Low Power Test of IHQ Linac for Heavy Ion Irradiation

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Abstract

At Tokyo Institute of Technology (TIT), An Interdigital-H type Quadrupole (IHQ) linac has been constructed for application of high energy heavy ion implantation. The linac can accelerate the particles with charge to mass ratio grater than 1/16 from 0.48 MeV up to 1.6 MeV (for $^{16}O^{+}$). As a result of the low power test, the resonant frequency is 36.26 MHz and the shunt impedance is 252 MΩ/m. Therefor, required power to accelerate $^{16}O^{+}$ ion is 39.5 kW.

1. Introduction

High energy heavy ion implantation has been expected to produce semiconductor devices. In a case of heavy ion implantation (for example P, As, etc.), the linear accelerators take place of conventional electrostatic accelerators because of a high current acceleration with strong focusing action. Especially, Radio Frequency Quadrupole (RFQ) linac has been developed and adopted for ion implantation [1,2]. RFQ linac has the best performance as low-energy accelerators for high current[3]. However, it has disadvantage concerning a low acceleration rate, and its complicated vane structure causes to be an expensive machine.

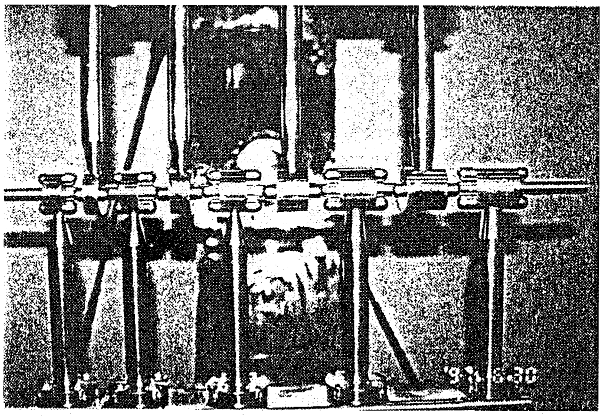

Fig. 1 Photograph of drift tubes in IHQ linac

We have proposed IHQ linac for industrial application. An IH structure has the high shunt impedance and high acceleration ratio[4-7]. Generally, at the drift tube in the linac, the accelerated particles are focused by magnetic quadrupole field generated by the electric or permanent magnet fitted in the drift tube. However, they have high production costs to make the drift tube with focusing elements. Increase in the cost of linac is serious problem for practical use. Therefore, we choose to use the drift tube with fingertips. The fingertip makes quadrupole field between the drift tubes to focus the particles. It is easy to produce the drift tube with fingertip at little expense. Fig. 1 shows the photograph of drift tubes in the IHQ cavity.

From a result of beam dynamics calculation, this electrode geometry was effective to beam focusing and it was possible to accelerate the particles sufficiently. On June 1997, a full scale IHQ linac was installed at TIT. The design parameters of an IHQ linac are shown in Table 1. In this paper, the results of low power tests of IHQ linac are presented.

Table 1. Design Parameters of the IHQ Linac

Input energy	15	[keV/u]
Output energy	100	[keV/u]
Cavity inner diameter	200	[cm]
Cavity inner length	104	[cm]
Gap length	20, 28	[mm]
Total number of cells	10	
Total cell length	52.84	[cm]
Drift tube inner diameter	14	[mm]
Fingertip diameter	14	[mm]
Operating frequency	30	[MHz]
Synchronous Phase	-90, -30	[deg.]
Maxmum Gap Voltage	214	[keV]
Charge to mass ratio	≥ 1/16	

2. Resonant frequency and gap voltage distribution

An rf measurement for the IHQ linac was performed. The measured resonant frequency was 36.26

MHz. This increase of resonant frequency to the designed value is caused by decrease of tank volume. To endure the vacuum pressure, the tank lid (input and output part of cavity) was changed from the flat plate to the spherical shape. Therefore, the resonant frequency was increased. To accelerate the particles correctly, an input power into the tank should be adjusted.

A measurement of the distribution for the gap voltage was performed by using the perturbation methods. A cylindrical acrylic rod that fills a whole gap was used as a perturbator. Fig. 2 shows the gap voltage distribution of the half scale model and the practical tank. Already the model test had been performed. The result of the model test was that the resonant frequency was higher than the design parameter. Therefore, the cavity diameter was changed to fit the resonant frequency[4]. In order to investigate the effect of changing the diameter on the gap voltage distribution, it was compared with the gap voltage distribution for the model tank and the real tank. The gap voltage distribution of the real tank is quite similar to the model tank. In conclusion, there is scarcely any influence owing to change of the tank diameter.

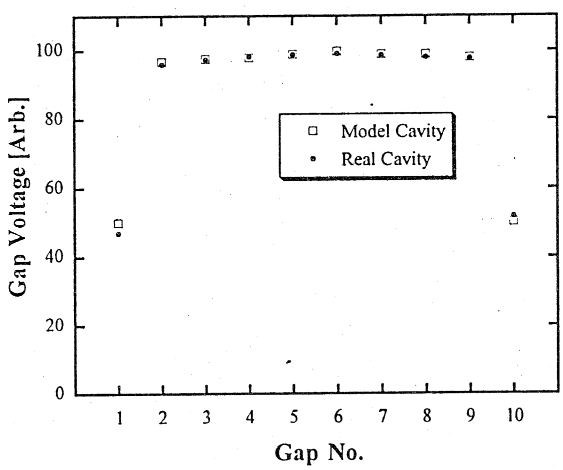

Fig. 2 Gap voltage distribution

3. Shunt impedance and Power Consumption

We measured the field distribution by using the well-known bead perturbation method to estimate the shunt impedance. Block diagram of measurement system is shown in Fig. 3.

Fig. 4 shows the electric field distribution in the IHQ linac. In this measurement, a frequency difference from the resonant frequency is measured as phase difference $\Delta\alpha$. The bead (Aluminum: radius is 1.013 mm) attached on the nylon thread (diameter is 0.07 mm) is moved at the constant velocity by using stepping mortar. Phase difference is measured with vector volt meter, and its signal is recorded on the pen recorder as a function of position.

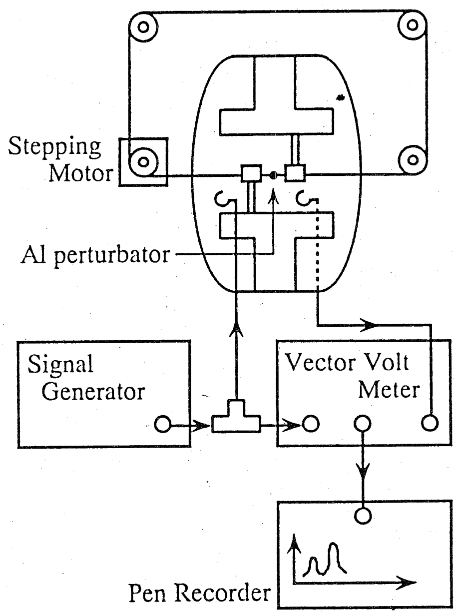

Fig. 3 Block diagram of measurement system of bead purtabation method

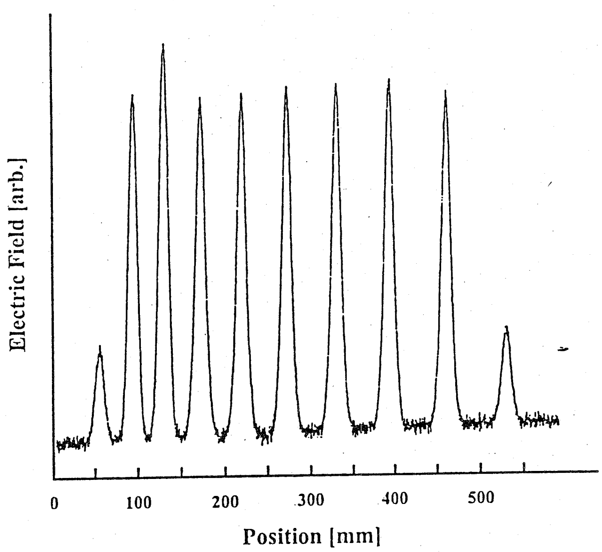

Fig. 4 Electric field distribution measured by bead pull methods

Shunt impedance Z_s is calculated as follows

$$Z_s = \frac{1}{2\pi r \varepsilon_0 \omega L_t} \int_0^{L_t} \sqrt{\Delta\alpha}\, dz \ , \qquad (1)$$

where

Z_s : Shunt Impedance

r : Bead Radius
ε : permittivity of vacuum
ω : Angular Resonant Frequency
L_t : Cavity Length
$\Delta\alpha$: phase difference
z : Position of bead (longitudinal).

From Fig. 4, it is possible to obtain $\int_0^{L_t}\sqrt{\Delta\alpha}\,dz$ and to calculate the shunt impedance. The IHQ linac length is 1.04 m (inside the cavity). The length is included the sections where the electric quadrupole lenses are mounted. Consequently, the shunt impedance and the required power for acceleration (of $^{16}O^{+}$) were calculated by using of the total cell length (0.5284 m) instead of cavity length L_t. Table 2 shows the shunt impedance and power consumption estimated from field distribution.

Table 2 Shunt impedance and power consumption

Z_S [MΩ/m]	Power [kW]
252	39.5*

* It is the value that the increase of resonant frequency is considered

4. Conclusion

The IHQ linac for application of high energy heavy ion implantation has been constructed. The following results were obtained from the low power test.

- The gap voltage distribution of the real tank is very similar to the result of the model test. Therefore it is possible to accelerate the particles without modification of the real tank and the drift tubes.
- The resonant frequency is 36.26 MHz
- Shunt impedance is estimated at 252 MΩ/m
- Power Consumption is 39.5 kW (for $^{16}O^{+}$)

These results are sufficiently satisfied as a practical machine. An Electron Cyclotron Resonance (ECR) ion source has been developed almost simultaneously at our laboratory[8]. This ECR ion source can make the many kinds of multi-charged ion. It is expected to combine with the ECR ion source. With that ECR ion source, this IHQ linac is useful for not only heavy ion implantation but also various field applications.

After the low power test, it will be started the vacuum and the ion source test soon. Then, high power pulse test will be performed and first acceleration with $^{4}He^{+}$ ion will plan on September 1997.

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