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Effects of Gas Mixing and Electron Injection in Production of Multiply-Charged Ion with The HyperECR

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Abstract

In an experiment by using the gas mixing technique and electron beam injection technique at a multiply-charged heavy ion source (HyperECR) with 14.25 GHz microwave frequency, an enhancement of the intensity for highly charged ions has been observed. It was confirmed that these methods work well also in this source.

1 Introduction

To increase the intensity of the highly charged ions, gas mixing is one of the common techniques in which one uses an *assist gas* together with a *main gas* for ionization. For the assist gas, He or O_2 are usually used. In these days, this effect is realized to come from the fact that the lighter ions cool the heavier ions – ion cooling. The heavy ions (atoms) in the plasma chamber get some energy from the electrons that are accelerated with the microwave power. But after the heavy ions collide many times with the light ions (atoms), they lose the kinetic energy (cooled), so that the heavy ions are trapped better in the negative potential well to be ionized into more highly charged states.

Electron injection to the plasma chamber is another technique for that purpose. It is commonly realized that supplying electrons into the plasma chamber from outside increases the electron density in the plasma and that the ionization efficiency becomes better. Actually in several sources, this phenomenon is confirmed experimentally [1].

In an ECR ion source, once an electron enters the mirror magnetic field, the electron gains energy at the ECR region in the perpendicular direction to the magnetic flux ($B_\perp$ direction). So the electron will be confined more strongly inside the mirror field. The electron will be lost by the electron capture process of ions, by losing the momentum in the $B_\perp$ direction in collisions with ions (escape from the mirror field) or by bombarding the inside wall of the plasma chamber.

An assumption that a negative potential is made by electrons inside a plasma chamber is reasonable [2]. This potential traps ions, and the higher an ion is charged, the stronger it is trapped. This suggests that the mean ion charge state in the plasma chamber is higher than that of the extracted beam. It is, therefore, important for the ion source development to find out not only how to trap ions but also how to extract raw ions in the plasma.

An experiment to show clearly the effects of gas mixing and electron injection has been carried out.

2 Experimental Setups

2.1 Gas Mixing

Two variable leak valves (ANELVA,951-7170) are used for the main gas and the assist gas. Their minimum controllable leakage rate is 5 $\times 10^{-8}$ TorrL/sec (0.004 sccm) according to the specification. This corresponds to the beam current of 286 eμA for Ar and 572 eμA for O_2 if all the atoms are singly ionized,

After passing the valves, two gases are admixed and fed into the plasma chamber (Fig.1). Since it was found that there is not much difference in performance between the cases when the gas is fed through a quartz pipe on the axis or fed directly into the plasma chamber without using the tube, usually a quartz tube is not used in this source. Instead, this space is used for other purposes.

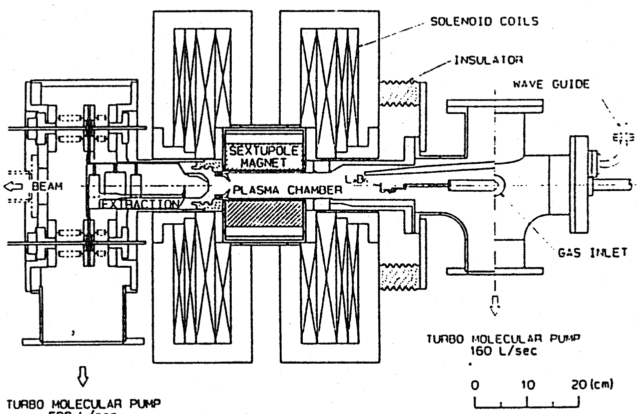

Fig.1. Drawing of the HyperECR.

Since a lighter gas should be more effective for ion cooling if the model on the gas mixing mentioned before is true, H_2 gas is also tried as the assist gas in this experiment.

2.2 Electron Injection

A commercially available filament made of lanthanum hexaboride (LaB_6, DENKA W-2) is used for an electron emitter. It is attached at on the electrodes at the top of a pipe inserted axially (Fig.1). The filament current was decided to be about 23 A from the catalog data and the electron emission current. An optimum position of the filament was found to be outside the one of the peaks of the mirror field in a search to get a good performance. The magnetic field at that position is about 4 kG.

3 Results

The experiment is carried out in the following procedure. The currents through the two mirror coils (600A/550A) and the microwave power (650W) were fixed. The source and the charge state analyzer were tuned to optimize the beam current of Ar^{8+} after the analyzer with oxygen gas admixed. The potential of the filament relative to the plasma chamber has been searched with a constant voltage power supply. It was found that a value of -600 V is the best although this is limited by the capacity of this particular power supply. This bias voltage is put on and off with the filament power supply.

The charge state distribution observed after the analyzer at this step is shown in Fig.2. Hereafter, the source parameters were not varied except the flow rates of the main and assist gas. The ion spectra in each step are shown as follows:

1. Tuned to Ar^{8+}, Ar+O_2 gas, filament on — Fig.2
2. O_2 gas closed, some Ar gas added — Fig.3
3. He gas added — Fig.4
4. He gas closed, H_2 gas added — Fig.5
5. Filament off — Fig.6

From these spectra, the beam current of Ar^{8+} and the total Ar ion current were deduced together with the mean charge state. They are summarized in Table 1.

Table 1. Ar beam after analyzing magnet.

	mean charge state	total Ar beam current(eμA)	Ar^{8+} beam current(eμA)
Fig. 2	6.54	693	255
Fig. 3	6.20	595	210
Fig. 4	6.76	784	315
Fig. 5	6.61	896	315
Fig. 6	6.03	609	190

It can be seen from these results, firstly, that any of the mixing of H_2, He or O_2 gas increases the total Ar beam current. Secondly, this gas mixing makes the mean charge state higher. Thirdly, it is clear that the electron injection from the filament works well.

According to the current model of ion cooling, the present experimental results are consistent with the fact that the gas mixing and the electron injection help to trap the highly charged ions in the negative potential.

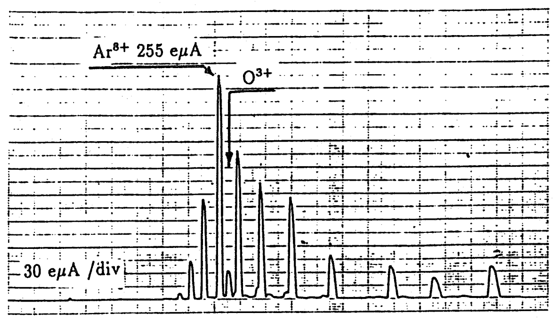

Fig.2. Tuned to Ar^{8+}, Ar + O_2 gas, filament on.

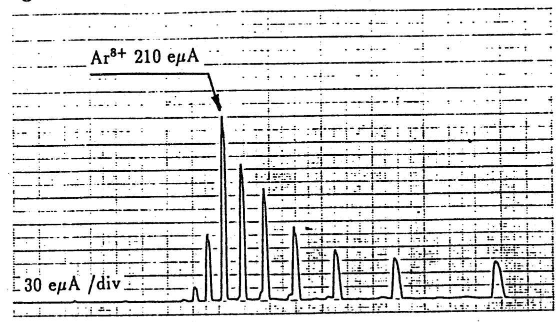

Fig.3. O_2 gas closed, some Ar gas added.

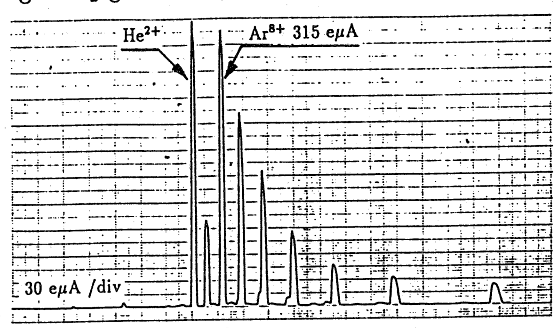

Fig. 4. He gas added.

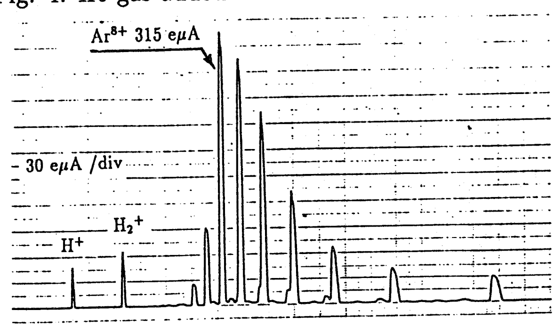

Fig. 5. He gas closed, H_2 gas added.

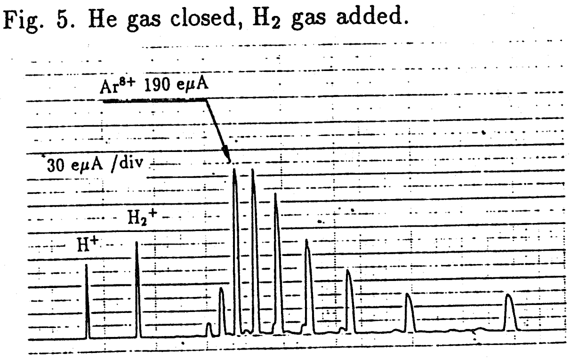

Fig. 6. Filament off

4 Discussions

Experiences on the operation of the HyperECR show that performance for the Ar beam becomes always better after oxygen beam production although oxygen beam is not detected so much in the spectra. After running the source for Ar for a while, however, this effect disappears. It is reported from several ECR sources that coating the inner surface of the plasma chamber with SiO_2, MgO, Al_2O_3 etc. works to increase beam current [1, 3].

Since oxygen is not so light as H_2 or He, it is difficult to expect that oxygen is contributing to the ion cooling. Instead, it is more natural to think oxygen plays a role of an electron emitter. The inner surface may be coated with oxide during oxygen production.

Higher energy electrons in the plasma have larger Larmor radius and they will eventually hit the inner surface of the plasma chamber and produce secondary electrons. If the number of the secondary electrons are enough, raising the temperature of the inner surface of the chamber and making it with a material whose work function is low will result in higher electron density of the plasma. In this case, the electron injection technique from outside of the chamber may not be necessary.

In this experiment the RF power was fixed at the level and the source was not necessarily in a best condition. When more RF power is fed and the source is tuned more carefully, it has been proved that this source can produce, for examples, 480 eμA of O^{6+}, 60 eμA for O^{7+} and 480 eμA for Ar^{8+} by using the techniques as described in this paper.

5 Conclusions

On the HyperECR ion source, an experiment has been carried out to show the following points:

- In an Ar beam production test, the gas mixing technique with H_2, He or O_2 and the electron injection technique increase the beam current and the mean charge state.
- Some other methods may produce more current than those currently employed.

References

1) C. M. Lyneis *et al.*, Proc. 10th Int. Workshop on ECR Ion Sources, ORNL, 1991, p.47.
2) G. D. Shirkov, Preprint JINR E9-92-33, Dubna, 1992.
3) T. Nakagawa *et al.*, Proc. 8th Symp. Acc. Sci. Tech., 1991, p.55.