kr^{23+}, 145 eμA of Xe^{27+}, but also very high charge state ion beams such as 22 eμA of Bi^{41+}. This paper will present the recent progress with LECR5, especially the intense ion beam production and the beam quality investigation.

INTRODUCION

Space Environment Simulation and Research Infrastructure (SESRI), which is one of the large-scale science projects proposed in the National Twelfth Five-Year Plan of China, will be constructed in Harbin Institution of Technology. It has kinds of accelerators designed and constructed by the Institute of Modern Physics (IMP), the Chinese Academy of Sciences (CAS). The 300 MeV proton and heavy ion accelerator is a significant radiation source, which will supply 100 - 300 MeV protons and 7 - 85 MeV/u heavy ions for studying the interaction of high energy space particle radiation with the material, device, module, and biological entity. Electron Cyclotron Resonance (ECR) ion sources are widely used to produce a multi-charged ion beam for heavy ion accelerators. The SESRI project dedicated to space radiation consists of a high performance ECR ion source, a high intensity ion linac, a synchrotron, and three research terminals to meet the above requirements. As shown in Fig. 1. Table 1 shows the required beam current and quality of the ion source. Some all permanent magnet ECR ion sources (LAPECR1, LAPECR2) and some room temperature ECR ion sources (LECR1, LECR2, and LECR3) have also been successively built at IMP [1].

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All permanent Magnet ECR ion source and 14.5 GHz room temperature ECR ion source cannot meet the bismuth ion beam requirement. Referring to the ECR ion source development at IMP [2], 18 GHz ECR ion source can meet this project's needs. As the critical part of the complex, a high performance room temperature ECR ion source (named LECR5) was proposed for various ion beams injection. Ac-cording to the scaling laws of an ECR ion source [3, 4]. Its design is based on LECR4 [5] parameters and optimized for the magnetic field of the SECRAL operating at 18 GHz [6]. Compared with a superconducting ECR ion source, a room temperature 18 GHz ECR ion source has the advantages of more accessible construction, lower cost, and more convenient maintenance.

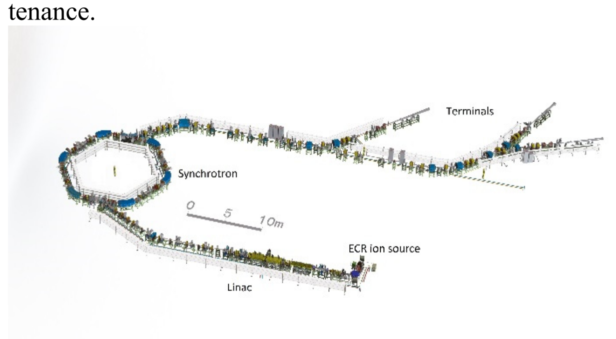

Figure 1: The layout of accelerator of SESRI.

Table 1: The Requirements of the Ion Source (*updated)

Ions	Current (eμA)	4RMS (π.mm.mrad)
H_2^+	≥250	≤0.8
$^{4}He^{2+}$	≥200*	
$^{84}Kr^{18+}$	≥84	≤0.6
$^{209}Bi^{32+}$	≥50	

DESIGN OF LECR5 AND FEATURES

As shown in Fig. 2. For most room temperature ECR ion source, the axial magnetic field to achieve a mirror field uses two coils that injection and extraction coils. LECR5 designed a third set of coils placed in the middle of the mirror field to control Bmin. It is advantages to tuning on the electron temperature through the magnetic gradient at resonance. Besides, the magnetic field at the injection side is reinforced by a thick iron plug that obtains a high-B mode magnetic profile. The axial field of 2.5 T at the injection is

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achievable. A hexapolar system gives the radial magnetic field. The optimum configuration for such a system is given by the so-called Halbach array composed of 36 block permanent magnets (88 mm inner diameter, 188 mm outer diameter, and 320 mm long). Using the higher remanence material N50M NdFeB (Br=1.407 T, Hc=-1043 kA/m) improves the radial magnetic field strength, and uses higher polarization coercivity material N48SH NdFeB (Br=1.386 T, Hc=-1011 kA/m) solves the self-demagnetization problem in the six critical magnetic segments. The radial magnetic field at a chamber wall of 1.2 T is achievable, and the large and long plasma chamber (80 mm in diameter and 340 mm long) allows a long lifetime for the ions to produce high charge states. Table 2 presents the design parameters of the LECR5 ion source. After the assembly, the magnet parameters are up to and better than the design value [7].

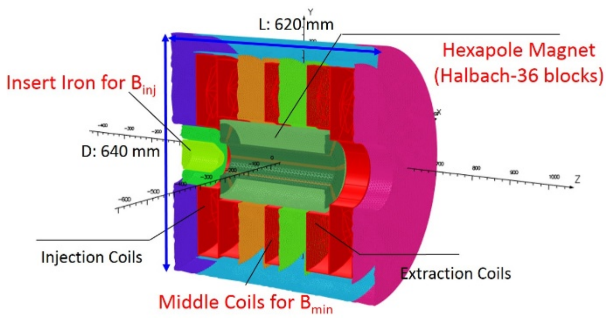

Figure 2: Layout structure of the LECR5 ion source.

Table 2: The Design Parameter of the LECR5 Ion Source

Parameters	value
Microwave frequency (GHz)	14.5 - 18
Maximum power (kW)	2.5
B_{inj} (T)	2.5
B_{ext} (T)	1.4
B_{min} (T)	0.33~0.53
B_{rad} (T)	1.2
Mirror Length (mm)	340
Plasma Chamber D (mm)	80
Maximum HV (kV)	30

COMMISSIONING ION BEAMS

Gaseous Ion Beams Production

The testing of LECR5 was started in August 2019 by producing high charge state ion beams from oxygen and argon plasmas [7]. The first extraction's beam intensity adopted dual-frequency (14.5 + 18 GHz) heating has produced 450 eμA O7+ and 260 eμA Ar12+, which verified the performance of LECR5. At the beginning of 2020. The commissioning of LECR5 for stable beam production was started from oxygen. 2.12 emA O6+ has been obtained after optimization. Depending on 14.5+18 GHz microwave power and comparing with other ECR ion sources given in Fig. 3. It was commissioned with a single frequency of 18 GHz, maximum power was 2 kW, and stainless steel plasma chamber for the SESRI project requirements. Optimization of typical charge states of gaseous ion beams was commissioned to explore the performance of LECR5 ion source. The record intensities for argon, krypton, and xenon are presented in Table 3. The beam results of LECR4 in Table 3 were commissioned with dual-frequency (18 +18 GHz), and microwave power was less than 2.2 kW [8]. Those of SECRAL in Table 3 were commissioned at 18 GHz [9]. It produces a higher charge state ion beam that is better than LECR4 and close to SECRAL operated at 18 GHz. The higher radial magnetic field (>1.2 T) can produce higher charged ion beams at the same conditions. It can meet the demand of ion beam current at less than 1 kW microwave power and supply stable ion beams. For the light ion beam, the magnetic field and microwave power can be reduced to meet its needs.

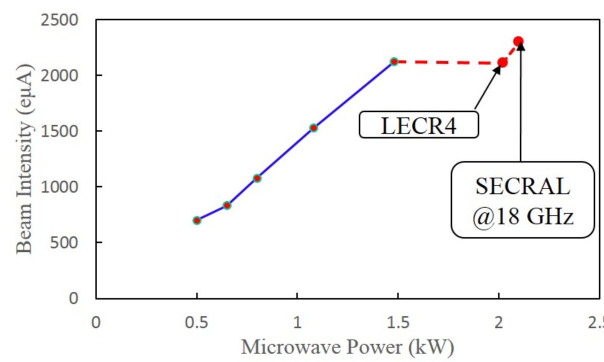

Figure 3: Depending on 14.5+18 GHz microwave power and comparing with other ECR ion sources.

Table 3: Comparison of the Gaseous Ion Beam Results of LECR5 with other ECR Ion Sources

	Q	**LECR5** (eμA)	**LECR4** (eμA)	**SECRAL** (eμA)
^{40}Ar	11+	521	620	
	12+	385	430	510
	14+	121	185	270
	16+	21	21	73
^{84}Kr	18+	220		
	20+	120		
	23+	73		
	26+	32		
^{129}Xe	20+	338	430	505
	23+	263	275	
	26+	200	205	410
	27+	145	135	306
	28+	104	92	

Metal Ion Beams Production

High intensity high charge state metal ion beam is essential for performance presentation of ECR ion source. The

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bismuth ion beam has been produced with LECR5 operated at dual-frequency (14.5 +18 GHz) and aluminum plasma chamber. By optimizing of LECR5 conditions, stable high charged bismuth ion beams had been obtained with an oven method at 25 kV extraction voltage. An internal oven was developed at IMP for metallic ion beam production. The central part of the oven (Fig. 4) consists of an alumina ceramic wound with a 0.5 mm diameter tantalum wire, and its working temperature is from 200 ℃ to 1300 ℃ [10]. A 15 A/20 V electrical power supply is used to heat the tantalum wire. Table 4 presents the commissioning beam results compared with LECR4 and SECRAL. Figure 5 shows the typical spectrum when Bi41+ is optimized. The results of higher charged bismuth ion beams are close to and better than those of SECRAL operated at 18 GHz.

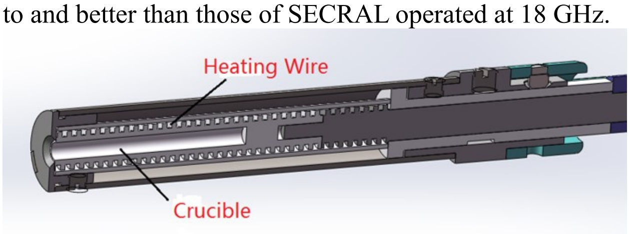

Figure 4: The layout structure of the oven used on the LECR5.

Table 4: Comparison of the Metal Ion Beam Results of LECR5 with Other ECR Ion Sources

	Q	LECR5 (eμA)	LECR4 (eμA)	SECRAL (eμA)
^{209}Bi	30+	119		191
	31+	101	92	150
	32+	81	63	
	41+	22		22
	45+	12.5		15
	50+	3.8		1.5

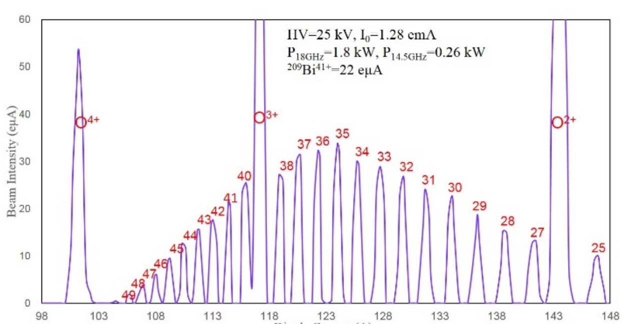

Figure 5: The spectrum of LECR5 optimized for Bi41+ at dual-frequency (14.5 +18 GHz) heating.

ION BEAMS EMITTANCE

LECR5 ion source can improve the efficiency of linac by providing high quality ion beam. It is difficult to control the beam quality of ECR ion source for light ion, but it can be optimized for heavy ion beam. The light ion beam emittance could be controlled by slits in two directions and optimization of low energy beam transmission. During the LECR5 beam commissioning heavy ion beam, 121 eμA Ar^{14+}, 145 eμA Xe^{27+}, 81 eμA Bi^{32+} and 22 eμA Bi^{41+} at 25 kV extraction voltage ion beam emittances were measured by an Allison-type emittance scanner. The results are shown in Fig. 6. It can be seen that normalized emittance of high intensity high charged ion beam is around 0.1 π.mm.mrad and could satisfy the requirement of SESRI.

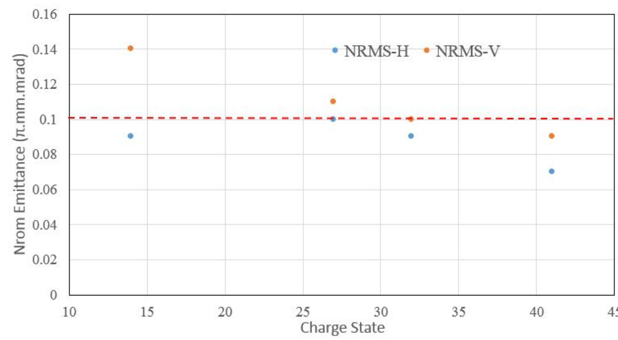

Figure 6: Ion beam Emittance for argon, xenon, and bismuth, H means horizontal, V means vertical.

CONCLUSION AND PERSPECTIVES

A high performance 18 GHz room temperature ECR ion source was successfully constructed. Some outstanding results of medium-high-charge ion beams have been produced. It can produce a higher charged heavy ion beam close to SECRAL operated at 18 GHz. The emittance of the ion beam is reasonable and better than the requirements of the SESRI project. The 18 GHz room temperature ECR ion source's performance can be further improved by increasing the radial magnetic field and effective confinement magnetic field. Better beam results will be obtained by multi-frequency heating and microwave power up to 3 kW in the future.

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