Experimental Studies on the Acceleration of Positive & Negative Ions with a Heavy Ion ISR RFQ*

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Abstract

With a 26 MHz water cooled Integrated Split Ring (ISR) RFQ, N^+ beam was accelerated to more than 300 KeV at Peking University. Experimental studies on the acceleration of positive and negative Oxygen ions have been carried out since then and the operating parameters were optimised respectively. Feasibility study of accelerating both positive and negative ion beam simultaneously in the same RFQ is also performed. The latter has the merit of enhancing the total number of ions and compensating the space charge both in the process of beam injection as well as on the target.

1 INTRODUCTION

Based on the investigation of conventional split ring resonator, an ISR RFQ with water cooled mini-vane electrodes has been developed at Peking University [1-2] since 1984. The properties of this type of structure have been explored by a series of rf measurements on full scale models together with theoretical analysis.It turns out that the ISR type RFQ suits well for low frequency operations and for heavy ion acceleration. A 26 MHz ISR RFQ for accelerating N^+ ions up to 300 KeV was then designed, and constructed for the purpose of ion implantation and it was tested to full power successfully both with and without beams since last year [3]. In order 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]. The acceleration of positive and negative oxygen ions was first performed separately and the operating parameters were optimised respectively. The average current maximum reached 17.5 μA (with a duty cycle of 1/6) and the corresponding micro-peak current is of 1 mA order.The feasibility study of accelerating simultaneously both positive and negative ions in one RFQ was then carried out. The result is quite encouraging. It turned out that the positive and the negative half period of an RF cycle can be used to accelerate both sign of ions at the same time and the interactions between negative and positive ion bunches are negligible. The above contents will be presented as follows.

2 THE EXPERIMENTAL LAYOUT

The layout of the experiments is schematically shown on fig. 1. The positive and negative ion sources are located at ±45° with respect to the beam axis. The ion beams extracted from both sources are to be focused by the Einzel lenses (EL) next to the source. The ions can be either bent one by the other or funnelled simultaneously on to the beam axis by a combining magnet (CM) and then focused by an matching Einzel lens (MEL) in front of the RFQ. The beam current of positive or negative ions accelerated by the RFQ is to be deflected by a small magnet (DM) and measured by two Faraday cups (FC) located at a range of ±8 cm off the central axis respectively. Two additional beam monitors (BM) are mounted at the RFQ entrance and exit to measure the input and output beam intensity. The energy spectrum of the beam is to be measured by using the analysing (AM) magnet.

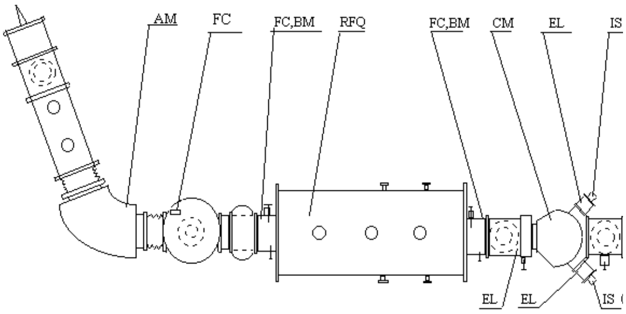

Fig. 1 Schematic layout of the experiment

2.1 *Ion Source and Injection*

Cold cathode PIG ion sources with permanent magnets have been developed at our lab for producing positive and negative oxygen ion beams. The one used for producing O^+ ions is of side extraction type, while the other one for O^- ions is an end extraction sputtering type PIG ion source. About one mA of negative and positive oxygen ions can be extracted from both sources at 20 KV. The percentage of O^- and O^+ are nearly 80% at a discharge current of 150 mA. The extracted O^- or O^+ beam is focused by a tri-cylinder Einzel lens with a diameter of 45 mm. The O^- and O^+ beams are then funnelled by a 2×45° combining magnet with a radius curvature of 20 cm. In order to compensate the undesired deflection caused by the magnetic fringe field of the side

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extraction PIG source, a pair of electrostatic deflection plates is placed between the einzel lens and the combining magnet of the positive ion beam line, so as to ensure that the O^- and O^+ beams are funnelled right to the beam axis.

2.2 ISR RFQ Cavity

The structure of an ISR RFQ resonator operating at 26 MHz is shown in Fig. 2. It consists of 3 pairs of right wounded and left wounded spiral arms connected to a common ground plate. The drift tubes in the conventional split ring cavities are replaced here by 4 mini-vane electrodes. The structure can be assembled as a whole outside the cavity and the electrodes can be replaced whenever necessary with fast easy. The whole structure is cooled by water flowing through the spiral tubes, supporting rings and quadrupole electrodes, so as to have high duty factor and hence high average beam current. The end section of the electrodes were specially shaped so as to minimize the end effect and to improve the transverse beam quality.

The diameter and the wall thickness of the spiral tubes are 30 mm and 1.5 mm respectively, which turn out to be strong enough to ensure mechanical stability. The parameters of this RFQ are listed in Table 1.

The rf power is fed by a linear power amplifier (XFD-D5) with maximum power output of 30 KW (CW) or 50 KW (pulsed) through a water cooled loop. A distributing capacitance of about 30 pf was added to the 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. [5-7]

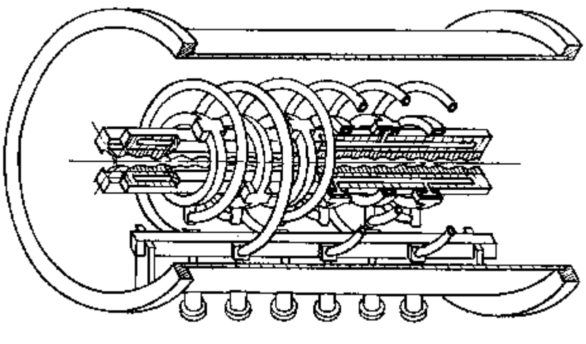

Fig. 2 View of a 26 MHz ISR RFQ

Table 1 Principal parameters of a 26 MHz ISR RFQ

f	(MHz)	26
Charge/Mass		~ 1/14
W_{in}	(KeV/ u)	1.4
W_f	(KeV/ u)	21.4
Diameter	(cm)	50
Length	(cm)	90
Vo	(KV)	80
ρ	(KΩ–m)	204
Q		1300

Table 2. Results of the high power test

P_{in}	KW	19.7	24.6	29.7	39.6	44.4
V_o	KV	62.3	66.9	71.6	78.5	81.7
f	MHz	25.7	25.7	25.7	25.7	25.7
T_{water}	^oC	16.5	18	19	22	23
ρ	KΩ–m	168	155	147	132	122

3 EXPERIMENTAL RESULTS

3.1 Acceleration of O^+ and O^- Beams

The DC current of O^+ ions obtained at the entrance of the RFQ after a deflection of 45^o ranges from 200-490 μA, which was extracted under 17-20 KV from the PIG source and focused by the Einzel lens. The beam energy after acceleration was determined by the analyzing magnet and was shown in Fig.3 as a function of RF power. It can be seen that the highest energy gain of 306 KeV was obtained at a RF power of 30 KW. The output beam was quite sensitive with the matching lens in front of the RFQ and is shown in fig. 4 as the beam transmission efficiency versus focusing voltage. The former is defined as the ratio of deflected output current received by the offset Faraday cup to that of received by the cup in front of the RFQ entrance. As the aperture of the latter is of 25 mm, which is considerably larger than that of the entrance diaphragm (15 mm) located at a distance 10 cm downstream. So the efficiency thus measured could possibly be underestimated. The beam efficiency increases with the vane voltage as shown in Fig.5. With a duty cycle of 1/6, the highest average current measured was 17.5 μA, and the highest transmission is more than 43 %. the DC equivalence of which is 105 μA and the corresponding microscopic peak current is estimated to be more than 1 mA.

On the acceleration of O^-, the transmission efficiency seems to be a little higher than that of the positive ions. The DC current obtained at the RFQ entrance was 175 μA. The transmission efficiency reaches a maximum of 48% at a matching lens voltage of 13 KV and tends to increase further with focusing voltage.

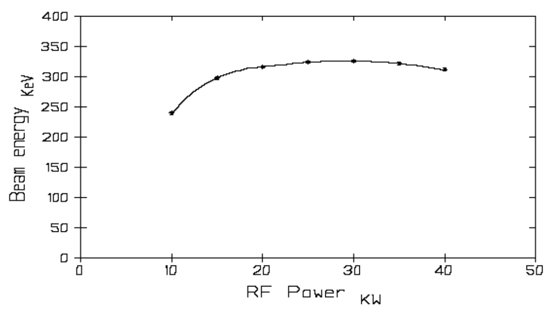

fig. 3 Beam energy of O^- versus RF power

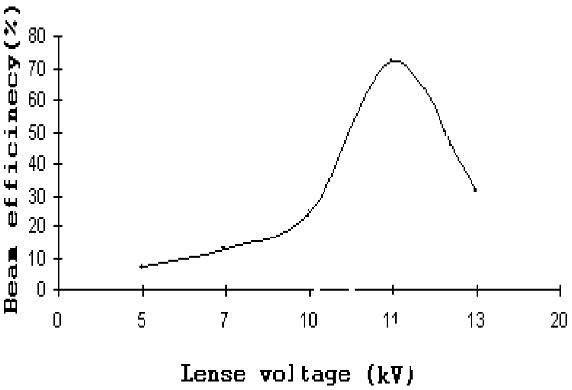

Fig. 4 Beam transmission efficiency of O^+ vs. lens voltage

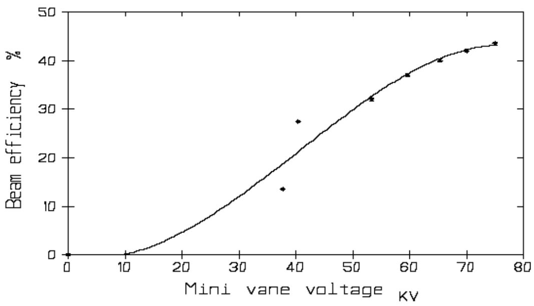

Fig. 5 Beam transmission efficiency of O^+ vs. vane voltage

3.2 Simultaneous Acceleration of O^+ and O^- Beams

For simultaneous acceleration of O^+ and O^- ions, the ion sources and the focusing lenses related are set according to their own characteristics. The extraction voltage for O^+ is normally ~ 20 KV, while for O^- is limited to 17 KV because of sparking. However, the optimum voltage of the matching lens for O^+ is about 11 KV while it should be ~18 KV for O^- ions. So the voltage setting has to be a kind of trade off, in our case ~13 KV was chosen for the time being. The simultaneous acceleration was performed at various RF power levels with the average current output varied from 0.1 to 21 μA under a duty factor of 1/6. The current ratio of O^+ to O^- varied from 0.1 to 5. The sum of O^+ + O^- current I_{sim} for simultaneous acceleration is compared with that of I_{sep} where O^+ and O^- were accelerated separately under the same condition in all cases. It appears that I_{sim} is about the same as I_{sep} in all the current ranges as can be seen from fig.6. This means that both the positive and the negative half period of the RF cycle can be used to accelerate both sign of ions at the same time and the interactions between negative and positive ion bunches are negligible, as it was expected, so far as the micro-peak current concerned is of 1 mA order. It is also worth mentioning that the result implies that dual species of ions of different amount can be implanted at once with deliberate ratio by using the present set-up.

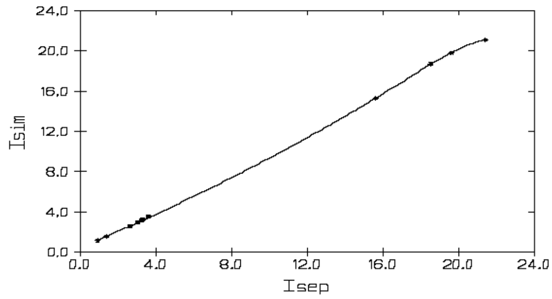

Fig. 6 Isim vs. Isep

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