DEVELOPMENT OF ECR ION SOURCE FOR THE HIMAC MEDICAL ACCELERATOR

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Abstract

The development of the ECR ion source for the HIMAC injector is reported. The HIMAC facility has two types of the ion source, one is the PIG ion source and the other is the ECR ion source. The ECR ion source is especially expected long lifetime, easy operation, and easy maintenance for the medical use. Now, the system of the ion source is under construction. However, the tests of fundamental performances have been started. In the present tests, the output electrical currents of Ions are 1300 eμA of He^{1+}, 210 eμA of Ne^{3+}, and 100 eμA of Ar^{6+}. And the good stability of the extracted beam is acquired. These performances satisfied the requirements for the radiotherapy.

Introduction

Now, the Heavy Ion Medical Accelerator in Chiba (HIMAC) is under construction at National Institute of Radiological Sciences (NIRS). The details of the HIMAC have been already reported.[1,2] The RFQ linac is the first accelerator in this accelerator complex. The beam extracted from the ion source is accelerated and injected in it through the low energy beam transport line. The energy of the beam is 8 keV/u. To accelerate, the ion sources are set on the high voltage platform, the maximum voltage is 60 kV. Therefore, the ion source must produce ions with a charge to mass ratio larger than 1/7. And it is desirable that the ion source itself is compact.

Moreover, for the use as the medical accelerator, the ion source is required some conditions as follows: high intensity, good stability, easy operation, long lifetime, and easy maintenance. In order to satisfy these requirements, two ion sources are adopted in the HIMAC project. One is a PIG ion source and the other is an ECR ion source. The PIG ion source is expected the high intensities in the region of lower charge state.[3] The ECR ion source is especially expected the long lifetime and the easy maintenance. The requirements of the beam intensity for radiotherapy are shown as Table 1.

Table 1
Requirements for the Beam Intensity

Ion species	He	Ne	Ar
Charge state	1+	3+	6+
Source			
Output current (μAe)	630	140	340
Injector			
Transport efficiency		0.5	
Stripper efficiency	1.0	0.67	0.18
Low Energy Beam Transport			
Transport efficiency		0.75	
Syncrotron			
Injected current (μAe)	340	120	69
Injected intensity (pps)	1.1×10^{15}	7.8×10^{13}	2.4×10^{13}
Extracted intensity (pps)	1.2×10^{10}	8.5×10^{8}	2.7×10^{8}
Dose rate (Gy/min)		5	

Ion Source Setup

The schematic view of the ion source is shown in Fig. 1. The structure is similar to the CAPRICE source at Grenoble and the Hi-ECR at TIT.[4,5] The microwave frequency is 10 GHz, too. The ion source has two ionization stage. The first stage is an open ECR zone, and the second stage is a closed ECR zone by the mirror field. The ECR zones are shown in the figure with dotted lines.

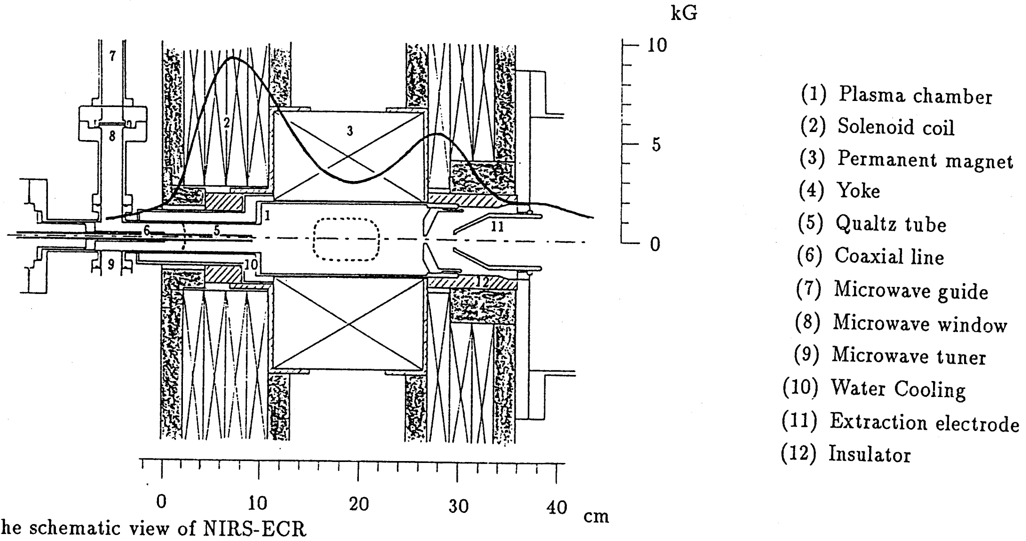

Fig. 1: The schematic view of NIRS-ECR

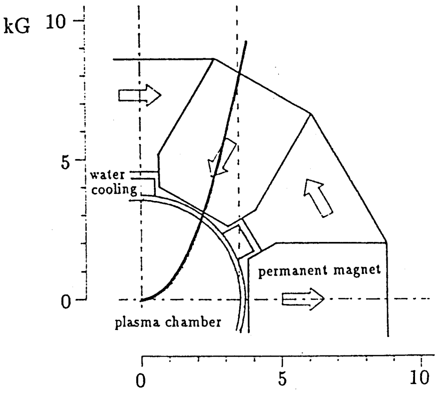

Fig. 2: Sextupole Magnet & Radial Magnetic Field

The magnetic structure of the source consists of two solenoid coils, a set of permanent magnets and the Fe return yokes. Two solenoid coils with return yokes generate an axial magnetic field, the maximum field is 9.3 kG on the axis. Twelve permanent magnets are assembled densely to make a loop, put in the Fe cylinder.(see Fig.2) This permanent magnet set gives the radial sextupole field, the maximum field is 8.0 kG on the wall of the chamber. Both of fields are shown in bold lines.

The plasma chamber consists of a cylindrical room and a pipe. The room is a diameter of 70 mm and a length of 160 mm. The pipe is a diameter of 28 mm. A quartz tube covered a sus pipe is installed on the center of the axis to make the coaxial line for the microwave and to transport the gas. The whole chamber is cooled by water. To prevent from reduction of the sextupole field, the water pipes are separated into six parts and set between poles of the permanent magnet. The chamber is inserted from the one side of the mirror magnet yoke, and can be removed easily for the maintenance.

The ionized gases are supplied at two inlets. One is the edge of the cylindrical room, and the other comes through the quartz tube. Each gaseous flux is controllable independently, so that the vacuum pressures at the first and the second stages are optimized independently. For the accurate control of the gaseous flux, the piezoelectric valve with the feedback from the flux meter is used.

In order to extract ions, the plasma chamber is kept on high voltage of 25 kV at maximum. Besides, the whole system including the magnet power supply and the microwave power supply is isolated from the ground. Therefore, the extraction voltage can be adjusted independently from the acceleration voltage required by the linac.

The principal specification is shown in Table 2.

Table 2
Specification of NIRS ECR

Dimensions		
Yoke outer length	358	mm
Solenoid outer diameter	650	mm
Sextupole inner diameter	76	mm
Plasma chamber inner diameter	70	mm
Quartz tube inner diameter	6	mm
Magnetic Field		
Maximum axial field on axis	9.3	kG
Sextupole field on chamber wall	8.7	kG
Mirror ratio	1.5	
Maximum solenoid current	600	A
Length of second ECR zone	70	mm
Diameter of second ECR zone	40	mm
Distance between first and second zone	110	mm
Microwave		
Frequency	10	GHz
Maximum power	1.8	kW
Beam extraction		
Maximum extraction voltage	25	kV

Control System

All operation of the ion source is under the computer control. Each operation is controllable from the operator console. These operations include the controls about the mirror magnetic field, microwave power, gas flux, extraction voltage, acceleration voltage, beam focussing, the monitors of the beam current and beam emittance, and the handling of the vacuum pump and gas exchange. All devices have universal device controllers (UDC), these are a microcomputer system, and link to the central minicomputer system. These operations can be synchronized with the pulse operation of the linac or synchrotron.

The ECRIS control system itself is a part of the central control system for the accelerator. Its overview and details have been already described.[6]

Performance

In the present time, the performances of several gaseous ions were investigated. For the measurement of yields of ions, the beam transport system was setup at Institute for Nuclear Study, University of Tokyo (INS), and the tests were also obtained at INS. The ion beams were focused by an einzel lens and analyzed by the 90° bending magnet. The transport efficiency of the analyzing system was more than 90 % in the case of H^+. A typical mass spectrum is shown in Fig.3.

Examples of the yields of ions are shown in Fig.4. The charge states indicated as closed circles can be accelerated by the HIMAC. As regards the charge state distribution, the lower charge state's yields are large, and the higher ones are small, compairing with the other ECR ion sources with the same structure. These results may come from poor vacuum pressure for multiple charged ions and can be improved by the simple modification in a vacuum system.

The stability of the ion beam mainly depends on the gaseous flux and the power of micro wave. This source has feedback loops only in each device and no feedback from the ion beam. However, the good stability was kept in the region of the ion species shown in Fig 3. The typical gaseous flux was about 5×10^{-4} torr·ℓ/s, so that the vacuum pressure was 1×10^{-6} torr at the second ECR zone. The typical power of microwave was about 500 W. And the extraction voltage was 20 kV. The power of microwave was too large. It seems that the power loss of microwave at the conversion from the wave guide to the coaxial line is the principal cause.

By the way, the yield was very sensitive to the structure of beam extraction. The change of position of extraction electrode or anode gave large reduction of the beam intensity, it was about 50 %. This reduction couldn't be explained by the simple calculation of beam transport with the leakage magnetic field caused by the mirror field. The design of beam extraction needs more detailed analysis about the plasma near the extraction hole.

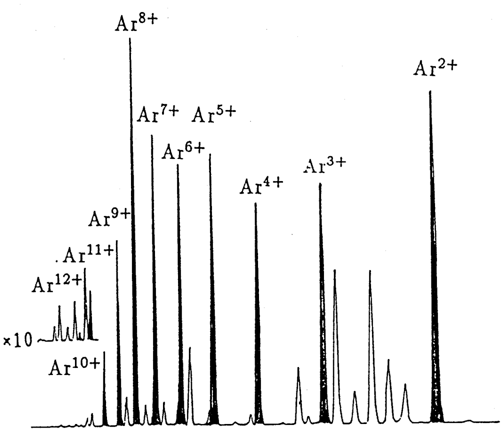

Fig. 3: Typical Mass Spectrum
Ar^{9+} ion was optimized. The vacuum pressure was about 1×10^{-6} torr at the second ECR zone. The input power of microwave was about 700 W.

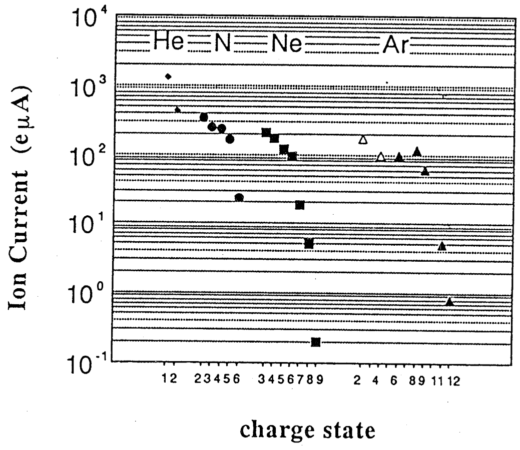

Fig. 4: Performance of Typical Ions
The extraction voltage was 20 kV. The closed marks can be accelerated by the HIMAC (charge mass ratio is over 1/7).

Conclusion

The other parts of the ion source system is now under construction. However, the fundamental performances, as the intensities of ions or the beam stability, are almost satisfied the requirements for the medical machine. The improvement of the carge state distribution for the multiple charged ions are now in progress. The investigation of the extraction structure have been continued, and the results give more information to compare with more detailed culculation. On the other hands, the tests for the pulse mode operation and any other improvement have just started.

The ECR ion source will be mounted in the building until the spring of 1992.

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