PRODUCTION OF INTENSE BEAMS OF HIGHLY CHARGED HEAVY IONS FROM RIKEN 18 GHz ECRIS AND LIQUID He FREE SC-ECRIS

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Abstract

We have constructed the high performance ECRISs for RIKEN RI Beam factory project and successfully produced intense beams of highly charged heavy ions. RIKEN 18 GHz ECRIS can especially produce intense beams of medium charge states of heavy ions (1.3 mA of Ar^{8+}, 200 $e\mu A$ of Xe^{20+}) by applying the various techniques, e.g., Al cylinder method, biased electrode method, optimization of the plasma electrode position. Very recently, we successfully produced intense beams of highly charged heavy ions (10 $e\mu A$ of Xe^{30+}, 1$e\mu A$ of Xe^{36+}) from the Liquid He free SC-ECRIS with operational frequency of 14 GHz.

1 INTRODUCTION

Since the invention of ECRIS for the production of highly charged heavy ions, ECRISs have been developed from a complicated prototype to a compact and high performance source for accelerators, atomic physics experimental apparatus [1]. In the last decade, ECR ion sources have been widely used as the external ion sources for heavy ion accelerators. ECRIS has become one of the key devices for the production of radio isotope beams. Since the middle of 1990s, RIKEN has undertaken to construct the new accelerator facility, so-called RI Beam Factory [2] for the further development of the fields of RI beam utilization. In this project, the production of intense heavy ion beams is crucial to obtain the intense RI beams. For this reason, two kinds of high performance ECRISs have been constructed, e.g. RIKEN 18 GHz ECRIS and liquid He free SC-ECRIS.[3] In this paper, we present the most recent results of RIKEN 18 GHz ECRIS and liquid He free SC-ECRIS.

2 RIKEN 18 GHZ ECRIS

Since the first beam was extracted from RIKEN 18 GHz ECRIS in 1995, two effective methods have been applied to increase the beam intensity of highly charged heavy ions, e.g. Al cylinder method[4] negatively biased electrode method[5]. Figure 1 shows the cross sectional view of RIKEN 18 GHz ECRIS and its plasma chamber. Using these methods, we have produced intense beams of highly charged heavy ions in great variety, e.g., 1mA of Ar^{8+}, 300eμA of Ar^{11+}, 200 eμA of Xe^{20+}.
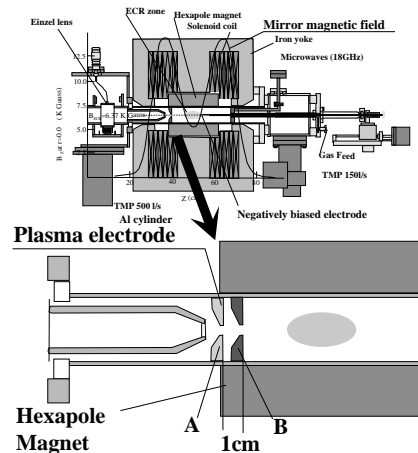

Figure 1: Cross sectional view of RIKEN 18 GHz ECRIS and its plasma chamber.

2.1 Effect of plasma electrode position

Very recently, we have changed the plasma electrode position to optimize the beam intensity of highly charged heavy ions in 18GHz ECRIS. As the plasma electrode makes a part of the boundary of ECR plasma, it is obvious that the position of plasma electrode affects its condition. Then, the beam intensity may be increased finding the most suitable position of the plasma electrode. As shown in Fig.1, a Al cylinder covered the inner wall of the plasma chamber [4]. We additionally used the negatively biased electrode method to increase the beam intensity.[5]

As shown in Fig.1, we have chosen two positions of the plasma electrode (position A and B) to test its on the beam intensity. Other parameters (gas pressure, magnetic field, microwave power and negative voltage of biased electrode) were optimized to maximize the beam intensity at each position. Figure 2 shows the beam intensities of Ar^{8+} as a function of the extraction voltage. The open and closed circles are the results at the electrode positions of A and B, respectively. At electrode position A, the best result of 1 mA was obtained at the extraction voltage of 15 kV. On the other hand, at the electrode position B, we obtained 1.3 mA at the extraction voltage of 13.5 kV. At the electrode position B, we could obtain the higher beam current at lower extraction voltage compared to that at the electrode position of A.

Figure 3 shows the beam intensity of Ar ions as function of plasma electrode position with the extraction voltage of 13 kV. Using this method, we produced 200 eμA of Xe^{20+}

at only 11 kV extraction voltage and 600 W RF power. If we extrapolate it to higher extraction voltage, we will obtain about 300 eμA at 15 kV .
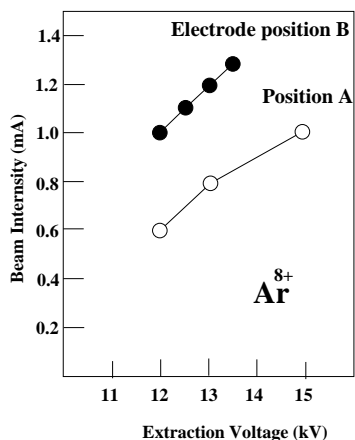

Figure 2: beam intensity of Ar^{8+} ions as a function of extraction voltage
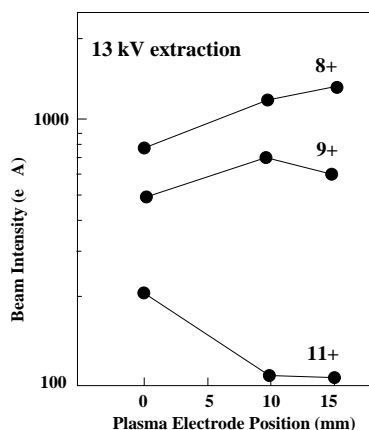

Figure 3: Beam intensity of Ar ions as a function of electrode position

2.2 *Al$_2$O$_3$ coating cylinder*

Since it was observed in RIKEN that the strong enhancement of highly charged heavy ion beam intensity after coating Al$_2$O$_3$ on the surface of plasma chamber[6], many laboratories have used this technique to increase the beam intensities of highly charged heavy ions. It is observed that large number of secondary electrons emitted from the Al$_2$O$_3$ surface reduces the plasma potential of ECR plasma[7], consequently, the ion confinement time of highly charged heavy ions becomes longer. For the extension of this method, the Al chamber or Al cylinder was used in many laboratories and the beam intensities were successfully increased. Because the surface of Al is easily oxided, it is expected to have the same effect as Al$_2$O$_3$ coating. Recently, we have sprayed Al$_2$O$_3$ directly on the surface of

the inner wall instead of the Al cylinder. The beam intensity increased from 200 eμA to 250 eμA using the Al$_2$O$_3$ spray at 12 kV extraction voltage. The maximum beam intensity of Ar^{11+} at 13 kV extraction was 290 eμA, which is the best result of RIKEN 18 GHz ECRIS.

3   LIQUID HE FREE SUPERCONDUCTING ECRIS

As the high magnetic field of a superconducting magnet, which can not be achieved by a room temperature magnet, will allow an ECRIS to deliver the intense beams of highly charged heavy ions, several SC-ECRISs have been constructed. [8,9]

There have been strong requests on the supply of the intense beams of highly charged heavy ions for RI beam production in RIKEN and for atomic cluster experiments in University of Tsukuba. To meet the both requirements, we have constructed the SC-ECRIS which has a small refrigerator to cool the solenoid. This allows us to cut the operation costs caused by liquid He consumption. It also helps to avoid the complicated operation and bulkiness of ordinary superconducting magnet operated with liquid He.

The design of the ion source was described in Ref.10 in detail. Figure 4 shows the cross sectional view of the liquid He free SC-ECRIS. The coils in the injection side generate the maximum filed of 3 T and those in the extraction side generate the maximum field of 2 T. The hexapole magnet for radial confinement of plasma consists of 24 pieces of Nd-Fe-B permanent magnets, mounted onto the cryostat warm bore of 220 mm. The inner diameter of the plasma chamber is 72 mm. To protect the hexapole magnet from demagnetization by high temperature, the plasma chamber has a double wall structure for the flow of the cooling water.
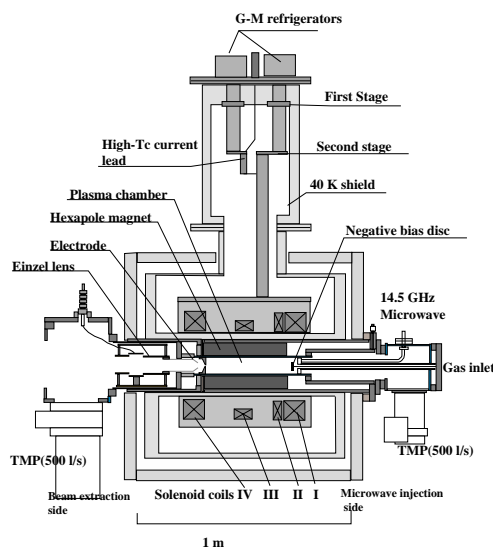

Figure 4: Cross sectional view of liquid He free SC-ECRIS

3.1 Production of highly charged Xe ions

At the end of the year 2000, we have successfully extracted the first beam of highly charged Xe ions from Liquid He free SC-ECRIS at University of Tuskuba, which has an operational frequency of 14 GHz. This source was named SHIVA. For production of Xe ions, we used an enriched ^{136}Xe gas (enrichment of 85 negatively-biased electrode was utilized in plasma chamber. The electrode is a circular disc (25 mm in diameter) made of stainless steel. The inner wall of plasma chamber was covered by a thin Al cylinder.

To obtain 10 eμA of Xe^{30+}, we only need the RF power of 650 W. This result is very remarkable, because the injected microwave power higher than 1.2 kW was required to obtain the almost same result in the other two ECRISs (the upgrade version of advanced ECRIS in Lawrence Berkeley National Laboratory (AECR-U)[9] and SC-ECRIS for the LNS, Catania (SERSE) [8]). These ion sources have achieved the highest beam intensities of highly charged ions in the world.

Figure 5 shows the beam intensities of highly charged Xe ions extracted from Caprice 14 GHz, SERSE (14 GHz) and SHIVA. To prolong the ion confinement time, we need to increase the magnetic field strength and the length of plasma chamber and to reduce the plasma potential. Main differences between Caprice and SHIVA are the length of plasma chamber and its magnetic field strength. The length of plasma chamber of SHIVA is 40 cm which is two times long as that of Caprice. The maximum magnetic field strength of SHIVA was 1.85T which is much stronger than that of Caprice (maximum magnetic field strength is 1.2T) These conditions of SHIVA make a longer confinement time of ions in the ECR plasma. As shown in figure 9, SHIVA and SERSE are more suitable to generate highly charged Xe ions than CAPRICE.
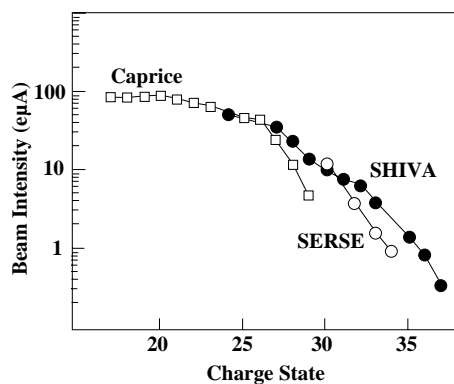

Figure 5: Beam intensity of Xe ions from CAPRICE, SERSE and SHIVA

In order to check the effect of Al cylinder, we compared the beam intensities of highly charged Xe ions when using a Al cylinder and a stainless steel cylinder. Figure 6 shows the beam intensities of highly charged Xe ions by using a Al cylinder (open circles) and a stainless steel cylinder (closed Circles). It is clearly seen that the beam intensities of highly charged Xe ions are strongly enhanced when using a Al cylinder. This was also observed in other ECRISs.
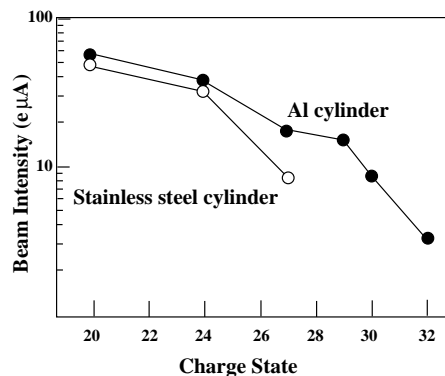

Figure 6: Beam intensity of Xe ions when using Al and Stainless steel cylinder

4 CONCLUSION

We have constructed two high performance ECRISs for RIKEN RI Beam factory project and successfully produced intense beams of highly charged heavy ions. RIKEN 18 GHz ECRIS can produce the intense beams of medium charge states of heavy ions (1.3 mA of Ar^{8+}, 200 eμA of Xe^{20+}) by applying the various technique, e.g. Al cylinder method, biased electrode method, optimizing the plasma electrode position. Very recently, we have successfully produced intense (10 eμA of Xe^{30+}, 1 eμA of Xe^{36+}) from SHIVA (Liquid He free SC-ECRIS at 14 GHz microwave frequency). Comparing SHIVA with other high performance ECRISs (CAPRICE and SERSE), it is concluded that the high magnetic field, long plasma chamber and Al cylinder achieve the long ion confinement time and more intense beams of highly charged heavy ions.

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