

HIGHLY CHARGED ECR ION SOURCE DEVELOPMENT AT IMP*

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Abstract

Highly charged ECR ion source development plays an important role in the heavy ion accelerators advancement at IMP, such as HIRFL upgrade, heavy ion treatment complex HIMM, future heavy ion facility HIAF, and so on. As requested by those projects, many high performance highly charged ECR ion sources with different technologies have been built, or under development. The representative ion sources are superconducting ECR ion sources SECRAL and recently built SECRAL-II, room temperature LECCR4 ion source with an innovative evaporative cooling method, permanent magnet ECR ion sources of LAPECR series, and a 45 GHz 4th generation ECR ion source FECCR. In this talk, a general review of highly charged ECR ion sources will be presented. The typical performances, operation status, as well as the future developments will be discussed.

INTRODUCTION

Requested by the development of cyclotrons at IMP, Electron Cyclotron Resonance (ECR) ion source had been incorporated to HIRFL dated to the late 1980s, when the first ECR ion source a Caprice type 10 GHz machine was bought from Grenoble, France in 1987 [1]. This ion source was lately modified and became the so called LECCR0 source in the IMP highly charged ECR ion source series. Based on the experience of LECCR0, a 10 GHz ECR ion source that was lately renamed as LECCR1 had been developed and also put into routine operation during the years from 1995 to 2005. Since then, series of LECCR type room temperature ECR ion source have been developed and put into operation for HIRFL successively, which has a fundamental impact to the performance of the facility and multiple discipline scientific goals (Fig. 1). The development of permanent magnet ECR ion sources was started after year 2000. The main goal of this type of compact machine is to prove intense multiple heavy ion beams for industrial applications and small-scale platforms that provide convenient beam time and ion species for users from diversity of fields. The development of superconducting ECR ion source is fundamentally boosted by the needs from the HIRFL upgrade, especially the heavy ion cooler storage ring synchrotron CSR program [2], and the nuclear sciences therein. The first superconducting ECR ion source SECRAL (Superconducting ECR ion source with Advanced design in Lanzhou) is also the 2nd so-called the 3rd generation ECR ion source after the VENUS ion source completed in 2002. Operated typically with the microwave power from a 24 GHz gyrotron generator and an 18 GHz klystron amplifier, SECRAL is one of the most powerful

ECR ion sources with many world records of highly charged heavy ion beam intensities.

This paper will give a brief review of the highly charged ion sources developed by the Ion Source Group at IMP. The typical features and the performances will be given. In the last section of this paper, a general introduction of the new activities towards the 45 GHz ECR ion source FECCR will also be given.

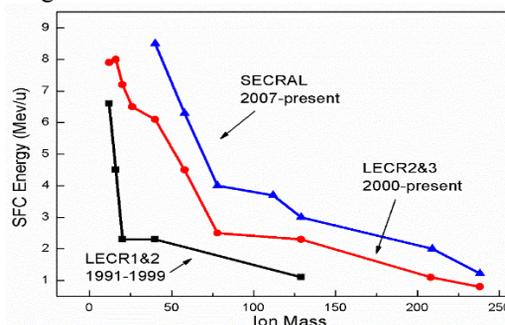


Figure 1: The impact of ion source development to SFC cyclotron performance at HIRFL.

PERMANENT MAGNET ECRIS

All permanent magnet ECR ion sources have many advantages over traditional ECR ion sources composed of several axial room temperature solenoids and one permanent magnet hexapole magnet, which make them the first choice for many heavy ion facilities and platforms. At IMP, three types of all permanent magnet ECR ion sources have been built for diverse applications, i.e. the very compact ECR ion source LAPECR1 for intense mono or multi charge state ion beams' production, the LAPECR2 ion source installed on the 320 kV high voltage multidisciplinary platform [3], and the LAPECR3 ion source dedicated to C⁵⁺ beam production for the cancer therapy facility HIMM [4].

LAPECR1

This ion source is designed with a very compact size of $\varnothing 200$ mm \times 300 mm (including the extraction structure) which makes the source body weighs only 25 kg that can be easily moved around by an adult. Despite of the compactness, the source is equipped with a $\varnothing 40$ mm ID plasma chamber that enables the direct microwave power feeding with a WR62 rectangular waveguide to simplify the injection plug structure. Iron plugs at both the injection and extraction sides have been incorporated to enhance the mirror peaks. The source is designed and operated at 14.5 GHz. Recently a LAPECR1 source has been used for LEAF platform beam commissioning at IMP. With 100~300 W microwave power, 5.0 emA He⁺, 1.5 emA He²⁺, 1.7 emA N²⁺,

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160 $\mu\text{A N}^{5+}$, and $\sim 100 \mu\text{A Ar}^{9+}$ have been produced. Fig. 2 shows the picture when LAPECR1 is under commissioning.



Figure 2: LAPECR1 source at test bench.

LAPECR2

LAPECR2 has been built and installed on a 320 kV multi-discipline platform to deliver intense ion beams. Based on the users' requirements, ion beam species from low to high charge states of gaseous or solid elements are required. For the purposes, the source was designed to operate at high magnetic field, high frequency mode with all permanent magnet structure. To produce intense high charge state ion beams, the plasma chamber is intentionally designed as big as possible. A tradeoff between the magnet compactness and the magnetic field strength makes $\varnothing 67\text{mm}$ the final plasma chamber ID value. During the machine commissioning in 2006, the source was fed with maximum 1.1 kW 14.5 GHz microwave power from a klystron amplifier to achieve high power density inside the plasma chamber. For routine operation, a 700 W maximum output TWTA is used as a result of the limited space on the high voltage platform. LAPECR2 is a very powerful permanent magnet ECR ion source. The preliminary performance during source commissioning is given in another paper [5].

LAPECR2 was put into operation on the 320 kV HV multidisciplinary platform in 2007 (shown in Fig. 3). And it has been running on it to delivery various ion beam species for the 6 experimental terminals since then. Up to now, LAPECR2 has been used for routine operation more than 78,000 hours with 53,000 hours on-target beam time. Ion beams from H up to U have been produced. Totally, 13 groups of gaseous elements including H, D, He, C, N, O, Ne, F, Cl, Ar, Kr, and Xe, and ion beams from 14 groups of solid elements including U, Pb, Bi, Au, Ag, Eu, Fe, Ni, Ti, Mg, Cs, I, S, and Li have been delivered. Typically, 11 $\mu\text{A Xe}^{30+}$, 84 $\mu\text{A Ag}^{19+}$, 20 $\mu\text{A Ag}^{24+}$, 6 $\mu\text{A Ag}^{30+}$, 20 $\mu\text{A Bi}^{31+}$, 4 $\mu\text{A U}^{31+}$ and so on have been extracted during routine operation.



Figure 3: LAPECR2 ion source at 320 kV platform.

LAPECR3

Several heavy ion treatment facilities called HIMM or Heavy Ion Medical Machine have been initiated in China. The prototyping machines located in Wuwei and Lanzhou have been already started around 2012. The entire facility consists of 2 ECR ion sources, a cyclotron injector, a compact synchrotron and four treatment terminals. For accelerator compactness and lower cost, intense C^{5+} beam from the ECR ion source is needed and pre-accelerated by the cyclotron and injected into the synchrotron with the charge exchange injection scheme. LAPECR3, a permanent magnet ECR ion source operating at 14.5 GHz is developed aiming to be capable of delivering more than 100 $\mu\text{A C}^{5+}$ within the beam emittance of $\leq 75 \pi \cdot \text{mm} \cdot \text{mrad}$ (4 rms). As LAPECR3 is eventually for commercial applications, it should be compact and cost-efficient. The ion source's magnet is mainly composed of the injection magnetic rings, extraction magnetic rings, middle magnetic ring and a 24-segmented Halbach structure hexapole magnet. An iron plug has been employed to boost the injection magnetic field peak to $\sim 1.8 \text{ T}$ which is essential for the high B mode operation for an ECR ion source at 14.5 GHz. Such a magnet can house a $\varnothing 50 \text{ mm}$ ID plasma chamber for intense medium charge state ion beams production.

During source commissioning, C^{5+} ion beam was optimized using CH_4 gas. But beam quality was quite poor as a results of strong space charge effect stemmed from the intense H beams produced as a result of high H proportion in CH_4 . Therefore, C_2H_2 , C_2H_4 , C_3H_8 , C_4H_{10} and so on have been all tried. Among them, C_2H_2 seems to be the best choice in terms of C^{5+} beam intensity and beam quality. But the obvious drawback is the heavy pollution caused by residual carbon. Beam intensity seems to be saturated after 600 W microwave power. About 120 $\mu\text{A C}^{5+}$ beam was produced at 500 W microwave power with CH_4 , and the total drain current was 4.7 mA. Under the same conditions, 262 $\mu\text{A C}^{5+}$ ion beam could be obtained when C_2H_2 was used as the working gas, and the total drain current was 5.5 mA [6]. Totally four LAPECR3 ion sources have been installed and used as the injector ion sources for HIMM up to now (Fig 4). The typical routine operation beam currents of 60~70 $\mu\text{A C}^{5+}$ (slightly steered by cyclotron stray fields) have been adopted with the regards of accelerator needs and ion source maintenance service issues. The typical maintenance period is better than 1 month before the plasma chamber is severely contaminated by residual carbon and obvious ion source performance degradation appears.



Figure 4: LAPECR2 ion source on a test bench.

LAPECR series have played important roles in the applications of high charge state ECR ion sources at IMP.

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These 3 types of permanent magnet sources can generally meet a wide diversity of application and scientific program needs. Table 1 gives a general overview of the key parameters of LAPECR series.

Table 1: Comparison of LAPECR Sources

Specs.	LAPECR1	LAPECR2	LAPECR3
ω_{ecr}	14.5 GHz	14.5 GHz	14.5 GHz
Axial Fields	1.3 T*/0.7 T*	1.28 T/1.07 T	1.8 T*/0.9 T
Br	1.1 T	1.2 T	1.1 T
Chamber ID	∅40.0 mm	∅67.0 mm	∅50.0 mm
Mirror Length	78 mm	255 mm	170 mm
Plasma volume	~0.1 L	0.9 L	~0.3 L
U_{max}	~50 kV	~25 kV	~30 kV
Size (mm)	∅204×300	∅650×560	∅450×380
Weight	~25 kg	~650 kg	~157 kg

*with iron plug

ROOM TEMPERATURE ECRIS

Room temperature ECR ion source features one high field hexapole magnet and room temperature solenoids cooled with high pressure deionized water. Bulky iron yokes are usually utilized to minimize stray field and increase the effective mirror fields inside the plasma chamber. As the mirror fields are continuously adjustable, a room temperature ECR ion source can provide optimum magnetic configurations for the operation with microwave frequency from 10 GHz ~18 GHz typically. At IMP, room temperature ion sources of 10 GHz, 14.5 GHz and 18 GHz have been developed over the last 15 years, which is a clear evidence of ECR technology evolution and advancement.

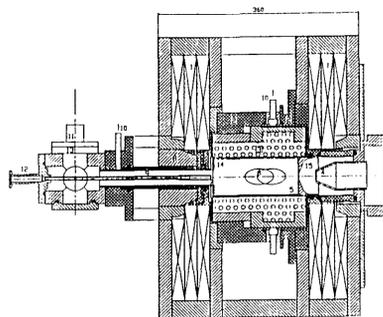


Figure 5: Schematic drawing LECCR1 source.

LECCR1 is still a Caprice type ECR ion source based on the famous 10 GHz Caprice source from CEA/Grenoble. Nevertheless, LECCR1 was not just a duplication of Caprice. Many new ideas and tricks had been tested, and some of them are still widely used among the ECR community. Fig. 5 gives the schematic drawing of LECCR1 source. By moving the plasma electrode position inside the plasma chamber, dependence of ion beam intensities of different charge states on the plasma electrode positions has been demon-

strated. With plasma chamber inner liner, typically an aluminium one, high charge state ion beam yield has been improved. With some tricks on the magnetic structure, B_{min} could be shifted towards the source extraction, which had been verified to be useful for intense beam production. Last but not least, a modified hexapole magnet had been tried as indicated in Fig. 5, and high charge state ion beam intensities had been obviously augmented, which was the first time high B mode applied to LECCR ion source. [7, 8]

The purpose of LECCR2 source was to produce intense ion beams with sufficiently high charge state particularly for heavy elements. This 14.5 GHz ECR ion source was based on the concept of Caprice and GANIL ECR4 [1, 9]. The schematic plot of LECCR2 is shown in Fig. 6. The design of the magnetic field configuration takes into account the latest understanding on the high-B and high frequency modes that are essential to improve the production of highly charged ions. High-B mode had been built with bulky iron yokes surrounding the solenoid pancakes for the axial mirrors, and radially with a very compact and efficient 24-segmented Halbach structure NdFeB hexapole magnet. The traditional diameter and length of the plasma chamber for CAPRICE is about ∅65 mm and 165 mm respectively. The dimensions of the plasma chamber for LECCR2 are ∅70 mm in diameter and 300 mm in length. Higher microwave frequency, bigger plasma volume, and sufficiently high magnetic confinement makes LECCR2 prevailed in intense highly charged ion beams production over LECCR1. Additionally, with a newly developed resistor oven and MIVOC method, metallic ion beams such as Ca^{12+} , Mg^{9+} , Ni^{12+} , Pb^{28+} and so on, could be made with LECCR2 and since then HIRFL was able to deliver to the users metallic beams. [10]

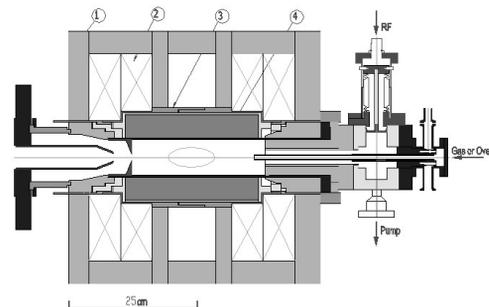


Figure 6: Schematic drawing LECCR2 source.

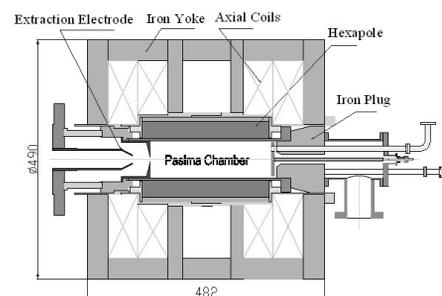


Figure 7: Schematic drawing LECCR3 source.

Inspired by the performance of LECR2, an upgraded version ECR ion source was proposed soon after LECR2 was used for routine operation. Obviously, higher fields and bigger plasma volume are favourable for highly charged ion beam production. LECR3 was designed with higher axial fields and bigger plasma chamber. The success of AECR [11] with a rectangular waveguide as microwave coupling scheme also gave LECR3 design good reference in terms of simpler ion source injection plug design and also sufficient room for iron plug to boost injection field peak. The schematic plot of LECR3 source is shown in Fig. 7. By adopting better NdFeB material with higher remanence and 36-segmented Halbach structure, the hexapole produces 1.0 T at the inner wall of a $\varnothing 76$ mm diameter plasma chamber [12]. LECR3 can produce very high intensity ion beams as well as ion beams of high charge states, for instance 1.1 e mA Ar⁸⁺, 0.5 e μ A Ar¹⁷⁺ and so on.

As LECR3 challenges almost the limit of room temperature technologies with regards to the water cooled copper pancakes that provide the axial mirror fields, we therefore collaborated with IEE/CAS to develop a higher field axial mirror that equips a high performance ECR ion source somehow comparable with an 18 GHz superconducting ECR ion source for intense beam production, such as SECRAL. Typically, the room temperature magnets cooled with de-ionized pressured water can barely work with excitation current density above 10 A/mm². Evaporative cooling method using a proprietary evaporative cooling medium developed by IEE, has some advantages over the conventional de-ionized pressured-water cooling: (1) Pressured de-ionized water free, and (2) average current density up to 12 A/mm² is possible. The detailed technical description can be found in references [13] and [14]. Incorporated with ECR ion source, axial solenoids immersed in Evaporative Cooling medium can provide much higher axial fields that can be optimum for the operation at 18 GHz microwave frequency. Based on this concept, LECR4 was developed based on the joint work between IMP and IEE. Fig. 8 is the layout of the LECR4 test bench. With higher mirror fields, even at a little bit low radial field, this prototyping ion source have produced many inspiring results that can prevail over any room temperature ECR ion sources and even competitive with those achieved with 18 GHz SECRAL.

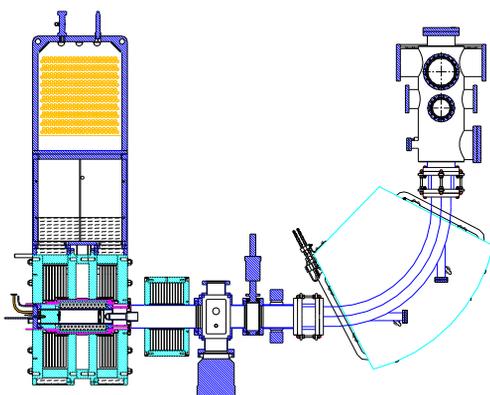


Figure 8: LECR4 source test bench layout.

Table 2 gives a comparison of the LECR series of ion sources. Obviously, the progress of ion source technologies and the understanding towards better performing machine is evidenced. Fig. 9 gives an overview of the ion source performance comparison with Xe ion beam production.

Table 2: Comparison of LECR Sources

Specs.	LECR1	LECR2	LECR3	LECR4
ω_{ecr}	10 GHz	14.5 GHz	14.5 GHz	18 GHz
Fields (T)	1.04 / 0.8	1.5 / 1.0	1.7 / 1.1	2.5 / 1.3
Br (T)	0.8	1.0	1.0	1.0*
Chamber ID	$\varnothing 65.0$ mm	$\varnothing 70.0$ mm	$\varnothing 76.0$ mm	$\varnothing 76.0$ mm
Mirror Length	165 mm	300 mm	300 mm	300 mm
Plasma volume	~ 0.7 L	1.1 L	~ 1.3 L	~ 1.3 L
RF Power	0.5 kW	1.0 kW	1.0 kW	2.0 kW

*with a salvaged hexapole magnet

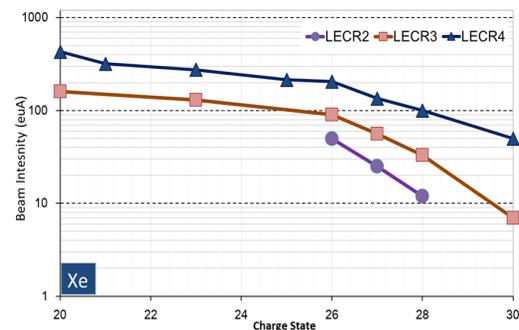


Figure 9: Evolution of Xe beam intensities with room temperature ion sources.

UPERCONDUCTING ECRIS

Superconducting ECR ion sources are representing the state of the art ECR ion source technologies. Typically operated at the microwave frequency of 24~28 GHz, superconducting ECR ion sources can produce ion beam intensities that are several times of an conventional 2nd generation machine. At IMP, the increasing needs of highly charged heavy ion beams to boost the performance of HIRFL, especially the CSR storage ring, are the driving force to build a high performance superconducting source. Two superconducting ECR ion sources have been successively developed at IMP, i.e SECRAL in 2005 and SECRAL-II in 2015.

SECRAL

The design of SECRAL has been optimized for maximum ion source performance at 24-28 GHz microwave frequency for very high charge state heavy ion beam production as well as for developing a compact fully superconducting ECR ion source with a magnet structure which is easier to build without great technical challenge. The fully superconducting ECR ion source SERSE [15] and VENUS

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[16] gave many useful references for design of the 3rd generation ECR ion sources. To satisfy the requirements of running at 24-28 GHz, the magnet of SECRAL should be able to excite on the axis the mirror peaks of more than 3.6 T at the injection side and 2.0 T at the extraction side, and a radial sextupole field more than 2.0 T at plasma chamber wall. Different from the traditional design, such as the VENUS/LBNL, SuSI/MSU [17] and SCECRIS/Riken [18], the axial solenoid coils of the SECRAL magnet are located inside of the sextupole. This innovative magnet structure design of SECRAL reduces the interaction forces between the sextupole coils and the solenoid coils which makes the cold mass clamping much easier and also a more compact structure. Fig. 10 gives the schematic structure of SECRAL cold mass.

To keep the cost within the budget limit, SECRAL magnet was completed with only one-stage cooling system that preserves the thermal shield at 70 K. Without LHe recondensation system, LHe must be refilled every day to keep the cold mass immersed safely inside the 4.2 K liquid. When the source was designed, bremsstrahlung radiation damage to the main insulator was not considered (or fully understood within the ECR community), therefore the lately inserted Ta shield tube made the plasma chamber ID size shrink down from $\varnothing 126$ mm to $\varnothing 120$ mm that makes SECRAL is only optimum for the operation at 24 GHz with regards to the radial field strength inside the plasma chamber. Even so, SECRAL is one of the most powerful ECR ion sources in the world and also the first ion source demonstrated >1 emA Ar¹²⁺ and >0.5 emA Bi³¹⁺ [19]. SECRAL was fully on-line for HIRFL operation since 2007, and has provided more than 31,000 hours' beam time for HIRFL with intense highly charged heavy ion beams that essential for HIRFL performance.

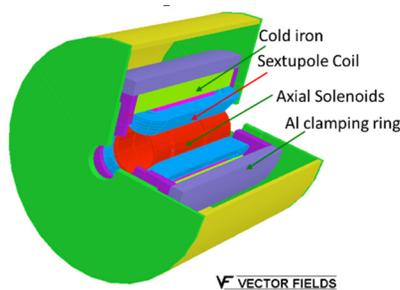


Figure 10: Sketch of SECRAL magnet structure.

SECRAL-II

SECRAL-II magnet is a close copy of SECRAL. The main difference is in the cryogenic system design. The cold mass will be housed in a $\varnothing 817$ mm ID \times 821 mm long LHe tank. Cold mass, LHe and the helium tank all together weighs about 1.54 tons. External to the 4.2 K reservoir, generally two thermal installation stages are designed. The first one is the 60 K copper thermal shield, and the second one is the vacuum buffer between 60 K and room temperature. Evaporated helium gas will be recondensed to LHe by 5 condensers bolted to the 2nd stage of five 1.5 W GM coolers individually. 5 HTS leads are used to minimize the ohmic and conduction heat load between 60 K and 4.2 K

stages. 5 Sumitomo RDK-415 D coolers can provide about 200 W cooling capacity at 60 K that is sufficient for the 60 K thermal shield cooling. A conservative estimate of the total static heat load at 4.2 K is about 1.86 W, which allows a maximum dynamic heat load of 5.64 W according to the calculation and it turned out to be ~ 6.0 W that is sufficient for the routine operation needs of about 5 kW at 28 GHz. Fig. 11 is the sectional plot of SECRAL-II magnet with most of the subsystems integrated. [20]

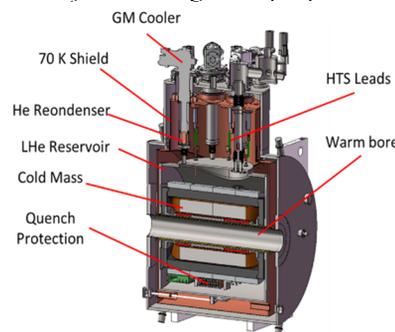


Figure 11: SECRAL-II magnet structure.

Table 3: High Intensity and Highly Charged Ion Beams Production with SECRAL-II

Ion	VENUS 2018	SECRAL 2016	SECRAL-II 2018
¹⁶ O ⁶⁺	4750	2300	6700
O ⁷⁺	1900	810	1750
⁴⁰ Ar ¹²⁺	1060	1420	1190
Ar ¹⁴⁺	840	846	1040
Ar ¹⁶⁺	525	350	620
Ar ¹⁷⁺	120	50	130
Ar ¹⁸⁺	4.0	--	14.6
⁷⁸ Kr ¹⁸⁺	770		1030
Kr ²⁸⁺	100		146
Kr ³⁰⁺			20
Kr ³¹⁺	17		7
Kr ³²⁺	8.0		0.5
¹²⁹ Xe ²⁶⁺		1100	
Xe ³⁰⁺		360	365
Xe ³⁴⁺	104	120	102
Xe ³⁸⁺	26	22.6	56
Xe ⁴²⁺	6	12	16.7
Xe ⁴⁴⁺	2	1	3.9
Xe ⁴⁵⁺	0.88	0.1	1.3

Robust cryogenic system design enables SECRAL-II to be able to operate at high microwave power. Maximum heated with 12.4 kW microwave power (10 kW@28 GHz + 2.4 kW@18 GHz), this ion source has produced many recorded beam intensities and charge states in recent ion source commissioning. Table 3 lists most of recent results with VENUS@28 GHz [21], SECRAL@24 GHz, and SECRAL-II@28 GHz. As given in the table, emA order ion beams such as Kr¹⁸⁺ and so on are achievable now, which is a very important benchmark for next generation heavy ion accelerations composed of either SRF linacs or synchrotrons. Very high charge state ion beams production such as Kr³ⁿ⁺, Xe⁴ⁿ⁺ and so on, has pushed the M/Q dc

beams extracted with an ECRIS from traditionally >4 to presently <3 , which is very attractive to cyclotrons and HCI physics, in terms of machine performance and possible physics investigations. [22]

NEXT GENERATION ECRIS

To meet the highly charged ion beam intensity needs of a next generation heavy ion accelerator, such as HIAF, beam intensity gain by a factor of ~ 2.3 should be made. According to ω_{ecr}^2 scaling, the next generation ECRIS is desired to be operated at $\omega_{ecr} = (2.3)0.5 * 28 \sim 43$ GHz. At IMP, a 45 GHz ECRIS is under construction with this guiding rule. To make an ECR ion source optimum for operation at the frequency of 45 GHz, magnetic fields of two mirror maxima 6.5 T and 3.5 T at source injection and extraction sides respectively, >3.2 T at the ion source plasma chamber wall are desired. For this purpose, approximately $1500 \text{ A/mm}^2 @ 12 \text{ T}$ will be seen inside the superconductor, which will only be made with state of the art superconductors, such as Nb_3Sn , YBCO or Bi-2212. With regards to the technology maturity and cost, Nb_3Sn is so far the feasible choice. Table 4 gives the typical parameters of a 45 GHz ECR ion source.

Table 4: Typical Parameters of FEER Magnet

SPECS.	UNIT	FEER
Frequency	GHz	45
Mirror Fields	T	$\geq 6.4/3.2$
B_{rad}	T	≥ 3.2
Mirror Length	mm	~ 500
Magnet coils	/	Nb_3Sn
Conductor J_c	A/mm^2	$>1500 @ 12\text{T}$
Cooling Capacity	W	≥ 10.0

Supported by LEAF (Low Energy heavy ion Accelerator Facility) project, which is mainly composed by a 45 GHz ECR ion source FEER, a 300 kV high voltage platform, LEBT, a 4-vane 81.25 MHz 0.5 MeV/u CW RFQ L-RFQ [23] and MEFT, a prototype 4th generation ECR ion source is under construction at IMP. Several critical challenges are foreseen and need corresponding solutions, i.e. i. the 45 GHz Nb_3Sn magnet, ii. 45 GHz/20 kW microwave power transmission and coupling for efficient ECRH, iii. strong bremsstrahlung radiation and the resultant issues, iv. intense beam extraction and transmission, v. high power operation with long term stability and reliability. A collaboration work between ATAP/LBNL and IMP has given a feasible design of the FEER cold mass based on bladder and keys assembly (Fig. 12) [24]. A cryogenic system design with 6 KDE-422 cryocoolers from a domestic company Nanjing Cooltech will provide $\sim 13 \text{ W}$ cooling power at 4.2 K state, which is promising for medium power operation at 45 GHz according to our estimate. A 45 GHz/20 kW gyrotron system from GyCOM Inc. has already been delivered to IMP. It has not only been used for long-time stability test, but also connected to SECRAL-II test bench for high power coupling PoP test and intense beam production. Once energized at full power, FEER is believed to deliver

a total current of 20–40 emA for heavy ion beams. As heavy ions have relatively low velocity given the same acceleration voltage, space charge effect will be apparent in such a beam transmission system. A four-electrode extraction system with the ion source floated at 50 kV potential is considered in the draft design. Challenges in v. are still open to the researchers, even for a 3rd generation ECR ion source. Very efficient cooling to the plasma surroundings and understanding of the behaviour of intense hot plasma (electrons) might help to mitigate the problems during high power operation. A 1/2 sized prototyping cold mass of FEER is under development at IMP. It will demonstrate the technologies of Nb_3Sn coils fabrication, bladder & key assembly, active quench protection power supply system and ms order quench detection system.

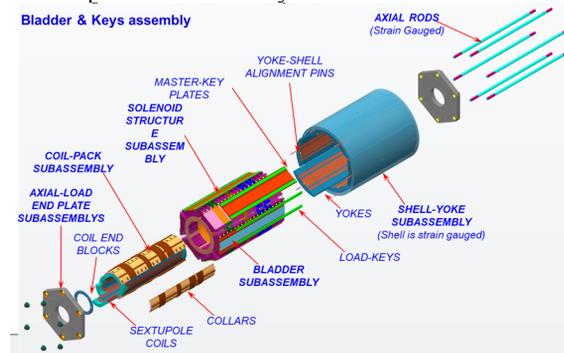


Figure 12: Explosive picture of FEER cold mass.

CONCLUSION

Boosted by the nuclear sciences and applications in China, highly charged ECR ion sources have got remarkable progress in the last 20 years. Typically, more than 5 types of ion sources can provide the highly charged ion beam solutions for versatile needs. For the heavy ion facilities development in China, there are at least 3 higher performance ECR ion sources to be completed in the coming 3 years, among them FEER is the most challengeable one.

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