DESIGN OF THE 4 MeV RFQ FOR THE HELIUM BEAM IRRADIATOR*

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Abstract

A radio frequency quadrupole (RFQ) is considered as a main accelerator of the helium beam irradiation system for the power semiconductor in Korea Multipurpose Accelerator Complex (KOMAC) The RFQ was designed to accelerate the He2+ beam up to 4 MeV with 10 mA peak beam current. We chose a vane type RFQ with 200 MHz operating frequency. The RFQ will be operated with the frequency tracking mode supplied by the digital low level RF control system. In this paper, the design of the 4 MeV RFQ is presented and the beam irradiation system including RF system, control system, utility system, is discussed.

INTRODUCTION

Power semiconductors are widely used in power converter and inverters and need to have higher voltage and current ratings with high frequency. It is necessary to reduce the switching loss in addition to the conduction loss in order to achieve the above requirement. There are several methods to enhance the switching characteristics such as gold diffusion, irradiation of gamma ray and irradiation of particle beam (for example electron or proton). Recently, irradiation with helium beam is under research for the complimentary method with the existing one.

A RFQ for helium beam is proposed by KOMAC for the purpose of the irradiation to semiconductor [1]. At first, the energy of the system was proposed as 3 MeV but we increased the energy up to 4 MeV in consideration that the penetration depth in the silicon is more than 15um and 1 MeV/u system has more application fields. The requirements of the irradiation system are summarized in Table 1.

Table 1: Requirements of the Helium Beam Irradiation System

Parameter	Value
Particle	Helium
Target	Silicon
Penetration depth	15um
Wafer size	8 inch
Dose	1×10^{14} / cm^2
Uniformity	± 3%
Production rate	500 wafers / day

The energy of the RFQ was determined from the possible penetration depth of the helium into the silicon. The calculation by using SLIM code showed that 4 MeV helium beam can penetrate 18um into the silicon. The average current was determined by the required dose and production rate. The irradiation time was less than 10 seconds when the average beam current was 0.1 mA. The specifications of the accelerator based on the above requirements are summarized in Table 2. The system consists of ion source, low energy beam transport (LEBT), RFQ, medium beam energy transport (MEBT), target system, RF system, vacuum system, beam diagnostics, control system and utilities including cooling water system and electricity. The block diagram of the system is shown in Fig. 1. The red dots include the main hardware system and the blue dots include the ancillary system.

Table 2: Specifications of the Accelerator

Parameter	Value
Particle	$^{4}He^{2+}$
Beam energy	4 MeV
Peak beam current	10 mA
Beam duty	0.1%

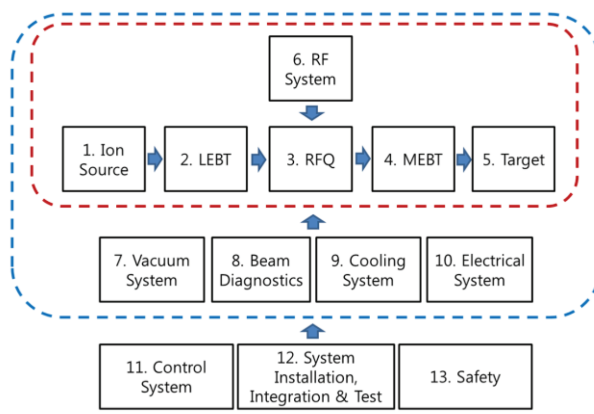

Figure 1: Block diagram of the helium irradiation system

SYSTEM DESIGN

Ion Source

The 2.45 GHz microwave ion source will be used as an ion source. The same type ion source has been used for KOMAC 100 MeV proton linear accelerator for 3 years. One of the characteristics of the microwave ion source of KOMAC 100 MeV proton accelerator is such that it uses single solenoid for system compactness. But the microwave ion source will be modified to have two solenoid magnets to produce mirror fields in order to facilitate the $^{4}He^{2+}$ production and enhance the confinement. Also the extraction geometry will be

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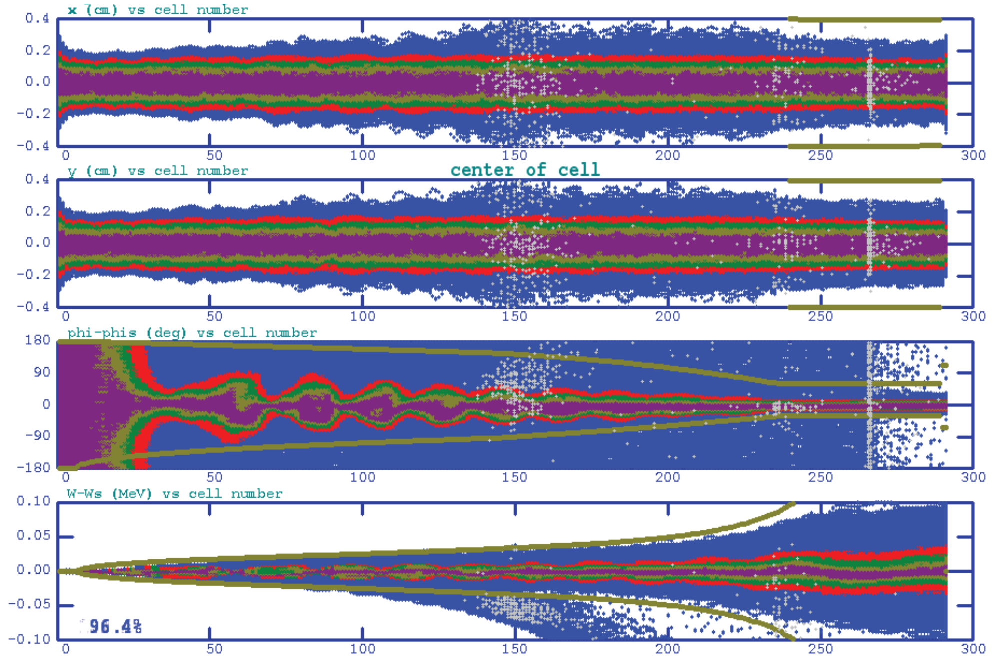

Figure 2: Beam trajectory through RFQ (1: x vs cell number, 2: y vs cell number, 3: $\Delta\phi$ vs cell number, 4: ΔE vs cell number)

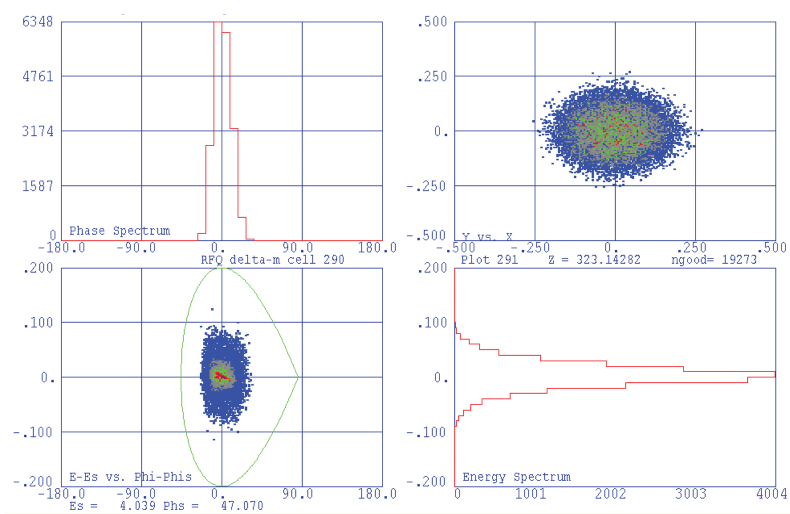

Figure 3: Output beam properties (upper left: phase spectrum, upper right: x vs y lower left: $\Delta\phi$ vs ΔE, lower right: energy spectrum)

optimized for the $^{4}He^{2+}$ beam. The extraction energy from the ion source is 100 keV (25 keV/u) and the peak beam current is 10 mA. The electrostatic lenses are considered at low energy beam transport for compactness and we are going to reduce the LEBT length as short as possible.

RFQ

The basic design parameters of the RFQ are the RF frequency of the cavity and the RF duty of the RF system. We chose the RF frequency of 200 MHz in order to avoid klystron as a RF amplifier which requires complicated high power RF system. For the RF duty, we chose 10% which is manageable and need not big cooling system.

We performed the basic structure design and the beam dynamic study. When we design the RFQ, we considered two points. The first is to limit the maximum RF power less than 200 kW in consideration of the RF source and the second is to limit the total length less than 3.2 m in

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consideration of the available brazing furnace and 4-section RFQ.

The design parameters are summarized in Table 3. We found energy spread is less than ±0.1%, the length is 3.2m which can be manufactured with 4 sections and the total RF power is 116 kW including beam power. The beam trajectory is shown in Fig. 2. Also the output beam properties including beam distribution in phase space are shown in Fig. 3.

Table 3: RFQ Design Parameters

Parameter	Value
Particle	$^{4}He^{2+}$
Input beam energy	100 keV
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	130 kW
Maximum electric field	1.6 Kilpatrick
ρ/r_0	0.87
Length	328 cm
Transmission	95.3 %

The structure is a conventional four vane type without window. The inner width of the cavity is 300 mm and the 100% quality factor is 13,400. The frequency sensitivities on the vane tip and vane wall displacement are 6.2 MHz/mm and 0.8 MHz/mm respectively. The frequency sensitivity of the cavity is 4 kHz/°C.

RF System

The total required RF peak power is 200 kW which includes 80% Q degradation in the cavity, 20 kW beam power, 10% loss in the transmission line and 20% control margin. The design strategies of the RF system are 1) Full digital LLRF system 2) Frequency tracking to the RFQ cavity 3) Two couplers in order to maintain the symmetrical perturbation into the RFQ cavity. To fulfill the full digital LLRF system, we are going to directly get the 200MHz RF signal with IQ modulation and produce 200MHz RF signal directly from the NCO by using commercially available signal processing digital board. In addition, we are going to implement the frequency tracking availability in the LLRF system in order to eliminate the cavity frequency stabilization system such as a movable tuners or resonance frequency control cooling system. The schematic diagram of the control system is shown in Figure 4. For frequency tracking, the temperature of the cooling system for RFQ should be within ± 2.5°C, which is easy to control by using commercial chiller system, based on the 4,700 of the loaded Q, 20% control margin and 4 kHz/°C cavity sensitivity.

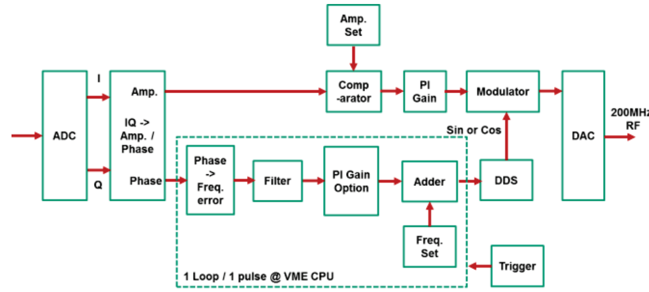

Figure 4: Schematic diagram of the LLRF control system

We consider the solid state RF amplifier for the high power RF system for the helium RFQ. The coaxial disk type window will be used for the RF window because of its compactness and well proven technology. Also coaxial coupler with loop is used because of the easy adjustment of the coupling coefficient.

Other Ancillary System

The base line of the control system will be based on the EPICS, which is well used for the control system of the KOMAC 100MeV proton accelerator. In addition, we are going to prepare the system based on the Ethernet based communication which includes the IOC inside. The power capacity of the electricity which is required for the system is 200 kW in 220 V, 3-phase. The required cooling water flow rate is 33 m^3/hr to limit the temperature increase of the RFQ structure within 1°C.

Building and Schedule

The construction of the beam utilization building where the helium irradiation system will be installed was started at Oct. 2013 and will be finished at Dec. 2014. It is located beside the accelerator building in the KOMAC site. Several rooms are prepared to accommodate low energy ion implanters in addition to the helium irradiation system. The room sizes for the helium system are 15 m × 9 m. The mile stone of the helium system is to complete the design, develop one section model of the RFQ and develop RF system in this year. And all of the system are planned to be installed by the end of 2015.

CONCLUSION

A design study on the helium beam irradiation was carried out. Most of the technologies including the ion source, RFQ, RF system and control system were already well developed through the KOMAC 100MeV proton linear accelerator development. The system will be installed by the end of 2015.

REFERENCES

[1] Yong-Sub Cho, et al., Basic Design Study of RFQ for Helium Implantation in Power Semiconductors, Transactions of the Korean Nuclear Society Spring Meeting, Gyeongju, Korea, Jeju, Korea, 2012.