

# DEVELOPMENT OF ECR ION SOURCES AT HIRFL

H. W. Zhao, Z. M. Zhang, L.T. Sun, Y.Cao, W. He, X. Z. Zhang, X. H. Guo,  
J.Y.Li, Y.C. Feng, P.Yuan, M. T. Song, W. L. Zhan, B. W. Wei  
Institute of Modern Physics (IMP), Chinese Academy of Sciences, Lanzhou, 730000, China

## Abstract

The latest development of ECR ion sources at HIRFL (Heavy Ion Research Facility in Lanzhou) is briefly reviewed. Intense beams with high and intermediate charge states have been produced from IMP LECR3 by optimization of the ion source conditions including rf frequency extended up to 18GHz. 1.1 emA of  $\text{Ar}^{8+}$  and 325 e $\mu$ A of  $\text{Ar}^{11+}$  were produced. Dependences of beam emittance and focusing image on the operation conditions of an ECR ion source were studied experimentally at LECR3 in order to match with the axial injection beam line of the injector SFC (Sector Focus Cyclotron). Furthermore, an advanced superconducting ECR ion source named SECRAL is being constructed. SECRAL is designed to operate at rf frequency 18-28GHz with axial mirror magnetic fields 3.6-4.0 Tesla at injection, 2.2 Tesla at extraction and sextupole field 2.0 Tesla at the wall. The superconducting magnet with sextupole and three solenoids was tested in a test-cryostat and 95% of designed fields were reached. Construction status and planed schedule of SECRAL are presented.

## INTRODUCTION

HIRFL (Heavy Ion Research Facility in Lanzhou) is a cyclotron and storage ring complex which consists of two cyclotrons and a heavy ion cooling storage ring (HIRFL-CSR)[1]. Heavy ion beams with intensity  $5 \times 10^{11}$ — $8 \times 10^{12}$  pps for Ca, Ni, Zn, Ge, Xe, Pb, are requested from the cyclotrons for radioactive ion beam physics, super-heavy nuclei and super-heavy element research. To satisfy the requirements, 50-100 e $\mu$ A stable beams for  $^{58}\text{Ni}^{17+}$ ,  $^{70}\text{Zn}^{17+}$ ,  $^{74}\text{Ge}^{20+}$ ,  $^{86}\text{Kr}^{23+}$ ,  $^{129}\text{Xe}^{34+}$  are expected from ion source. For this reason, great efforts have been made to develop intense highly charged ECR ion sources at IMP in the past few years including successful operation of LECR2 (Lanzhou ECR ion source No.2), intense highly charged ion beam production by LECR3 (Lanzhou ECR ion source No.3)[2], systematic studies for ECRIS beam emittance and beam extraction [3], and construction of an advanced superconducting ECR ion source named as SECRAL (Superconducting ECR ion source with Advanced design in Lanzhou)[4].

The emphasis of this article will focus on the most recent results from LECR3 for intense beam production and beam quality studies, and in particular, SECRAL construction status and preliminary test of the SECRAL magnet are reported.

## RECENT STUDIES AND RESULTS FROM LECR3

## Test of LECR3 at rf 18 GHz

LECR3 was tested at rf 18 GHz to enhance the ion source performance. The beam intensity of  $\text{Ar}^{11+}$  can be raised up to 325 e $\mu$ A at 18 GHz 1.0-1.2 kW rf power with 20-25 kV extraction voltage and  $\phi$  9 mm extraction aperture. During the test at 18 GHz, the axial magnetic field peak at the injection side was finally optimized to 1.7 Tesla which is the maximum value of the coil safety permitted.

In order to produce intense intermediate charge state ion beams,  $\phi$  13 mm extraction aperture of a plasma electrode was tested. The ion source LECR3 was optimized for  $\text{Ar}^{8+}$  at 18 GHz and 22 kV extraction voltage. The ion source can produce 1.1mA of  $\text{Ar}^{8+}$  with 1.0-1.2 kW rf power, while only 0.5 mA of  $\text{Ar}^{8+}$  can be produced at similar condition with  $\phi$  10 mm extraction aperture. Emittance measurements demonstrate that  $\text{Ar}^{8+}$  beam emittance with  $\phi$  13 mm aperture could be 70% higher than that with  $\phi$  10 mm extraction aperture.

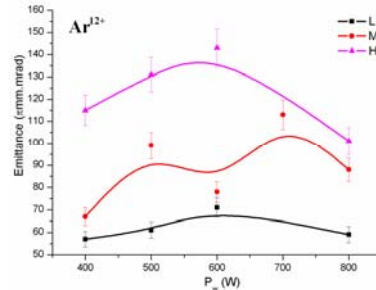


Figure 1: Dependence of  $\text{Ar}^{12+}$  beam emittance on different B modes.

## Studies of beam quality

To study beam quality, dependences of beam emittance and beam image on the key parameters of ECR ion source were experimentally measured at LECR3. Surprisingly, beam emittance could be increased by more than a factor 2 for different axial magnetic field distributions and different rf power while keeping the other conditions constant, as shown in Figure 1. In figure 1, H, M and L represent high ( $B_{inj}=1.58\text{T}$ ,  $B_{min}=0.45\text{T}$ ,  $B_{ext}=1.17\text{T}$ ), moderate (1.53T, 0.41T, 1.05T) and low (1.45T, 0.36T, 0.93T) magnetic field configuration respectively. The feeding RF frequency is 14.5GHz, and the power varies from 400 W to 800 W for  $\text{Ar}^{12+}$ . Beam image and beam phase pattern could be changed dramatically by different plasma conditions as shown in Figure 2. Detailed measurements can be found in Ref[3,5].

Under the condition of 500 W RF power feeding with different RF frequency 14.5GHz and 18GHz, we measured the influence of RF frequency on the ion beam emittance, as shown in Figure 3. It demonstrates that higher RF frequency can deduce larger emittance for the same charge state ion beam. This might be the reason of the increment of the ion temperature  $T_i$  with increase of RF frequency when the same RF power is fed.

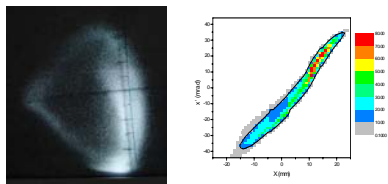


Figure 2 : Beam image and emittance phase pattern.

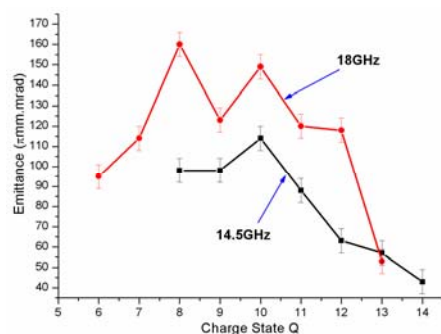


Figure 3: Dependence of beam emittance on RF frequency.

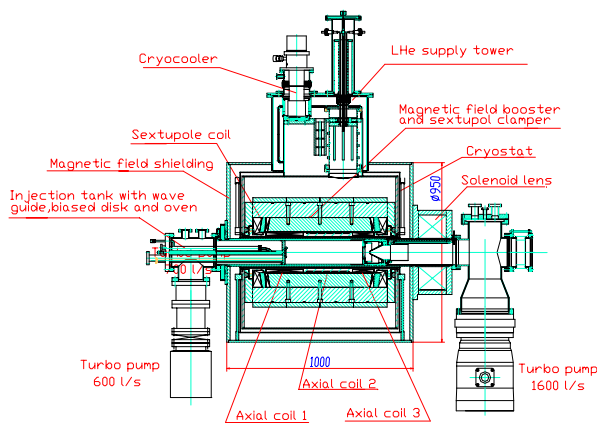


Figure 4: Schematic view of SECRAL ion source

## SECRAL CONSTRUCTION STATUS

### SECRAL source design

SECRAL aims for developing a very compact superconducting ECR ion source with a completely new structure and high performances for highly charged ion beam production. The ion source will work at 18 GHz at initial test operation, and finally will be extended to 28 GHz. SECRAL will be operated at 30-40 kV extraction

voltage so that very intense highly charged ion beams could be efficiently extracted and transported.

The design of SECRAL is illustrated in Figure 4. The superconducting magnet assembly consists of three axial solenoid coils and six sextupole coils with a cold iron structure as field booster and clamp. At full excitation, this magnet assembly will produce peak mirror fields on axis 3.6-4.0 Tesla at injection, 2.2 Tesla at extraction and a radial sextupole field of 2.0 Tesla at plasma chamber wall. What is different from the traditional design, such as LBNL VENUS[6] and LNS SERSE[7], is that the three axial solenoid coils are located inside of the sextupole bore in order to reduce the interaction forces between the sextupole coils and the solenoid coils. The superconducting coil configuration is shown in Figure 5. The three axial solenoid coils polarized by the same direction current are supported by one piece stainless steel bobbin. Each coil of the sextupole assembly is wound around one piece of iron pole as a sextupole field booster. Another six iron segments are fixed around the sextupole coils as magnet clamp and field booster. Four aluminum shrinking rings surround the sextupole assembly for tight clamping. Detailed SECRAL design can be found in Ref[4].

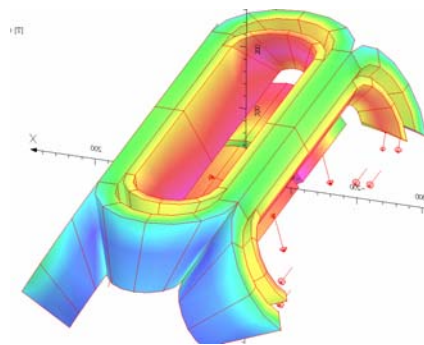


Figure 5: SECRAL superconducting coil configuration. The three solenoids are located inside the sextupole bore.

The superconducting magnet assembly with those superconducting coils and the iron parts are all immersed into 4.2 K liquid helium for cooling down. The cryogenics is designed to operate at low liquid helium consumption. This is realized by use of one stage cryocooler providing pre-cooling at 50 K and radiation shields around the liquid helium container, and also by use of high critical temperature (HTc) current leads that conduct electric current and minimize the heat leakage. The current leads are mounted within the cryostat supply tower and are thermally linked to the cryo-cooler at the hot end. The total heat load on the liquid helium reservoir is approximately 1 W at 4.2 K. The consumption of liquid helium is expected to be less than 1.5 l/h. The cryostat is surrounded by a warm iron shielding yoke to further reduce stray magnetic field.

The low energy transmission line should be able to transport more than 15 mA total current of intense highly charged heavy ion beams. The beam transport line

consists of an accel-decel extraction system, a solenoid lens and 110 degree analyzing magnet. To reach high transmission efficiency and high resolution, a 110 degree analyzing magnet with a large gap 120 mm and 600 mm bending radius is particularly designed. Considering large beam emittance and beam blow up due to intense space charge effect, the beam transport line is designed as short as possible and the solenoid lens is directly attached on the extraction side flange of the source body so as to focus the beam immediately after extraction, furthermore,  $\phi$ 150 mm beam pipe between the ion source and the analyzing magnet is used.

### SECRAL construction status

The SECRAL superconducting magnet assembly is being constructed at ACCEL Instruments Inc, Germany. The magnet assembly including the superconducting axial solenoid coils and the sextupole has been completed and the tests are being conducted. The magnet assembly with the wiring and quench protection diodes is shown in Figure 6. The other components of the ion source and its beam line including the plasma chamber, the injection tank, the extraction system, the solenoid lens, the analyzing magnet and so on have been fabricated in Lanzhou and ready for final assembling.



Figure 6:SECRAL superconducting magnet assembly.

The test of the superconducting magnet in a test-cryostat was conducted in August 2004. The sextupole was separately ramped to 95% of designed current after some quenches as shown in Figure 7. It does not make much sense only to ramp the sextupole separately. So the magnet was tested by ramping the sextupole firstly, or by ramping the three solenoids firstly, or ramping the sextupole and the three solenoids in parallel. Generally speaking, the tests demonstrate that the SECRAL magnet has reached 95% of designed fields when the sextupole and the axial solenoids are energized simultaneously in a

test-cryostat. This is a milestone of SECRAL project. The magnet will be accommodated into the real cryostat and a formal magnet test with real cryostat is expected in February 2005. The final acceptance test of the magnet will be conducted at Lanzhou by April 2005. The ion source assembling will be in May 2005 and the first plasma from SECRAL at 18GHz is planned in June 2005.

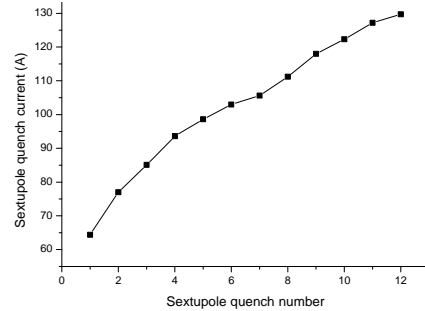


Figure 7: Sextupole quench numbers and quench current. 95% of designed current was reached.

### ACKNOWLEDGEMENTS

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