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RFQ Based Helium Beam Irradiation System

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1. 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 high efficiency. There are several methods to enhance the switching characteristics, for example, gold diffusion, irradiation of gamma ray and irradiation of particle beam such as electron beam or proton beam. Recently, irradiation with helium beam is gaining interest and under research for the complimentary method with the existing one.

For the purpose of the helium beam irradiation to the semiconductors, a RFQ is proposed by KOMAC [1]. The output energy of the RFQ is determined to be 4 MeV to make the penetration depth in the silicon more than 15um. The basic requirements of the irradiation system are summarized in Table 1. 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 estimated to be 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.

Table 1. Requirements of the He 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

Table 2: Specifications of the accelerator system

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

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. The overall layout of the irradiation system is shown in Fig. 2.

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 proton injector. One of the characteristics of the microwave ion source of the KOMAC 100-MeV proton accelerator is such that it uses single solenoid for system compactness. The microwave ion source for helium beam irradiation system will be modified to have two solenoid magnets to produce mirror fields in order to facilitate the $^4He^{2+}$ production and enhance the confinement. In addition, the extraction geometry will be optimized for the $^4He^{2+}$ 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 as a low energy beam transport system for compactness.

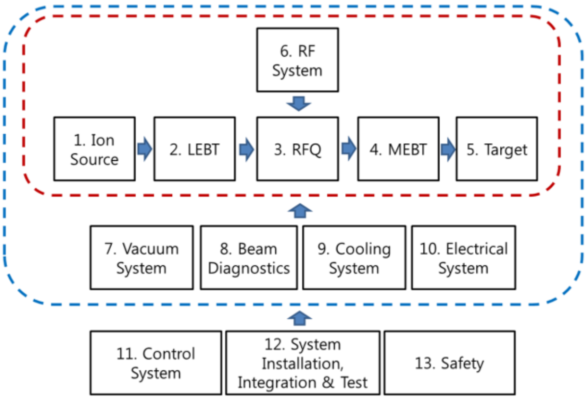

Fig. 1. Block diagram of the helium irradiation system

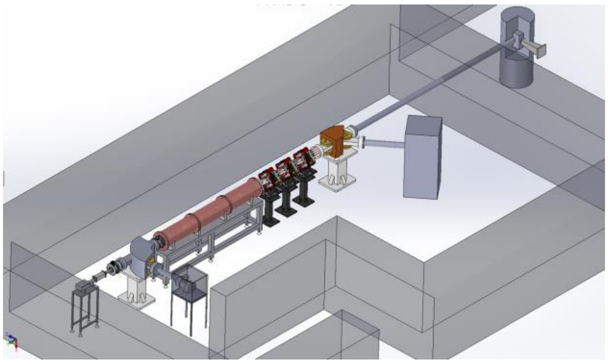

Fig. 2. Overall layout of helium irradiation system

2. RFQ Design Study

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 no 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 consideration of the available brazing furnace and 3-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 3 sections and the total RF power is less than 130 kW including beam power. The beam trajectory is shown in Fig. 3. Also the output beam properties including beam distribution in the phase space are shown in Fig. 4.

Table 3: RFQ design parameters

Parameter	Value
Particle	$^{4}He^{2+}$
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 %

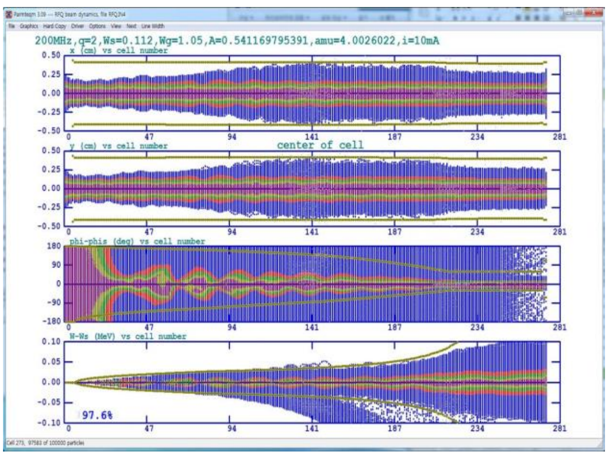

Fig. 3. Beam dynamics results through RFQ

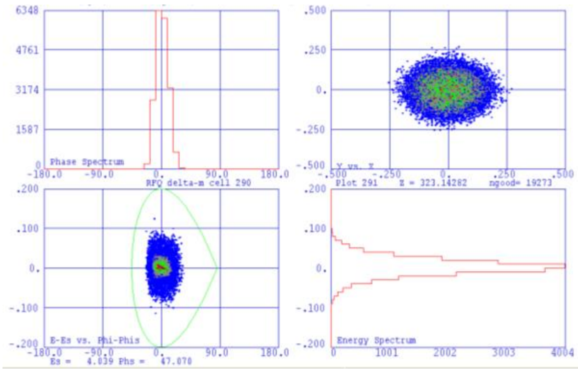

Figure 4: Output beam properties
Upper left: phase spectrum, upper right: x vs y
Lower left: $\Delta\phi$ vs ΔE, lower right: energy spectrum

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 estimated to be about 13,400. The designed RFQ is shown in Fig. 5.

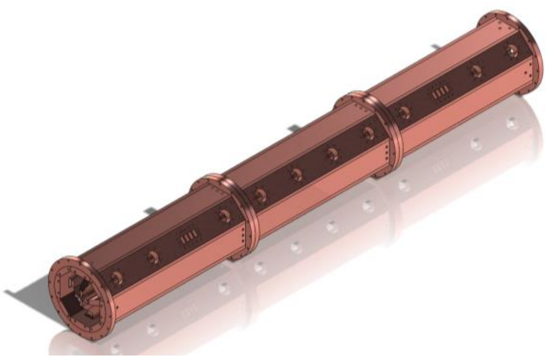

Fig. 5. Designed RFQ

3. 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 100-MeV proton linear accelerator development. The RFQ is under fabrication and all of the system are planned to be installed by the end of 2015.

Acknowledgements

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REFERENCES

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[2] H. J. Kwon, et al., Design of the 4 MeV RFQ for the Helium Beam Irradiator, proceedings of LINAC2014.