DESIGN OF A COMPACT ECR ION SOURCE FOR VARIOUS ION PRODUCTION

M. Muramatsu, A. Kitagawa, T. Fujita, Y. Iwata, S. Sato, S. Hojo,
Y. Sakamoto, K. Katagiri, and A. G. Drentje,
National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage, Chiba 263-8555, Japan

Abstract

Carbon ion therapy facilities need not only carbon ions for medical use but also other ions for research. Ion source is required: 1) H to Fe ion production, 2) enough intensity of various ions for medical use and research, and 3) low cost. Our previous compact ECR ion sources (Kei series) are optimized for carbon ion production. In order to produce various ion beams, we design a new compact ECR ion source, named Kei3, based on previous Kei series. Manufacturing of the Kei3 will be finished in end of this year.

INTRODUCTION

Carbon ion radiotherapy is started in 1994 by the Heavy Ion Medical Accelerator in Chiba (HIMAC) at the National Institute of Radiological Sciences (NIRS). The total number of patients reached to 6,500 and various types of tumor have been treated. NIRS carried out R&D studies for various components and designed a hospital-specified carbon ion radiotherapy facility [1]. The construction of the Gunma University Heavy Ion Medical Centre (GHMC [2]) was funded by the Japanese government and Gunma prefecture beginning in 2006, and construction started in 2007 at the Centre site in Maebashi, Gunma. The technologies concerned were transferred from NIRS to Gunma University. Gunma University already started a clinical trial since March 2010.

Compact ECR ion source with all permanent magnets, named Kei2, was developed for high energy carbon ion therapy facility at NIRS. Kei2 source was designed for producing enough intensity of carbon ion for medical treatment. A compact ECR ion source for GHMC, the KeiGM, is also based on the development of the compact ECR ion sources (Kei series) at NIRS [3]. These ECRISs are developed for production of C^{4+} ions for medical treatment. Table 1 shows beam intensity of H_3^+, $^{11}B^{4+}$, $^{12}C^{4+}$, $^{16}O^{6+}$, $^{40}Ar^{11+}$, and $^{56}Fe^{13+}$ ions by prototype Kei2 source at 30 kV extractions. Ion source parameters (microwave power and frequency, gas flow, biased disk voltage and position) were tuned for each ion. In the case of bigger q/A than 1/3, beam intensity was reached requirement value. However, in the case of smaller q/A than 1/3 and molecule ions, sufficient intensity was not obtained. Kei series were designed for production of C^{4+} ions. Therefore, it is difficult to produce enough intensity of heavier ions and molecule ions.

Some carbon ion radiotherapy facilities need to use H to Ne ion beam for biological experiment like irradiation of mouse, Ar and Fe beam for irradiation of cells and physical experiment. In order to produce various ion beams, we design a new compact ECR ion source, named Kei3. Kei3 is designed based on previous Kei series. Target ion species are molecule hydrogen to iron. Charge to mass ratio of ion is up to 1/3, because, we don't want to change the injector linac. Therefore, ion source has to produce H_3^+ to Fe^{19+} ions.

Table 1: Beam Intensity of Various Ions at Kei2

Ion	Required intensity [eμA]	Kei2 intensity [eμA]	Material
H_3^+	500	270	H_2 gas
$^{11}B^{4+}$	100	120	$C_2H_{12}B_{10}$
$^{12}C^{4+}$	200	680	CH_4 gas
$^{16}O^{6+}$	100	60	O_2 gas
$^{40}Ar^{11+}$		2.5	Ar + O_2 gas
$^{56}Fe^{13+}$		0.5	Metal iron +He gas

DESIGN OF THE KEI3

There are five important points for improvement from Kei2: 1) Same magnetic field and microwave system will be used for easy maintenance and the cost effectiveness, 2) Improve the vacuum in the plasma chamber and extraction region for production of heavier ion and increase the extraction voltage, 3) Movable beam extraction system for various extraction current densities, 4) Biased disk method and double frequency heating method for heavier ions, and 5) An evaporator and MIVOC method for production of ion from solid materials and metal. Figure 1 shows schematic drawing of Kei3 source. The Kei3 has an outer diameter of 280 mm and a length of 1120 mm. Kei3 consists of injection side vacuum chamber, permanent magnets and plasma chamber, and extraction side vacuum chamber with extraction system. The magnetic field was copied from Kei2 [4]. Magnetic field of upstream mirror peak, downstream peak and minimumB are 0.877 T, 0.579 T and 0.26 T, respectively. Based on experimental studies with a conventional 10 GHz ECR source [5] at HIMAC, the field distribution of the mirror magnet for compact source was designed so that a charge distribution of carbon ions was optimized at 4+. Radial magnetic field by hexapole magnet on the plasma chamber wall is 0.757 T.

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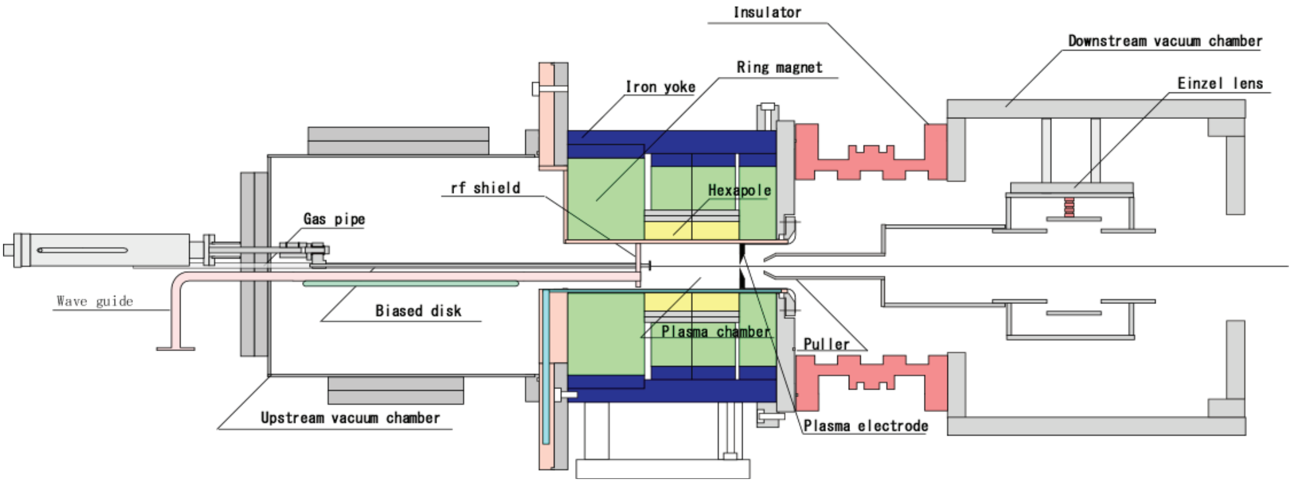

Figure 1: Schematic drawing of Kei3 source.

A microwave source with the traveling-wave-tube (TWT) was adopted, with a frequency range and maximum power of 9.75 - 10.25 GHz and 750 W, respectively. Microwave power is fed into the plasma chamber through a rectangular wave guide from the axial direction. The plasma chamber is made of copper for a good cooling efficiency, in order to avoid a decrease in the magnetic field due to high temperature. The plasma chamber has an inner diameter of 50 mm. Inner diameter of the insulator is larger than the Kei series for improve the vacuum for production of heavier ion and higher voltage extraction. Movable extraction system is used for various extraction current densities. We can change the distance between puller and plasma electrode 0 to 50 mm.

Figure 2 shows the Kei3 with high voltage platform. Extraction voltage is applied to high voltage platform with ion source, microwave system, vacuum pump, gas bottle, and control system. 300 l/sec and 500 l/sec Turbo-Molecule-Pumps (TMP) connect to the injection side and extraction side of the vacuum chamber, respectively.

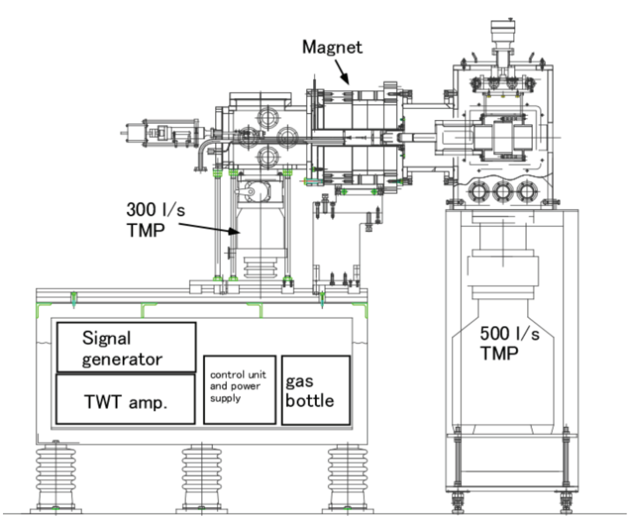

Figure 2: Kei3 with high voltage platform.

In order to obtain enough heavier ion intensity, we will use three methods: 1) biased disk method, 2) gas mixing method, and 3) two frequency heating method. Biased disk was already used Kei series. It is effective for production of highly charged ion (HCI). Gas mixing method is also useful method for production of HCIs. Moreover, we want to test double frequency heating method. Some groups already test this method. We expect that this method is also useful for production of HCI production. On the other hand, an evaporator and MIVOC method are used for production of ion from solid materials and metal.

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