DESIGN OF COMPACT ECR ION SOURCE FOR C^{5+} PRODUCTION

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Abstract

The Heavy Ion Medical Accelerator in Chiba (HIMAC) was constructed as the first medical dedicated heavy ion accelerator facility at National Institute of Radiological Sciences (NIRS). Over 10000 cancer patients have been treated with 140-430 MeV/u carbon beams since 1994. Compact ECR ion source with all permanent magnets, named Kei2, was developed for production of C^{4+} ions for medical treatment at NIRS. A compact ECR ion source for Gunma University (Gunma University Heavy Ion Medical Center: GHMC), Saga carbon-ion radiotherapy (Saga Heavy Ion Medical Accelerator in Tosu: SAGA HIMAT) and Kanagawa carbon-ion radiotherapy (Ion-beam Radiation Oncology Center in Kanagawa: i-ROCK) facility has been operated for medical use. It is a copy of the Kei2 which was developed by NIRS.

In order to reduce operation cost of the injector for next designed carbon ion facility, we start design of new compact ECR ion source for C^{5+} production. Some dependence (mirror field, microwave power and frequency) were checked for optimal parameter of C^{5+} production at 18 GHz NIRS-HEC.

INTRODUCTION

Four ion sources have been operated in HIMAC for medical treatment, physics and biological experiments at NIRS. Two ECR ion sources with normal conducting mirror coils, named 10 GHz NIRS-ECR [1] and 18 GHz NIRS-HEC [2], produce carbon ion for treatment and heavier ions (i.e. Ar, Fe, Xe) for experiment. Compact ECR ion source with all permanent magnet, named Kei2 [3], was installed to HIMAC with prototype injector [4] for backup of existing injector. Cold cathode type of PIG source, named, NIRS-PIG, produces ions of hydrogen, helium and neon from gases. Boron and aluminium ions are also produce by spattering method at NIRS-PIG.

There are five carbon ion radiotherapy facilities in Japan and two are under construction. If we can reduce the size and the operating cost of a facility, the spread of carbon ion radiotherapy is expected. Compact ECR ion sources (Kei series) at Gunma University, Saga carbon-ion radiotherapy and Kanagawa carbon-ion radiotherapy facility have been operated for medical use. Those are copies of the Kei2 which was developed by NIRS. Mirror magnetic field of the Kei series is optimized for production of C^{4+} under the experiment of 10 GHz NIRS-ECR. It is possible to reduce of the size of injector Linac when an ion source produces carbon 5+ or 6+ for a next facility. However, it is difficult to separate C^{6+} from other ions such as nitrogen and oxygen. Therefore, we design a new compact ECR ion source with all permanent magnets to produce C^{5+} ions with an output current of 300 eμA. The other requirements are similar as the Kei series.

TRIAL EXPERIMENTS

NIRS-HEC has produced C^{5+} with 500 eμA. So the size of the magnets and their arrangement of the new ion source were determined in such a way that both the maximum peak and B minimum values of the mirror field would become close to those of the NIRS-HEC. For design of the magnetic field, beam test was done for production of the C^{5+} at NIRS-HEC. NIRS-HEC are usually operated with two microwave amplifiers, 18 GHz klystron power amplifier and 17.10 – 18.55 GHz Traveling-Wave-Tube (TWT) amplifier. Output power of these amplifier are 1400 W and 1200 W, respectively. However, we plan that the frequency of the new ion source is around 14 GHz because high magnetic field is difficult to produce by using permanent magnets. Therefore we used other TWT amplifier for this trial experiment. Microwave frequency and output power are 10 – 18 GHz and 300 W, respectively.

In this experiment, some dependences (mirror field, microwave power and frequency) were checked for optimal parameter of C^{5+} production.

Production of Carbon Ion with CH_4 and CO_2

Usually, CH_4 gas is used at Kei series in carbon-ion medical facility. At first, we compared between CH_4 and CO_2 gas for production of C^{5+}. Figure 1 and 2 show charge state distribution (CSD) of carbon with CH_4 and CO_2 gases, respectively. Operation parameters were optimized for C^{5+}. Extraction voltage was 30 kV. In the case of CH_4, there was little oxygen peak from residual water. Beam intensity of C^{5+} was 160 eμA. in the case of CO_2, beam intensity of C^{5+} was only 36 eμA. CSD of CH_4 was better than CO_2.

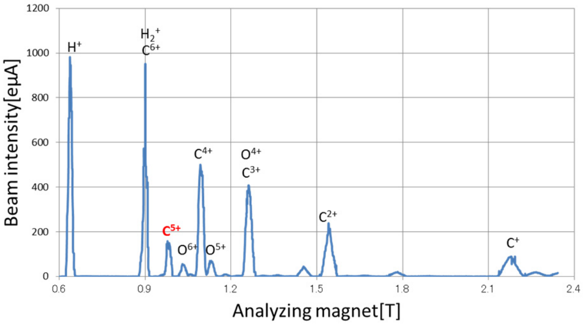

Figure 1: Charge state distribution under the CH_4 gas.

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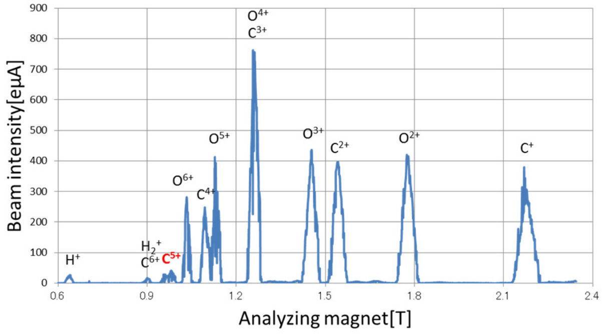

Figure 2: Charge state distribution under the CO_2 gas.

Dependence of Mirror Field

Figure 3 and 4 show dependence of mirror magnetic field for C^{5+} with CH_4 and CO_2 gases. Operation parameters except coil current were optimized for production of C^{5+}. Microwave frequency and power were 14.6 GHz and 300 W. Extraction voltage was 30 kV.

Maximum beam intensity of C^{5+} was obtained under the upstream mirror coil current of 840 A and downstream 500 A with CH_4 gas. Beam current of C^{5+} was 160 eμA. In the case of CO_2, coil currents of 840 A and 530 A were good for C^{5+} production. However, beam intensity of C^{5+} was lower than the case of CH_4. Higher coil current of upstream coil was better for the production of C^{5+}. Otherwise, for downstream coil current, around 500 A was best.

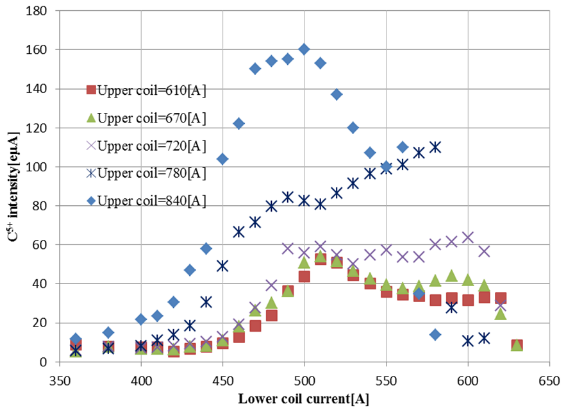

Figure 3: Mirror magnetic field dependence under CH_4 gas.

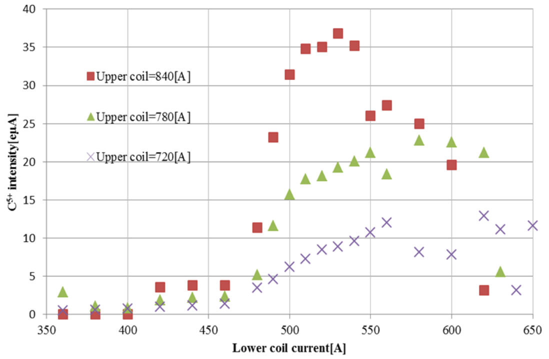

Figure 4: Mirror magnetic field dependence under CO_2 gas.

Microwave Frequency Dependence

Figure 5 shows microwave frequency dependence at C^{5+} under the upstream coil current of 610, 670, 720, 780 and 840 A. From this result, characteristics of frequency dependence at all case of coil current were similar, however, beam intensity changed dramatically at high coil current. Maximum beam intensity of C^{5+} was over 200 eμA at frequency of 14.45 GHz. But other beam tests use frequency of 14.60 GHz, because beam stability is better than 14.45 GHz. It is evident that the fine tuning of frequency is necessary for the operation of the new ion source.

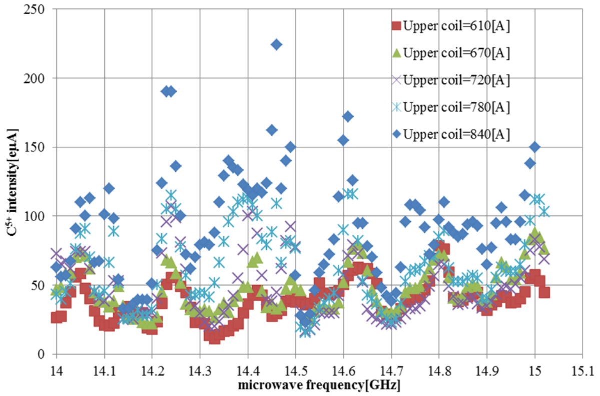

Figure 5: Microwave frequency dependence.

Microwave Power Dependence

Figure 6 shows microwave power dependence for C^{5+} under the upstream coil current of 610, 780 and 840 A. Maximum beam intensity of C^{5+} was obtained when microwave power becomes the highest at each coil current. In this experiment, it is evident that the present microwave power was not enough for production of C^{5+}. In order to increase the C^{5+} intensity, we estimate that a high power microwave amplifier with 500 W is necessary, at least.

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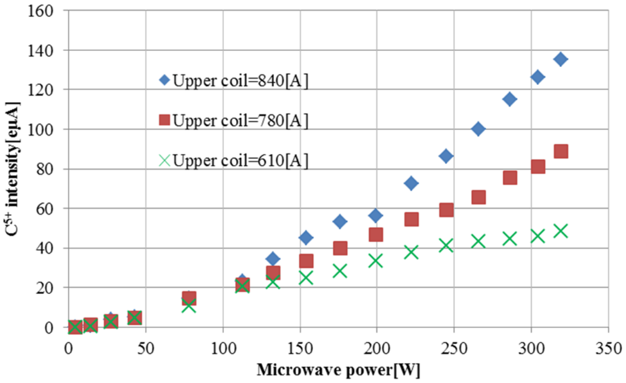

Figure 6: Microwave frequency dependence.

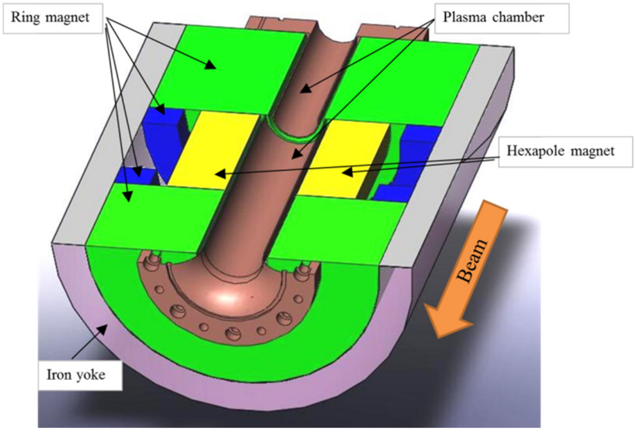

Figure 7: Schematic drawing of permanent magnets and plasma chamber.

CONCLUSION FOR THE NEXT STEP

Some dependences (mirror field, microwave power and frequency) were checked for the design of the new compact ECR ion source at NIRS-HEC with the 14 GHz operation. From the present result, we guess that 1) necessary coil currents of upstream and downstream mirror coil for production of C^{5+} were around 840 and 500 A, 2) CH_4 gas was better than CO_2 gas for the production of C^{5+}, 3) microwave power of over 500 W will be necessary.

We verified that the above necessary magnetic field distribution was able to be realized by permanent magnets from the calculation by POISSON/SUPERFISH code [4]. Figure 7 shows a typical schematic drawing of the permanent magnets. Four ring magnets produce mirror magnetic field. A hexapole magnet produces radial confinement field.

In order to fix the design structure of permanent magnets, we plan the next trial at NIRS-HEC with higher power 14 GHz operation since September 2016. We will check more detailed dependences of an extraction voltage, a distance between puller and plasma electrode, other and so on. We also have tried to use other ionisation gasses. It seems that C_4H_{10} is promising and we would like to test the long-term operation.

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