STUDY AND DEVELOPMENT OF RFQ AT PEKING UNIVERSITY*

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Abstract

Based on the study of Integral Split Ring (ISR) RFQ structure, two 26 MHz heavy ion RFQ's (ISR-300 and ISR-1000) have been built at Peking University for ion implantation. The ISR-1000 is a 1 MeV 2.6 meter long RFQ and needs only 25kW peak rf power input. To study the simultaneous acceleration, O^+ and O^- ions have been accelerated simultaneously in the RFQ's. It shows that the simultaneous acceleration with different species and ratio of positive and negative ions in a RFQ will benefit the implantation. To increase accelerating efficiency of RFQ at its higher energy region, the feasibility of Separated Function RFQ (SFRFQ) is explored . In addition, a cavity section of 4 vane proton RFQ with 352 MHz and with the length of 1.18 m is constructed for experimental and technological studies.

1 HEAVY ION RFQ

RFQ accelerator was proposed by Kapchinsky and Tepliakov in 1970 and the first 4 vane proton RFQ operated at LANL successfully. In 1980. Due to its outstanding features, since then the proton RFQ developed rapidly. With the increasing interest in heavy ion RFQ, then the RFQ at low frequency were developed. Based on the investigation of conventional split ring cavity, an ISR RFQ has been developed at Peking University since 1984 [1]. The property of this type of structure have been explored by a series of RF measurements on full scale models together with theoretical analysis and high power test. It turns out that the ISR RFQ suits well for low frequency operations and for heavy ion acceleration. A 26 MHz ISR RFQ for N^+ ions up to 300 keV was then built for ion implantation in 1994 (Fig.1)[2]. Based on the experiences of ISR-300 and to meet the requirement of 1 MeV energy, ISR-1000 RFQ for 1MeV O^+ and O^- ions has been built in 1999 (Fig.2)[3]. The 2.6 meter long cavity needs only RF power of 24 kW for I MeV O^+, which correspond to the specific shunt impedance of 510 kΩm. The ISR RFQ uses mini-vanes with two-dimensional cutting to make the electrodes more rigidity and easy to fabricate and water-cooling. The RFQ operates with duty factor of 16.7% stably. Their main parameters are listed in Tab.1. Now ISR RFQ are available for applications as the study of material. In addition, they can also be used to some extent as a test bench for the study of new structures and experiments.

Table 1: Main Parameters of ISR RFQs

Type	ISR-300	ISR-1000
Ions	N^+, O^+, O^-	N^+, O^+, O^-
F_0 (MHz)	26	26
W_{in} (kev)	20	22
W_f (kev)	300	1000
I_{avr} (μA)	38.4	100
I_p (mA)	~1	5
L (cm)	90	260
D_{out} (cm)	50	75
V_0 (kev)	75	70
Duty Factor	16.7%	16.7%

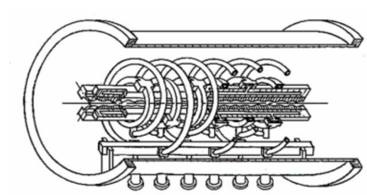

Fig. 1 RFQ structure of ISR-300

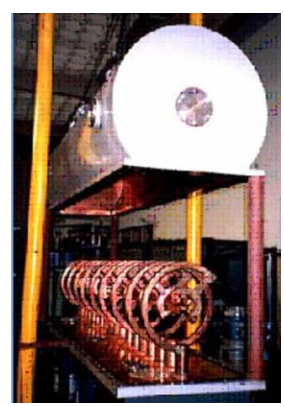

Fig. 2 RFQ structure of ISR-1000

2 SIMULTANEOUS ACCELERATION

To enhance the total number of accelerated ions in one RF cycle and to compensate the space charge both in the process of injection as well as on the target, a new test bench capable of accelerating of both positive and negative ions was suggested and constructed [4,5] (Fig. 3). The positive and negative ions came from both ion sources (IS) are to be focused by the Einzel lenses (EL) next to the ion sources and then funnelled by a combing magnet (BM). After focusing by an matching Einzel lens in front of RFQ, the ion beams are accelerated by RFQ

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and then analysed by analysing magnet (AM). The ion beams are measured by Faraday cup (FC) and fast Faraday cap at the end of line to show the pulse forms..

In the experiment, O^+ and O^- ions are simultaneously accelerated and around different phases Φs (Fig. 4). The experimental pulse forms are measured by fast Faraday cup and shown in Fig. 5 , in which the RF sine wave forms are also shown. The relative pulse position can be compared with the phases. The experimental result of one example is listed in Tab. 2. It demonstrates that the output beam current can be increased by simultaneous acceleration obviously, even though the beam line is not optimized for both ion beams, which needs to make the matching very carefully. In the experiment, the space charge effect did not appeared, which may appear in the next experiment at higher beam current. The study also demonstrate that the simultaneous acceleration with different species and ratio of positive and negative ions in a RFQ will benefit the implantation.

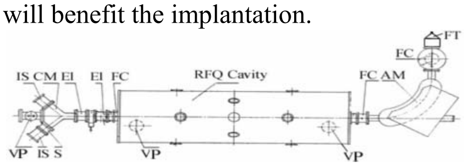


Fig.3 Layout of bean line for simul. acceleration

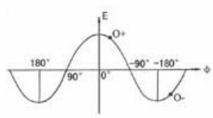


Fig.4 Positive and negative ions at different phases Φ s

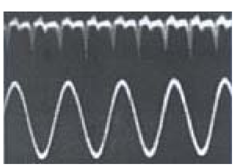


Fig.5. Beam pulses .from experiment

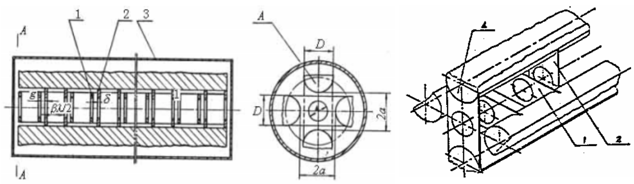
Table 2: Compared results of simul. with individual accel.

Individual acceleration			Simul. acceleration		
	O^+	O^-	O^+	O^-	Plus
Input(μA)	730	778	826	530	1356
Output(μA)	554	594	468	352	820*

* Beam line is not optimized for both ion beams

3 SF RFQ

RFQ is a very useful and efficient accelerator in low energy region. However, its efficiency decreases with the increase of energy. Therefore, RFQ is used usually below 2 MeV per nucleon. To overcome the energy limit, two kinds of new RFQ, Separated Function RFQs, have been proposed and explored. The idea is to separate the axial field from the quadrupole field and to accelerate ions with a series of periodically loaded gaps. The RF accelerating field in the SFRFQ structure mainly occurs at gaps between cells, while the electrical quadrupole field inside the cells provides the transverse focusing [6,7] .The structure of a SFRFQ with periodically loaded diaphragms is shown schematically in Fig.6, where diaphragms are mounted on to the electrodes with no surface modulation.



1&2 –diaphragms, 3 -cavity , 4 –quadrupole electrodes

Fig.6 Structure of the SFRFQ with diaphragms

In the SFRFQ, acceleration mainly takes place inside the gaps. However, there is a decelerating field at the back of the gap induced by the diaphragm inside the cell. Nevertheless, the effect of the decelerating field depends strongly on the geometry. As a thick diaphragm will shield off some of the decelerating field and also by tuning the thickness of the diaphragm, the RF phase can be adjusted to weaken the effect of deceleration.

To further enhance the energy gain, an asymmetrical structure was developed, where one side of the diaphragm pair is stretched to ~ $\beta\lambda/4$ so as to shield off more decelerating field. The ions will be accelerated inside the gap of the diaphragm pair, and then drift freely in a distance of ~ $\beta\lambda/4$. At the exit, ions will experience some extent of axial decelerating field, and then drift in an alternatively focusing quadrupole field.

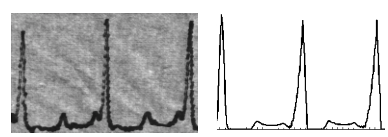


Fig. 7 Measured(left) & calculated(right) axial field E^2~Z

The calculated field pattern is verified by the measurement on the 26 MHz ISR RFQ testing model, and is plotted in Fig.7. The specific shunt impedance measured is 124 kΩ·m, and Q=1400.

To avoid the decelerating field in the SFRFQ, a structure with periodically loaded mini-vanes of no surface modulation has been studied. Its central part of the structure is shown in fig. 8. 4 (I-I) is a pair of long mini-vanes with no modulation at ground potential and is supported by ring B, D, and etc. while 1,2,3,4, ---(II-II) consist of another pair of mini-vane series. Among them, 2,4,6,--- are supported by ring B, D and etc. at ground potential, but 1,3,5,--- are excited to RF potential V and are supported by ring A, C,---. Therefore, there are accelerating electric field between vanes 1, 3,-- and 2, 4,--. As the length of each short mini-vane is equal to $\beta\lambda/2$ respectively, ions can be accelerated continuously at these gaps. The ions drift inside the odd number vanes will experience focusing by the quadrupole field, but will drift freely inside the vanes with even numbers. This version of SFRFQ-mini-vanes does not have any decelerating field (Fig.9).

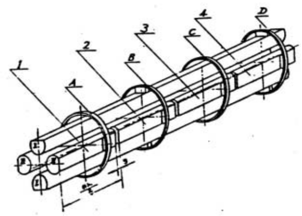


Fig.8 Central part of SFRFQ with mini-vanes

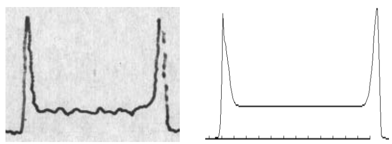


Fig. 9 Measured(left) & calculated(right) axial field E^2~z

Tab.3 shows the comparison of SFRFQs with the conventional RFQ. It demonstrates that the SFRFQs can meet the requirement well, and expected to be used in higher energy after conventional RFQ. Further studies will be carried out for a SFRFQ version after 1 MeV ISR RFQ, including dynamics design and structure technology.

Table 3: Comparison of SFRFQs with conventional RFQ

	SFRFQ		ISR-1000 RFQ
	diaphragm	Mini-vane	
φ_s	-25°	-25°	-25°
a(mm)	8.5	6.8	6.33
$\beta\lambda/2$(mm)	68	68	67
Win(MeV)	0.95	0.95	0.95
Voltage(kV)	70	70	70
ΔW (keV)	51	32	30
Q value	1390	1700	3453
ρ (kΩm)	124	201	100

4 PROTON RFQ

These years the high power proton accelerators are being developed rapidly for Accelerator-Driven-Systems, Spallation Neutron Source , and neutrino, et al. In China the ADS project has been started. As the first step, a project of 3.5MeV proton RFQ has been proposed and the preliminary study was started in Peking University, China Institute of Atomic Energy and Institute of High Energy Physics of China Academy Science co-operatively. The 4 vane 352 MHz RFQ will accelerate protons from 75 KeV to 3.5 MeV with beam current of 60 mA and duty factor of 6 % firstly. It consists of 4 sections of cavity with total length of 4.75m [8]. For the preliminary technology and experimental study, a 1.18 m model cavity with oxygen-free copper has been machined by NC milling without modulation and brazed in a vacuum furnace (Fig. 10 and Fig.11). After assembling, the mechanical tolerances are within ± 20 μm. The measured quadrupole mode frequency is 348.95 MHz, and dipole mode frequency 345.06 MHz. Further studies are being carried out.

Fig. 10 RFQ cavity before brazing

Fig.11 RFQ cavity after brazing

5 CONCLUSION

Since 1984, a series of studies and constructions of RFQs have been carried out in Peking University. Now based on the two 26 MHz heavy ion RFQs, the studies of implantation, materials, and the development of new RFQs is being performed. Meanwhile, the study of proton RFQ is started for ADS project and the use of neutron physics and techniques. On the other hand, RFQ specially designed for the applications in AMS is to be started.

6 ACKNOWLEGMENT

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