Beam Dynamics in an Energy-variable RF-Accelerator for Ion Implantation*

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Abstract

Some applications in ion implantation require deep implants and high implant doses, which means high ion energy and high beam currents. Both requirements can be fulfilled at the same time by rf accelerators. A design study of an energy-variable implanter, consisting of a splitted Radio Frequency Quadrupole (RFQ) Accelerator and a Spiral Loaded Cavity (SLC) has been carried out earlier. This combination is well suited for the acceleration of beam currents up to 10 mA of e. g. O^+ ions to output energies from 0.6 to 1.7 MeV. Special attention must be given to the beam behaviour in the case of energy variation under space charge conditions. Beam dynamics calculations have been performed to improve the beam quality with respect to particle losses, energy spread and emittances. A layout of such an implanter is presented and its beam properties will be discussed.

1. INTRODUCTION

Ion implantation is a widely used tool in development and production of new materials of high quality. For many applications implanter systems are available - mainly static machines - which cover a large range of energy and current. For some new applications like hardening of metal surfaces or SIMOX or SIMNI techniques [1] high energies for deep implants and high doses for reasonable irradiation times are required, which means average currents of some mA of N^+ or O^+ ions must be accelerated to energies up to 1 or 2 MeV. For these energies and currents RFQ accelerators [2] are best suited which are already in operation as e.g. injector to larger machines, pre- or postaccelerators for light and heavy ions [3]. The RFQ is a linear quadrupole channel, in which the accelerating field is produced by a geometrical modulation of the quadrupole electrodes. It combines strong rf focusing and rf acceleration. This allows the capture, bunching and acceleration of intense ion beams extracted from an ion source with energies as low as 1 keV/u up to some MeV/u with high efficiency, good transmission and beam quality. For a fixed frequency the velocity profile is fixed too, the variation of energy is difficult, e.g. by changing the resonant frequency of the structure in a wide range [4]. For smaller energy variations a spiral loaded cavity can be added to the RFQ [5]. Beam measurements showed discrete steps in output energy when the electrode voltage is changed, even ion drifting through the RFQ has been observed [6-8]. Based on these results, which were confirmed by calculations, an implanter has been designed, consisting of a splitted RFQ and a SLC, which provides a continuous variation of the output energy over a wide range [9].

2. LAYOUT OF AN IMPLANTER

A schematic view of the designed high-energy high-current implanter for light ions up to O^+ is shown in fig. 1. The ions are extracted from an ion source and focused into the first RFQ, where the beam is captured, bunched and preaccelerated. In the second RFQ transport, acceleration to different discrete energies or even deceleration of the beam bunches are possible. The final continuous variation of energy can be done by changing voltage and phase in the SLC. Table I and II summarise main parameters of both RFQs and the SLC.

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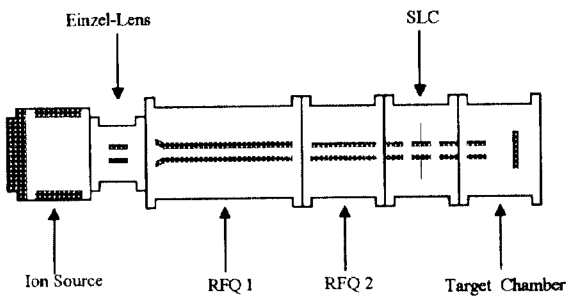

Fig. 1 Schematic layout of the implanter

Table I: Main parameters of RFQs

Parameters	RFQ1	RFQ2
Input energy(keV/amu)	3.13	50.0
Output energy(keV/amu)	50.0	93.8
Frequency(MHz)	80.0	80.0
Electrode voltage(KV)	80.0	110.0
Aperture(mm)	4.0-3.0	4.2-3.8
Modulation factor	1.0-1.5	1.3-1.6
Length(m)	1.75	0.95
Norm.input emit.(πmmmrad)	0.30	0.40

Table II: Main parameters of SLC

Max. energy variation	+/-200KeV
Frequency	80MHz
Max. gap voltage	154KV
Aperture	0.8cm
Gap length	0.4cm
Drift tube length	4.76cm

The beam dynamics in such an combination has been studied already before [9], where the energy variation turned out to be critically in case of high current, i.e. high space charge forces. Therefore the layout of RFQ2 and SLC were reconsidered and the necessary output conditions (emittance, bunch size) for the beam coming from RFQ1 investigated [10].

3. BEAM DYNAMICS CALCULATIONS

Beam dynamics calculations were done with PARMTEQ and TRANSPORT. The first RFQ accelerates the beam to an energy of 0.8 MeV, which can be lowered to 0.75 MeV when the beam is decelerated in RFQ2. Further deceleration by the SLC gives then the lowest output energy of 0.6 MeV. RFQ2 has been designed such that in case of acceleration two energies can be achieved with good transmission and emittance: 1.1 MeV with lowered electrode voltage and 1.5 MeV as highest design energy. For the SLC a layout had to be made with a wide transit time factor to cover the whole range of energies from 0.6 to 1.75 MeV. Calculations showed that the design energy of 1.05 MeV gave the best results in particle dynamics for all cases. In fig. 2 the final energies, which can be achieved are shown as function of the rf phase in the first gap of the SLC.

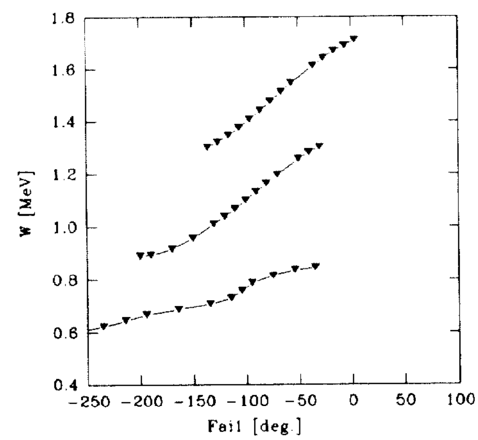

Fig. 2 Output energies as function of rf phase in the first gap of the SLC designed for an energy of 1.05 MeV

Single particle calculations were made for the combination of RFQ2 and SLC for bunched beam with transverse input emittances of 0.4 π mm mrad (norm.). In Table III results of these calculations are compiled, which gave in all cases high transmission and reasonable energy spreads. Fig. 3a and 3b give examples of the longitudinal output emittance for the lowest and highest energy and full input current of 10 mA.

4. CONCLUSION

A layout of an energy-variable rf implanter has been developed, which allows an energy variation with fixed RFQ frequency. In case of O^+ the output

Table III: Results of dynamics calculations for O^+ at design current

RFQ2				SLC				
VF	P.Shift[°]	W_{out} [MeV]	I_{out} [mA]	φ_1 [°]	φ_2 [°]	W_f [MeV]	ΔW/W [%]	I_{out} [mA]
1.0	0	1.5	9.57	4.1	-46.3	1.70	8	9.30
1.0	0	1.5	9.57	-145.7	-172.2	1.28	8	9.36
0.83	-70	1.05	10	-30.0	-30.0	1.28	10	10.0
0.83	-70	1.05	10	-200.0	-165.0	0.85	10	10.0
1.0	-180	0.75	9.96	-34.4	51.3	0.90	10	9.60
1.0	-180	0.75	9.96	-254.1	-133.1	0.64	10	9.90

energy can be varied continuously from 0.6MeV to 1.7MeV. The coupling between second RFQ and SLC has been improved leading to high transmission and low energy spread. Further work must be done on beam stability in the system with respect to tolerances.

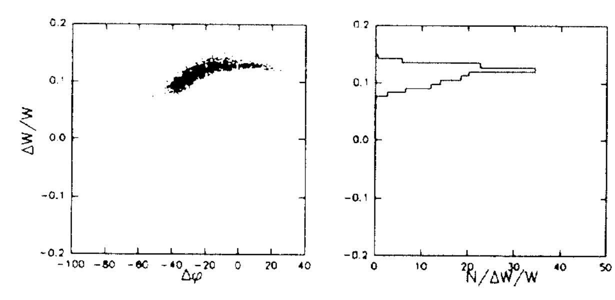

Fig. 3a Longitudinal distribution after SLC with the maximum energy 1.7MeV.

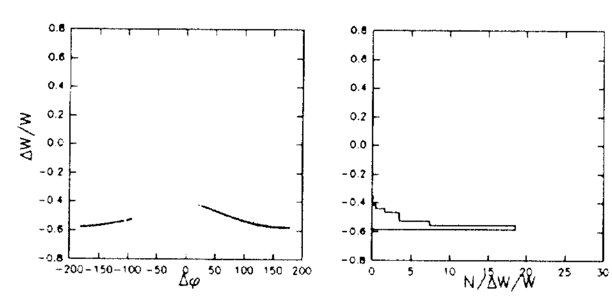

Fig. 3b Longitudinal distribution after SLC with the minimum energy 0.64MeV.

5. ACKNOWLEDGEMENT

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