Production of intense highly charged ion beams by IMP 14.5 GHz electron cyclotron resonance ion source*

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Abstract A new 14.5 GHz Electron Cyclotron Resonance (ECR) ion source has been constructed over the last two years. The source was designed and tested by making use of the latest results from ECR ion source development, such as high mirror magnetic field, large plasma volume, and biased probe. 140 μA of O^{7+}, 185 μA of Ar^{11+} and 50 μA of Xe^{26+} could be produced with a RF power of 800 W. The intense beams of highly charged metallic ions are produced by means of the method of a metal evaporation oven and volatile compound through axial access. The test results are 130 μA of Ca^{11+}, 70 μA of Ca^{12+} and 65 μA of Fe^{10+}. The ion source has been put into operation for the cyclotron at the Institute of Modern Physics (IMP).

Keywords ECR ion source, Highly charged ion beams, Metallic ions, Beam intensity

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1 INTRODUCTION

A new electron cyclotron resonance (ECR) ion source with a RF frequency of 14.5 GHz was built to satisfy requirements of the cyclotron at the Institute of Modern Physics (IMP). The purpose of this new ECR ion source is to produce intense ion beams with sufficiently high charge state, particularly for heavy elements. The production of metallic ion beams are also one of the main tasks for the new ECR ion source.

In recent years, several groups have reported that using a high axial and radial magnetic field could improve the performance of ECR ion source for highly charged ions.[1~7] Therefore, increasing both the axial and radial magnetic field is the key point of design of the new ECR ion source. Another point is to increase the plasma volume, which is believed to be beneficial to the production of high charge state ions. Hence a plasma chamber with a large volume was designed.

In this article, the latest results achieved from the 14.5 GHz IMP ECR ion source for the production of intense highly-charged ion beams are presented.

2 DESCRIPTION OF IMP 14.5 GHZ ECR ION SOURCE

Fig.1 illustrates the structure of the IMP 14.5 GHz ECR ion source. The axial

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magnetic field is produced by two solenoids and a surrounding iron yoke. Each solenoid consists of 6 double layer pancakes with two types of internal diameters. The total power consumption of the two solenoids is about 80 kW which is provided by two power supplies. The maximum axial magnetic field on the axis is 1.5 T. The hexapole consists of 24 pieces of trapezoidal NdFeB magnets, which are mounted into an iron cylinder. The hexapole field on the plasma chamber wall can reach 1.0T. The plasma chamber is made of stainless steel, which has a double wall that cooling water is running inside. The internal diameter of the plasma chamber is 70 mm and the effective length is 300 mm. The RF power is fed into the ion source through a coaxial line. The RF generator with THOMSON klystron (14.5 GHz, 2.5 kW) was manufactured in China.

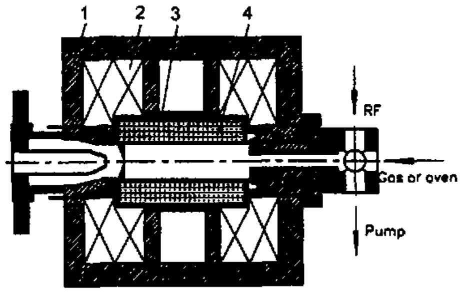

Fig.1 Schematic view of the IMP 14.5 GHz ECR ion source with the coaxial line RF feeding system

1 Iron yoke, 2 Coils, 3 Insulator, 4 Hexapole

3 PERFORMANCE OF GASEOUS IONS

The ECR ion source for production of highly charged ion beams always suffers from starvation to cold electrons. Thus some extra cold electrons have to be provided to the ECR plasma in order to enhance the performance of highly charged ion beam production. In the IMP 14.5 GHz ECR ion source a biased probe at injection side was used and an aluminum tube was inserted into the plasma chamber.[9,10] By using the aluminum tube Ar^{11+} beam current could be increased from 130 μA to 160 μA with a RF power of 600~800 W, but the plasma electrode has to be put deeply into the chamber, because the position of the plasma electrode is sensitive and the gas consumption is decreased obviously. Sometimes the beam is not very stable in the case of the aluminum tube inside the chamber. It is probably because the aluminum tube and the plasma electrode are over heated and the emission of second electron are changed. At this moment, when we decrease RF power about 100 W and wait for a few seconds, and then raise the RF power again, the beam will come back and remain stable.

In order to keep the ion source running quite stable, the aluminum tube was pulled out of the plasma chamber. A new plasma electrode with a special structure was installed into the chamber, so that the plasma electrode could be cooled down through the chamber. The test indicates that the source running is much more stable and the results are a little bit better. The ion beam currents for gaseous elements we could obtain so far from the IMP 14.5 GHz ECR ion source are listed in Table 1. In this test, 99% enriched isotope ^{129}Xe was used. The spectra for the optimized $^{40}Ar^{11+}$ and $^{129}Xe^{26+}$ are given in Fig.2 and Fig.3 respectively. The 99% enriched ^{129}Xe isotope and natural krypton were used during the tests.The ion beams in Table 1 were extracted at voltage of 15 to 18 kV through a 9 mm aperture of the plasma electrode. The beam defining slit was opened from 6 mm×6 mm to 20 mm×20 mm. Beam currents were measured by a Faraday cup biased at 100 V to suppress the secondary electrons. The transmission efficiency of the test bench was estimated only about 50%.

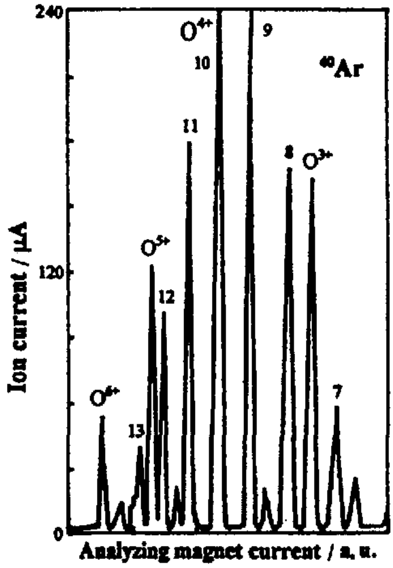

Fig.2 Sepctrum for the optimzed $^{40}Ar^{11+}$

Table 1 Performance of the 14.5 GHz IMP ECR ion source for gaseous ions.

Ions	Beam currents/μA
O^{6+}	610
O^{7+}	140
Ar^{11+}	185
Ar^{12+}	105
Ar^{14+}	12
Kr^{18+}	60
Kr^{19+}	50
Kr^{20+}	25
Xe^{26+}	50
Xe^{27+}	25
Xe^{28+}	12

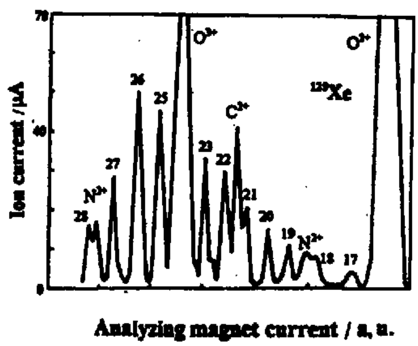

Fig.3 Spectrum for the optimized $^{129}Xe^{26+}$

4 METALLIC ION BEAM PRODUCTION

A small evaporation oven and MIVOC (Metal Ions from Volatile Compounds) method were used for metallic ion beam production. The small oven consists of a tantalum tube for thermal radiation shielding and electrical connection, a ceramic tube as an electrical insulator, and a ceramic heater wound with 0.5 mm diameter tantalum wire.[11] The oven is able to reach more than 1300°C with about 110 W electrical power. The oven is installed into the source axially through a copper tube. The ion source with this oven could deliver the beam current more than 130 μA, 70 μA and 35 μA for $^{40}Ca^{11+}$,

$^{40}Ca^{12+}$ and $^{40}Ca^{13+}$, respectively. The consumption of calcium sample was less than 1 mg/h when the ion source running for the cyclotron. The spectrum for the optimized $^{40}Ca^{11+}$ is shown in Fig.4.

The volatile compounds $Fe(C_5H_5)_2$ and $Ni(C_5H_5)_2$ were used to produce iron and nickel ion beams, respectively, by means of MIVOC method.[7,12] A small stainless steel

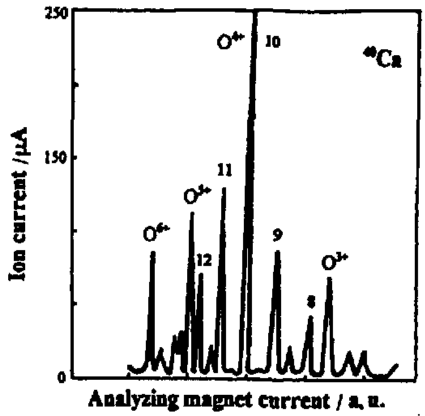

Fig.4 Spectrum for the optimzed $^{40}Ca^{11+}$

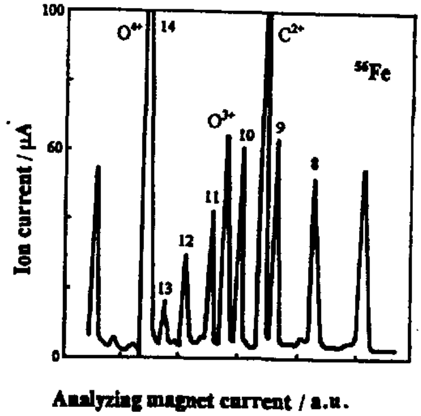

Fig.5 Spectrum for the optimzed $^{56}Fe^{10+}$

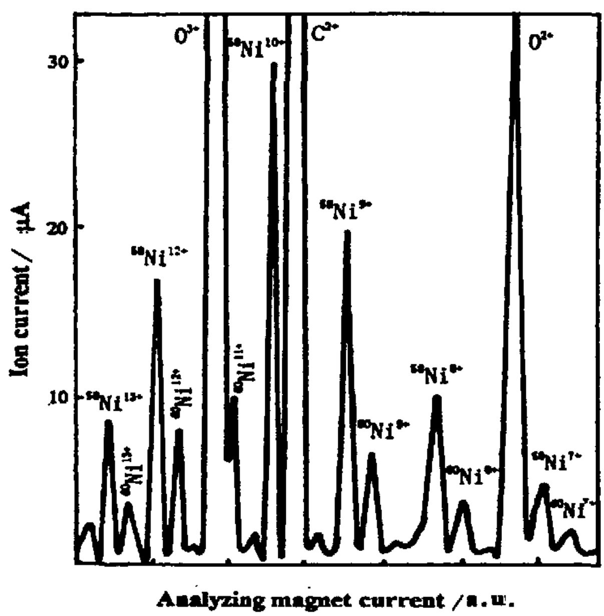

Fig.6 Spectrum for the optimzed $^{58}Ni^{10+}$

chamber was connected to the ion source through a large conductance regulation valve to control the flow rate of the compound vapor. The main problem is that the volatile compound vapor contaminates the vacuum components of the ion source. The typical operation pressure measured at the extraction side is 2.5×10^{-6} mbar. It is difficult to optimize the highly charged ions such as Fe^{15+} and Ni^{15+} in such vacuum. With this method, the ion source could produce 65 μA of $^{56}Fe^{10+}$, 45 μA of $^{56}Fe^{11+}$ and 25 μA of $^{58}Ni^{10+}$. The source vacuum was not good enough during the test of nickel ion beam. The spectra for the optimized $^{56}Fe^{10+}$ and $^{58}Ni^{10+}$ are shown in Fig.5 and Fig.6, respectively.

For application of the ECR ion source to a cyclotron, to get intense ion beams with higher charge state and better beam stability is more important for metallic ion beam production. In the near future, a particular emphasis will be made to aim at those heavy elements and refractory metals such as tantalum, uranium, and so on. A new method for production of metallic ion beams, using an electron beam to heat up a crucible, is being tested in this ECR ion source.

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