ISBN: 978-3-95450-196-0 doi:10.18429/JACoW-ECRIS2018-THA4

DEVELOPMENT OF LECR4 ION SOURCE FOR INTENSE BEAM PRODUCTION AND LECR5 FOR SESRI PROJECT*

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Abstract

Several intense highly charged heavy ion beams have been produced from Lanzhou ECR ion source No.4 (LECR4) since 2014. Recently an attempt to generate intense light ion beam was tested by High-B mode of LECR4 ion source. We firstly produced 8.72 emA of $^{4}He^{2+}$ beam with 1.7 kW of 18 GHz microwave power at 30 kV extraction voltage. According to the experience of LECR4. A new room temperature ECR ion source (named LECR5) has been designed to deliver multiple charge ion beams for the Space Environment Simulation Research Infrastructure (SESRI) at Harbin Institute of Technology. It aims to produce almost all ion beams from H_2^+ to $^{209}Bi^{32+}$. This article reviews the latest result of LECR4 and preliminary design of LECR5 in detail.

INTRODUCION

ECR Ion Sources are used to produce highly charge state ion beams of intermediate and heavy mass elements. They are widely used to produce ion beams for accelerators, atomic physics research and industrial applications. Some room temperature Electron Cyclotron Resonance ion sources (LECR1, LECR2 and LECR3) have been successively built at IMP [1, 2]. One unique feature of LECR4 is that the solenoid coils are fully immersed in a special me-dium and cooled by evaporative cooling technology when excited [3]. To satisfy the requirement of intense multi-charged ion beam, a research program named Space Envi-ronment Simulation and Research Infrastructure (SESRI). LECR5 was proposed in 2016. The traditional cooling technology that solid quadrate copper wire was used to wind the solenoid pancakes instead of hollow copper wire, which means it is high pressure de-ionized water free.

DEVLOPMENT OF LECR4

LECR4 is used for SSC-Linac injector at Institute of Modern Physics (IMP). The SSC-Linac consists of an ECR ion source, low energy beam transport (LEBT), a 4-rod RFQ, medium energy beam transport (MEBT) and IH-DTL, as shown in Fig. 1. LECR4 was redesigned from DRAGON concept in 2012. Its radial field at plasma cham-ber wall of 76 mm inner diameter is about ~1.0 T. LECR4 was built and started commissioning at 18 GHz in 2014. The source has successfully delivered H_2^+, O^{5+}, C^{4+}, O^{4+}+C^{3+}, Ar^{8+} and Bi^{30+} ion beams for RFQ and DTL com-missioning.

Heavy Ion Beam Production

Based on the original research of LECR4 M/Q selector, an updating selection system for LECR4 has been designed to handle the higher beam intensities. Figure 1 shows the schematic design of the new M/Q selection system. As the actual beam envelope and beam waist cannot be controlled with a single solenoid lens, an additional solenoid is introduced before the dipole magnet. To further study the production of very high charge state heavy ion beams, LECR4 was tested with bismuth by oven, the attempt to produce uranium ion beam by sputtering. Table1 shows some of the latest results from LECR4 and compares beam intensity with other high performance sources for reference [4]. The microwave power is less than 2.3 kW with operation frequency 18 GHz (beam intensity: eμA).

Table1. Latest Results of LECR4 at 18 GHz in Comparison With Other High Performance ECRIS

	Charge State	GTS	LECR4
^{16}O	6+	1950	2110
	7+		560
^{40}Ar	8+	1100	1717
	9+	920	1230
	11+	510	620
	12+	380	430
	14+	174	185
^{129}Xe	20+	310	430
	21+	274	320
	23+		275
	25+	244	215
	27+	168	135
^{209}Bi	28+		170
	29+		145
	31+		92
	32+		63
^{238}U	31+		35
	32+		30

* This work was supported by the NSFC (National Nature Science Foun-dation of China) research program with Contract No. 11427904
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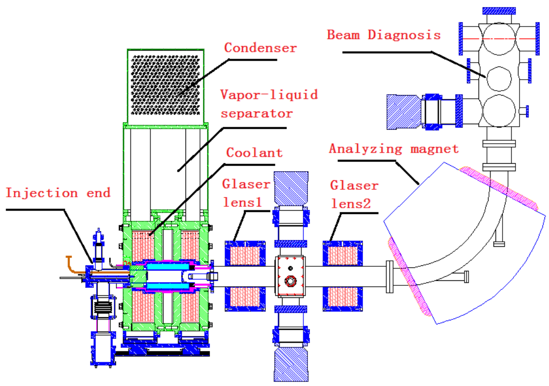

Figure 1. A schematic cross-section view of the LECR4 source body and M/Q selector system

Table 2. Yield Comparison of Various Ion Sources

Ion Source	f (GHz)	Pw (kW)	He^{2+}(emA)
LECR4	18	1.7	8.74
VENUS	18+28	1.7+1.0	11

High intensity helium ion beam

Multi-charged helium ion is a critical ion in particle physics, material science and medical science. Multi-charged helium ion beam instead of deuterium ion beam for pre-acceleration experiments. With the improvements to the LECR4 lower energy transmission line a new record intensity for the production of helium was achieved. High intensity helium ion beam was tested. Table 2 shows the yield of multi-charged helium ion beam and compares beam intensity with other high performance sources for reference [5]. The extraction high voltage is 30 kV with all total beam is 14.43 emA. The stability monitoring is about 17 hours which the 5 emA multi-charged helium ion beam was produced. As shown in Fig. 2.

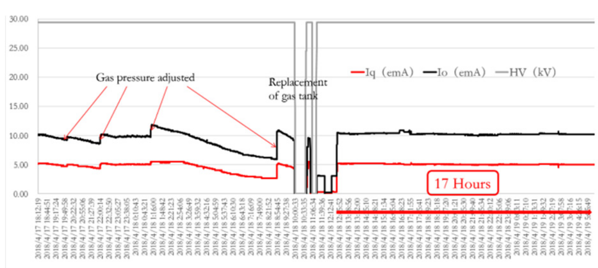

Figure 2. Long period stability monitoring @ 30 kV-5 emA

Double Solenoids To Improve M/Q Resolution

In 2014, The Bismuth ion beams were optimized, the M/Q resolution of LEBT is relatively poor. The beam spots were overlapped for highly charged bismuth ions. Some schemes of improving the M/Q resolution as follows: a) Increasing the deflection angle of the dipole magnet, b) De-creasing the deflection radius of the dipole magnet, c) In-creasing the distance between the dipole magnet and the slit, d) another solenoid to control the beam spot size of the slit. According to the experiments, the solenoid focusing before the M/Q separation can result in strong degradation of the beam quality and can create a hollow beam structure due to different focal points of different charge states [6]. The hollow beam structure has been observed by several ion source groups. It could possibly be avoided by increas-ing the space charge compensation and by using electro-static focusing. The beam spot is hollow when optimized the intensity Bismuth ion beams on this ion source. In last, to solve this problem, a Dual-solenoid scheme is proposed, as shown in Fig. 1.

LECR5-SESRI PROJECT

Space Environment Simulation Research Infrastructure (SESRI), which is a scientific project for a major national facility of fundamental research, has recently been launched at Harbin Institute of Technology (HIT). It fills in the blank in national simulation facilities, comprehensive space environment interacting with the material science research platform in the integrated environment of large space. Granted the national funds of 1.8 billion RMB (about 261.4 million USD) to construct 9 sub-system and its supporting infrastructure. Heavy ion accelerator is one of the most important systems. LECR5-SESRI ion source as the injector provides various ion beams from H to Bi. All requirements of ion beams need to be produced by LECR5 is shown in the Table 3. the emittance requirement of hydrogen molecular ion beam is a challenge due to the high-B mode.

Table 3. Requirements of ion beams

Ions	I(euA)	HV (kV)	Beam Emittance (π.mm .mrad)
H_2^+	250	8	0.8（norm, 90%）
$^4He^{2+}$	50	8	0.6（norm, 90%)
$^{84}Kr^{18+}$	80	18.667	
$^{209}Bi^{32+}$	50	26.125	

Design of LECR5 Ion Source

The LECR5 has been designed according to the magnetic specification and the experiment of LECR4. To enhance the magnetic field strength, an iron plug is added on the injection side: in such a way, an axial field of 2.6 T at the injection is achievable. The magnetic field value at the extraction of 1.4 T is achievable. As shown in Fig. 3. The radial magnetic field at chamber wall of 1.2 T is achievable. The radial magnetic is composed of 36 segments with traditional Halbach. N50M and N48SH NdFeB permanent magnetic materials are used. The double wall plasma chamber is made of aluminium to enhance the secondary electron emission. The large and long plasma chamber (80

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mm in diameter and 340 mm long) allows a long lifetime for the ions in order to produce high charge states. In such a configuration, the 18 GHz resonance is 132 mm long. As it is a source for tests, one has chosen several frequencies: 14 and 18 GHz. All frequencies could be launched together. The ion source being equipped with a 2 wave guides rf injector. The general picture of the source is presented in Fig. 4. (SN: SoleNoid; AM: Analyzing Magnet; BD: Beam Diagnosis)

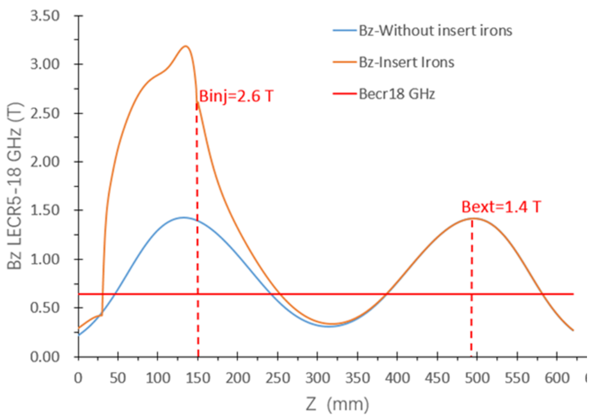

Figure 3. The axial magnetic field configure by simulation

Design of M/Q Selector System

The layout of the beam lines in the ECR vault including the diagnostic beam line for the LECR5-SESRI, which still has to be installed, is shown in Fig. 3. The diagnostic beam line of the LECR5 will have a solenoid directly in the front of the 90° bending magnet. The solenoid focuses the beam into the focal point of the 90° magnet (double focusing action) and behind the magnet a horizontal slit in the second focal point will ensure sufficient mass resolution. The initial focusing distance from ion beam extraction to solenoid inlet is 300 mm. The drift distance from analysis magnet outlet to slit is 900 mm. The diagnostic line is completed with a chamber containing an Aillsion Emittance device for both transversal planes and a Faraday cup.

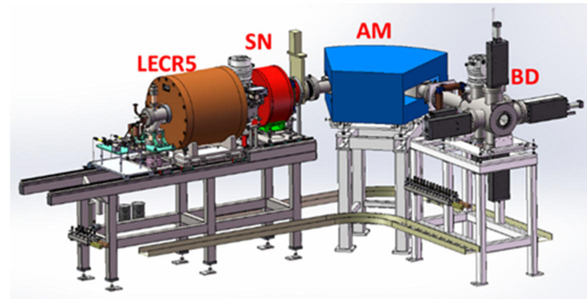

Figure 4. Layout of LECR5 source body and M/Q selector system.

SUMMARY

Double solenoids can control beam toward the ana-lyzing magnet better than single solenoid in more compact Q/A selector system. The 1st or 2st generation ECRIS is the most potential for produce high current high beam qual-ity multi-charged helium ion beam. The performance of LECR4 is still promising when improving the radial mag-netic field and improving the extraction system. Larger plasma chamber and more flexible magnetic field with LECR5.

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