DEVELOPMENT OF 1 MeV/n RFQ FOR ION BEAM IRRADIATION*

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Abstract

For the purpose of the ion beam irradiation, especially for helium beam application to semiconductor industry, an ion beam RFQ is under development at KOMAC (Korea Multi-purpose Accelerator Complex). The output energy of the RFQ is determined to be 1 MeV/n, which corresponds to 4 MeV in helium beam case, in consideration of the penetration depth in the silicon substrate. The RFQ is a four-vane type and will be fabricated through vacuum brazing technique. The RF power of 130 kW at 200 MHz will be provided to the RFQ by using a solid-state RF amplifier through two coaxial RF couplers with coaxial RF windows. The details of the RFQ development including some design features and fabrication methods will be given in this paper.

INTRODUCTION

An RFQ (radio-frequency quadrupole) with the output beam energy of 1 MeV/n is under development at KOMAC, mainly for acceleration of helium beam with applications including semiconductor irradiation and membrane fabrication. Small-scale accelerator based neutron source is another application in consideration. The output helium beam energy is going to be 4 MeV, which is enough to penetrate the silicon wafer up to 18 um. To reduce the irradiation time, higher beam current is preferred. With consideration of the ion source performance for He^{2+}, the beam current of the RFQ was determined to be 10 mA [1].

The layout of the ion beam irradiation system based on RFQ is shown in Figure 1. The system includes the ion injector, low energy beam transport (LEBT), RFQ, beam lines and the irradiation target. For the ion source, we are going to use microwave ion source with 2.45 GHz magnetron. The same type of the ion source is routinely used for the 100-MeV proton linac at KOMAC.

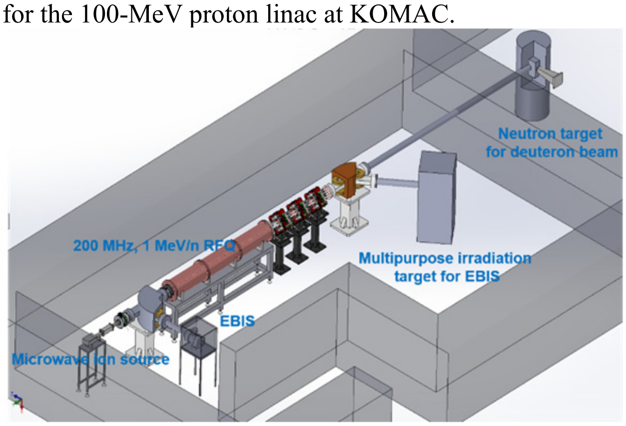

Figure 1: Layout of the ion beam irradiation system.

For the LEBT system, a compact electrostatic system is under consideration. In this case, the length between the ion source and RFQ should be as short as possible. As a backup a magnetic LEBT based on two solenoids is also prepared.

Ancillary systems to drive the RFQ include the RF system, the control system and the cooling system. The main RF amplifier system for the RFQ is solid-state type driven by digital low-level RF system. EPICS based control system will be used for controlling the overall system. The required cooling water flow rate is estimated to be about 33 m^3/hr to limit the temperature rise of the RFQ less than 1 degree centigrade.

RFQ DESIGN

Beam Dynamics

The operation frequency of the RFQ was determined to be 200 MHz. With this choice of the RF frequency, we can design the RFQ with a four-vane type, which shows better performance than the four-rod type in high duty operation point of view, while keeping the overall size of the RFQ within reasonably compact size [2]. In addition, we can use a commercially available solid state amplifier and avoid the use of high power klystron, which requires high voltage DC power supply.

We used PARMTEQ code for beam dynamics optimization for the RFQ [3]. The optimization design parameters include the shaper energy, gentle buncher energy, vane voltage, and the aperture radius. During the optimization, we restricted the RF power and total length no more than 130 kW and 3.3 m, respectively.

Variation of the optimized RFQ parameters as a function of cell number are shown in Figure 2. Design parameters are summarized in Table 1.

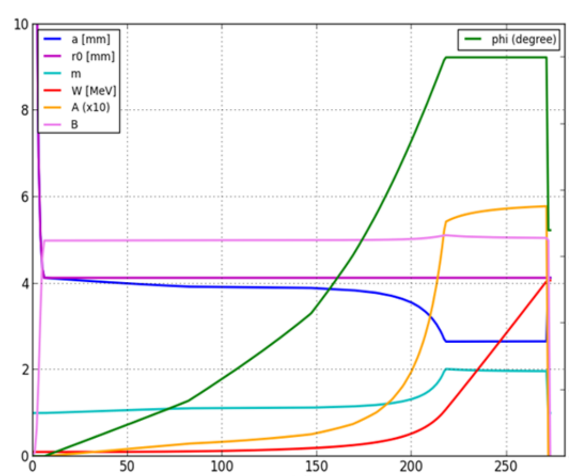

Figure 2: Variation of RFQ parameters.

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Table 1: Summary of the RFQ Design Parameters

Parameter	Value
Particle	$^4He^{2+}$
Vane voltage	72 kV
Input beam energy	100 keV
Shaper energy	0.112 MeV
Gentle buncher energy	1.05 MeV
Output beam energy	4 MeV
Peak beam current	10 mA
Emittance (nor. Rms)	0.2 π mm mrad
Type	Four vane
RF frequency	200 MHz
RF power	126 kW
Maximum electric field	1.63 Kilpatrick
ρ/r_0	0.87
Length	3158.92 mm
Transmission	97.6 %

We carried out the error analysis including the displacement, divergence, energy, and beam emittance of the input beam. The results are given in Figure 3.

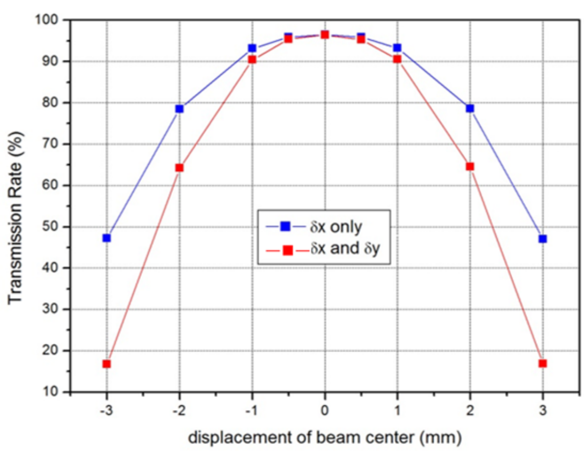

Figure 3(a): Beam transmission as a function of displacement.

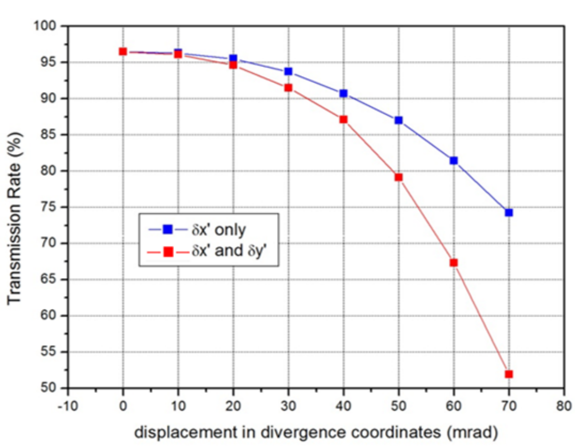

Figure 3(b): Beam transmission as a function of divergence.

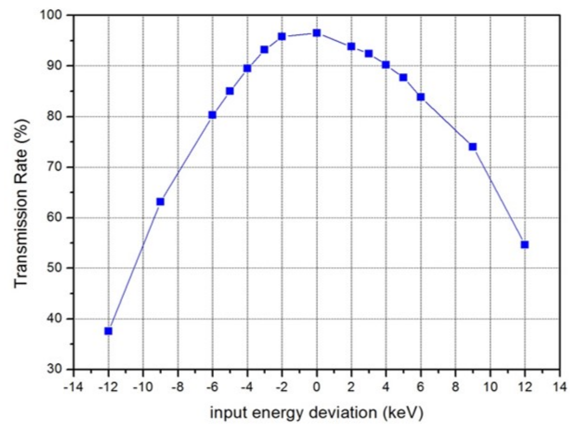

Figure 3(c): Beam transmission as a function of input energy.

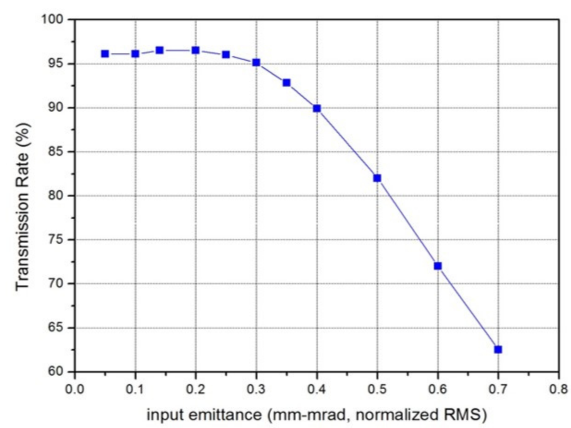

Figure 3(d): Beam transmission as a function of emittance.

Cavity Design

RFQ cavity is designed as a four-vane structure made of OFHC. It consists of 3 sections and each section is about 1 m long. Under cut region at both ends of the structure is designed such that it results in flat field distribution better than 1 %. Each quadrant of single section contains four ports and total number of ports are 48. Eight of them are used for vacuum pumping and two of them are for RF power couplers. Rest of them are dedicated for slug tuner ports. Slug tuner diameter is 70 mm and the frequency shift of 1 MHz is estimated with 9.7 mm insertion.

Four vanes and four quadrant are joined by using vacuum brazing to make a section and three sections are assembled by using flanges. Wall thickness of the cavity is determined to be 45 mm to give enough mechanical stability and space for cooling channel. Total average heat load on the cavity with 10 % RF duty is estimated to be about 10 kW. To limit the temperature increase of the RFQ cavity, we designed cooling channels such that two channels on each quadrant and one channel at each vane. Required coolant flow rate is about 12 lpm per each cooling channel. The cooling channel will be machined as through hole by using a gun drill and plugged at both ends by vacuum brazing. Figure 4 shows the designed RFQ on the support structure.

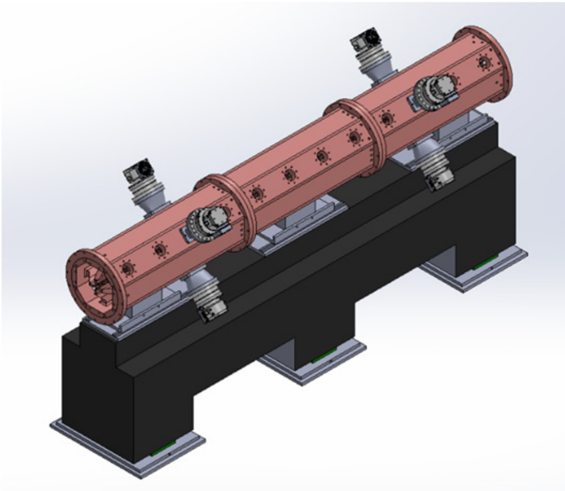

Figure 4: Designed RFQ.

FABRICATION STATUS

To make a RFQ cavity, twelve pieces of vane and the same number of pieces of quadrant are needed. All of the vanes and quadrants are rough-machined as shown in Figure 5, waiting for heat treatment to release the stress during machining. During the heat treatment, the cooling channels are plugged. For that purpose, Au-Cu brazing alloy will be used. Brazing temperature of the Au-Cu alloy is as high as 1000 degree centigrade and that makes it possible to apply second brazing for assembling a section from four vanes and four quadrants by using Ag-Cu alloy.

We prepared a vacuum furnace for brazing as shown in Figure 6. Base pressure of the furnace is better than 5E-7 torr and maximum temperature is 1200 degree centigrade. Effective working volume is 800 mm in diameter and 1900 mm in height.

Figure 5: Rough machined RFQ vanes and quadrants.

Figure 6: Vacuum brazing furnace.

The room for installation of the ion beam irradiation system is also prepared as shown in Figure 7. The size of the room is 15 m by 9 m. The magnetic LEBT system, RFQ support structure, and the beam line quadrupoles were already installed in the room.

For the high power RF system, a solid state amplifier with 240 kW peak power at 200 MHz was procured as well as RF transmission components such as a rigid coaxial lines, coaxial RF window, RF circulator, and high power dummy load. A digital LLRF system is developed based on commercial FPGA with direct sampling and non-IQ modulation features [4].

Figure 7: Room for ion beam irradiation system.

SUMMARY

A 200 MHz, four-vane type RFQ for ion beam irradiation system is under development at KOMAC. Design is finalized and cavity is under fabrication. Subsystems such as RF system, cooling system, and control system is under preparation and most of them were already installed at a dedicated room. Fabrication and installation of the RFQ will be finished by the end of this year.

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