STATUS OF THE HIGHLY CHARGED ION BEAM PRODUCTION FROM THE RIKEN 18GHz ECRIS

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Abstract

Electron Cyclotron Resonance Ion Sources (ECRIS) provide highly charged intense beams for the RI Beam Facility (RIBF) at RIKEN. One of the high-performance ion sources is the R-18GHz ECRIS where heavy ions of $^{40}Ar^{11+}$, $^{84}Kr^{20+}$, and $^{129}Xe^{25+}$ are being accelerated then injected to the Azimuthally Varying Field (AVF) cyclotron. With the demand for more intense ion beams, optimization of ECR parameters and techniques to increase beam intensity have been used. Biased-disk position and dependence on RF power and gas pressure have been investigated to determine the conditions for increasing the beam intensity. For high charge state ion production, studies on gas mixing effect on the charge state distribution is currently ongoing.

INTRODUCTION

Intense beams of multi-charged heavy ions are produced from ECR Ion Sources (ECRIS) and accelerated in the radioisotope beam factory (RIBF) at RIKEN. The RIKEN 18-GHz ECRIS has been continuously developed to provide intense beams of $^{40}Ar^{11+}$, $^{84}Kr^{20+}$, $^{129}Xe^{25+}$ and other heavy ions.

To increase the beam intensity, optimized conditions of the magnetic field configuration and plasma electrode position have been previously determined [1, 2]. It was also known that beam intensities were strongly dependent ECR conditions such as the microwave power and gas pressure, so it is important to systematically study the effects of these parameters. Other techniques to increase the beam intensity such as bias disc tuning, and the effect of gas mixing are also investigated. Optimizing these parameters aims to increase the beam intensities for the various RI beams supplied in the facility.

RIKEN 18-GHz ECRIS

The RIKEN 18-GHz ECRIS has been previously described in the following references [3]. The magnetic field configuration of the ECRIS uses two sets of solenoid coils to produce the mirror magnetic fields and 36-segments of Nd-Fe-B permanent magnets for the hexapole magnetic field. A TWT amplifier is used to inject 18 GHz microwaves of up to 600 W to the cylindrical plasma chamber of inner diameter ϕ 72mm and length 250 mm. The specifications are described in Table 1.

A cross section of the R18GHz ECRIS is shown in Fig 1. A gas feed is used to introduce neutrals into the chamber for plasma production through step-by-step ionization from energetic electrons due to the ECR phenomenon. A movable bias disc is positioned from the microwave injection side and can be inserted further towards the central part of the plasma chamber.

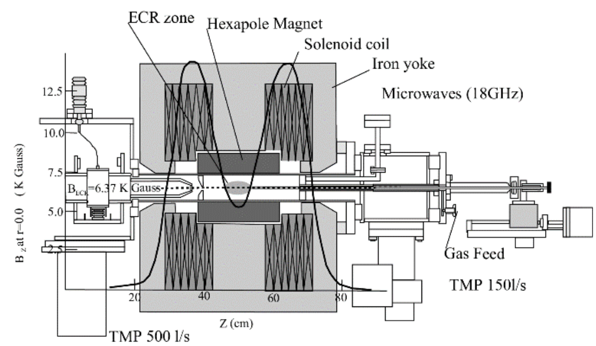

Figure 1: Cross-sectional diagram of the R18GHz ECRIS.

Table 1: Specifications of the R18GHz ECRIS

Operational Frequency	18 GHz
Microwave Power	~600 W max (TWTA)
Magnetic Mirror	1.4 T (room temp. solenoid coils)
Extraction Voltage	<18 kV
Chamber Dimensions	Φ 72 mm L 250 mm

The R18GHz ECRIS is currently providing heavy ion beams of ^{40}Ar, ^{84}Kr and ^{129}Xe with beam intensities as shown in Fig. 2. The charge state distribution for the different ion species have been optimized for high charge ion production. The magnetic mirror fields, microwave power, gas pressure, bias disc and other ECR parameters have been tuned for stable operation of ion beams of $^{40}Ar^{11+}$, $^{84}Kr^{20+}$ and $^{129}Xe^{25+}$. For heavier ions such as ^{129}Xe and ^{84}Kr, the ECRIS requires more microwave power with optimized ECR conditions to be able to produce stable intense beams. The dependence of these parameters to the produced beam intensity is discussed in the following sections.

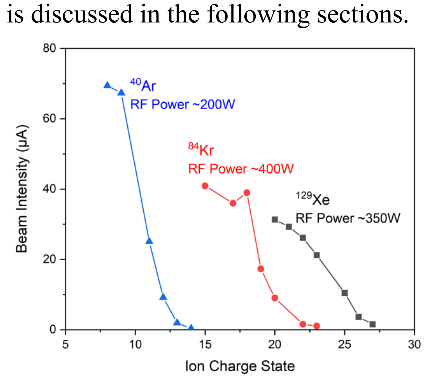

Figure 2: Beam Intensity of multi-charged ions of Ar, Kr and Xe produced from the R18GHz ECRIS.

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Microwave Power Dependence

The microwave power is one of the key parameters in the ECRIS as it observed to linearly increase with beam intensity.

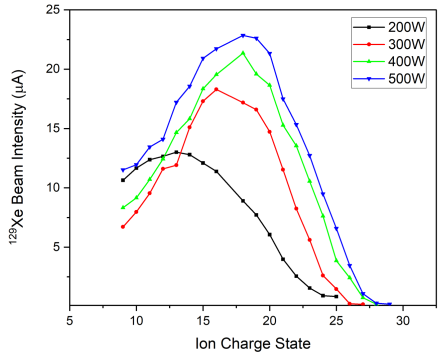

Figure 3: Beam Intensity of the produced Xe ion charge states with microwave power varied from 200 W to 500 W.

For ^{129}Xe ion production, the beam intensities of the produced charged states are shown in Fig. 3 with injected microwave power ranging from 200 W to 500 W. Fixing the microwave power, the ion charge state distribution is measured while parameters such as gas pressure, magnetic field distribution, bias disc are optimized.

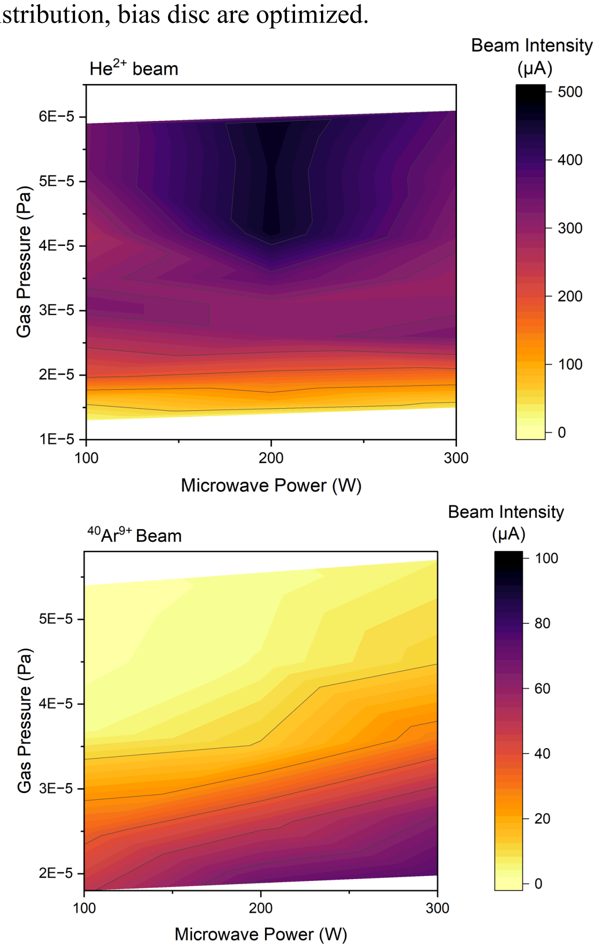

Figure 4: 3D contour plot of the produced beam intensities of He^{2+}(top) and $^{40}Ar^{9+}$(bottom) with respect to plasma chamber gas pressure and microwave power.

The shift in low to high charge state ion production greatly depends on ECR parameters which can be indirectly controlled by adjusting the gas pressure. For higher microwave power, the optimum condition for stable operation occurs at higher gas pressures.

Gas Pressure Effect

As previously mentioned, the produced beam intensities depend on the ECR conditions which can be controlled through the chamber gas pressure and injected microwave power. A 3D contour plot of the beam intensities for He^{2+} and Ar^{9+} charge states for the range of gas pressures and microwave power are shown in Fig. 4. In the case of lighter ions such as He^{2+}, it can be observed that high beam intensities are achieved for gas pressures of $4\text{x}10^{-5}$ Pa and higher. For heavier ions such as Ar^{9+} ions, a lower gas pressure condition is necessary to achieve higher electron temperatures for high charge state ion production and beam intensities start to increase when the gas pressures are under $3\text{x}10^{-5}$ Pa. The increase in gas pressure corresponds to conditions with high neutral particle densities and this affects the optimum electron temperature inside the ECR plasma. The gas pressure is one of the major parameters that affects not only the ion beam intensities but also mean ion charge state of the ECR plasma.

Bias Disc Tuning

In the ECR plasma, high electron population is essential for the ionization of highly charged ions. For this reason, one of the techniques to increase the beam intensity is using a ϕ25 mm thin cylindrical disc inserted from the microwave injection side. A negative potential is applied to the bias disc aiming to repel the electrons back to the central part of the plasma chamber. The bias disc position along the beam axis can be adjusted accordingly. The beam intensity of He ions are shown in Fig. 5, as a 3D contour plot for the range of bias voltage of -15 to -35 V and disc position of 15 to 35 mm towards the center of the plasma chamber. It is observed that the beam intensity oscillates with respect to the bias disc position. In the case of bias voltage, beam intensity increases and reaches to a maximum and saturates as the negative voltage is increased. Other parameters such as gas pressure and power are held constant during measurements. Additional experiments to relate the bias disc position to the magnetic field configuration and other ECR parameters will be further investigated to understand the fundamental mechanisms involved in using this technique.

Gas Mixing Method

Another method to increase the beam intensity is the use of support gas with lighter mass to interact with the main gas and increase the collisional mechanisms in the plasma [4]. One of the explanations is the increase in ion-ion collisions which creates an ion cooling effect leading to longer confinement times that allow for higher charge state ion production. However, other explanations also infer an increase of electron densities that can lead to highly charge ion production. Further investigations are needed to confirm these mechanisms.

Measurements of the ^{84}Kr ion charge states and the beam intensities are shown in Fig. 6, with O_2 as the support gas. For this experiment, the Kr gas pressure was held constant as the O_2 support gas was slowly increased. For O_2 percentages of up to 23%, the intensity for highly charged ions increases and shows the effectiveness of the technique. For microwave power 200 W and 400 W the increase in the mean charge state is observed as the O_2 percentage is increased. Since the total gas pressure affect the microwave power conditions, careful considerations should be made when introducing support gases. Studies are ongoing for different ^{84}Kr gas pressures and additional experiments are necessary to determine the optimum mixing ratios required for highly charged ion production. This aims to determine an effective methodology for optimization of ECR parameters with the gas mixing method.

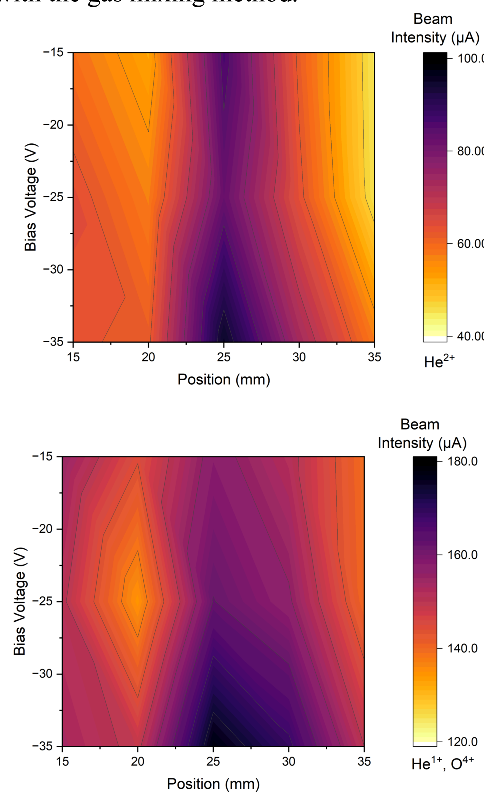

Figure 5: 3D Contour plot of the beam intensity of He^{2+}(top) and He^{1+}/O^{4+}(bottom) with respect to the applied bias voltage and disc position along the beam axis at constant microwave power 200 W.

CONCLUSION

The RIKEN 18GHz has been supplying intense heavy ion beams such as $^{40}Ar^{11+}$, $^{84}Kr^{20+}$, and $^{129}Xe^{25+}$ in RIBF at RIKEN. The operation of ECRIS requires the proper optimization of key ECR parameters and the effect of gas pressure and microwave power has been described. Some methods such as the use of bias disc tuning, and gas mixing were discussed on its effectiveness in increasing beam intensities of produced highly charged ions. Experiments are still ongoing to determine the methods and optimization conditions for ECRIS to further increase beam intensities and stable production of RI beams.

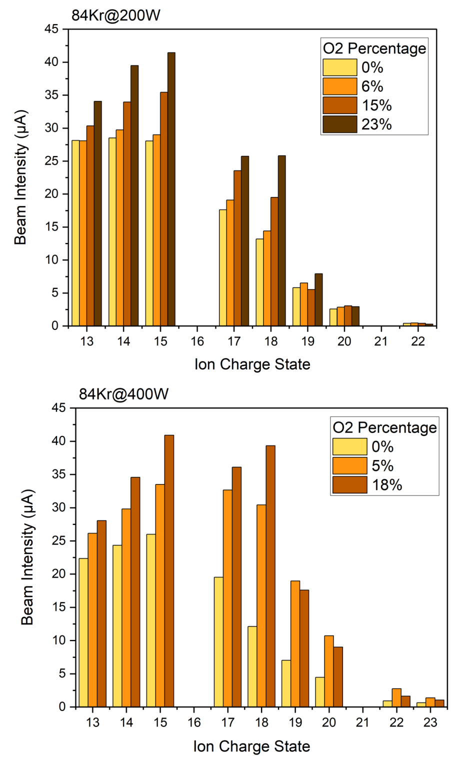

Figure 6: Beam intensities of ^{84}Kr ion charge states for fixed microwave power of 200 W (top) and 300 W (bottom) with varying O_2 support gas percentages.

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