OPERATION STATUS OF SECRAL AT IMP

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Abstract

SECRAL (Superconducting ECR ion source with Advanced design in Lanzhou) is an advanced superconducting ECR ion source built with an innovative solenoid-inside-sextupole structure in 2005. Since 2007, SECRAL has delivered a good variety of highly-charged ion beams to HIRFL (Heavy Ion Research Facility in Lanzhou), such as $^{129}Xe^{27+}$, $^{78}Kr^{19+}$, $^{209}Bi^{36+}$ and $^{58,64}Ni^{19+}$ etc., and its beam delivery time increased greatly year by year. So far up to July 2011, the beam delivery by SECRAL has totalled up to almost 8000 hours. To meet the increasing demands, further improvements are planned and undertaking to enhance the capability of SECRAL. Detail results and discussions are presented in this paper.

INTRODUCTION

At IMP there are two ECRIS's in operation with the HIRFL facility, LECR3 and SECRAL. LECR3 is a conventional ECR ion source built with room temperature solenoids and an NdFeB permanent hexapole. Operating at 14GHz operation, it can produce a peak mirror field of 1.7 T on axis at the injection and 1.1 T at extraction side. The main purpose of LECR3 is to deliver light ion and medium charge state heavy ion beams to HIRFL accelerator. As science advances, new research opportunities require a significant increase on both the ion charge state and beam intensity. To meet the new demands, development of a higher performance ECR ion source is the only cost-effective solution to upgrade the HIRFL injector. SECRAL is a SC ECR ion source operating at 18 to 24 GHz dedicated for the production of intense highly-charged heavy ion beams, especially for metallic ion beams. The SECRAL SC magnet has been designed and constructed to generate maximum axial magnetic field up to 3.6 T at injection, 2.2 T at extraction and a radial field of 2.0 T at plasma chamber wall of ID 126 mm [1-2]. To reduce the interaction forces between the sextupole and solenoids, an innovative solenoid-inside-sextupole structure in which the three axial solenoids sit inside the sextupole bore is used in SECRAL leading to a compact and very reliable ECR ion source. Commissioning of the source at 18 GHz took place in 2005 and at 24 GHz in 2009, SECRAL had so far produced many world record ion beam intensities [3]. To further enhance the capability of SECRAL and deliver more intense highly-charged heavy gaseous and metallic ion beams, an aluminium plasma chamber with ID 116 mm was installed in SECRAL for operation with double-frequency heating at 24 + 18 GHz. The double-frequency heating at 24 GHz wave power of 3-5 kW has produced many promising and exciting results, though the test lasted only a few weeks.

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As described in reference [4], the X-ray of SECRAL at 24 GHz is much stronger than at 18 GHz which dumps a great amount X-ray power, likely up to a few watts, in the cryostat which leads to a severe increase of LHe consumption. To mitigate the high X-ray power dumping, an additional Liquid Helium Re-condensation System (LHRS) with five GM cryocoolers has been fabricated and installed atop of SECRAL to liquefy the boil-off helium gas to minimize the LHe consumption.

SECRAL AND ITS FEATURES

Magnet Design of SECRAL

The layout of SECRAL is illustrated in Figure 1. The design of SECRAL was optimized for maximum performance at 24 GHz of microwave frequency. Its superconducting magnet consists of three axial solenoids and a sextupole with a cold iron structure as the field booster and magnet clamp. The achieved maximum magnetic fields are 3.6 T (injection side), 0.81T (middle), 2.2 T (extraction side) on axis and 2.0 T at the plasma chamber wall. Both the stainless steel and aluminium plasma chambers are fabricated with a 4 mm thick double-wall with water cooling channels embedded. Different from the traditional magnet structure design, such as LBNL-VENUS [5] and LNS-SERSE [6] sources, all the axial superconducting solenoids of the SECRAL sit inside of the sextupole bore as shown in Figure 2. This innovative magnet structure reduces the strong interaction forces between the sextupole ends and the solenoids which results in a smaller source size at lower cost.

Ion Beam Extraction and Analysis

Figure 3 shows the layout of the SECRAL beam line to the accelerator. This beam line is designed to transport 15 emA intense high charge state heavy ion beams with high transport efficiency and high resolution. To reduce the influence of strong space charge force, the beam transport line was designed to be as short as possible. It consists of a Glaser lens, a 110-degree analyzing magnet and other auxiliaries. The solenoid lens is directly attached to the extraction flange of the source body to reduce the drift distance between beam extraction and the Glaser lens. Ion beams are analyzed by a 110-degree analyzing magnet with a 120 mm gap and 600 mm bending radius. Beam defining slits and Faraday Cup are installed at the end of the transport beam line to assure the beam resolution and measure the beam intensity. To minimize the influence of the secondary electrons on the beam intensity, an electron suppressor negatively biased at 150-200 V is installed right in front of the de-ionized water cooled cone-shaped faraday cup.

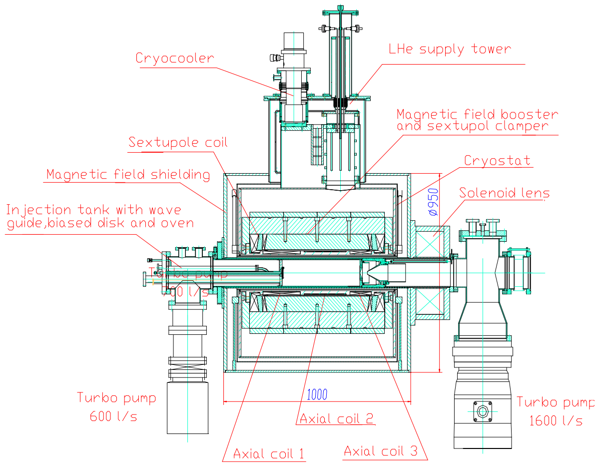

Figure 1: Elevation view of the SECRAL ECR ion source.

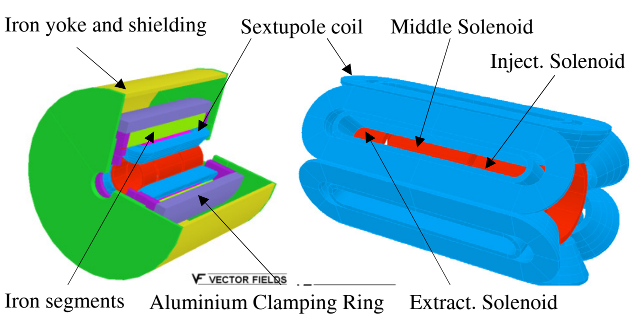

Figure 2: SECRAL superconducting magnet structure.

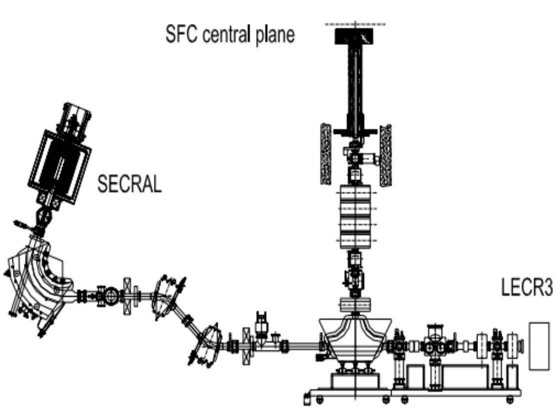

Figure 3: Layout of the axial injection beam line of SFC with two ECR ion sources: SECRAL and LECR3.

SECRAL OPERATION WITH HIRFL ACCELERATOR

Since 2007, SECRAL has been in routine operations at 18 GHz, 24 GHz and delivering a good variety of high charge state ion beams to HIRFL. The ion beams are extracted at source bias voltages of 10-23 kV to meet the different acceleration requirements. For instance, 140-160 euA of $^{129}Xe^{27+}$, $^{78}Kr^{19+}$, 50-70 euA of $^{58,64}Ni^{19+}$ (at only 9.8 kV extraction voltage), 50-60 euA of $^{209}Bi^{36+}$ and so on. Figure 4 shows the beam delivering time by SECRAL from May 2007 to July 2011 in comparison to LECR3 and the yearly beam increase with SECRAL is clearly seen. So far up to July 2011, SECRAL has been delivering ion beams up to almost eight thousand hours in which the proportion of metallic ion beams is about 40% as indicated Figure 5.

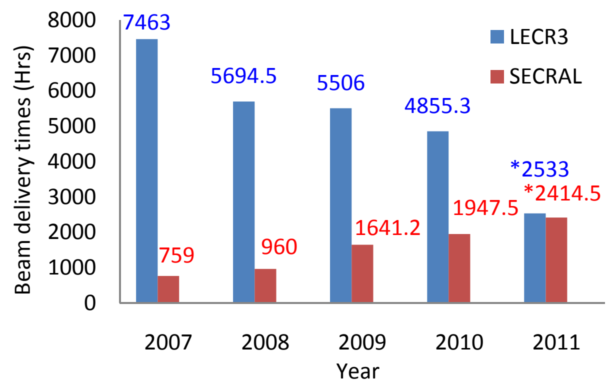

Figure 4: Beam delivery times of LECR3 (blue colour) and SECRAL (red colour) from 2007 to so far of 2011.*

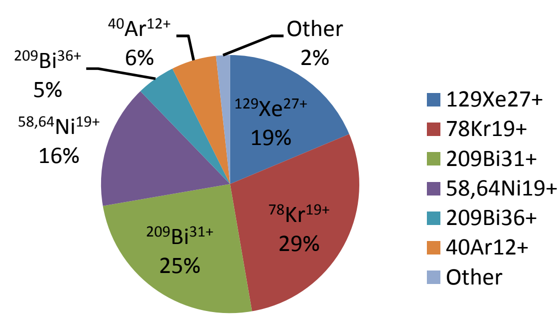

Figure 5: Distribution of the ion beam species delivered by SECRAL from May 2007 to July 2011.

Gaseous Ion Beam Production

Production of gaseous ion beams with SECRAL at 24 GHz in 2009 had yielded many world record beam intensities [4]. To further enhance the performance of SECRAL, an aluminium plasma chamber has been installed in 2010 and the source was tested with a double-frequency (24+18 GHz) heating. The use of an aluminium plasma chamber is to increase the emission of secondary electrons from the aluminium oxides on the chamber surface for better plasma stability to increase the yields of high charge state ions. Great results, such as 236 euA of $^{129}Xe^{30+}$, 64 euA of $^{129}Xe^{35+}$, 22.6 euA of $^{129}Xe^{38+}$ etc. were produced at 3–4 kW of 24 GHz power with typically 1 kW of 18 GHz power. Figure 6 shows a typical spectrum when the source was optimized for $^{129}Xe^{30+}$.

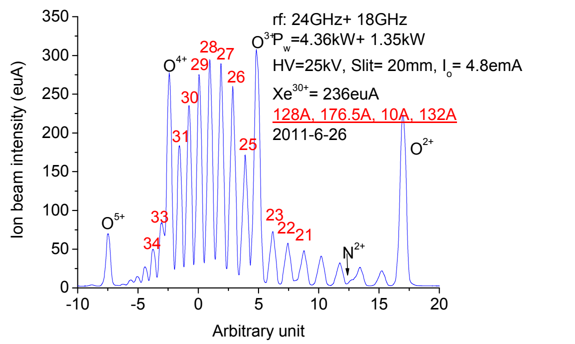

Figure 6: Xe spectrum of SECRAL optimized for $^{129}Xe^{30+}$ with double-frequency (24+18 GHz) heating with an aluminium plasma chamber.

Metallic Ion Beam Production

Production of metallic ion beams is much difficult than producing the gaseous beams, due to that the metals have to be vaporized or sputtered off before being inputted into the plasma and very often the metal coatings on the chamber surface severely deteriorate the wave coupling and plasma stability. The increasing demands from nuclear physics research require more intense highly-charged metallic ion beams delivered by the ECR ion sources. Sputtering solid materials off to the plasma works but the beam intensity typically is not higher enough in comparison to using an oven. That is the why using a heated oven to introduce the solid materials remains the best method. A good variety of metallic ion beams, such as $^{58,64}Ni^{19+}$ of 40-50 euA and $^{209}Bi^{36+}$ of 80 euA, had been delivered to HIRFL for experiments in 2010 and 2011. The HIRFL-CSR has successfully stored and accelerated the Bi ions to 170 Mev/u. Figure 7 shows a typical spectrum when $^{209}Bi^{36+}$ is optimized and the tuning indicates that the production is not yet saturated.

Liquid Helium Re-condensation System (LHRS)

The LHe consumption of SECRAL almost scales with wave frequency and operation at 24 GHz requires much more intermittent refilling, sometimes a couple of times daily depending on the wave power, that interrupts the beam delivering to the accelerator. To minimize the beam interruptions to increase the HIRFL acceleration efficiency, an LHRS to liquefy the boil-off room temperature he gas was designed and installed in November 2009. This LHRS consists of five 4.2 K GM crycoolers in a two-shell drum cryostat and sits atop the SECRAL cryostat as shown in Figure 8. The boil-off room temperature helium gas flows from the SECRAL liquid helium Dewar to the inlet of the LHRS through a stainless steel pipe. The re-condensed liquid helium is collected and then gravitationally drifts down to the SECRAL liquid helium Dewar. With the LHRS system, up to two weeks continuous operation has been achieved on SECRAL at 18GHz/1.5kW without liquid helium refilling. However a few weeks later, it completely stopped working due a small vacuum leaking. It has been since under repaired and optimization and hopefully it will work better in the near future.

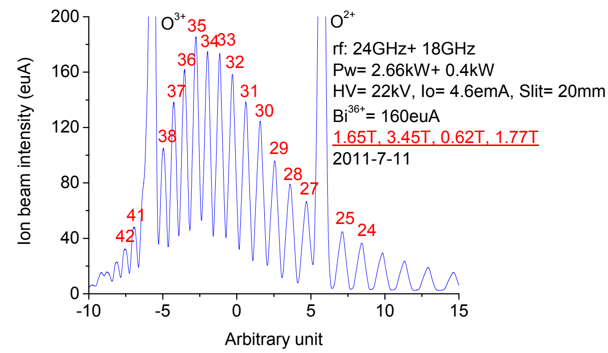

Figure 7: Bi spectrum of SECRAL optimized for $^{209}Bi^{36+}$.

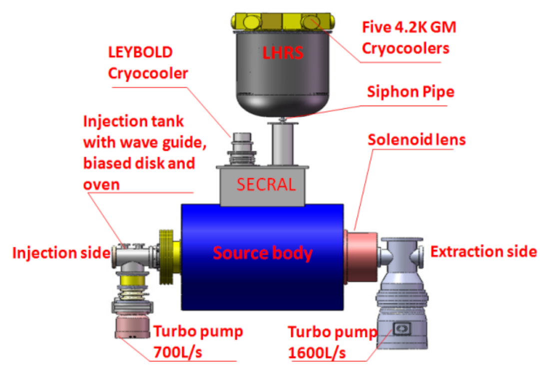

Figure 8: Layout of the LHRS system atop SECRAL.

CONCLUSIONS

SECRAL operation with highly charged heavy ion beams has enhanced the capability of the HIRFL on both the beam energy and intensity. The HIRFL-CSR is now able to deliver the very heavy ion beams such as ^{58}Ni, ^{78}Kr, ^{129}Xe and ^{209}Bi to the physics experiments that have created new research opportunities, as evidenced by the recent direct mass measurements of the short-lived nuclides with very high mass resolution[7].

ACKNOWLEDGEMENT

This project is supported by Nature Science Foundation under Contact No. 10921504.

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