# Beam Tests of a cw 4-rod RFQ

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*Abstract*

The results of a series of the initial beam tests of the 4-rod RFQ are presented. The measurements include determining an ion beam transmission, surveying the beam emittances both at the input and output of the linac, and obtaining the momentum spectrum of the input and output beam. In addition a SIMS (secondary ion mass spectroscopy) analysis was performed for an ion implanted silicon wafer to get the definitive information on the energies and identification of an RFQ output beam.

## I. INTRODUCTION

A cw RFQ linac system of "modified" 4-rod type has been constructed. The cross-section of the RFQ electrodes are not circular as usually proposed in literature but rectangular and the electrode poles are three-dimensionally machined. We propose that this design makes the handling and maintenance of the RFQ electrodes particularly easier [1,2].

An ion injector to the RFQ comprises of a Freeman type ion source, a 90 degree analyzing magnet, magnetic quadrupole lenses, and a HV (high voltage) rack where a mass flow controller and electrical power supplies are all installed. The vacuum system comprises of a 550 liter/sec. turbo molecular pump and a 350 liter/min. oil rotary pump. All those beam optical, electrical, and vacuum components are arranged and installed in a X-ray shielded cabinet. Details of the ion injector is found in ref. [3].

Beam tests have been in progress since the first beam acceleration experiment in late December 1992. The ion beams used so far for the acceleration tests of the 4-rod RFQ are $He^+$, $N^+$, and $C^+$.

## II. EXPERIMENT SETUP

*A. Setup*

Fig. 1 is a schematic drawing of the beam experiment setup of the RFQ linac. The purpose of this experiment is to draw as much information as possible of both the input and output beam of the RFQ. The input and output beam current are measured with Faradays cups. The emittance and orientation in the trace-space of the beam are surveyed using an emittance monitor. The energy of the input beam can be known accurately (better than $\pm 0.5$ %) by measuring a terminal voltage of the ion extraction high voltage power supply using an appropriate resistor divider. The output beam energy of the RFQ can be estimated by taking a momentum spectrum of a beam with a 15 degree bending magnet system.

*B. Faraday*

There are five Faraday cups in total to measure the intensity of the ion beam. F1 is retractable and practically works as a beam stopper as well as a pseudo-Faraday . F2 and F3 are retractable, too and true Faradays. F2 and F3 are used to measure the intensity of a beam at the upstream and downstream of the RFQ, respectively. F4 and F5 are both de-mountable true Faraday systems and are similar to F2 and F3 in construction.

*C. Emittance monitor*

The emittance monitors EM1 and EM2 are of "a slit and multi-wires" type, both exactly identical in construction. In the emittance monitor, there are only 10 detector wires. The construction is simple and the total costs is relatively low in such configuration however, the angular separation of the detector wires is such that only a rough measurement is possible in the present design. This is preferred anyway for the very first study of the beam emittances. The performance of the emittance monitor will be upgraded to better angular resolution in an appropriate timing in the course of our future development.

## III. EXPERIMENT DATA

*A. Transmission*

Fig. 2 is a plot of $He^+$ and $N^{2+}$ ion beam transmission of the RFQ as a function of rf power. Please note that the value of ion current obtained at F3 represent a total un-analyzed beam current. The beam transmission of $He^+$ approaches 90 % and those of $N^{2+}$ and $C^+$ ion beam are approximately 80 %. The typical beam currents obtained at the RFQ output are 32, 13, and 220 pμA for $He^+$, $N^{2+}$, and $C^+$ ions, respectively.

*B. Emittance*

Fig. 3 typifies the results of beam emittance measurements for a $He^+$ ion beam. The measurements were done at the probe position of 233 mm upstream of and 388 mm downstream of the RFQ electrode boundaries. In those figures, the trace-space ellipses obtained by the calculations using PARMTEQ and TRACE-3D are superposed on the raster image of the measured emittance data. Although crude the experimental data are, it is adequate for making comparison.

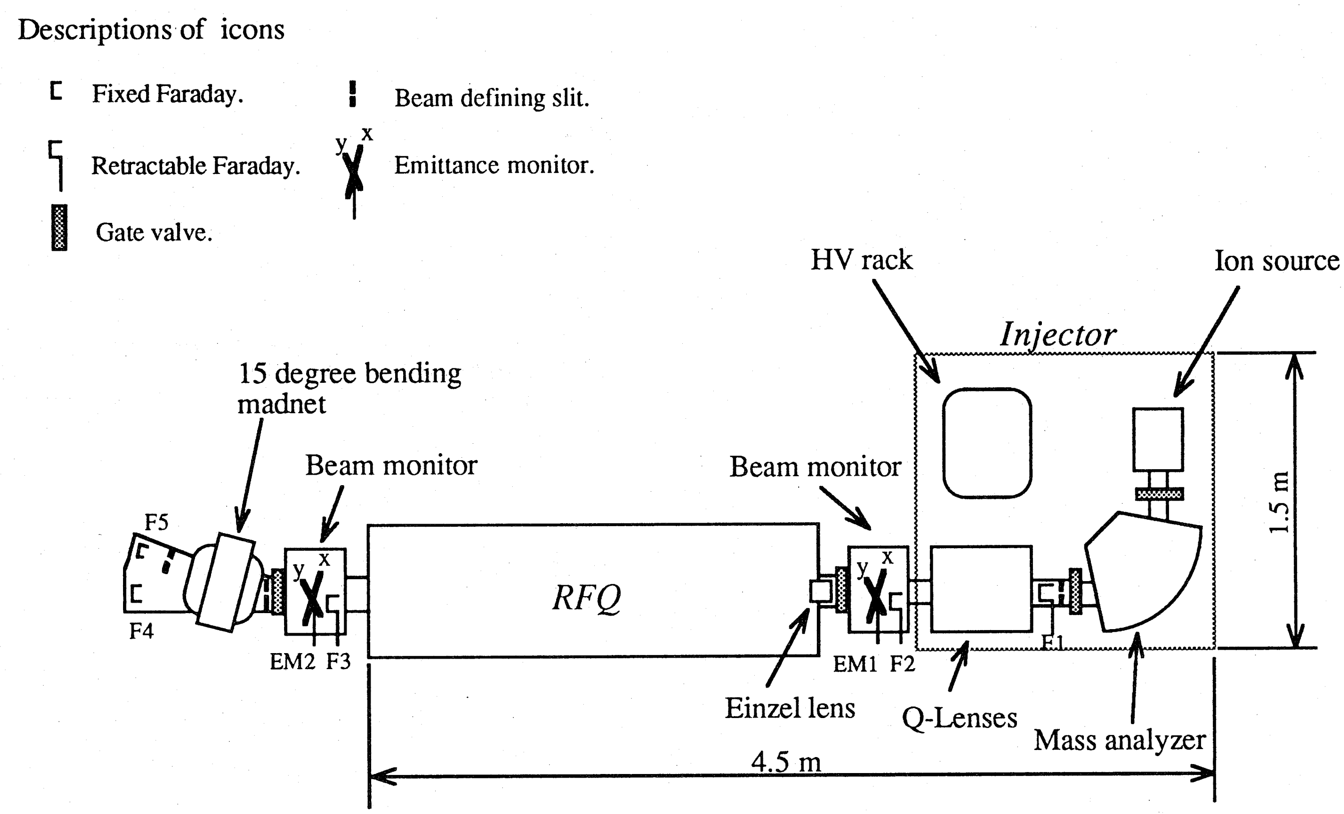


Figure 1. Schematic drawing of the experiment setup for the 4-rod RFQ beam acceleration tests.

*C. Momentum spectrum*

Fig. 4 exemplifies the momentum spectra of beams from the ion source operated in various source gases. The measurements were done by recording an ion current at F1 in varying mass analyzer's current. The extraction was in all cases set at the synchronous energy required for the RFQ injection.

The expected mass resolution M/ΔM of the 15 degree bending magnet is about 50. F5 measures the analyzed current of the beam which is collimated through the slits located both at the entrance and exit of the 15 degree magnet system. Fig. 5 typifies the momentum spectrum of $He^+$, $N^+$, and $C^+$ beams accelerated by the RFQ.

The energy of the accelerated beam can be approximated by extrapolating from the spectrum of a mono-energetic beam from the ion source with the 15 degree bending magnet system. The rf power is put off in this measurement. The estimated output energies for instance of $He^+$ and $C^+$ beams are 346 KeV ± 2 % and 1071 KeV ± 2%, respectively. These values are off by + 2.2 % and + 5.4 % from the calculation of $He^+$ and $C^+$ output synchronous energies, respectively.

*D. SIMS analysis of implanted ions*

To confirm the acceleration of a beam by the RFQ, an output ion beam was implanted in a silicon wafer and SIMS analysis was used to get the range distribution of the implanted ions. This sensitive analysis gives a definitive information on what is where by how much. Fig. 6 shows the range profile of nitrogen in a silicon wafer measured after the implantation of $N^{2+}$ beam at dose of approximately $1\times10^{16}$ atoms/cm$^2$. The expected energy of the $N^{2+}$ beam is 1.17 MeV. The peak of the profile corresponds to the depth of 1.6 μm. This is in good agreement with available range profile data [4-6].

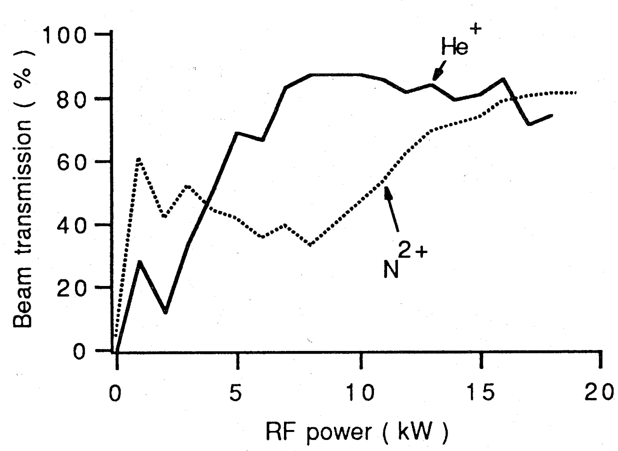


Figure 2. Beam transmission of $He^+$ and $N^{2+}$ ion beam as a function of rf power.

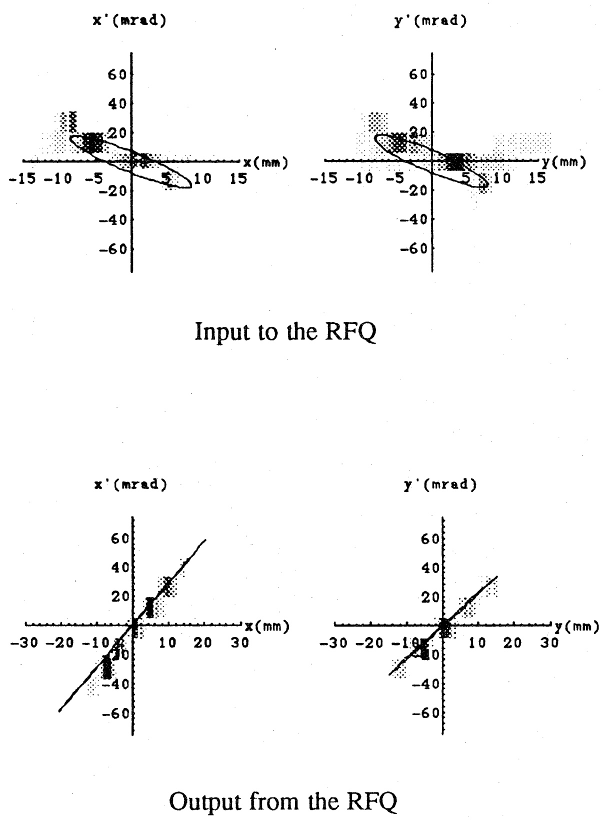


Figure 3. Comparison of He$^+$ beam emittance with the results of calculations.

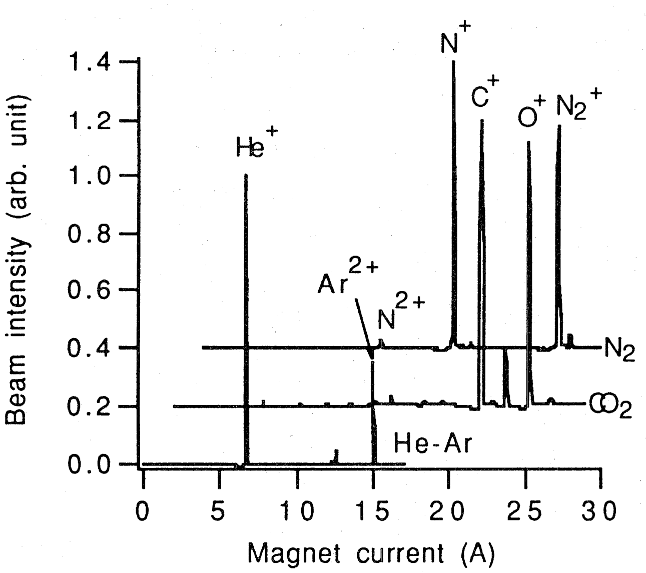


Figure 4. Momentum spectra of the ion source operated in various gases.

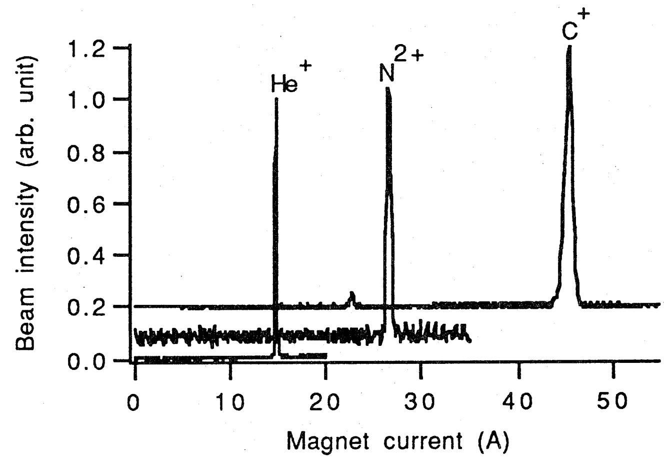


Figure 5. Momentum spectra of He$^+$, N$^+$, and C$^+$ accelerated beams as analyzed with the 15 degree bending magnet system.

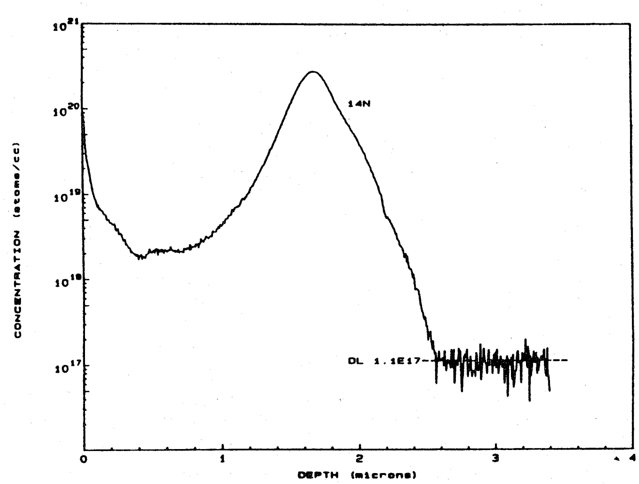


Figure 6. Range profile of nitrogen implanted in a silicon wafer.

## IV. REFERENCES

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