HIGHLY IONIZING MECHANISM IN THE ECR TYPE HEAVY ION SOURCE

T. Yamamoto, N. Abe, K. Oda and M. Kawanishi

Institute of Scientific & Industrial Research, Osaka University

It is indispensable to make heavy ions highly ionized states for them to be effectively accelerated to very high energy. The prevailing method to produce multi-charged ions is that the outer-shell electrons are stripped off the singly ionized atoms or molecules by letting them pass through thin films. Lots of ions, however, are lost with this method and are obtained very little amount of multi-charged ions.

Recently, Multi-charged ion sources of higher current output are expected to be developed in various fields, especially in the field of the heavy ion therapy.

Roughly classifying, there are two kinds of multi-charged ion sources, one is the ECR (electron cyclotron resonance) type described here, and the other is the EB (electron beam) type. In each case the temperature of the plasma electrons are very high, which is useful to produce highly ionized ions.

In the EB type ion source the neutral gases are ionized by an electron beam and the resultant beam-plasma interaction causes the electrostatic waves, with which the plasma electrons are heated to a high temperature; while in the ECR type ion source resonant microwave discharge in the magnetic mirror field brings about high-temperature plasmas.

At present more multi-charged ions are obtained with the EB type, but there remains room for improvement in the ECR type and it is expected that the ECR type becomes superior to the EB type as a multi-charged ion source in future.

In this paper it is estimated by solving the rate equation which parameter should be mainly controlled to obtain more multi-charged ions than singly ionized ones.

In the ECR type ion source as the temperature of the plasma electrons easily becomes very high, the following two ionizing mechanisms are considered to exist. One is the successive ionization, and the other the direct ionization. The former means the outer-shell ionization one by one, and the latter means the inner-shell ionization and the resultant Auger effect, with which the atoms becomes highly stripped at one stroke.
It is necessary that the temperature of the plasma electrons should be high enough for the K-shell ionization to occur.
For example, in case of Xe gases the temperature of the plasma electrons should be much higher over 30 keV, which is comparatively easier to achieve in the ECR plasma. Actually sharp characteristic X-rays near 30 keV due to K-shell ionization of Xe are observed in the present experiment.

As a result of K-shell ionization whether Auger effect to occur or characteristic X-rays to be radiated can be estimated from the fluorescence yield inherent in each element. Accordingly it is reasonable to consider that there is some correlation between the output of characteristic X-rays and charge distributions of the multi-charged ions, and a study about that is now in progress.

In solving the rate equations the followings are assumed. The total number of particles, namely the sum of the number of both neutral particles and ions of each charge state, are kept constant during the two ionizing process described above. The confinement time τ of the ions are assumed to be independent of the charge state, and every ion becomes neutral by recombination at the wall with an average life time of τ. Considering the time scale, both recombination and charge exchange can be neglected in these equations. The calculated results under these assumptions are shown in Figs. 1, 2 and 3. As is clear from the figures, when the product of the electron density n_e by the confinement time τ, that is, $n_e\tau$ is relatively large, the time depending upon n_e can be determined from the figure when the number of multi-charged ions exceed that of singly-charged ones.

Consequently, in order to produce multi-charged ions more and more, there are three parameters to be controlled. The first is to make τ longer by improving the magnetic field configuration, the second is to make n_e higher by applying higher power to the plasma under the lower vacuum circumstances, and the third is to make the pulse duration of the microwave power as long as possible.

In Fig. 4 is shown the experimental apparatus, with which multi-charged ions are produced and extracted in case of the microwave power of both 1.3 kW and 600 W. The experimental results can well be explained by applying the calculated ones.

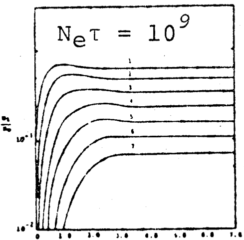

Fig. 1
N_i/N_o vs. $N_e \cdot t$

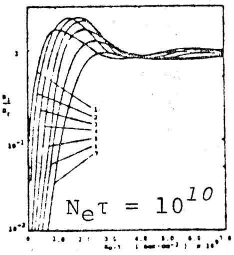

Fig. 2
N_i/N_o vs. $N_e \cdot t$

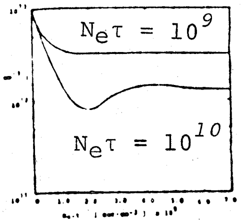

Fig. 3
N_o vs. $N_e \cdot t$

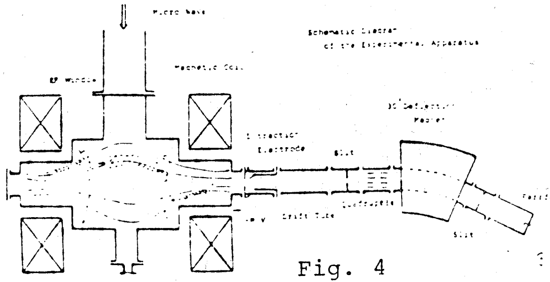

Fig. 4
Experimental Apparatus