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PRESENT STATUS OF HIMAC ECR ION SOURCES

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Abstract

High-energy carbon-ion radiotherapy is being carried out at Heavy Ion Medical Accelerator in Chiba (HIMAC). Over 12000 cancer patients have been treated with carbon beams having energies of between 56-430 MeV/u since 1994. There are two injectors in the HIMAC for medical and experimental use. First injector consists of two ECR ion sources and one PIG ion source, the RFQ linac and the DTL. Usually, this injector suppling the carbon ion for cancer therapy and various ion such as H, He, Fe, Xe are accelerated for biological and physical experiment. The 10 GHz NIRS-ECR ion source produce the carbon ion for cancer therapy. The 18 GHz NIRS-HEC ion source produce He to Xe ions for experimental use. Second injector consists of the compact ECR ion source with all permanent magnet, the RFQ linac and the APF IH-DTL. This injector supplies the carbon ion for experimental use. Additionally, we tried production of the Indium and the Tin ions by using the $In(C_5H_5)$ and the $Sn(i\text{-}C_3H_7)_4$ at the NIRS-HEC. Beam current of the $^{115}In^{20+}$ and $^{120}Sn^{18+}$ were 90 and 15 μA, respectively.

INTRODUCTION

The National Institute of Radiological Sciences (NIRS) was founded by the Japanese Government in 1957 as a core research institute concerning the interactions between radiation and human beings. The National Institutes for Quantum and Radiological Science and Technology (QST) was established in April 2016 to combine NIRS and several institutes that were previously under the Japan Atomic Energy Agency (JAEA). The main aims of QST-NIRS are comprehensive research and development on: (1) the effects of radiation on the human body; (2) protection from radiation, including diagnosis and treatment of radiation injuries; and (3) medical applications of radiation.

Four ion sources produce various ions for medical use, biological and physical experiment in the Heavy Ion Medical Accelerator in Chiba (HIMAC) [1] at the NIRS. The multi-ion irradiation with dose distribution and Liner Energy Transfer (LET) optimization is being studied at NIRS [2, 3]. Helium, carbon, oxygen and neon ions are considered as ion species for multi-ion irradiation. When we use more than one ion sources, it is possible to switch different ion species easily. However, we considered the switching method with only one ion source. Ionization gases were helium, CO_2 and neon to produce He^{2+}, C^{2+}, O^{3+} and Ne^{4+} ions. Present status of ion sources in 2019 and development of gas switching system for multi-ion irradiation and production of Indium and Tin ion production at the 18 GHz NIRS-HEC ion source [4] are described in this paper.

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OPERATION OF THE HIMAC ION SOURCES IN 2019

The project to develop the world's first medical dedicated heavy-ion synchrotron was started in 1984 as the HIMAC. Since HIMAC was fully developed by NIRS as an accelerator complex. HIMAC has four different types of ion sources, a penning ion source, named NIRS-PIG [5] a 10 GHz electron cyclotron resonance ion source, named NIRS-ECR, an 18 GHz electron cyclotron resonance ion source, named NIRS-HEC, and a 10 GHz permanent magnet electron cyclotron resonance ion source, named Kei2 [6]. The HIMAC ion sources were produced various ion beam for medical and experimental use. Figure 1 shows ratio of operation time and ion species in 2019. Carbon ion is the most utilized the various ion species. The carbon bean from NIRS-ECR was used for medical use. Beam from Kei2 was used for biological experiments. Total number of the patient in 2019 was 876.

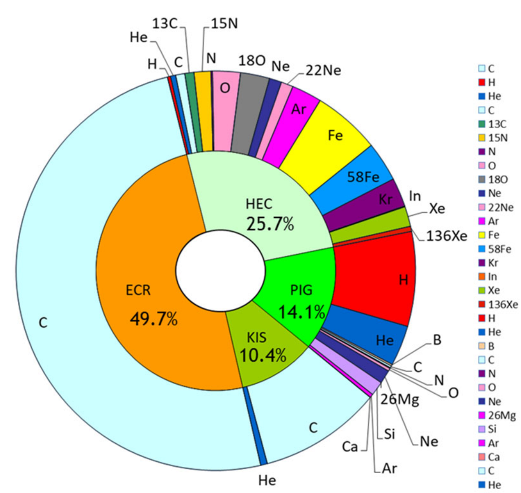

Figure 1: Ratio of operation time and ion species in 2019. ECR: 10 GHz NIRS-ECR, HEC: 18 GHz NIRS-HEC, PIG: NIRS-PIG, KIS: Kei2-source

Figure 2 shows the operation time of various ion species in 2019. Total operation time of ion sources were 9787.16 hours in fiscal year 2019. Operation time of the carbon was higher than other ion species. Operation times of NIRS-ECR and Kei2 sources for carbon ion production were 4865.3 and 969.5 h. Boron and silicon ions were produced by NIRS-PIG with spattering method. We can operate the PIG source during 1 week without maintenance. Iron, krypton and xenon were produce by HEC. Operation

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time of Fe, Kr and Xe were 533, 228 and 158 h, respectively. Ions of isotope such as 13C, 15N, 18O and 58Fe were also produced at 18 GHz NIRS-HEC ion source.

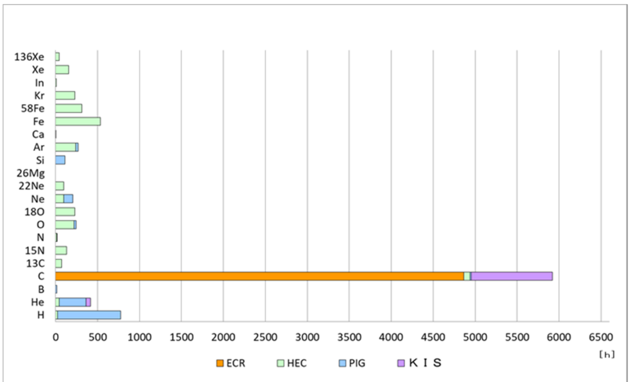

Figure 2: Operation time of various ion species in 2019. ECR: 10 GHz NIRS-ECR, HEC: 18 GHz NIRS-HEC, PIG: NIRS-PIG, KIS: Kei2-source

DEVELOPMENT OF NIRS-HEC

Gas Switching System for Multi-Ion Irradiation

In previous tests, switching time of the ion species using existing gas system could be shortened by using a solenoid valve [7]. Helium, CO_2 and neon gases were used for production of He^{2+}, C^{2+}, O^{3+} and Ne^{4+} ions. A new gas switching system for multi-ion irradiation was manufactured and an ion species switching test was conducted in this time. Figure 3 shows photograph of gas switching system at NIRS-HEC. The high speed solenoid valve (Parker, Series 9) and controller (Parker, Iota One) were used for CO_2, Helium and Neon gases line.

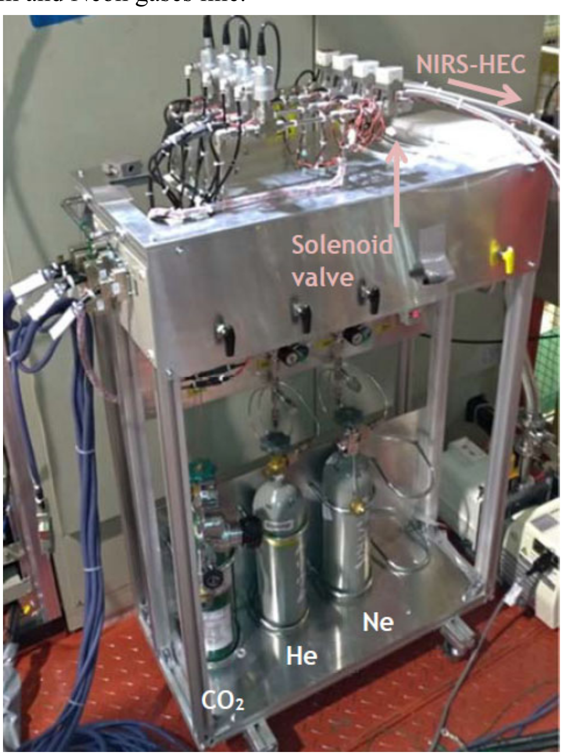

Figure 3: Photograph of gas switching system.

First, the gas was pulsed and the gas exhaust time was measured. Figure 4 shows exhaust time of CO_2. It took 11 seconds for the degree of vacuum in the upstream vacuum box to drop below 1E-5Pa after the gas supply was stopped. In the case of helium and neon, it took 5 and 7 seconds, respectively. Table 1 shows condition of solenoid valve.

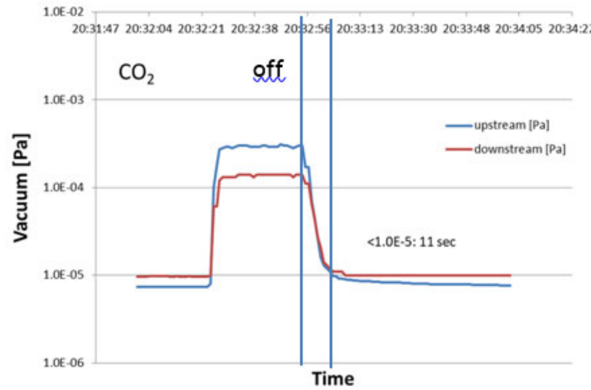

Figure 4: Exhaust time of CO_2. Blue line is vacuum pressure in upstream chamber. Red line is vacuum pressure in downstream chamber.

Table 1: Condition of Solenoid Valve

Gas	Pulse width [msec]	Repetition frequency [Hz]	Pressure [MPa]	Time to 1E-5Pa [sec]
He	0.12	1.2	0.00	5
CO2	0.3	1.2	-0.05	11
Ne	0.25	1.2	0.00	7

Next, an ion beam switching test was performed. As in the previous experiment, we try to produce He^{2+}, C^{2+}, O^{3+} and Ne^{4+} ions by using helium, CO_2 and neon gases with new gas switching system.

Figure 5 shows beam switching time from He^{2+} to Ne^{4+}. In the previous gas system, it took 20 seconds for the beam to stabilize, but in the new system it took 7 seconds. When switching from CO2, where gas exhaust was slow, the beam is stabilized at 35 seconds at the time of switching to Ne^{4+}. (Fig. 6)

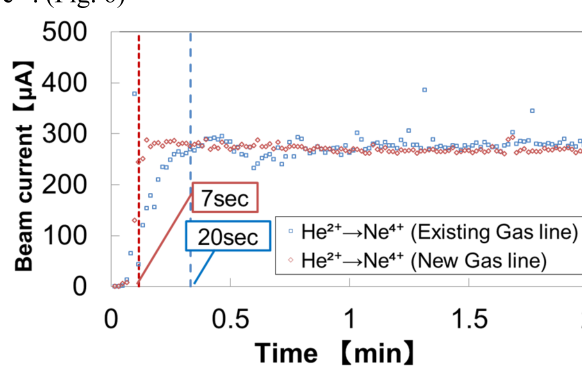

Figure 5: Beam switching time from He^{2+} to Ne^{4+}.

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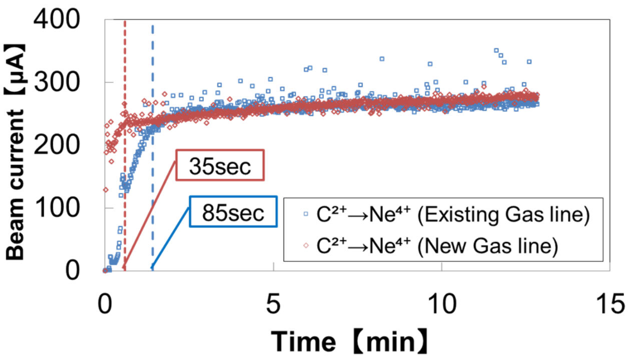
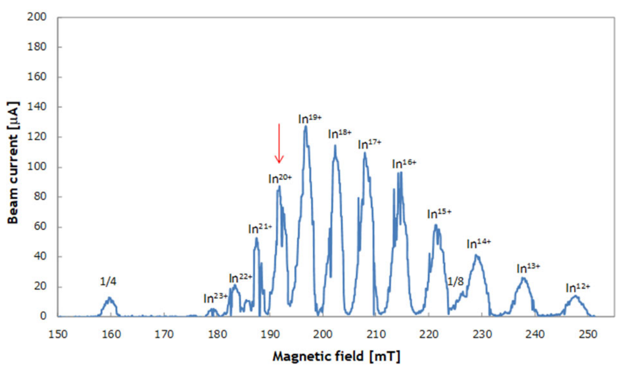


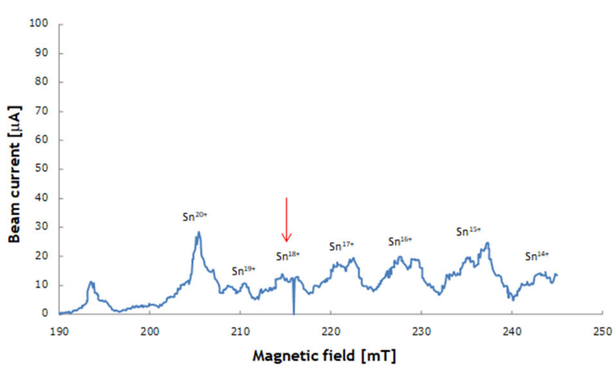
Figure 6: Beam switching time from C^{2+} to Ne^{4+}.

Indium and Tin Ion Production

Production of Indium and Tin ion were tested using $In(C_5H_5)$ and $Sn(i\text{-}C_3H_7)_4$ at NIRS-HEC. A beam test was performed by cooling the container using a Peltier device, because, the vapor pressure at room temperature is high [8]. Figure 7 shows charge state distributions of Indium (a) and Tin (b). The operating parameters of the ion source have been optimized for In^{20+} and Sn^{18+}. The temperatures of the Indium and Tin containers were 6.2 and 9.2 degrees, respectively. The beam currents for In^{20+} and Sn^{18+} were 90 and 15μA, respectively. The extraction voltages at this time were 31 and 32 kV, respectively. In the case of tin, $^{120}Sn^{18+}$ could not be separated due to the presence of isotopes.



(a)



(b)

Figure 7: Charge state distributions of Indium (a) and Tin (b) ions.

CONCLUSION

Total operation time of ion sources were 9787.16 hours without big problem in fiscal year 2019. Operation time of the carbon was higher than other ion species. We made new gas switching system for the multi-ion irradiation at 18 GHz NIRS-HEC. We obtain result of switching time of less than 35 sec using solenoid valve. Indium and Tin ions were produced by using $In(C_5H_5)$ and $Sn(i\text{-}C_3H_7)_4$at NIRS-HEC. The beam currents for In^{20+} and Sn^{18+} were 90 and 15μA, respectively.

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