DEVELOPMENT OF HIGHER ORDER MODE ECR (HiECR) ION SOURCE
(TEST OF 6GHz OPERATION)

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Abstract

A new ECR (HiECR) ion source for the multiply charged heavy ions has been designed and manufactured to demonstrate operational capabilities of higher order mode ECR (Electron Cyclotron Resonance) discharge. Results of 6GHz first operation are described for CW and pulse operations.

Introduction

The ECR ion source (named HiECR)[1-3] for multiply charged heavy ions has been constructed and tested. The source was manufactured for developing a compact ECR ion source for linear accelerators in cooperation with Institute for Nuclear Study, the National Institute of Radiological Sciences and Sumitomo Heavy Industry, Ltd.

The outer edge of one of the peaks of the mirror field is used as the open ECR zone for the first stage and the hexapole magnet is placed outside the plasma chamber. Since the HiECR has only one mirror field, it is short and compact. This source was designed following the model FERROMAFIOS, CAPRICE and MINIMAFIOS at Grenoble[4-6].

Table 1 Main parameters of the HiECR ion source

Microwave power source	
frequency	6/10/14 GHz
chamber diameter	70 mm
Multipole magnet	
multipolarity	hexapole/quadrupole
field strength on surface	6.4 / 7.6 kG
material	Nd-Fe-B
inner diameter	84 mm
length	15 cm
Mirror coil	
no. of coils	5
max. field on axis	8.5 kG
max. current	600 A
max. power	30 kW
Vacuum pump	520 l/m TMP
Size	
length	0.36 m
width	0.53 m

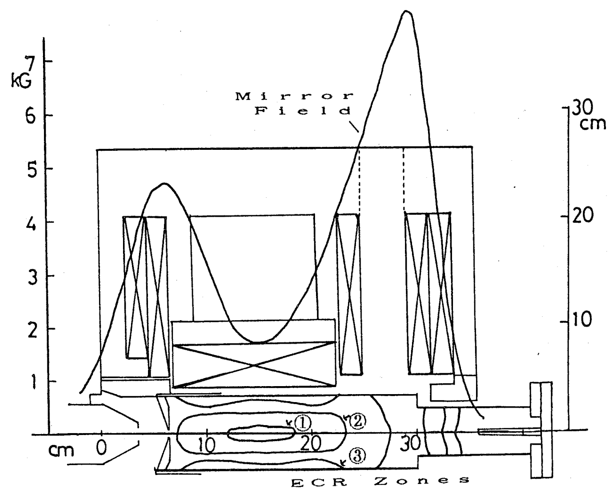

Fig.1 Relationship between the axial field profile and the higher order mode ECR zones

Design

This source has been designed to develop the compact ECR ion source of single stage. The main parameters are shown in table 1. This source has an axial field, produced by five coils, strong enough to satisfy the ECR conditions higher than the fundamental; up to the third order for 6 GHz as shown in Fig.1 and to the second order for 10GHz microwave frequency. The position of five coils are determined by the results of calculation of computer program TRIM. A return yoke of 5cm thickness reduces the power consumption of coils, and shields X-rays from the plasma chamber. The hexapole (quadrupole) field is produced with permanent magnets of Nd-Fe-B (B_{res}=12kG; NEOMAX35H) alloys, which has a field strength of 5.8kG (6.8kG) on the wall of the plasma chamber. The magnetic field distribution of hexapole and quadrupole permanent magnets are shown in fig.2. The discharge chamber is 7cm diameter and 23.5cm long. The power from a microwave transmitter (Varian VZJ2700) with maximum output power of 3.3kW is fed into the second stage radially through quartz window of 3mm thickness.

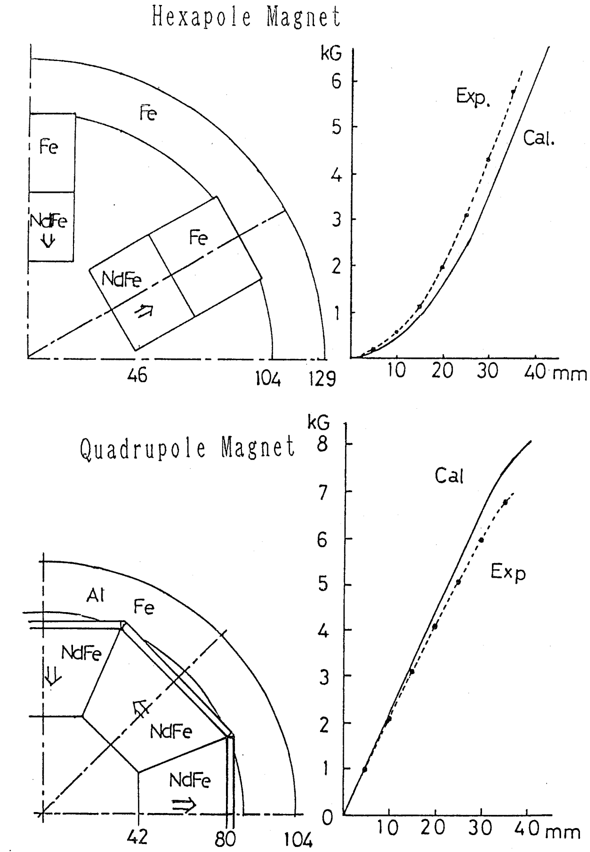

Fig. 2 Hexapole and Quadrupole magnets and their magnetic field distributions

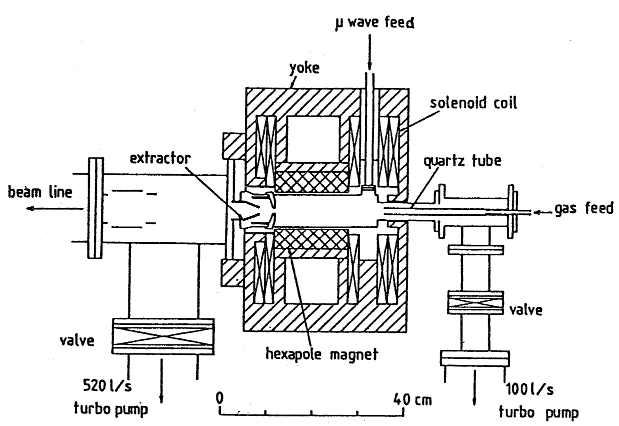

Fig. 3 Drawing of HiECR ion source

Test Stand

The source has been installed at a test bench and the performance has been studied. A bending magnet with a circular pole of diameter 12cm and a pole gap of 5cm has been used with 45deg deflection angle as a charge state analyzer. The object of the analyzer is the extraction hole with a diameter of 7mm. After extracted ions are focused to the image slit by an einzel lens. In order to get enough mass resolution, most data were taken with slit widths of 20mm and 4mm for the image slit.

Table 2 Intensity (e μA) obtained in HiECR ion source

q	H	He	C	N	O	Ne	Ar
1+	800	885	60	105	132	380	157
2+		337	66	196	160	160	144
3+				196	110	84	89
4+			28	140	108	68	63
5+			4.9	79	65	54	61
6+				8.7	31	18	46
7+					2.8	4.4	32
8+						0.24	21
9+							3.9
10+							0.9
11+							0.12

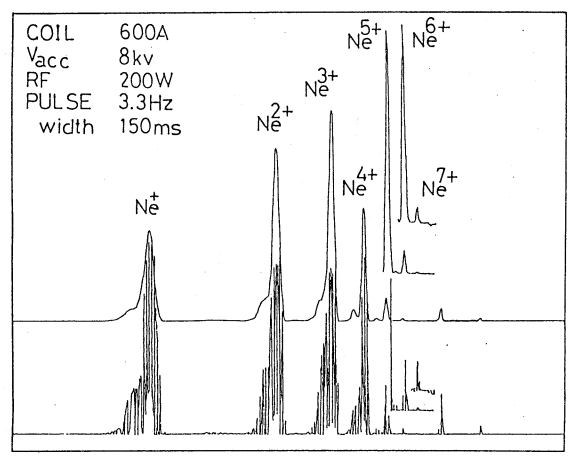

Fig. 4 Charge state spectra of Ne ion in CW and pulse mode operation.

Since the pumping is carried out from both sides of the mirror coils, as shown in fig. 3, the vacuum pressure in the main ECR zone seemed to be worse than 1×10^{-6}Torr and improvement on this point is under way as well as on the other parts.

Experimental Results

After installation at the test bench, performance was studied in CW and pulse mode operations of microwave power. Typical spectra measured with the analyzing system are shown in fig. 4. In this case, tuning is made for Ne^{6+} ions. Upper spectrum is CW mode operation and lower spectrum is pulse mode operation. From this spectra, it is shown that the most probable charge state of Ne ion is 3^+ in CW mode and 1^+ in pulse mode, respectively. The beam intensity of obtained for CW mode without gas mixing is given in table 2 and fig. 5. Typical RF power is 200W and the extraction voltage is 8kV.

Fig. 6 shows Faraday cup signals for various charge state of Ne ion in pulsed microwave operation. The ECR ion source creates higher charged ions not by means of high density of the source plasma, but by means of good ion containment in a step by step ionization process.

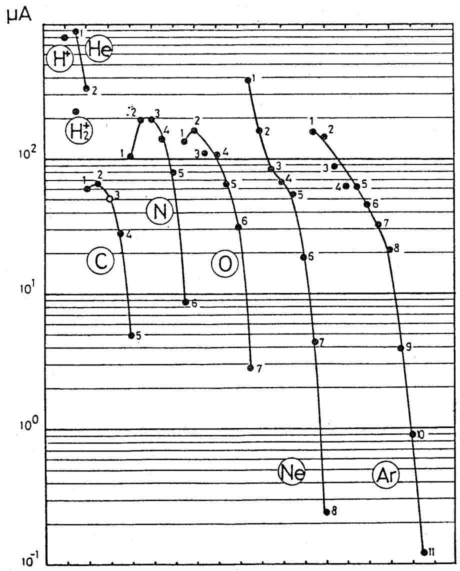

Fig.5 Charge state distribution of various gas elements obtained in HiECR ion source

Thus about 100ms are required to build up the maximum current (=CW operation current) for higher charge states than 4^+ in pulsed operation. Moreover, the decay of higher charge states gives an afterglow (after turn off of the microwave power) output of the lower charged ion Ne^+ as shown in fig.6 [7].

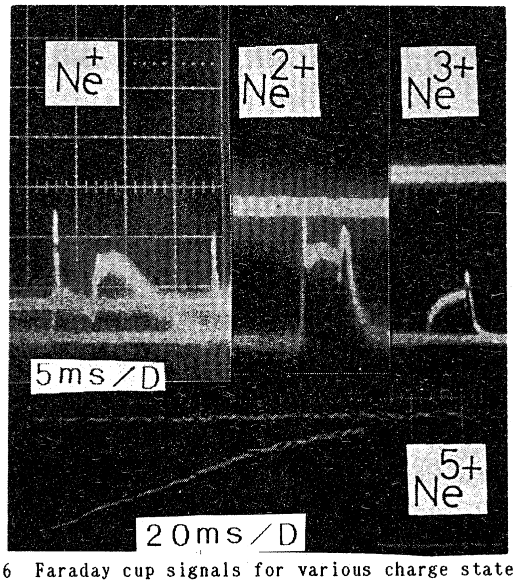

Fig.6 Faraday cup signals for various charge state of Ne ion. Microwave pulse width and repetition period were 5ms(150ms) and 40ms(300ms) for 1^+, 2^+, 3^+ (5^+) of Ne ion

Summary

It is shown that the HiECR ion source is compact and stable in 6GHz microwave operation. According to the scaling rule of Geller[8], the most probable charge state varies as $\log(f^{7/2})$ and the intensity of the ions in the charge state as f^2, where f is the microwave frequency. If this rule is applied, it is natural that the two sources yielded similar results because both use the same microwave power source. In addition, the intensity at 6GHz is roughly one third of that at 10GHz and one fifth of that at 14GHz. Our results presented in this report are not far from the results obtained in other laboratories. We are planing to test with a modified HiECR ion source in 10 and 14GHz microwave operation.

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