FIRST COMMISSIONING RESULTS OF AN EVAPORATIVE COOLING MAGNET ECRIS-LECR4*

W. Lu, L.T. Sun, X.Z. Zhang,C. Qian, B.H. Ma and H.W. Zhao, IMP, Lanzhou 730000, China
B. Xiong, S. Q. Guo and L. Ruan, IEE, Beijing 100190, China
D. Z. Xie, LBNL, USA

Abstract

LECR4 (Lanzhou ECR ion source No.4) is a room temperature ECR ion source, designed to produce high current, multiple charge state ion beams for SSC-LINAC project at IMP. The ion source has been optimized to be operated at 18 GHz. A unique feature of LECR4 is that all of its axial solenoid coils are fully immersed in a special coolant and cooled by evaporative cooling technology when excited. At design currents, the coils can produce peak mirror fields on axis 2.5Tesla at injection, 1.3 Tesla at extraction and 0.5 Tesla at minimum-B. The nominal radial magnetic field is 1.0-1.1 Tesla at plasma chamber wall, which is produced by a Halbach structure 36-segmental hexapole magnet. Recently, the project has made significant progress. In January 2014, the first plasma at 18 GHz was ignited. During the ongoing commissioning phase with a stainless steel chamber, tests with ion beams: Oxygen, Argon,Xenon and Bismuth have been conducted. Some intense ion beams have been produced with microwave power less than 1.6 kW, such as 1.97 emA of O^{6+}, 1.7 emA of Ar^{8+}, 1.07 emA of Ar^{9+}, 290 euA of Xe^{20+} and so on.

INTRODUCTION

A room temperature ECR ion source named LECR4 (Lanzhou ECR ion source no.4) was designed and built at Institute of Modern Physics (IMP) to meet the demand of intense multiple charge state ion beams for SSC-LINAC project [1]. The other purpose of the LECR4 project is to test an evaporative cooling technology for its application to accelerator magnet. SSC-LINAC is a new CW heavy ion LINAC used as the injector for the Separated Sector Cyclotron (SSC) at 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 Figure 1. The required ion species are from Carbon to Uranium. According to the demand, traditional room temperature ECR ion sources with operation microwave frequency 14- 18 GHz were considered. According to Prof. Geller's famous scaling laws, we know that higher magnetic fields and higher frequencies will increase the performance of ECR ion source. Following these guidelines, many high performance room temperature ECR ion sources like AECR-U [2], RIKEN 18 GHz [3], IMP-LECR3 [4] and GTS [5] have been built. All these ECR ion sources need high pressure de-ionized water system to cool the high current axial mirror field magnet coils. Recently, with advances in evaporative cooling technology at Institute of Electrical Engineering of Chinese Academy of Science (IEE, CAS) [6], a de-ionized water free room temperature ECR ion source with new cooling technology is possible. IEE institute has been researching the evaporative cooling technology since 1958. Up to now, this technology has been applied in many high-power, high current density devices, such as Three Gorges Power Station. According to careful simulation and prototype experiments [7], the final design of ECR ion source (named LECR4) was completed in 2012. About one year later, the source body assembly was fabricated at IMP. In October 2013 the axial magnet reached 100% of the design fields. The first beam of LECR4 was extracted and analyzed in February 2014. The ion source commissioning of intense multiple charge state ion beams was performed from February 2014 to July 2014.The first test with RFQ was performed on 4th April 2014. The preliminary results will be presented in this paper.

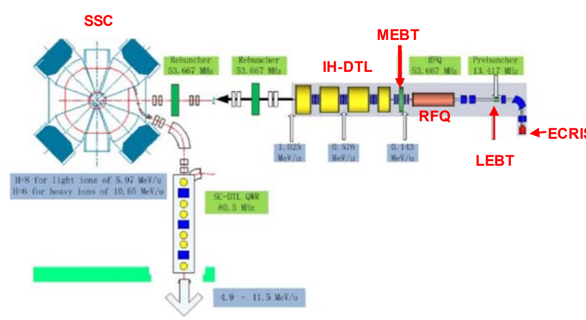

Figure 1: General view of the SSC_Linac.

LECR4 ION SOURCE

Figure 2 shows the layout of LECR4 and its beam transport line. There is no vacuum pump at the injection side for simplicity. The detail design of LECR4 ECR ion source can be found in the reference paper [8].The features of LECR4 are following:

- LECR4 is the first ECR ion source using evaporative cooling technology in the world. All the coils are fully immersed in a special coolant, named ZXB-21. Its boiling temperature is 47.7 degree in a standard atmospheric pressure. Solid square copper wires (3.32 mm×5.77 mm with insulation) are used to wind the solenoid coils. The maximum exciting current is 300 A, that means an average current density about 12 A/mm^2, slightly higher than using

*This collaboration project was supported by the Research Foundation of Chinese Academy of Sciences.

ISBN 978-3-95450-158-8

normal hollow copper conductor with pressurized water cooling at IMP.

- LECR4 is the first high performance ECR ion source with only one pump for vacuum evacuation, which greatly simplifies the ion source injection components and reduces the cost. The typical vacuum without plasma is 7×10^{-8}mbar at extraction side and 3.0×10^{-8}mbar at the beam line.
- The optimization of magnetic field distribution and effective application of other advanced technologies: such as double 18 GHz heating, biased disk, insert iron, result in an excellent performance for intense multiple charge state ion beam production. The axial magnetic field of LECR4 is similar to SECRAL (Superconducting Electron Cyclotron Resonance ion source with Advanced design in Lanzhou) ECR ion source operating at 18 GHz. At full excitation, the measured peak mirror field on axis are 2.5 T at injection (slightly higher than calculation), 1.3 T at extraction and 0.5 T at minimum-B position, as shown in Figure 3. The measured field distribution agrees well with the calculated result.

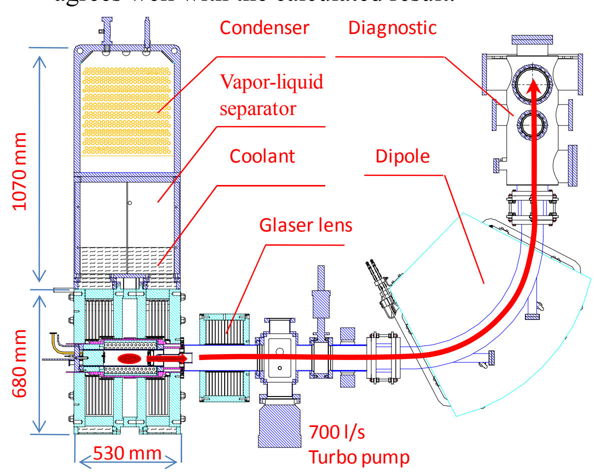

Figure 2:A schematic cross-section view of the LECR4 source body. No mechanical pumping at the injection side for simplicity.

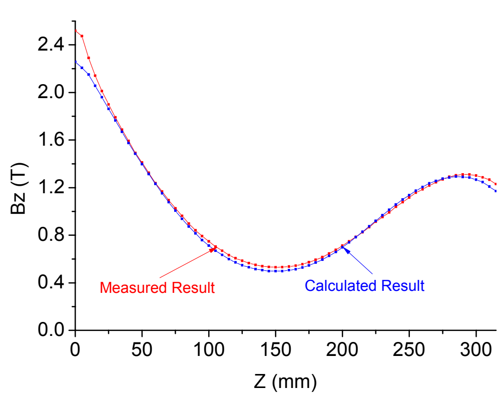

Figure 3: Axial magnetic field distribution of LECR4.

Preliminary Commissioning Results with Single 18 GHz Microwave Generator

A single 18 GHz CPI microwave generator with the maximum microwave power output of 1.2 kW was connected to the ion source through a HV DC-BREAK.

Two-electrode extraction system has been installed at the first commissioning phase. The insulation cover is made by PP material with a thickness of 3 mm. Extraction high voltage up to 28 kV has been tested. In the commissioning, the maximum applied high voltage was 25 kV, and the drain current was 5-10 emA depending on the operation conditions.

The first plasma was ignited on January 28th 2014 and the first analyzed ion beam was obtained on February 20th 2014. After about one week's continuous conditioning and outgassing, the plasma became comparably stable. With about 1.0 kW single rf power injection, 1.4 emA of O^{6+}, 285 euA of O^{7+} were obtained with the total drain current of about 7.6 emA. The extraction high voltage was 25 kV. Figure 4 shows the typical spectrum when O^{6+} optimized. In addition, the relationship between transmission efficiency and extraction high voltage has been tested. The preliminary results indicated that the efficiency was increased from 28.3 % to 82.5 % when extraction high voltage was increased from 10 kV to 20 kV, as shown in Fig.5.

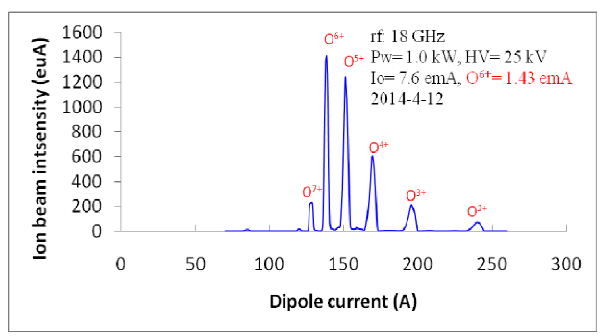

Figure 4: CSD spectrum with the source when optimized on O^{6+} at 1.0 kW with single rf generator.

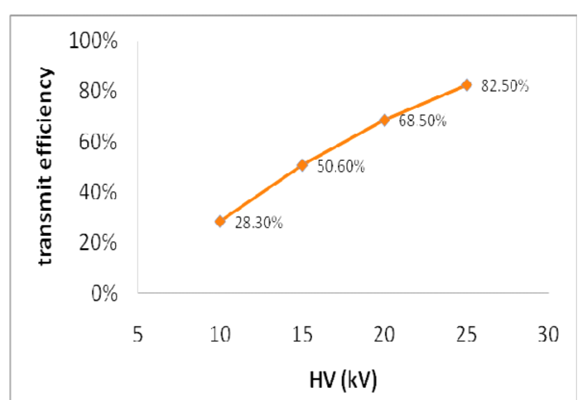

Figure 5: Transmit efficiency of Oxygen beam with different extraction high voltage.

ISBN 978-3-95450-158-8

Preliminary Commissioning Results with Double 18 GHz Microwave Generators

To get better results, certainly higher microwave power is necessary. Another 18 GHz CPI microwave generator was installed.

With total input power about 1.6 kW (0.8 kW+ 0.8 kW) from two 18 GHz microwave generators, some outstanding results were achieved in three month's tuning, such as 1.97 emA of O^{6+}, 1.71 emA of Ar^{8+}, 293 euA of Xe^{20+}, 118 euA of Bi^{28+}, and so on. 1.97 emA of O^{6+} was produced at microwave power of 1.45 kW with the field configuration as B_r= 1.0 T, B_{inj}= 2.5 T, B_{ext}= 1.01 T. Fig.6 shows the typical spectrum with the source optimized for O^{6+}. Fig.7 shows the axial magnetic field distribution. Fig.8 shows the typical spectrum when Ar^{9+} optimized at 1.4 kW. Figure 9 shows the typical spectrum when Xe^{20+} optimized at 1.5 kW. Table 1 gives the preliminary results of LECR4 in comparison with other high performance ECR ion sources: SECRAL [9], GTS and LECR3.

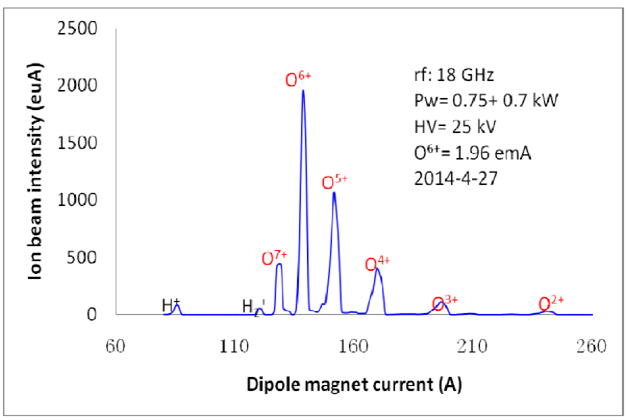

Figure 6: CSD spectrum with the source when optimized on O^{6+} at 1.45 kW.

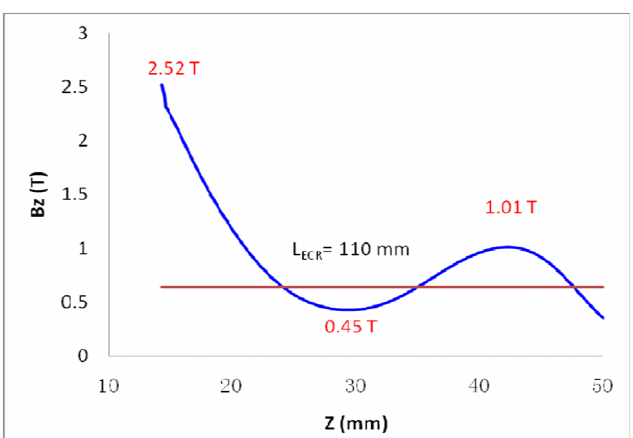

Figure 7: Axial magnetic field distribution when O^{6+} optimized.

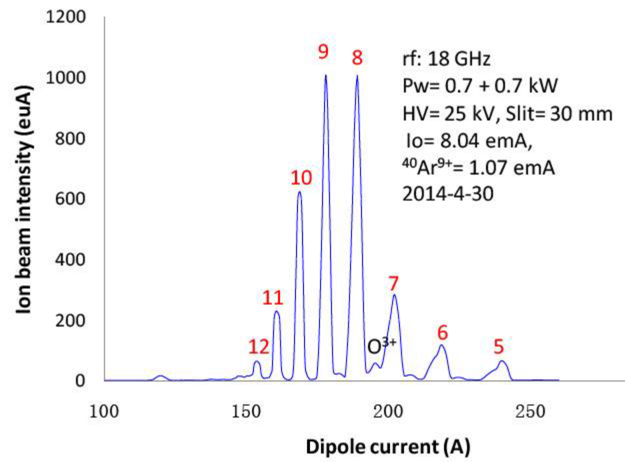

Figure 8: CSD spectrum with the source when optimized on Ar^{9+} at 1.4 kW.

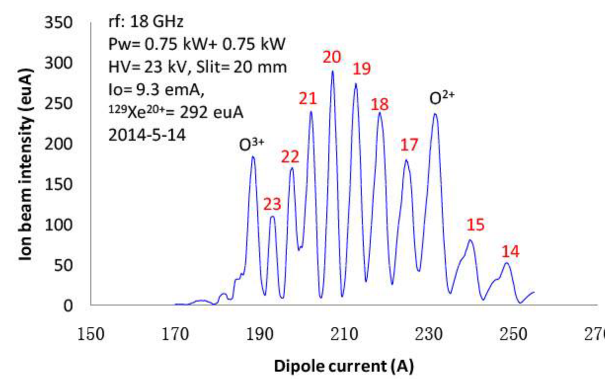

Figure 9: CSD spectrum with the source when optimized on Xe^{20+} at 1.5 kW.

Table 1: comparison of the preliminary results of LECR4 with other high performance ECR ion sources

f (GHz)		*SECRAL* 18 <3.2 kW	*GTS* 18 >2 kW	*LECR3* 14 &18	*LECR4* 18 <1.6 kW
^{16}O	6+	2300	1950	780	1970
	7+	810		235	438
^{40}Ar	8+		1100	1100	1717
	9+	1100	920	720	1075
	11+	810	510	325	503
^{129}Xe	20+	505	310	160	293
	23+			130	143
^{209}Bi	28+	214			118
	30+	191			78

Commissioning with RFQ

The first commissioning with RFQ was performed on 4th April 2014. With only 0.1 kW microwave power injection and 11.92 kV extraction voltage, over 200 euA

ISBN 978-3-95450-158-8

of O^{5+} beam was produced and delivered to RFQ continuously for three days without breakdown. The second test was done with heavier Ar^{8+} beam on 21th May 2014. With 0.2 kW microwave power and 18.6 kV extraction voltage, about 210 euA of Ar^{8+} beam was delivered to RFQ. The transmission efficiency is better than 90% according to the test result. The normalized rms emittance of Ar^{8+} ion beam from LECR4 is 0.07 π.mm.mrad in horizontal direction and 0.13 π.mm.mrad invertical direction, respectively, as shown in Fig. 10.

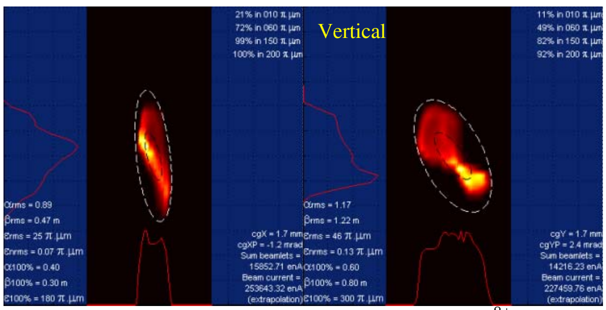

Figure 10: Normalized rms emittances of Ar^{8+} ion beam extracted from LECR4 ECR ion source.

CONCLUSION AND DISCUSSION

A high performance room temperature ECR ion source has been built successfully at IMP. Preliminary test results at 18 GHz demonstrated that LECR4 ECR ion source and its subsystems can operate with a nice reliability and stability. Many good results for intense medium charge state ion beams have been produced in three month's commissioning. Better results will be coming soon after further optimum tuning test and some technology improvements.

ACKNOWLEDGMENT

This project is under the support of the key basic research of Chinese Academy of Science. The authors also gratefully acknowledge the helpful advice from Dr. D. Xie and P. Spaedtke for their kind help and fruitful discussions during the design and commissioning of LECR4.

REFERENCES

[1] X. N. Li *et al,* CPC (HEP & NP), 36, 1126 (2012)
[2] Z. Q. Xie *et al*, RSI, 69, 625 (1998).
[3] T. Nakagawa *et al*, RSI, 75, 1394 (2004).
[4] Z. M. Zhang *et al*, RSI, 749, 238 (2005).
[5] D. Hitz *et al*, RSI, 75, 1403 (2004).
[6] L. Ruan*et al*, "The comparison of cooling effect between evaporative cooling method and inner water cooling method for the large hydro generator", Proc. of ICEMS, p. 67 (2007).
[7] W. Lu *et al*, RSI, 83, 02A328 (2012).
[8] W. Lu *et al,* RSI, 85, 02A926 (2014).
[9] H. W. Zhao *et al,* RSI, 79, 02A315 (2008).

ISBN 978-3-95450-158-8