SECRAL STATUS AND FIRST BEAM TEST AT 24GHZ

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Abstract

SECRAL (Superconducting ECR ion source with Advanced design in Lanzhou) has been in routine operation at 18GHz for HIRFL (Heavy Ion Research Facility in Lanzhou) accelerator complex since May 2007. It has delivered a few highly charged heavy ion beams for the HIRFL accelerator and the total beam time so far has exceeded 3500 hours. To further enhance the SECRAL performance, a 24GHz/7kW gyrotron microwave amplifier has been installed and tested. Very exciting results were produced with quite a few new record highly-charged ion beam intensities. The latest results and reliable long-term operation for the accelerator have once again demonstrated that SECRAL is one of the best performance ECR ion source for the production of highly-charged heavy ion beams.

INTRODUCTION

SECRAL (Superconducting ECR ion source with Advanced design in Lanzhou) is a fully superconducting compact ECR ion source designed to operate at microwave frequency at 18-28GHz, which is dedicated for highly charged heavy ion beam production. SECRAL with an innovative superconducting magnet structure of solenoids-inside-sextupole [1-2], is different from all existing or under development high-magnetic-field superconducting ECR ion sources which utilize the conventional ECR magnetic structure of sextupole-inside-solenoids. The commissioning of the SECRAL at 18 GHz in 2006 and the experiments with double-frequency (18+14.5 GHz) heating in 2008 had yielded many world record ion beam intensities [2-3]. All these results and reliable operation have demonstrated that SECRAL performance at lower frequency is comparable or even better than those ECR ion sources operating at higher frequency of 28 GHz. To further enhance the performance of SECRAL and produce more intense highly charged heavy ion beams, a 24GHz/7kW gyrotron microwave generator was installed and SECRAL was tested at 24GHz. Some promising and exciting results at 24GHz with new record highly charged ion beam intensities were produced although the commissioning time was limited within a few weeks and RF power only 3-5kW. Bremstrahlung measurements at 24GHz have shown that X-ray is much stronger at higher RF frequency, higher RF power and higher minimum B field. An additional cryostat with five GM cryocoolers was installed at the SECRAL top to liquefy the boil-off helium gas to minimize the liquid helium consumption. The detailed results and the new development achieved at SECRAL in the past two years will be presented in this article.

SECRAL PRELIMINARY TEST RESULTS AT 24GHZ/3-5KW

To further enhance the SECRAL performance in production of highly charged heavy ion beams, finally a 24GHz gyrotron system with maximum output power 7 kW was chosen and installed. The SECRAL excellent results at 18+14.5 GHz double frequency heating for highly charged heavy ion beam production have convinced us that the best performance for SECRAL should be achieved at 24+18 GHz double frequency heating. The reason to choose 24GHz instead of 28GHz is that it is more difficult to compromise the magnetic field distribution for 28+18 GHz double frequency heating because the frequency difference is larger than that of 24+18 GHz. SECRAL does not need to couple very high RF power to reach the best performance because of its smaller plasma chamber, so 5-6 kW operational power is quite enough. The 24GHz transmission line and RF coupling system to SECRAL is similar to that developed at SERSE source [4-5]. The 24GHz transmission line from the gyrotron cabinet to the SECRAL source consists of arc detector, directional coupler, polarizer, mode convertor from T_{02} to T_{01}, mode filter, compensator, DC-breaker, 90-degree corrugated bend and bore-nitride microwave window, as shown in Fig.1. All components at the transmission line are water cooled and designed as compact as possible. The 24GHz microwave is coupled into the SECRAL source through the oversized waveguide WRC621D14. The 24GHz gyrotron system and all components at the transmission line were manufactured by Russia GYCOM.

The first beam tests at 24GHz were conducted in August 2009 with a stainless steel chamber in order to have quite stable beam. The beam commissioning has focused on Argon and Xenon beam production. The source extraction voltage was limited to 22kV due to the DC-breaker problem and the output power from the gyrotron system was limited to 5 kW due to problem of the high voltage power supply for the gyrotron cathode. The SECRAL magnet was set at 90%-95% of the maximum design field during 24 GHz beam tests in terms of the optimized beam and charge state, typically the axial injection field from 3.3 Tesla to 3.5 Tesla and the radial sextupole field at the chamber wall from 1.65 Tesla to 1.75 Tesla. The source conditioning at 24GHz was

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conducted firstly with pure Oxygen. It turns out that the source conditioning and out-gassing at 24GHz take much longer time than that at 18GHz. Beam spectra obtained during the source conditioning at 24 GHz indicate that there are so many ion species coming out from the out-gassing and plasma sputtering to the chamber wall although the plasma chamber has been operated at 18GHz for more than one year. It took about one week for the SECRAL to raise the RF power more than 3.0 kW during the source conditioning, and the overloading due to out-gassing and higher power could happen sometimes. After one week continuously source conditioning, a stable plasma condition can be achieved easily at 3.0 kW and SECRAL can be tuned for stable beam production and optimization.

Figure1: SECRAL with 24GHz/7kW gyrotron system.

SECRAL commissioning for stable beam production was started from Ar^{12+} and Ar^{14+}. After two days optimized tuning to those key parameters, such as the magnetic field distribution, the main gas Argon, the mixing gas Oxygen, the coupled RF power, the biased probe voltage, the beam focusing from the solenoid lens and so on, some good results were produced at the 24GHz power level of 3-4 kW, for instance, 650 eμA of Ar^{12+}, 440 eμA of Ar^{14+}. SECRAL was switched to $Ar^{16+}$and Ar^{17+} beam tuning after $Ar^{12+}$and Ar^{14+}beam optimization. It seems much more difficult to achieve optimum plasma conditions for $Ar^{16+}$and Ar^{17+} productions at high RF power. Much more mixing gas Oxygen and main gas Argon is required, otherwise the plasma could be out of igniting. After some time tuning and optimization, only 149 eμA of Ar^{16+} and 14 eμA of Ar^{17+} were produced at about 4 kW RF power. The typical magnetic fields for Argon beam production are: B_{inj}=3.46 Tesla, B_{min}=0.68 Tesla, B_{ext}=1.6 Tesla and B_{rad}=1.74 Tesla. Probably longer time conditioning and Aluminium chamber are needed for higher charge state beam production.

SECRAL was commissioned with Xenon beam at 24GHz after Argon beam production. The emphasis was put on optimization of $^{129}Xe^{27+}$, $^{129}Xe^{30+}$ and $^{129}Xe^{35+}$ beams. Even after two weeks source conditioning, the out-gassing or some kind of plasma instability at high RF power still occurred from time to time which could result in beam instability and even overloading. However, stable plasma conditions for optimum tuning of $^{129}Xe^{27+}$ and $^{129}Xe^{30+}$ can be easily obtained because of two weeks source conditioning. After two days test and tuning, some new record Xenon beam intensities have been produced at 3.5 kW RF power of 24 GHz, such as 480 eμA of Xe^{26+}, 455 eμA of Xe^{27+}, 350 eμA of Xe^{28+} , 152 eμA of Xe^{30+} and 85 eμA of Xe^{31+}. Fig.2 shows a typical spectrum to optimize $^{129}Xe^{27+}$ at 3.5 kW RF power. The typical magnetic fields for Xenon beam production are: B_{inj}=3.3 Tesla, B_{min}=0.67 Tesla, B_{ext}=1.54 Tesla and B_{rad}=1.63 Tesla. The situation for production of highly charged Xenon beams such as Xe^{35+} and Xe^{42+} is similar to that of Ar^{16+} and Ar^{17+} beams at 24GHz. The optimum plasma conditions have not been found for those very high charge state Xenon beams. Fig.3 shows a spectrum to optimize $^{129}Xe^{34+}$ at 3.5kW. Xenon beam test at 24GHz had to be stopped because SECRAL was requested to deliver Kr beam for HIRFL accelerator.

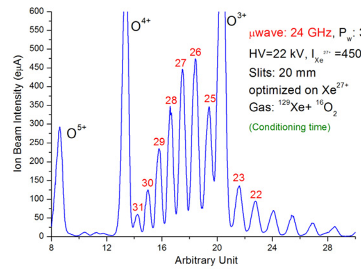

Figure 2: Spectrum to optimize $^{129}Xe^{27+}$ at 3.5 kW of 24GHz.

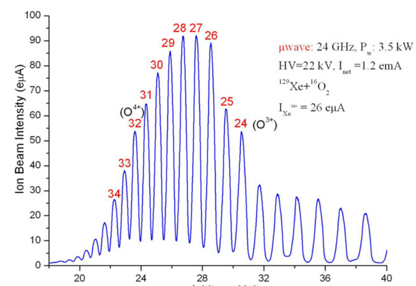

Figure 3: Spectrum to optimize $^{129}Xe^{34+}$ at 3.5 kW of 24GHz in September 2009.

Xenon beam test at 24GHz was conducted again in November 2009 after one month Kr beam operation at 18GHz. Surprisingly, the source tuning at high power 24GHz/3-4 kW was much better than previous test in terms of beam stability, beam intensity and charge state distributions for high charge state Xenon beams. Fig.4 shows a spectrum to optimize $^{129}Xe^{35+}$ at 5kW. By comparing with Fig.3 and Fig.4 and also taking into account the beam test condition, it seems that longer time source conditioning for higher charge state Xe beam at 24GHz is needed. Finally, a few new record Xenon beam intensities for higher charge state beams have been produced at 3.5-5 kW RF power of 24 GHz, such as 60 eμA of Xe^{34+}, 45 eμA of Xe^{35+}, 17 eμA of Xe^{38+} and 3 eμA of Xe^{42+}. Optimum test for very high charge state Xenon beams Q>42 needs to be done in near future. Unfortunately, a high voltage power supply for the

24GHz gyrotron system failed to work and SECRAL beam test at 24GHz had to be stopped.

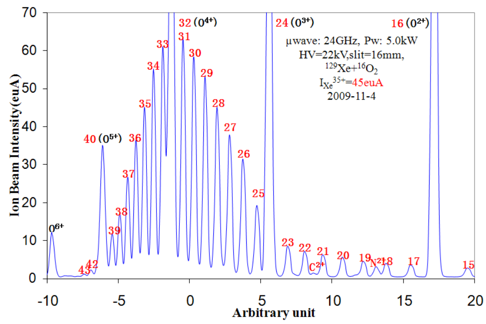

Figure 4. Spectrum to optimize $^{129}Xe^{35+}$ at 5 kW of 24GHz.

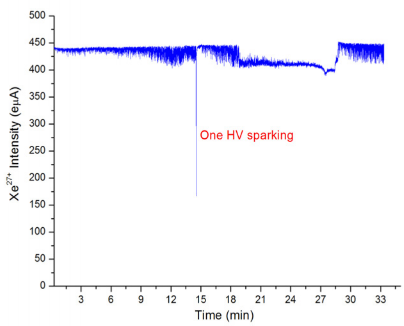

Figure5: $^{129}Xe^{27+}$ beam intensity instability at 3.5 kW rf power of 24GHz in September 2009

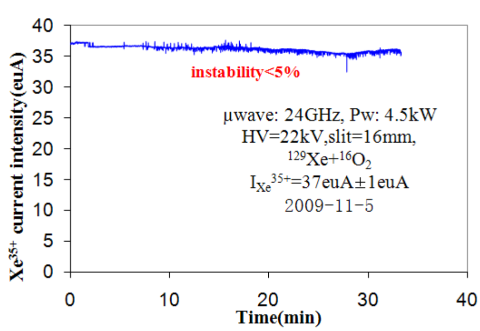

Figure 6: $^{129}Xe^{35+}$ beam intensity stability at 5 kW rf power of 24GHz in November 2009.

Generally speaking, beam stability at 24GHz is worse than that at 18GHz at the RF power level 3 kW. Fig.5 shows $^{129}Xe^{27+}$ beam intensity variation around 440 eµA during 30 minutes at the coupled RF power 3.5kW at 24GHz recorded in September 2009. Fig.6 shows $^{129}Xe^{35+}$ beam intensity stability around 37 eµA during 30 minutes at the coupled RF power 4.5kW at 24GHz recorded in November 2009.The beam intensity instability and big jump in the Fig.5 might be caused by the out-gassing and ECR discharge inside the 24GHz waveguide of the injection part. There is an ECR zone in the 24GHz waveguide in terms of the axial field distribution, where the pumping conductance is low and the vacuum is not good. It is easier to result in the out-gassing and the ECR discharge in that region. However, any evidence to support ECR discharge inside the 24GHz waveguide was not found after the source was opened. Beam instability at high power of 24GHz may not be understood completely and further experiments and studies are needed.

Table 1 lists the latest Xenon beam results achieved by SECRAL at 18GHz and 24GHz and comparison with recently published data from the high performance ECR ion source VENUS[6].

Table 1. Latest Xe beam results of SECRAL at 18GHz and 24GHz in comparison with other high performance ECR ion source (beam intensity: eµA).

		SECRAL	**SECRAL**	**VENUS[6]**
f **(GHz)**		***18(+14.5)***	***24***	***28(+18)***
P(kw)		**<3.2**	**3-5**	**5-9**
^{129}Xe	20^+	505		320
	27^+	306	455	270
	30^+	101	152	116
	31^+	68	85	67
	35^+	16	60	28
	38^+	6.6	17	7
	42^+	1.5	3	0.5
	43	1		

SECRAL OPERATION TO HIRFL ACCELERATOR

SECRAL ECR ion source has been put into operation to deliver highly charged heavy ion beams for the HIRFL accelerator complex since May 2007. SECRAL has been operated at 18GHz in an axial injection beam line of the HIRFL cyclotron and only dedicated to very high charge state heavy ion beams, while the other light ion beams with low charge state are provided by the room temperature ECR source LECR3. Four different ion beams, such as $^{129}Xe^{27+}$, $^{78}Kr^{19+}$, $^{209}Bi^{31+}$and $^{58}Ni^{19+}$, have been delivered to the HIRFL accelerator complex for various experiments. During operation the typical RF power of 18 GHz is 1.2-2.0 kW and extraction voltage is about 10-22 kV according to the cyclotron requirements. The operational beam intensity is typically around 100-150 eµA for $^{129}Xe^{27+}$, $^{78}Kr^{19+}$, and 50-70 eµA for $^{209}Bi^{31}$,$^{+58}Ni^{19+}$ (only 9.8 kV extraction voltage). The total operated beam time from SECRAL has been more than 3500 hours up to July 2010. SECRAL operation with higher charge state and higher beam intensity has made a great contribution to HIRFL performance enhancement in terms of beam energy and intensity.

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