Manufacture and Performance of S-Band Compact ECR Ion Sources with Permanent Magnets

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Abstract

Two kinds of new compact ECR ion sources have been developed by use of permanent magnets only, for the purpose of acceleration tests of the INS heavy ion linac. One is a mirror plus sectupole field type and the other is a monocusped one. In this paper structures, magnetic field distributions and extracted beam properties of these sources are described.

I. INTRODUCTION

As for the acceleration test of the INS heavy ion linac, there are following some requirements for the performance of these sources: 1) Usually beams should be extracted with variable pulse mode because these sources are operated synchronously with the linac system. 2) Comparatively low emmittance beams must be extracted from small aperture ($\leq$3 mmϕ) electrode within several multiple charged states. 3) The shape and stability of generated beams should be within the same order of properties of the pulsed microwave power supplied to the RFQ linac. 4) The extracted beam intensity is expected as possible as high so that it is also accelarated in the space charge limited region. 5) The build-up time of ion beams should be short sufficiently in comparison with the pulsed beam width. In order to satisfy these requirements, two types of a new compact source have been developed by use of permanent magnets only: one is mirror plus sectupole field type and the other is monocusped field one.

The former source is constructed by a pair of franges with radially built rectangular magnets for the axial mirror field and by sectupole magnets for the transverse field [1]・[2]. It is suitable for the production of multiplied charge state ions (within several state) and has enough field strength to be operated at a second harmonic mode including the first one. The latter source is designed on basis of the studies by M. Delaunay and R. Geller [3]・[4] and is constructed by a pair of rectangular magnets with same polarity facing to the others [5]. The generated plasma is perfectly confined inside the chamber both on axial and transverse directions by cusped fields. It is adapted for the extraction of single charged state ions, mainly. Further details of these two sources will be described in the folowing sections.

In connection with the conditions 1), 3) and 5), a highly stabilized magnetron oscillator has been also developed.

II. THE MIRROR PLUS SECTUPOLE TYPE SOURCE

A. Structure of the source

The inner dimension of the plasma chamber is set to ϕ 38×72mm^3 on basis of limitations in configuration of the transverse magnetic field and in connection with a microwave guide. In this source, in order to form the axial magnetic mirror, twelve rectangular magnets are placed radially in a pair of specially manufactured "mirror field forming franges" [1]. Because when the axial mirror is formed by ring magnets, it limits the shape and dimension of the extractor electrode very seriously. The axial and transverse field are commonly shielded by a cylindrical return yoke, which is composed of six same pieces. The outlined structure of the source is shown in Fig.1. Two RF windows (3mmt quartz plate) are set at the opposite position in radial direction with axial symmetry in the plasma chamber. Usually the one port is offered for an obserbation of the plasma, or terminated with a short plunger.

B. Magnetic field distribution

In this source, the magnetic field configuration is decided by considering the following points: 1) The maximum field intensity should be exceed 2Becr in order to form the first and second harmonic ECR zones (where Becr=875G is the field value that generates the basic mode ECR at the given microwave frequency =2.45GHz) ; 2) RF windows are set at the position that unstable ECR surfaces cannot be formed ; 3) It is desirable that the axial mirror ratio is variable in an range of 2.0-2.5 by adjusting the position of an auxililiary ring magnet on the axis. A typically measured magnetic field distribution of the source is shown in Fig.1. It is obvious that the desired B-minimum structure is realized.

C. Beam extraction

The first beam was extracted according to the typical magnetic field pattern as was shown in Fig.2. But in a succeeding works on the beam extraction, it turned out that the stable beam was extracted when permanent magnets mounted in the extractor frange were all taken off. At present the stable beam extraction is realized only by use of a fringing field between the plasma electrode and the extractor electrode. Fig.2(a) shows a typical characteristics of extracted Ar beams in the basic mode operation. Total current 270 μA of Ar beams are extracted stably from a 2.5mmϕ aperture of the plasma electrode at 5.5kV (Its current densiy J is 4.3mA /cm^2.) As for the second harmonic mode operation, several states of multiple charged Ar ions are extracted at 20 kV : Ar^{1+} and Ar^{2+} amount to 23～20μA and Ar^{3+}-Ar^{5+} 1.0～0.4μA respectively. Fig.(b) shows such an example of the pulsed shape of beams extracted at 25kV. There is much left to improve about the beam intensity.

III. THE MONOCUSPED TYPE SOURCE

A. Structure of the source

Fig.3 shows the outlined structures of the source. The inner diameter and the axial length of the plasma chamber are limited by the transverse field configuration of rectangular magnets and by the waveguide connected in radial direction, respectively. In order to adjust and optimize the ratio of the magnetic flux distribution in the transverse and the longitudinal direction, the distance between a rectangular magnet and the return yoke cover in the cross section is set to 10-20 mm. The total weight of the source (including the extractor part) is within 6kg. Two RF windows are set at the opposite position in radial direction (same as the mirror+sectupole type).

B. Magnetic field configurations

In the preceding study of ref. [3] · [4] , the longitudinal cusp field is optimized but the transverse one is not considered. In our new source the cusp fields are optimized both in the axial and the transverse directions so that the perfectly closed ECR zones are formed inside the chamber. Furthermore, in order to generate the required three dimensional cusp field, the aspect ratio of each faced surface of two magnets is optimized within the range of 1～ several. The measured result in Fig.2 shows that the transverse field is quadrupole-like.

The position of the RF windows are set so that unstable ECR surfaces are not formed in the plasma chamber. The repulsive magnetic flux is fairly well returned in a relatively narrow space ($\phi 130\times 132mm^3$) by using a cylindrical yoke. As a result, the axial field Bz with the return yoke is increased by ～50% compared to the case of without one.

C. Beam extraction

The extracted beam is measured by a 35mmϕ Faraday cup at about 80cm from the ion source. In this distance three sets of an einzel lens are placed as a tranport system to the linac. By use of this set up, from the 2.5 mmϕ plasma cathode, 990μA of pulsed hydrogen beam (its current density is $J=15.8mA/cm^2$) is stably extracted at 4 kV (shown in Fig. 4). When the degree of vacuum at an extractor side is smaller than 7×10^{-7} [Torr] , the build-up time of hydrogen beam current is within 3 hours and if it is greater than the value the growth of the beam becomes more slowly. But in the case of Ar ion, a constant beam is generated from the beginning and have no problems. Fig.5 shows the hydrogen beam current vs. the injected microwave pulsed power. When the microwave power is increased above ～700W, the H^+ beam tends to decrease slightly. Very stable beams are extracted within widely ranges of the microwave power and a gas flow rate. At present various kinds of ions such as Ne^+, He^+ and C^+ are also extracted.

IV. CONCLUSIONS

Two kinds of new compact ECR ion sources with the B minimum structure has been developed successfully by use of permanent magnets only. In each source, very stable beams are extracted by exception of the unstable ECR zone in the plasma chamber and by use of highly stabilized microwave source with broad range of pulsed power level.

Hereafter the tasks to be done are to increase the beam current in each source and to extract many kinds of ions including metalic one.

Acknowledgements

This work was supported by the inner grant for scientific and engineering research in INS. The authers wish to thank members of the INS-SCRFQ group and the machine shop for their cooperations. Authors also wish to thank the Nihon Kosyuha Co. for making the high quality microwave source.

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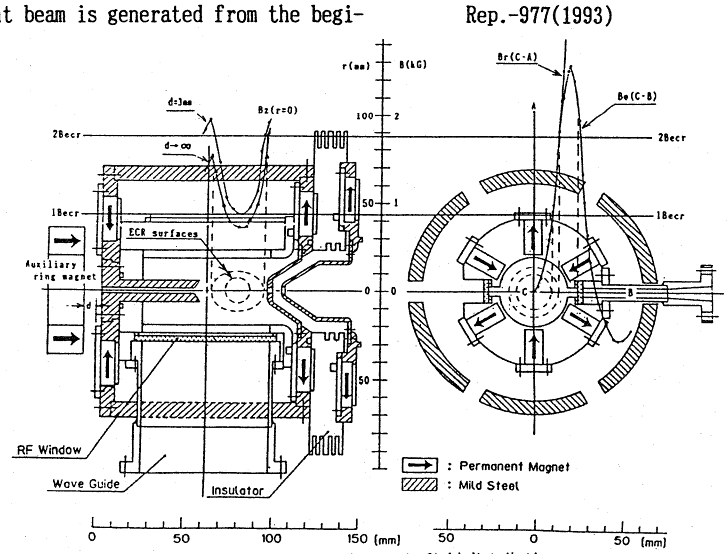
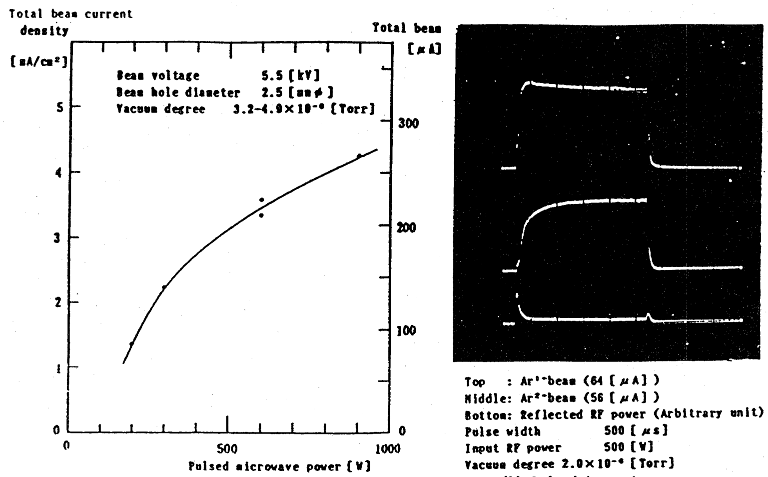


Figure 1. Structure and magnetic field distribution of the mirror+sectupole type ECRIS



(a) Total current density vs. input RF power

(b) Pulsed beam shape

Figure 2. Examples of extracted Ar beam properties (mirror+sectupole type)

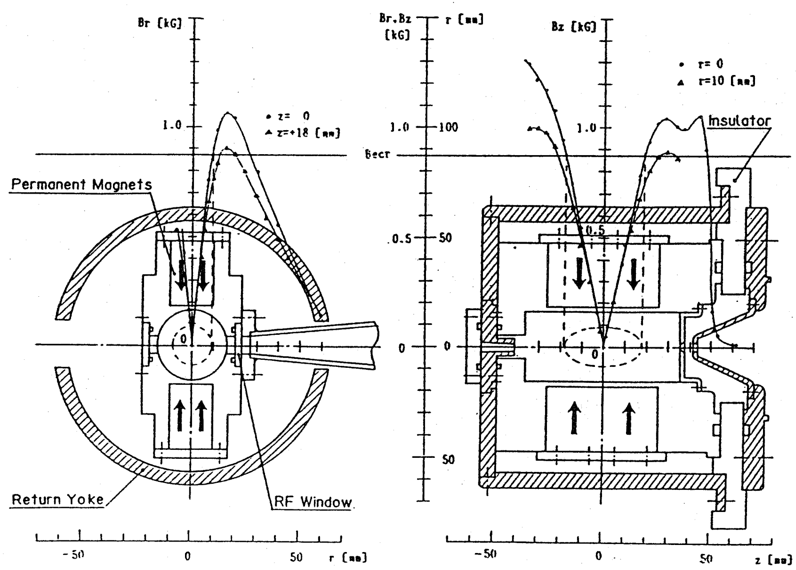


Figure 3. Structure and magnetic field distribution of the monocusp type ECRIS

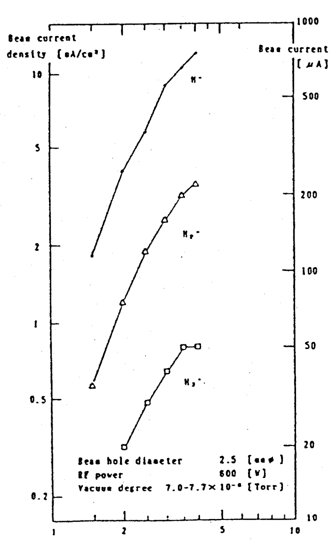


Figure 4. Extracted hydrogen ion beams vs. beam voltage (monocusp type)

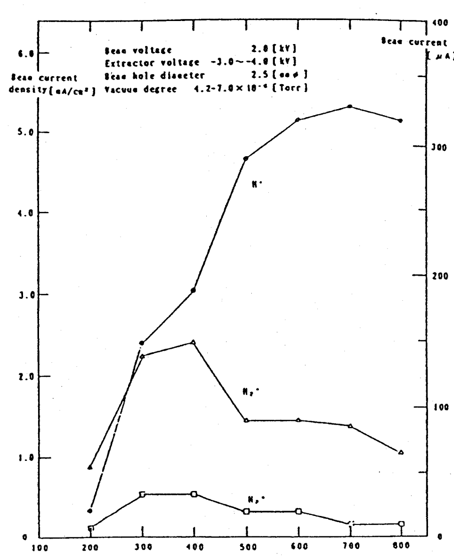


Figure 5. Extracted hydrogen beams vs. RF pulsed power(monocusp type)