6 - 18 Status Report of On-line Ion Sources in 2016

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HIRFL-CSR accelerator facility has been operating with 3 ion sources, which are LAPECR1, LECR3 and SECRAL. These ion sources can provide different kinds of ions with different energy. For example, LAPECR1 mainly provides H^+ and He^+ with eextraction voltage above 25 keV, LECR3 can provide the ion beams with low to medium charge states, including the metallic ions with low mass, such as C^{4+}, Ar^{11+}, B^{3+}, Mg^{7+}, *etc.*, while SECRAL aims to produce intense and highly charged ion beams, especially metallic ones, such like Kr^{19+}, Xe^{31+}, Ni^{19+}, Bi^{31+}, U^{33+}, and so on. In 2016, there were 18 kinds of ion beams delivered successfull by the two on-line ion sources: LECR3 and SECRAL, and the service time of the two sources are 3 219.5 and 4 211 h, respectively, amouting to 7 430.5 h in total, in which SECRAL provided all the 4 kinds of metallic ion beams, and the total service time with the metallic ones is 3 008 h, accounting for 71.4% of the SECRAL total service time. The total failure time of the SECRAL and LECR3 counts only 24 h in this year. Table 1 summarizes the main information about the ion beams delievered by the two ion sources.

Table 1 Ion beams delivered by SECRAL and LECR3 to HIRFL in 2016.

Equipment	Ion beam	Extraction HV/kV	Ion beam intensity/eμA	Service time/h
SECRAL	$^{209}Bi^{31+}$	10.34	30	872.5
	$^{112}Sn^{26+}$	17.75	50	1 215
	$^{86}Kr^{17+}$	18.86	120	102
	$^{58}Ni^{19+}$	21.60	30	643.5
	$^{56}Fe^{17+}$	22.80	50	277
	$^{40}Ar^{15+}$	20.15	50	420
	$^{40}Ar^{14+}$	21.97	75	470
	$^{40}Ar^{12+}$	23.58	85	211
LECR3	$^{40}Ar^{11+}$	19.37	60	165
	$^{36}Ar^{11+}$	19.24	80	186.5
	$^{32}S^{9+}$	15.30/21.15	60	351
	$^{20}Ne^{7+}$	19.38	110	69
	$^{18}O^{6+}$	20.37	120	234
	$^{16}O^{6+}$	22.60/23.40	110	301
	$^{16}O^{5+}$	18.90	140	394
	$^{12}C^{4+}$	17.73/23.07	160	879.5
	$^{12}C^{3+}$	18.55	200	263
	$^{4}He^{+}$	17.66	250	376.5

The average consumption rates of the metal materials are as follows: 0.36 mg/h for ^{56}Fe, 0.7 mg/h for ^{58}Ni, 0.94 mg/h for ^{112}Sn and 3.12 mg/h for ^{209}Bi, which depend crucially on the operation state of the ion source. Generally speaking, the more stable the ion source is, the lower the consumption of the metal materials is.

In 2016，the service time of SECRAL reached to more than 4 200 h, which is the most among the past few years. Fig. 1 shows the comparison of the ion beam delivering time for HIRFL-CSR accelerator facitily from the three ion sources, LAPECR1, LECR3 and SECRAL since 2007.

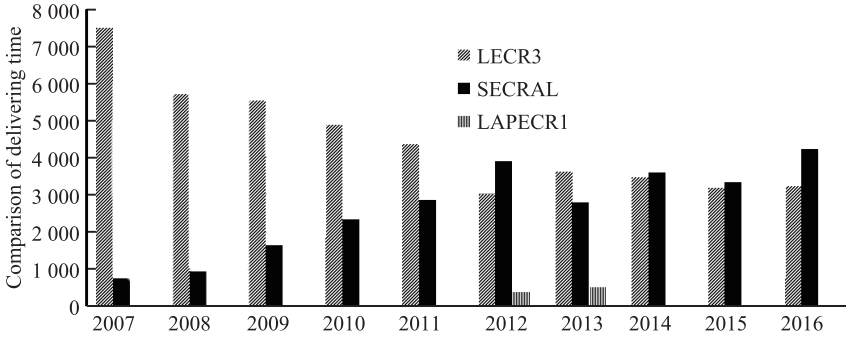

Fig. 1 Beam delivering time of the three on-line ion sources from 2007 to 2016.

At the beginning of 2017, the pulsed $^{40}Ar^{12+}$ beam of 120 eμA was provided to HIRFL by SECRAL with afterglow mode for the first time, as shown in Fig. 2. The pulsed beam was injected into the storage ring, CSR, accelerated and accumulated successfully. The running time of SECRAL with the pulsed mode was more than 48 h. However, the gain of the pulsed beam compared with the continuous one was less than 2. The further researches on afterglow mode will focus on the increasing of the gain.

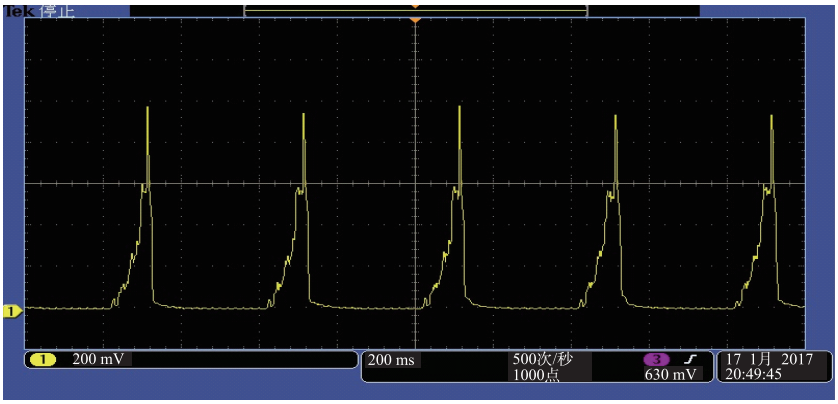

Fig. 2 The pulsed beam provided by SECRAL source with afterglow mode.

6 - 19 On-Line Operation and Machine Study of LECR4

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LECR4 is the first ECR ion source using evaporative cooling technology in the world. Its unique feature is that the solenoids were made from solid square copper wires (3.32 mm × 5.77 mm with insulation), and that all the coils are entirely immersed in the room temperature coolant. The coils can produce a maximum axial magnetic field up to 2.5 T. LECR4 aims to provide intense multiple charge state ion beams for SSC-Linac project - a new Linear injector for the Separated Sector Cyclotron (SSC). Presently, some ion beams with different M/Q ratio have been accelerated successfully with the RFQ and DTL, such as 200 eμA of $^{16}O^{5+}$, 200 eμA of $^{40}Ar^{8+}$, 50 eμA of $^{209}Bi^{30+}$ *etc*. The measured transmission efficiency of RFQ is up to 90%. The layout of LECR4 ion source and the LEBT is shown in Fig. 1.

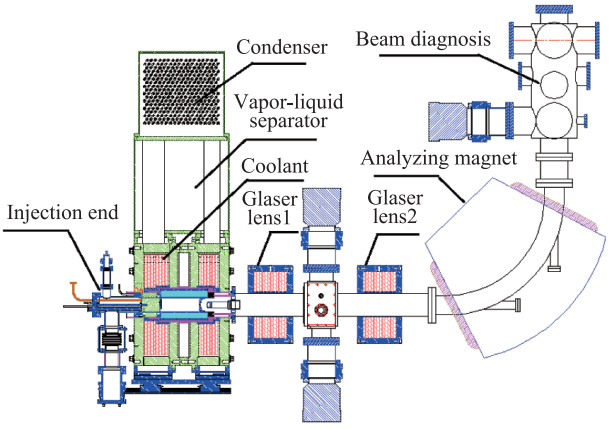

Fig. 1 Layout of LECR4 ion source and the LEBT.

In 2016, the influence of injection stage of LECR4 was studied systematically. The test results demonstrated that the injection pump is critical for the production of intense highly charge state ion beams, such as: $^{40}Ar^{14+}$, $^{129}Xe^{20+}$. While it is not necessary for the production of low or medium charge state ion beams, such as: $^{16}O^{6+}$ and $^{40}Ar^{11+}$. A dual-solenoid prefocusing system has been implemented to improve the beam quality and transmission efficiency. As a result, the beam resolution problem at the Faraday cup after the analyzing magnet has been solved, and hollow beam issue has been improved. LECR4 ion source has been optimized for the operation at 18 GHz with a microwave power of about 1.6 kW. Table 1 shows some latest results from LECR4.