THE PRELIMINARY EXPLANATION OF A NEW WORKING MODEL ON 10GHz ECR2 SOURCE [1]

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A new working model and a new magnetic field configuration were employed on the 10GHz ECR2 source of the heavy ion research facility in Lanzhou(HIRFL). That resulted in an obvious enhancement of beam currents of ECR2 ion source, the beam current of Ar^{9+} increase from 125 eμA to 320 eμA, for Ar^{11+} ion beam increase from 40 eμA to 80 eμA. In this paper, primary analysis and explanation of this working model is presented, we will also discuss the action of low energy electrons in ECR plasma and get an important conclusion, which the low energy electrons injection is more effective in the extraction region of ECR ion sources.

1 Introduction

We have been endeavoring to improve the performance of our 10GHz ECR sources since 1992. After modified the magnetic field of ECR1 and used a cold electron gun inside it,[1] another 10GHz ECR ion source (ECR2) was constructed.[2]Because of the financial support limitation, although the axial magnetic field and the hexapole field of ECR2 are elevated, these value are still lower than those of typical ECR ion sources in the world. A lot of methods have been put forward and tested on our ECR sources to enhance beam current of ions with high possible charge state. Among them, the low energy electron injection into ECR plasma were rather effective and frequently practised, it included cold electron gun and aluminum coating. On this base, we have tried to used metallic tubes in ECR source cavity to emit the secondary electron into the plasma, during these tests a new working model and a new magnetic field configuration have been found on our 10GHz ECR ion sources.[3]

2 The new working model for ECR2

The structure of our ECR2 source is shown in Fig.1. Microwave of 10GHz frequency is coupled to the plasma cavity to ionize and heat the plasma. The superposition of a magnetic hexapole and mirror field offers a magnetic configuration with minimum B field in the center region of the plasma cavity. Ions in such a confined plasma have enough opportunity to be ionized to high charge state, and finally are extracted through the hole on plasma electrode.

Normally, the best position of the plasma electrode, is optimized to just the most external magnetic closed-contour enveloped by the cavity. However, in this case the plasma density near the extraction hole is not so high as that in the ECR zone, thus the ion output is limited accordingly. If the plasma electrode were put deeper into plasma chamber, the ion current would increase much. But this would cause to deterioration of source performance for the plasma near the extraction region would suffer from a loss in magnetic confinement.

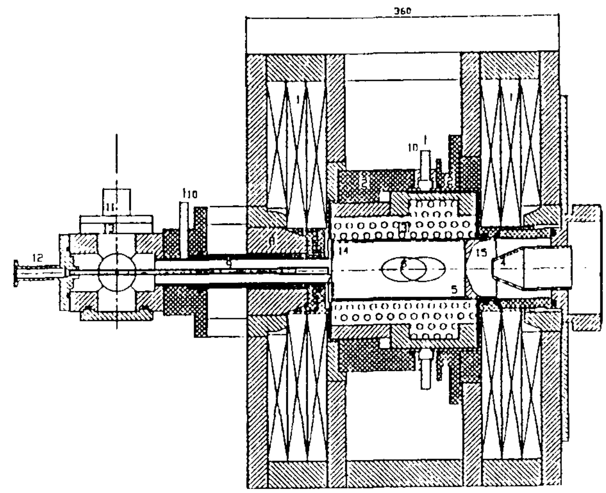

Fig.1 10GHz ECR2 ion source for HIRFL.

Nevertheless if a sufficient amount of low energy electrons could really be introduced to the plasma around the extraction region, the situation could be significantly changed. In our tests, those low energy electrons were emitted from an aluminum plasma electrode and a special thin aluminum tube, which was tightly inset into the plasma cavity. On the aluminum surface a thin oxide film was formed, that's a good material in secondary electron emission. Therefor, if the plasma electrode was gradually pushed toward the center of the cavity, because of the plasma bombardment, the secondary electrons emitted from the electrode would become more and more. In the beginning of pushing the plasma electrode into the cavity from the ordinary position, the high charge state ion current was slowly increasing. However, when the plasma electrode

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protruded to a certain position, about 10mm deeper than its ordinary position, the source performance and its working characters were changed in some abrupt way: the gas feeding and microwave power required were decreased apparently, and the extracted high charge state ion current was enhanced obviously. From this position, the electrode position could be tuned slightly to optimize the source performance for the ion with expected charge state. While this electrode was over-inserted, the extracted ion current became unstable and oscillating. In Fig.2, it shows the dependence of Ar^{8+} beam current on the position of the plasma electrode to the end of the cavity. So these working conditions are quite different from the traditional working model of ECR ion source, and might be called a new working model of ECR source. On the other hand, the dependence of the extracted Ar^{8+} ion current on microwave power is shown in Fig.3. We can see from Fig.3 that 320eμA of Ar^{8+} was got at only 120W microwave power. Simultaneously 250eμA of Ar^{9+} was obtained at only about 180W. At medium microwave power, the ion current changed less, even decreased sometimes with the microwave power. At high microwave power, the ion current increased slowly and showed a saturation behavior.

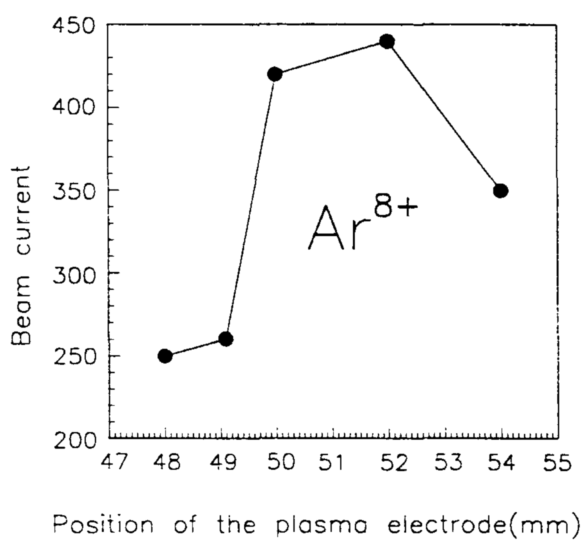

Fig.2 Dependence of Ar^{8+} beam current(eμA) on the position of the plasma electrode.

3 New magnetic field configuration

As mentioned above, the ECR source operated in the new working condition realizes ion extraction from a denser plasma density because the inserted plasma electrode is closer the ECR zone where higher plasma density is located. However it should be equivalent, if the ECR zone could be moved to extraction region. The ECR source shown in Fig.1 is an example of new magnetic configuration. By using a new hexapole and other adjustable iron parts, the position of B_{min} is moved roughly 10mm toward the extraction region. The outer jacket of the hexapole is made of brass and soft iron for the injection and extraction half respectively. The magnetic field strengths on the hexapole surface are 6kGs, 7.5kGs and 6.5kGs at the positions of A, B, C. Test results indicated that the ECR source performance with new magnetic configuration was better than that of the old one. The best results gotten on our ECR source by using the technologies mentioned above are 430eμA, 320eμA and 80eμA for Ar^{8+}, Ar^{9+} and Ar^{11+} ion respectively. This source should also be suitable for producing other high z ions. As a compact 10GHz ECR source with medium magnetic mirror field and hexapole field, such a performance is quite satisfactory.

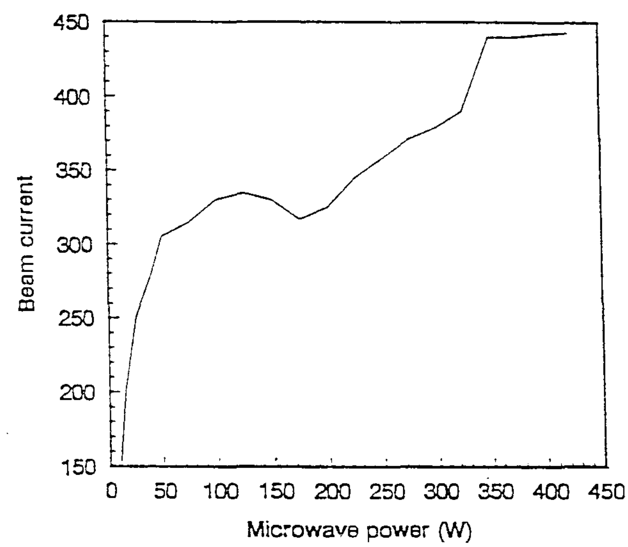

Fig.3 Dependence of Ar^{8+} beam current(eμA) on microwave power.

4 Primary explanation and discussion of the new working model

It is known that injection low energy electrons into the ECR plasma is the crux of the new working model, then what's role do low energy electrons play in the ECR plasma?

Firstly, from plasma physics we know the ramping rate of plasma perturbation in magnetic mirror field system, under restriction of low β, is direct ratio the square root of the electron temperature in plasma(T_e). Because there is lower neutral gas pressure and more efficient microwave heating the ECR plasma in the extraction region and some low energy electrons are diffused into the injection region from the first stage, the starvation for low energy electrons in the extraction region is more serious than that in the injection region. Therefor, that can reduce the plasma instability and improve the performance of source when low energy electrons are introduced into the ECR plasma.

Secondly, injecting low energy electrons in the extraction region will change the local distribution of the plasma potential due to adding this area electron density and form a negative electric field, which can catch high charge state ions surrounding this area and drag those high charge state ions from the small negative dip in the ECR region and make it moving toward the extraction region. In this case, that will enhanced the high charge state ion output.

Thirdly, low energy electrons adding can help the plasma near the extraction region to be sustained at even lower gas pressure. As a result, the ion loss rate of charge exchange between high z ions and neutrals inside the source plasma is obviously reduced, the ionization degree of the working gas is enhanced accordingly.

As described above, we can make a conclusion which the low energy electrons injection in the ECR plasma will enhance the high charge state ion beam current, furthermore, it's immission in the extraction region is more effective than in the injection region. That was already demonstrated in our tests by adding and reducing the emitting area of secondary electrons in the injection region and the extraction region respectively. When increased the emitting area of secondary electrons in the injection region the ions current didn't rapidly go up, for Ar^{9+} ions from 140eμA to 150eμA at the same plasma electrode position, but decreased this area in the extraction region the ions current did quickly go down, for Ar^{9+} ions from 120eμA to 80eμA at another plasma electrode position.

In ECR ion source cavity, low energy electrons are mainly from two aspects due to bombardment of the plasma: one is produced by high energy electrons, another is caused by the potential emission of high charge state ions.

According to cathodal electronics, the collected-current ratio δ is equal to the number of secondary electrons dividing to the number of bombardment electrons. With adding the bombardment electrons energy, the ratio δ will increase too in the beginning and gradually reach to the maximum ratio δ_m, then it begins to decline. The δ_m of the pure metal is between 0.5 to 1.8, correspondingly the bombardment energy E_{pm} is from 200eV to 800eV; But for some active metal, such as Be, Ca, Ba and Al, are very easy to adsorb gas to form an oxide film on the metal surface, the δ_m of these oxide film will increase about 2 to 5 times, correspondingly the bombardment energy E_{pm} is changed from 400eV to 1500eV. For example the δ_m of Al is only 1.0, but that of Al_2O_3 is 4.8. Therefor, the thin oxide film on the aluminum surface is a good material in secondary electron emission, it will provide a lot of low energy electrons toward the ECR plasma in the extraction region when aluminum tube and plasma electrode are bombarded by high energy electrons.

For high charge state ions have very strong ionization potential U_i, it is larger than two times the escape potential of the bombarded metal, $eU_i >> 2\phi$. High charge state ions would bombarded the electron if it impacted on the metal surface, simultaneously the ion would be neutralised and transit to exciting state, some electrons inside the metal would obtain the exciting energy and escape from the metal. In this case, it is rather effective to produce secondary electrons, the number of electron will increase with the square of ion's z.

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Reference

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