DEVELOPMENT OF A PERMANENT MAGNET MICROWAVE ION SOURCE FOR MEDICAL ACCELERATORS

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Abstract

A permanent magnet microwave ion source was developed to use in proton accelerator application systems. The source is based on solenoid coil microwave ion source technologies. Because it uses a permanent magnet, the ion source needs no coils, no coil power and no coil coolant, which leads to better reliability and fewer parts to maintain. The hydrogen beam of over 60 mA has been extracted from a single 5mm diameter aperture with a proton fraction of 85% at a microwave power of 1.3kW. Rise times of the microwave power and beam current to 90 % of the final value were about 20 and 100 µs respectively at a pulse operation mode with 400 µs pulse width and 20 Hz repetition rate. These performance parameters are equal to the solenoid coil ion source parameters, making the ion source applicable for accelerator uses like proton therapy systems.

INTRODUCTION

Various versions of the microwave ion source have been developed at Hitachi since around 1980. The microwave ion source has been used in many applications including the injection of high-current proton beams into linacs. Linacs are used for proton accelerator systems. The proton accelerator has been developed for such applications as proton beam cancer therapy, neutron generation by atomic reaction at a proton beam target, and RI production systems, etc. We have developed a permanent magnet microwave ion source to reduce the cost and to increase the reliability for the accelerator application systems. Recently, we have studied microwave ion sources for industrial applications. Tokiguchi and Seki [1] have worked on oxygen microwave ion sources to fabricate SOI wafers. We have also worked on development of high-current low-emittance bucket type ion sources for nuclear fusion devices and accelerators [2,3].

Tanaka [4] started to develop a proton microwave ion source based on the above technologies to improve performance of the proton linac application systems like medical accelerators applied to cancer therapy. Although Wills et al. [5] had already developed permanent magnet microwave ion source, they used auxiliary coils for matching microwave impedance. High beam current generation without auxiliary coils was not investigated in detail. We especially worked on production of hydrogen ion beams without auxiliary coils. A short pulse width (several hundred µs) and high beam current (several dozen mA) were achieved for pulse operation accelerator systems. In this paper, we outline the developed permanent magnet microwave ion source and describe experimental results on pulse hydrogen ion beam generation.

PERMANENT MAGNET DESIGN

The main body is made from small size permanent magnet pieces in order to minimize the cost. The principal components of the permanent magnet are neodymium and iron. We analysed the magnetic field along the z axis of the cylindrical discharge chamber. The magnetic field analysis results are shown in Figure 1. The discharge chamber area is found up to z=5(cm). Our version of the microwave ion source used solenoid coils. The solenoid coil magnetic field is also shown in Figure 1 for comparison. We design the permanent magnet main body structure so that the magnetic field distribution generated by the permanent magnet can emulate the magnetic field distribution generated by the solenoid coils. The magnetic field distribution can be tuned by varying the gap length which is between the downstream side permanent magnet block and the upstream side permanent magnet block. The permanent magnet block shape is the letter L so that the magnetic field distribution of the discharge chamber is flat. We design the gap length of permanent magnet blocks so that the magnetic field of the chamber center exceeds about 875 G which is the ECR magnetic field.

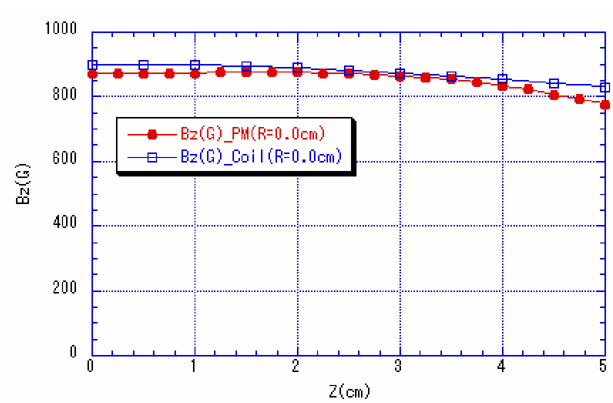

Figure 1: Magnetic field analysis results

AN OUTLINE OF ION SOURCE

The permanent magnet microwave ion source is shown schematically in Figure 2. The permanent magnet is installed around the discharge chamber. The permanent magnet block is divided by the gap spacer. The magnetic field distribution is adjusted by the gap space to couple the generated microwave with the plasma which was produced in the discharge chamber. Microwave generated by a magnetron are led to the cylindrical discharge chamber through a wave guide and rectangular-circular mode converter. The microwave frequency is 2.45 GHz. The ion beam extraction system uses three grids, plasma grid (PG), deceleration grid (DG) and grounded grid (GG). Deceleration voltage (-2kV) is applied to the DG in order to suppress back streaming of electrons from the beam plasma generated downstream of the grids.

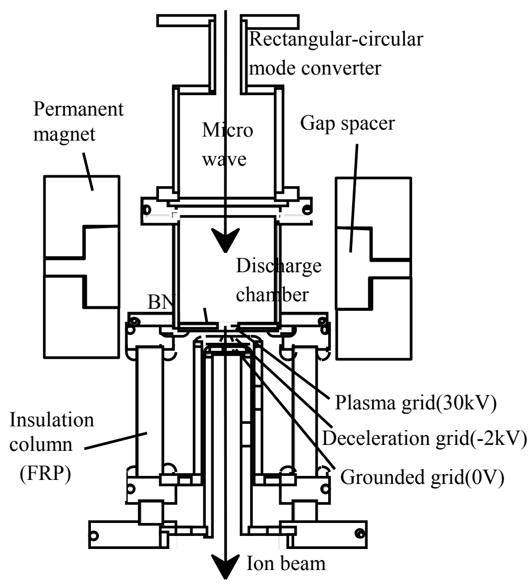

Figure 2: Schematic of the permanent magnet microwave ion source

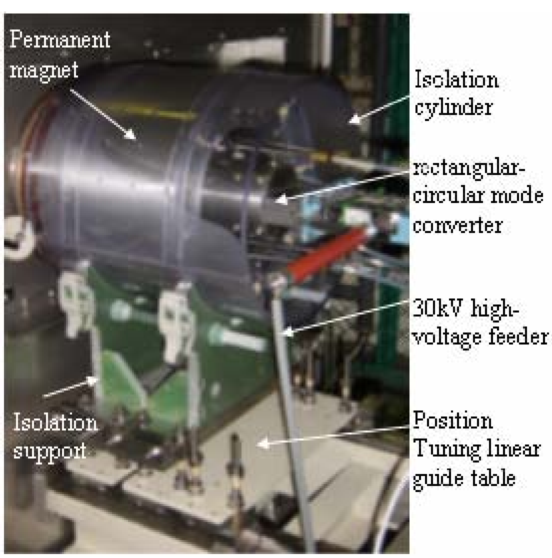

Figure 3: Photograph of the permanent magnet microwave ion source

The extraction aperture is 5 mm in diameter. Hydrogen ion beams are accelerated by 30kV between the PG and GG. The extraction aperture structure of the grids and gaps between grids are designed using beam trajectory simulation so that they reduce beam divergence and emittance using beam trajectory simulation. Total extracted ion beam current is measured with a Faraday cup located at 130 mm downstream from GG. Mass spectra of the extracted ion beams are measured with a magnetic mass separator and a Faraday cup. A photograph of the permanent magnet microwave ion source is shown in Figure 3.

EXPERIMETAL RESULTS

The beam current is adjusted by sliding the position of permanent magnet along the z axis. The dependence of pulsed beam current on displacement of permanent magnet is measured as shown in Figure 4.

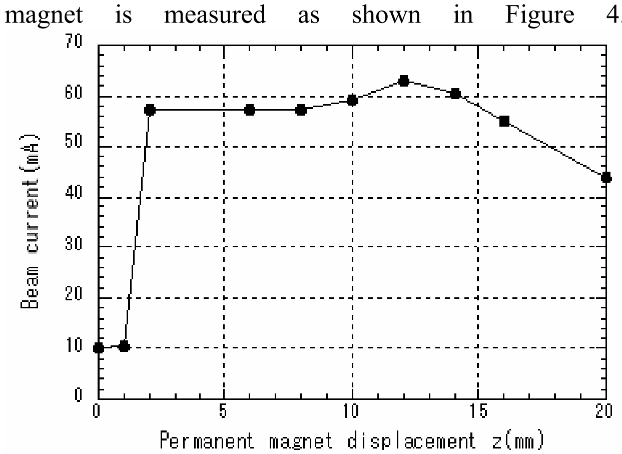

Figure 4: Dependence of beam current on displacement of permanent magnet

Pulse width is 400 µs, repetition rate is 20 Hz and microwave power is 1300 W. When the displacement is smaller than 1mm, the beam current is too small. However, when the displacement is larger than 2mm, the beam current increases drastically. The beam current is above 50 mA and reaches 63 mA at z=12 mm. This beam current is almost equal to that produced by the solenoid coil microwave ion source version.

The mass spectral fragments are listed in Table 1. The proton fraction is 85% and that is enough to inject into a proton linac. Impurities are very low level in the hydrogen plasma.

Table 1: Mass spectral fragments of the extracted ion beams

Ion	H+	H_2+	H_3+	N+	Other
Fraction	85 %	10.3 %	2.7 %	0.45%	1.55%

Spatial distribution of the extracted ion beam is measured on 130 mm downstream from the GG by using a slit and a Faraday cup and it is shown in Figure 5. The profiles are well fitted by a Gaussian curve. The 90% beam diameter is around 9.6 mm for the permanent magnet. The beam diameter is smaller than that of solenoid coil case.

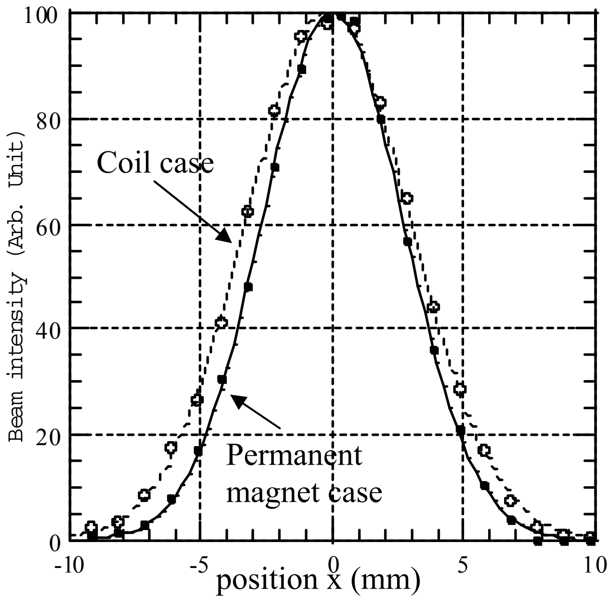

Figure 5: Spatial distribution of the extracted ion beam

The waveforms of the beam current and rf power with 400 µs pulse width and 20 Hz repetition rate are shown in Figure 6. It is preferable to shorten rise time of the pulsed beam current for injecting the beam into pulse operation accelerators. Typical output beam pulse width of linacs for proton therapy synchrotrons is 50 µs and injection beam pulse width for the linacs is several hundred µs. Rise times of the rf power and the beam current to 90 % of the final value are 20 and 100 µs respectively. Beam pulse after the 200 µs rise time can be appropriately used for the pulsed beam acceleration of the linacs.

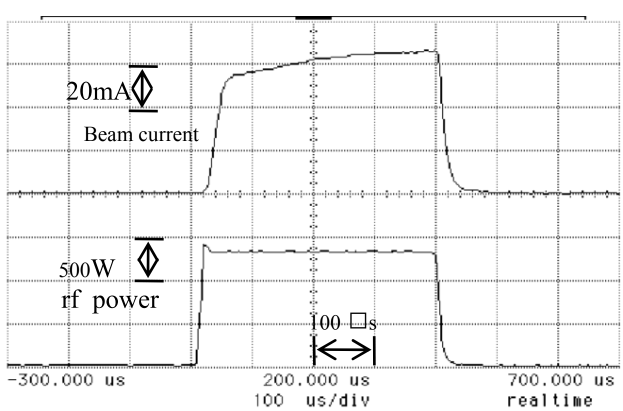

Figure 6: Pulse waveforms of beam current and rf power

SUMMARY

We developed a permanent magnet microwave ion source to use in proton accelerator application systems. The source was based on solenoid coil microwave ion source technologies. The ion source needs no coils, no coil power and no coil coolant, which leads to better reliability and fewer parts to be maintained.

The hydrogen beam of over 60 mA was been extracted from a single 5mm diameter aperture with a proton fraction of 85% at a microwave power of 1.3kW. Spatial distribution of the extracted ion beam was measured 130 mm downstream from the grounded grid. The 90% beam diameter was around 9.6 mm. The beam diameter for the permanent magnet was smaller than that of solenoid coil case.

REFERENCES

[1] K. Tokiguchi, T. Seki, et al., Rev. Sci. Instrum., 71 (2000) 952.
[2] M. Tanaka, et al., IEEE Trans. Plasma Sci. 25(1997)1412.
[3] M. Tanaka, et al., Proc. of 2000 Meeting of the Atomic Energy Society of Japan, Aomori, Japan, 2000, p.171(in Japanese)
[4] M. Tanaka, et al., Rev. Sci. Instrum., 75 (2004) 1894.
[5] J. S. C. Wills, et al., Rev. Sci. Instrum., 69 (1998) 65.