ECR ION SOURCES AT HIRFL

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Abstract

There are two Electron Cyclotron Resonance (ECR) ion sources in operation at the axial injection beam line of HIRFL (Heavy Ion Research Facility in Lanzhou). In most cases, the IMP 14.5 GHz ECR ion source is operated for the cyclotron to achieve intense beams. Intense beams of highly charged gaseous and metallic ions could be produced by the ECR ion source. A particular emphasis has been focused on the production of metallic ion beams recently. Metallic ion beams of Ca, Mg, Fe, Ni and Pb were tested with the IMP 14.5 GHz ECR ion source to improve beam intensities and long-term stability considering cyclotron operation. The stable beams of 60 eμA of $^{24}Mg^{7+}$, 130 eμA of $^{40}Ca^{11+}$, 45 eμA of $^{56}Fe^{11+}$, 25 eμA of $^{58}Ni^{10+}$ and 17 eμA of Pb^{27+} were successfully produced. A new ECR ion source, an upgraded version of the IMP 14.5 GHz ECR ion source but with double rf frequency heating (10GHz + 14.5GHz), is under commissioning.

To satisfy the requirements of the heavy ion cooling storage ring which is under construction at Lanzhou, a fully superconducting ECR ion source is being developed for production of intense heavy ion beams of very high charge states, such as Xe^{30+} and U^{40+}.

1 METALLIC ION BEAM PRODUCTION BY IMP 14.5 GHz ECR ION SOURCE

There are two Electron Cyclotron Resonance (ECR) ion sources in operation at the axial injection beam line of HIRFL (Heavy Ion Research Facility in Lanzhou). One is 10 GHz ECR ion source and the other one is 14.5 GHz ECR ion source. The two ECR ion sources have been described in previous papers [1-3]. The IMP 14.5 GHz ECR ion source has been put into operation for the cyclotron since June of 1999. In most cases, the IMP 14.5 GHz ECR ion source is operated for the cyclotron to achieve intense beams. Higher beam intensities are always expected especially for highly charged metallic ion beams for the cyclotron. So recently an emphasis has been focused on the production of metallic ion beams to improve beam intensities and long-term stability.

Production of metallic ion beams of ^{40}Ca, ^{56}Fe and ^{58}Ni was tested when the ion source was located at the test bench in May of 1999. A small evaporation oven was used to produce ^{40}Ca beam [2]. The volatile compounds $Fe(C_5H_5)_2$ and $Ni(C_5H_5)_2$ were used to produce ^{56}Fe and ^{58}Ni ion beams by means of MIVOC method [4]. A small stainless steel chamber was connected to the ion source through a large conductance regulation valve to control flow rate of the compound vapor. The main problem was that the volatile compound vapor contaminates the vacuum components of the ion source. The typical operation pressure measured at the extraction side was 2.5×10^{-6} mbar. It is difficult to optimize the highly charged ions such as Fe^{15+} and Ni^{15+} with such vacuum.

Production of metallic ion beams of ^{24}Mg and ^{208}Pb was tested with the oven when the source is at the axial injection beam line of the cyclotron in July of 2000. It seems the magnesium beam is easier to handle than calcium, and the beam long-term stability is much better than calcium. It was easy for the ion source to achieve 60 eμA of Mg^{7+} and 15 eμA of Mg^{9+} with a nice long-term stability. The lead beam was tested for four days. The beam intensity of Pb^{24+} was at similar level to Pb^{27+}. We had intended to enhance the beam Pb^{24+}. But we failed to get more intense beam of Pb^{24+}no matter how to optimize the source parameters and the oven temperature.

So far the metallic ion beams of $^{40}Ca^{11+}$, $^{40}Ca^{12+}$ and $^{24}Mg^{7+}$ have been provided to the cyclotron for nuclear physics research. The ion source was run at moderate level due to long-term stability and sample consumption during operation to the cyclotron. The beam stability was satisfied. But the oven had to be refilled by the sample within 100-140 hours. The average consumption of calcium and magnesium sample was estimated about 1 mg/h during the ion source running for the cyclotron. Table 1 summarizes the results of metallic ion beam production by the 14.5 GHz ECR ion source.

Table 1: Results of metallic ion beam production

Ion beam	Beam current for test (eμA)	Beam current for operation (eμA)	Operation time (hours)
$^{24}Mg^{7+}$	60	35	300
$^{24}Mg^{9+}$	15		
$^{40}Ca^{11+}$	130	30	250
$^{40}Ca^{12+}$	70	25	490
$^{56}Fe^{10+}$	65		
$^{56}Fe^{11+}$	45		
$^{58}Ni^{10+}$	25		
$^{208}Pb^{27+}$	17		
$^{208}Pb^{29+}$	12		
$^{208}Pb^{30+}$	8		
$^{208}Pb^{36+}$	2		

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2 A NEW ECR ION SOURCE — AN UPGRADED VERSION OF THE IMP 14.5 GHz ECR SOURCE

A new ECR ion source, an upgraded version of the IMP 14.5 GHz ECR ion source, was built. The goal of this new ion source is to provide highly charged ion beams for atomic physics research. On the other hand, we hope to further enhance the performance of our existing ECR ion sources through this modification to the IMP 14.5 GHz ECR ion source. The different points between this new source and the IMP 14.5 GHz ECR ion source are as following:

- Larger plasma chamber.
- Double RF frequency heating (10 GHz +14.5 GHz) with inserted rectangular wave-guide feeding system.
- Aluminum chamber.
- Higher axial magnetic field.
- Larger space at extraction region.

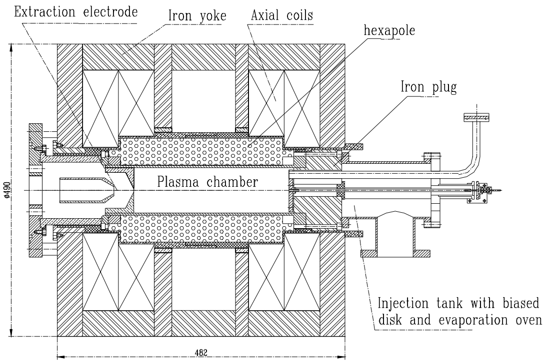

Figure 1:Mechanical layout of the new ECR ion source.

Table 2: Comparison of the main parameters between the new ion source and the IMP 14.5 GHz ECR

Parameters	New ion source	14.5GHz IMP ECR
RF frequency (GHz)	10+14.5	14.5
Mirror field on axis (T)	1.7, 1.1	1.5, 1.1
Radial field at wall (T)	1.0	1.0
Segments of hexapole	36	24
ID of the chamber(mm)	76	70
Material of the chamber	Aluminum	316L steel

Figure 1 shows the mechanical layout of this new source. The main parameters compared with the IMP 14.5 GHz ECR ion source are summarized in Table 2. The ion source was already assembled and a new analyzing beam line for this ion source is being installed. The first beam is expected to come out in June of this year.

3 DESIGN OF A COMPACT FULLY SUPERCONDUCTING ECR ION SOURCE

To satisfy the requirements of the heavy ion cooling storage ring that is under construction at Lanzhou , a fully superconducting ECR ion source with a completely new structure is being developed for the production of intense heavy ion beams of very high charge states, such as Xe^{30+} and U^{40+}. The designed parameters of this advanced superconducting ECR ion source are given in Table 3.

Table 3: The designed parameters for IMP SC-ECR

RF frequency	18 (28) GHz
Mirror field on axis	4.0 T (at injection) 2.2 T (at extraction)
Mirror to mirror space	420 mm
Max. radial field at wall	2.0 T
ID of the plasma chamber	105 mm
Source body size	670×840 mm
NbTi wire for solenoid	0.9mm Cu/Sc ratio 1.35
NbTi wire for sextupole	1.9×1.0 mm Cu/Sc ratio 3.0
Max. current for solenoid	240 A
Max current for sextupole	380 A

The superconducting magnet consists of three axial solenoid coils and six saddle-like sextupole coils with a cold iron structure as field booster and clamp. The three-dimensional code TOSCA is used to calculate magnetic fields and interaction forces. The total interaction force between the sextupole coils and the solenoid coils at the ends is as large as 40 kN. So the support and clamp to the superconducting coils become a key issue. The three axial solenoid coils polarized by the same direction current are supported and clamped by one piece aluminum bobbin. Between the sextupole coils and the axial solenoid coils there is a stainless steel tube that is used to prevent excessive deformation of the sextupole assembly under large magnetic force. Each saddle-like coil of the sextupole assembly is wound around one pole piece made of iron as a sextupole field booster. A stainless steel wedge is inserted in between the adjacent sextupole coils to make them more tightened. Six iron segments are fixed around the sextupole coils as magnet clamp and field booster. The cryostat is surrounded by a iron shielding yoke to reduce stray magnetic field. The cryogenic system is designed to operate at 4.2 K with two cryocoolers to provide about 50 K and 4 K cooling respectively. The magnet assembly is immersed into liquid helium to speed up the initial cool down, during stable operation the cryocooler will run in a closed loop mode without further helium transfer. This cryogenic system is quite similar to that of LBL VENUS [5].

The plasma chamber is made of a double wall aluminum tube with water cooling channel in between. In order to cool down the chamber effectively, the chamber is designed such that the cooling water could come into from one end and get out from the other end. The two microwave guides, metallic evaporation ovens and biased disk system are inserted into the ion source through an injection vacuum tank by the way off-axis. A 500 l/sec and 1000 l/sec turbo molecular pump is located at injection and extraction side respectively. One of big challenges for this superconducting ECR ion source is extraction and transmission of very intense highly charged ion beams. The estimated total current could be more than 10 mA and space charge effect would be very serious. After extraction both einzel lens and magnetic solenoid lens will be used to focus the beam. The both lenses will be arranged as close to the extraction as possible.

Presently this superconducting ECR ion source is under technical design. The fabrication will be under way after the bid. The ion source is scheduled to begin test operation in the end of 2003.

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