STATUS OF RIKEN SC-ECRIS

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Abstract

To increase the beam intensity of highly charged heavy ions for RIKEN RIBF project, we constructed and tested the RIKEN new SC-ECRIS. After producing the first beam in the spring of 2009, we tried to optimize the ion source condition for maximizing the beam intensity with 18GHz microwave. We observed that the gentler field gradient and lager ECR zone size give higher beam intensity. Based on these studies, we produced 550μA of Ar^{11+} and 350μA of Ar^{12+} at the RF power of 1.8kW. In this summer, we will try use the 28GHz microwave to increase the beam intensity.

INTRODUCTION

Since middle of the 1990s, RIKEN has undertaken construction of new accelerator facility so-called Radio Isotope Beam Factory (RIBF) [1] and successfully produced 345MeV/u U beam (~0.4pnA on target) in 2008[2]. Using it, more than 40 new isotopes were produced with the in-flight fission reactions for only 4 days experiment.[3] It is clear that the intense U beam is strong tool to produce new isotopes in the region of medium mass nuclei and to study the mechanisms of the r-process in nuclear synthesis. For these reasons, the intense U beam is strongly demanded. To meet the requirement, we started to construct the new superconducting ECR ion source (SC-ECRIS) which has an optimum magnetic field strength for the operational microwave frequency of 28 GHz in the summer of 2007. In the end of 2008, we obtained the 102% of the designed value for the magnetic field strength. In the spring of 2009, SC-ECRIS produced first beam with 18GHz microwaves. Till now, we made various test experiments to increase the beam intensity of highly charged heavy ions with 18 GHz microwave [4].

In this article, we present the structure of the new ion source, new experimental results and the future plan to meet the requirements.

SC-ECRIS

The detailed structure of the ion source was described in refs [4, 5]. Schematic drawing of the Sc-coils is shown in Fig.1. For operation of 28GHz microwave, the B_{inj}, B_{ext} and B_r are 3.8, 2.2 and 2.2T, respectively. The main feature of the ion source is that it has six solenoid coils for producing magnetic mirror for the axial direction. Using this configuration, one can change the magnetic field gradient and ECR zone size independently. This magnetic system allows us to produce "conventional B_{min} "and so-called "flat B_{min}" [6] configurations. For keeping the superconductivity, the cryostat is equipped with three small GM refrigerators with 4 K, 20K and 70 K stages and operated without supplying liquid He after poured once. Amount of the liquid-He in the cryostat is ~500 L. The nine current leads made of high temperature superconducting material are used to minimize the heat load to 4 K stage. The heat load to 70 K stage is 123 W caused by copper current leads, supports of a cold mass and radiation through the multi-layer insulation. In the winter of 2009, we installed one GM-JT refrigerator, which have total cooling power of 5W at 4K, to increase the cooling power.

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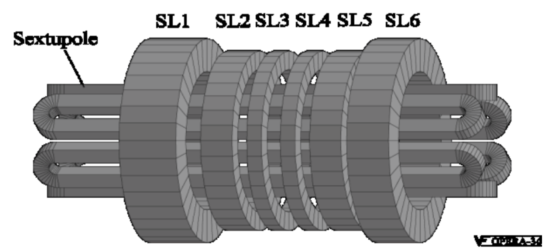

Figure 1: Schematic drawing of the Sc-coils.

EXPERIMENTAL RESULTS

The one of the strong interests for increasing the beam intensity of highly charged heavy ions are the effect of the resonance surface size and field gradient at ECR zone. As described in the previous section, the ion source has six solenoid coils for creating the mirror magnetic field. Using these coils, the ECR surface size can be changed without changing the average magnetic field gradient. Fig. 2 shows the beam intensity of Xe^{20+} as a function of the average magnetic field gradient for several ECR zone sizes at the RF power of 500W. For investigating these effects, B_{inj}, B_{ext} and B_r were fixed to 2.3, 1.2 and 1.3T, respectively. The extraction voltage was fixed to 17kV. It is clearly seen that the beam intensity increases with decreasing the field gradient. Furthermore, it seems that the beam intensity is higher for larger zone size at same field gradient. Fig. 3 a) and b) show the ratio of highly charged Xe beam intensity between two conditions. The ratio between two different field gradients increases with increasing the charge state (fig.2 a)) on the other hand, the ratio between different zone sizes are almost constant and independent on the charge state (Fig.3 b)). It is well-known that the energy transfer from microwave to electron increases with decreasing the gradient. It means that the electron temperature becomes higher at the gentler field gradient. The production rate of the higher charge state Xe ions increases with increasing the electron temperature. For this reason, we observed the phenomena shown in Fig.3 a).

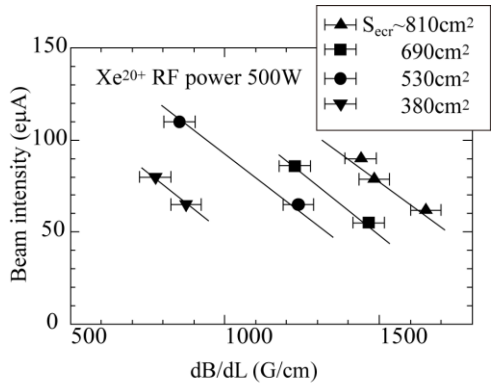

Figure 2: Beam intensity of Xe^{20+} as a function of average field gradient for several ECR zone size.

Fig. 4 shows the beam intensity of Ar^{11+} as a function of average magnetic field gradient for several ECR zone size. We can see the same tendency as Xe^{20+} case except for the beam intensity at gentler field gradient (dB/dL < 800G/cm). The beam intensity saturated or even decreased with increasing field gradient in this region.

The estimated beam intensities (dashed line) are shown in this figure. Simultaneously, we measured the heat load of the X-rays. (see Fig. 5) It is clearly seen that the heat load increases with decreasing field gradient. The heat load of the cryostat is strongly dependent on the X-ray energy, i.e., higher energy X-ray gives large heat load. It means that the very high energetic electron generate at dB/dL<800G/cm. We observed same tendency for Ar^{12+} and higher RF power (>1kW). It is still unclear why we do not obtain higher beam intensity in this region. To understand this phenomenon, we need further investigations.

Fig. 6 shows the beam intensity of Ar^{11+} as a function of RF power under two conditions (A and B). The conditions (field gradient and ECR zone size) A and B are shown in Fig.4. The beam intensity increases with increasing RF power up to 1.8kW and we obtained 500 eμA of Ar^{11+}.

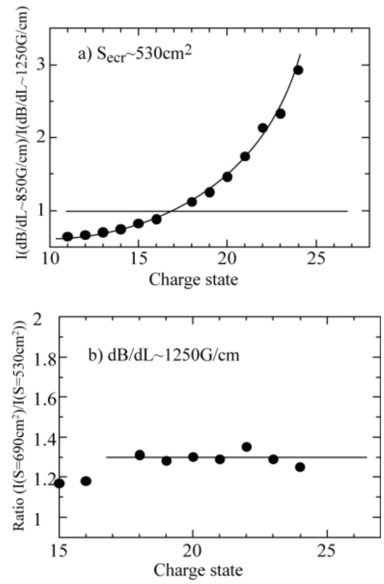

Figure 3: Ratio of beam intensity between two conditions

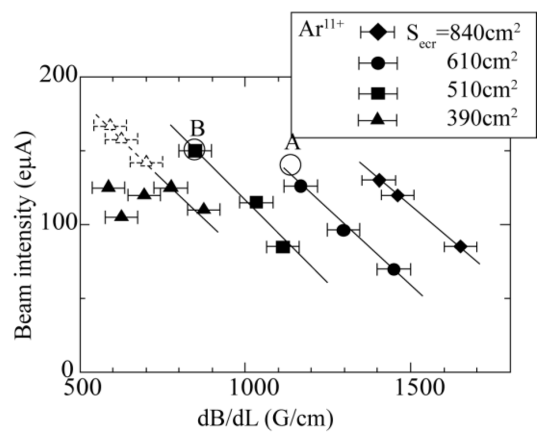

Figure 4: Beam intensity of Ar^{11+} as a function of average field gradient for several ECR zone size.

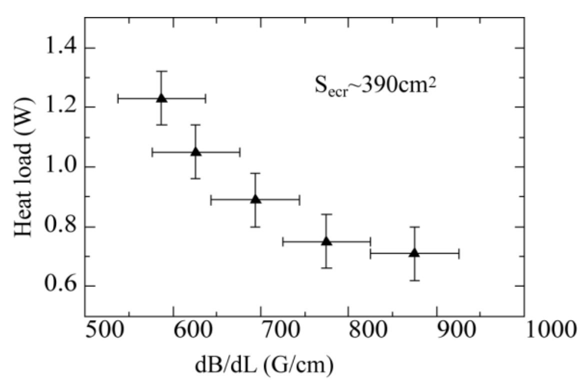

Figure 5: Heat load of the cryostat as a function of average field gradient

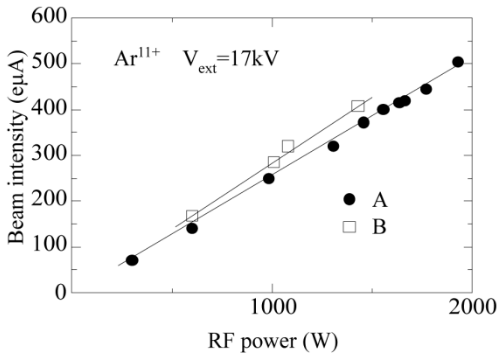

Figure 6: Beam intensity of Ar11+ as a function of RF power.

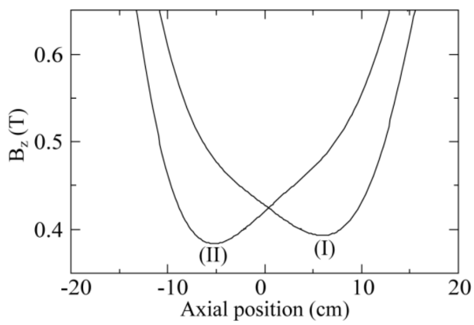

Figure7: magnetic field strength in the B_{min} region

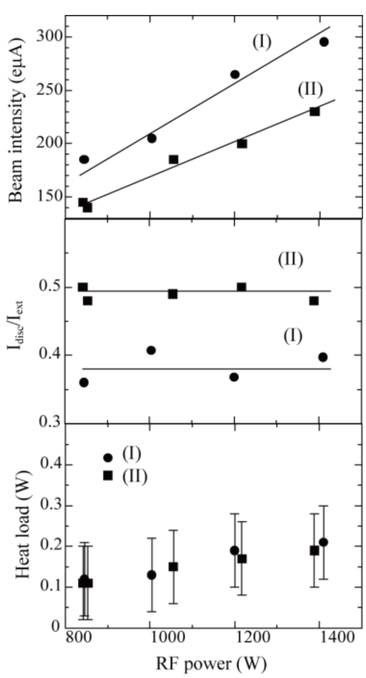

Figure 8: Beam intensity of Ar^{11+} (upper), ration between the extracted beam and biased disc current (middle) and heat load (lower) as a function of RF power

Fig. 7 shows the magnetic field distributions (I) and (II) in the B_{min} region. Fig. 8 shows the beam intensity of Ar^{11+}, ratio between biased disc current and extracted current, and heat load for two cases ((I) and (II)) as a function of RF power.

The beam intensities in case (I) are always higher than those in case (II). The average field gradient and ECR zone size for case (I) is same as those for case (II). The heat load of X-ray for case (I) was almost same as those for case (II) (lower figure). It means that the electron energy distribution may be same. Main difference is the position of the B_{min}. As shown in Fig.8, it seems that the ratio between the extracted beam intensity and current of biased disc in case (I) is always higher than those in case (II). It may indicate that the plasma flow to the extraction in case (I) is higher than that in case (II). To understand this mechanism, we need further investigation.

FUTURE PLAN

It is obvious that the higher frequency gives higher beam intensity of highly charged heavy ions, if we can make optimum magnetic field distribution for higher frequency. To increase the beam intensity of highly charged U ions, we will operate the new SC-ECRIS with 28GHz microwave instead of 18GHz after moving the ion source to the ion source room for new injector system of the RIBF in the summer of 2010. The 28GHz gyrotorn was already installed and tested at RIKEN in this spring of 2010. In the winter of 2010, the test with uranium will be made to meet the requirement of the RIKEN RIB factory project

CONCLUSIONS

We investigated the effect of the magnetic field gradient and ECR zone size on the beam intensity of highly charged heavy ions, independently. In this experiment, we clearly observed that the gentler field gradient and large zone size gives higher beam intensity. We also observed that the beam intensity was saturated or even decreased at smaller zone size and very gentle field gradient. To understand these phenomena, we need further investigation.

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