PROGRESS OF RFQ FOR ION IMPLANTATION AT PEKING UNIVERSITY*

C.E. Chen, J.X. Fang, J.X. Yu, Y.R. Lu, W.G. Li, J.F. Guo, M.L. Yu,
Z.Y. Wang, Z.F. Zhang, Y. Wu, H.L. Zhang D.S. Li, O.J. Pan,
Institute of Heavy Ion Physics, Peking University
H. Klein, A. Schempp, H. Deitinghoff
Institute for Applied Physics, J. W. Goethe-University

Abstract

On the basis of the successful running of a 26 MHz Integral Split Ring RFQ as an Ion Implanting machine at Peking University, and the simultaneous acceleration of 300 keV O^+ and O^- ions, a 1 MeV RFQ for implanting N and O ions has been completed. The RFQ tank is 2.6 m in length and 75 cm in diameter. The mini-vane electrodes are of two-dimensional cutting with cooling water channels. The ion beam reached 1 MeV at a peak RF power of 25 kW with a duty factor of 1/6. The beam transport efficiency for both O^+ and O^- ions reached more than 83%. The performance and parameters of the RFQ are presented in the paper. The simultaneous implantation of both positive and negative ions at deliberate ratios is to be further studied.

1 INTRODUCTION

The radio frequency quadrupole (RFQ) proposed by Kapchinsky and Teplyakov [1] in 1970 has been developed intensively due to its outstanding features. With the increasing interest in ion implantation for material modification and microelectronics, a number of heavy ions RFQs have been developed. However, heavy ions RFQs are much preferable to operate at low frequency so as to reach high beam current. Based on the studies of the integral split ring (ISR) type resonator [2], two ISR RFQ accelerators have been developed. It turns out that this type of RFQ suits well for heavy ion acceleration as it has high RF efficiency at low operating frequency with good stability [3,4]. A 26 MHz prototype RFQ for 300 keV N^+ ions (ISR RFQ-300) was first designed and constructed. The main parameters are listed at Table 1, and the structure is shown in Fig.1. The RFQ was tested to full power successfully both without and with N^+, O^+, and O^- beams [5-7]. In order to enhance the total number of ions accelerated in one RF cycle, and to compensate at least partially the space charge both in the process of injection as well as on the target, a new test bench capable of accelerating both positive and negative ions in one RFQ was constructed (Fig.2) [8]. The feasibility study of accelerating simultaneously both positive and negative ions was then carried out. The result is quite encouraging. It turns out that both the positive and negative half period of a RF cycle can be used to accelerate corresponding sign of ions at the same time. The interactions between the positive and negative ion bunches can be negligible if the micro peak current is in the order of mA.

Table 1: Main Parameters of ISR RFQs

Type	ISR RFQ--300	ISR RFQ--1000
Ions	N^+, O^+, O^-	N^+, O^+, O^-
F_0[MHz]	26	26
W_{in}[keV]	20	22
W_f[keV]	300	1000
I_{av}[µA]	38.4*	~100*
I_p[mA]	~1*	5
L[cm]	90	250
D_{out}[cm]	50	70
V_0[kV]	75	70
Duty Factor	16.7%	16.7%

* Measured figure, limited by input beam current

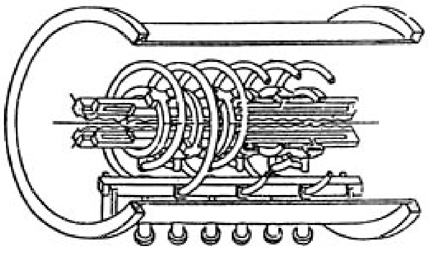

Figure 1: The structure of the ISR RFQ-300

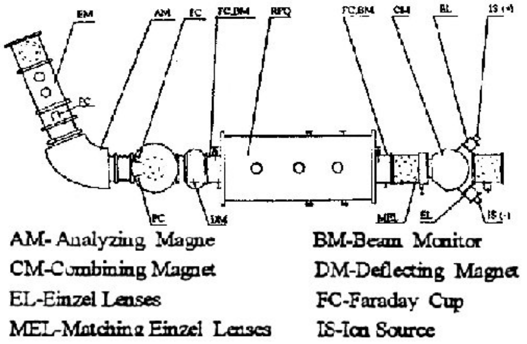

Figure 2: The schematic layout for the beam test

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[*] Work supported by NSFC

The micro-pulses of both the beams are shown in Fig.3, in comparing with the RF sine waves. Based on the experience of the ISR RFQ-300, a 26 MHz RFQ for 1 MeV O^+ and O^- ions (ISR RFQ-1000) has been constructed and tested successfully with full RF power and ion beam acceleration.

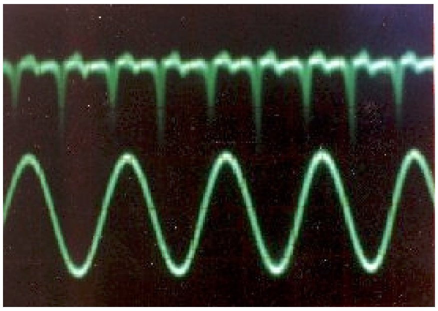

Figure 3: Micro-pulses of positive & negative ions

2 ISR RFQ-1000 RESONATOR

Considering the obvious advantages of both high beam current and higher energy, a 26 MHz ISR RFQ-1000 has been constructed as an ion implantor of 1 MeV O^+ and O^- ions. The dynamics design [9] is shown in Fig. 4, and main parameters are listed in Tab.1. The structure of the resonator is shown in Fig. 5. The tank of which is 2.6 meter in length and 75 cm in diameter.

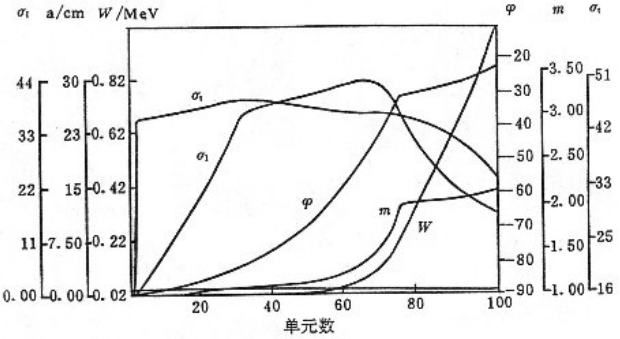

Figure 4: Dynamics design of ISR RFQ-1000

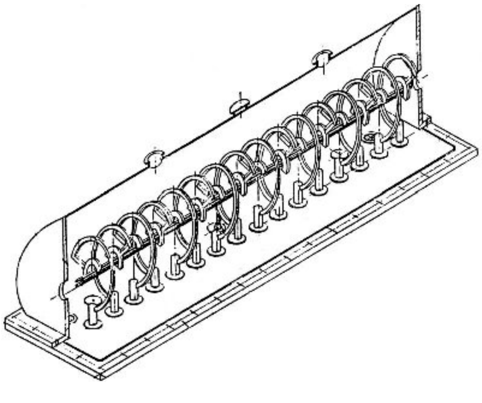

Figure 5: The structure of ISR RFQ-1000

It consists of a bottom plate and an upper cover. The supporting arms are directly fixed on to the bottom plate, and the upper cover of the cavity can be lifted freely for setting up or adjusting either the quadrupole electrodes or the supporting arms (Fig.6). The cooling water from the leg port flows through the arms and electrodes so as to ensure the high duty factor i.e. 1/6 or higher (Fig. 7).

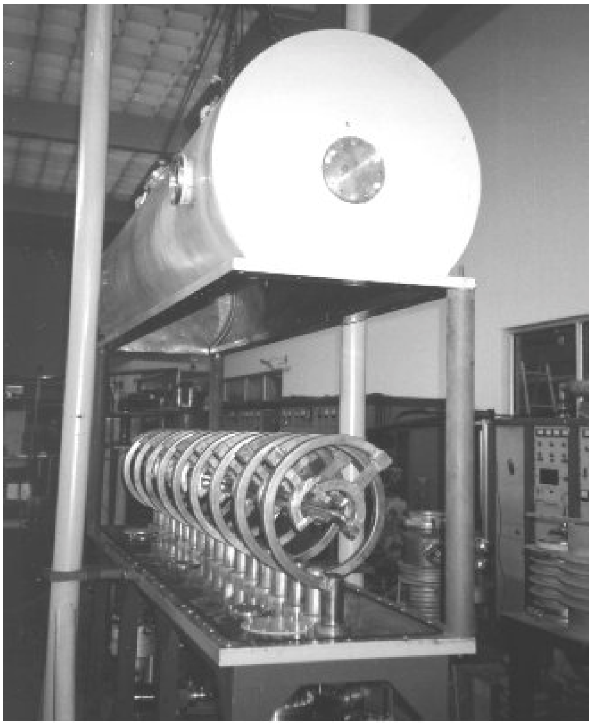

Figure 6: The ISR RFQ-1000 resonator

The cross section of the supporting arms is 3cm×3cm and it makes the whole structure very rigid. A NC milling machine fabricates the quadrupole electrodes, consisting of mini-vanes of two-dimensional cutting. The tip of the electrodes has a constant circular cross section of radius R; hence it can be machined with fast easy (Fig. 8). Meanwhile, it makes the electrodes relatively thick to enhance the rigidity and to hold a cooling water channel inside.

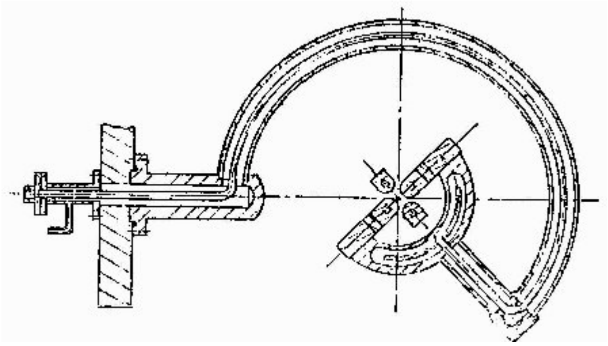

Figure 7: Supporting arm with cooling water channel

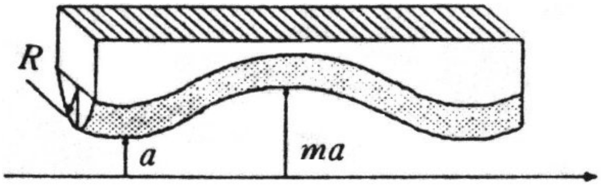

Figure 8: Mini-vane with two-dimensional cutting

It can be shown that the difference of focusing characteristics between the mini-vanes and ideal vanes reduces to a minimum if the radius R takes 1.25 times the characteristic radius of RFQ [10]. For ISR RFQ-1000, it means that R should be 2.0 cm. The mini-vanes are made of Cr-Cooper to strengthen their rigidity. The resonant frequency of 26 MHz is mainly determined by the length of arms when the radius *a* and the shape of the electrodes (Fig.8) are fixed [11]. In these cases, an empirical formula showed that the product of frequency times the arm length is proportional to the length of arms [4]. To determine the length of arms, a full-scale model was built. As a result, a frequency of 25.8963 MHz has been achieved when the length of the arms is 128.1 cm [12]. The frequency can be adjusted according to the needs by changing the effective length of arms with the shortening plate.

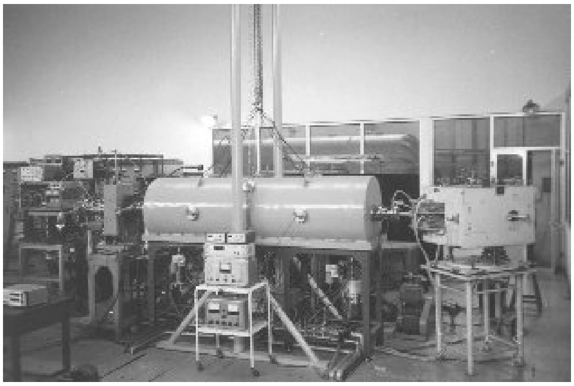

Figure 9: The ISR RFQ-1000 under beam test

3 HIGH POWER AND ION BEAM TESTS

The RF amplifier XFD-X5 can deliver 30 kW through a water-cooled loop in CW mode or 50 kW in pulsed mode. A distributive capacitance of about 30 pf is added to RF feeder so as to compensate the inductance of the input impedance. The amplitude of the field gradient in the RFQ cavity is stabilized by a feedback loop with a Double Balance Mixer. The voltage between quadrupole electrodes is determined by the corresponding Roentgen spectrum, the energy of which can be calibrated by the characteristic Gamma rays of proper isotopes. The shunt impedance Rp and the specific shunt impedance ρ are derived from the results of high power test nearby the working voltage of 70 kV. They are 205 kΩm and 522 kΩm respectively. The Q-value is 3450. It turns out that the ISR RFQ-1000 has a very high RF efficiency. Actually only 24 kW of RF power is needed to reach the working voltage of 70 kV. Comparing these figure with that of ISR RFQ-300, which has a Q-value of 1300 and specific shunt impedance 128kΩ, it shows that the ISR RFQ-1000 has improved greatly in terms of the RF efficiency. The layout of the beam test for ISR RFQ-1000 is similar to that of Fig. 2, and the photo of the set-up is in Fig. 9. The positive ion source is of side extraction PIG type with permanent magnets, and the negative source is of end extraction PIG type. At a discharge current of 150 mA, the content of N$^+$, O$^+$ and O$^-$ ions are nearly 80%. The extracted ions are focused by a three-cylinder Einzel lens with a diameter of 45 mm, and then deflected by a 45^o combining magnet with a radius curvature of 20 cm onto the beam axis. After being focused by a matching Einzel lens, ions are accelerated to 1 MeV in the RFQ. Two Faraday cups are mounted at the RFQ entrance and exit to measure the corresponding input and output beam current, and to derive the beam transmission efficiency. As for O$^-$ ions, the peak output beam current reached 660 μA with a beam efficiency of 83%, while for N$^+$ and O$^+$ ions, they are 300 μA and 320 μA respectively, both with an efficiency of 86 %.

4 CONCLUSION

RFQ implantors in MeV energy range have the obvious advantage of both high beam current and higher energy. From ISR RFQ-300 to RFQ-1000, the RF efficiency has been improved greatly. Further study will be concentrated on enhancing both the beam current and the beam transmission efficiency of heavy ions. The simultaneous acceleration of positive and negative ions with deliberate current ratio will be carried out in the light of increasing the effective beam current and broadening the application of RFQ implantors.

REFERENCES

[1] I.M.Kapchinskij, et al., Prib. Tech. Eksp.,4(1970)19
[2] J.X. Fang, C.E. Chen, IEEE NS-32(1985)2981
[3] C.E. Chen, O.J. Pan, J.X. Fang, 3-rd Japan-China Symposium on Accelerators (1987)116
[4] C.E. Chen, J.X. Fang, W.G. Li, et al., Progress on Natural Science, Vol.4, No.3(1994)271
[5] C.E. Chen, J.X. Fang, A. Schempp, EPAC'90 (1990)1225
[6] C.E. Chen, J.X. Fang, W.G. Li, O. Pan, H. Klein, H. Deitinghoff, A. Schempp, EPAC'92 (1992)1328, 93(1993)116
[7] C.E. Chen, J.X. Fang, W.G. Li, O. Pan, Y.R. Lu, D.S. Li, 5-thJapan-China Symposium on Accelerators (1993)
[8] J.X. Yu, C.E. Chen, et al,. Trends in Nuclear Physics, Vol.13, No.2(1996)34
[9] D.S. Li, Dissertation, Peking University(1996)
[10] O.J. Pan, Dissertation, Peking University(1992)
[11] J.X. Fang, A. Schempp, EPAC 92(1992)1331
[12] Y. Wu, Dissertation, Peking University(1999)