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# Design Study for Helium Beam Irradiation from RFQ on Circular Targets

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## 1. Introduction

Implantation of the helium ions of a few MeV into semiconductors is a method to make devices efficient. Cyclotrons and electrostatic accelerators are commonly used to obtain the accelerated helium beams. They can accelerate beam currents up to 10μA. So it takes long time in the irradiation process. However RFQ (radio frequency quadrupole) can accelerate more than 1mA. Considering this advantage, we have studied the RFQ to accelerate helium ions of 0.1-mA current and 3-MeV energy for power semiconductor production. At the same time, we have studied a simple and reliable method for uniform irradiation with beams a few mm in diameter on silicon wafer which is circular and more than 200mm in diameter.

## 2. Helium RFQ Design

The design requirements for this design study are summarized in Table 1. The RFQ has been designed with PARMTEQM code [1] and Table 2 shows the results of the simulation.

Table 1. RFQ design requirements.

| Parameters | Values |
|---|---|
| Reference Particles | $^4He^{2+}$ |
| Frequency | 200 MHz |
| Input Energy | 10 keV/u (40 keV) |
| Output Energy | 750 keV/u (3MeV) |
| Beam Current | 0.1 mA |
| Beam Duty | 2% |
| Kilpatrick | < 1.8 |

Table 2. RFQ beam parameters (PARMTEQM result).

| Parameters | Values |
|---|---|
| Energy | 3.06 MeV |
| Energy Spread | ±0.1MeV |
| Transmission Rate | 97.8% |
| Input Emittance (rms) | 0.2 mm-mrad |
| Output Emittance (rms, transv.) | 0.2 mm-mrad |
| Output Emittance (rms, long.) | 0.27 deg-MeV |
| RF power | 130kW |
| Kilpatrick (max.) | 1.69 |
| RFQ length | 2,954mm |

We found that the RFQ is 2.95m long, transmission rate is 97.8%, and the energy spread is ±0.1 MeV. The required rf power is estimated to 130 kW. The simulated beam size is 2 mm in diameter at the exit of the RFQ as shown in Figure 1.

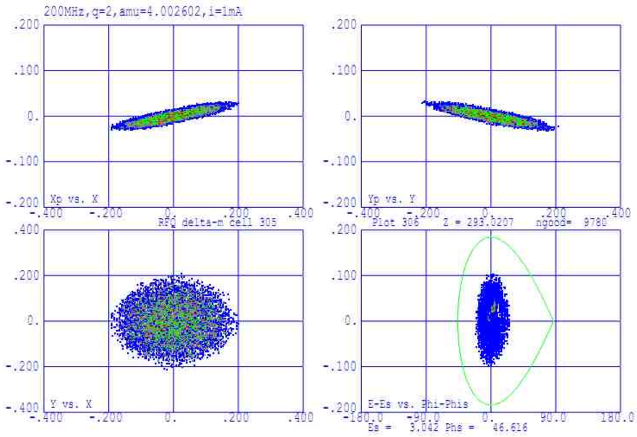


Fig. 1. RFQ output beam in phase spaces.

The specification of the high power RF system is 200kW by considering the 20% shunt impedance degradation, 10% transmission loss and 10% control margin. Figure 2 is the RF system for the RFQ.

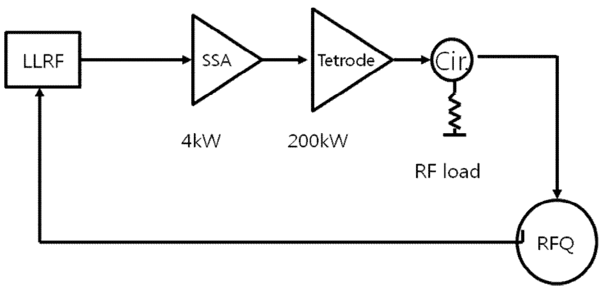


Fig. 2. RF system for the case of a tetrode amplifier.

The system consists of single RFQ cavity. Therefore it is easier to change the driving frequency following the cavity frequency than to keep the cavity frequency constant, because cavity resonant frequency control systems such as movable tuners or temperature controlled cooling system are required to keep the cavity constant. The low level RF system to control the RF frequency and amplitude is planned by using the FPGA based digital control technology. By comparing the pickup signal with the reference signal, the error signal can be used to change the driving frequency by using the internal DDS. The PI control logics are implemented in the FPGA to control the DDS and RF amplitude.

## 3. Wobbler Design

A simple and reliable method for irradiation on a circular target is to use a Scott transformer which transforms a 3-phase ac power to two single-phase ac powers with 90 degree phase difference as shown in Figure 3. If we apply the two single-phase ac output from the Scott transformer to a wobbler which is a pair of a horizontal- and a vertical- magnetic deflectors, the beam trajectory on the target is circular. As we control the amplitude of the 3-phase ac input, we can control the radius of the circle.

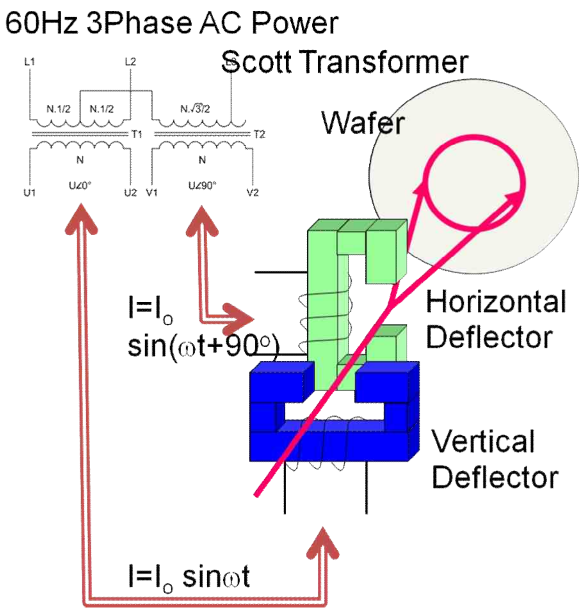


Fig. 3. Irradiation on a circular target.

## 4. Beam Irradiation System Design

The design requirements for the beam irradiation system are shown in Table 3.

Table 3. Beam irradiation design requirements.

| Parameters | Values |
|---|---|
| Wafer size | >200mm diameter |
| Wobbling frequency | 60Hz |
| Beam repetition rate | 134Hz |
| Dose | ~$1x10^{14}cm^{-2}$ |
| Irradiation uniformity | ±3% |
| Dose | 10 keV/u (40 keV) |
| Process rate | >500 sheets/day |
| Water cooling | <10kW |
| Electricity | <20kW |

With this simple irradiation method with a Scott transformer, the schematic diagram of the whole system is shown in Figure 4. We are considering a microwave ion source for this system. The irradiation rate can be controlled by changing the beam pulse width from the ion source. The study for radiation shielding system, which can be a constraint for the design, is required for the real system. And also a heat removal method from the wafer due the beam power and an automatic loading-and-unloading system for wafers in the stage with a conveyer is important topics for the real system.

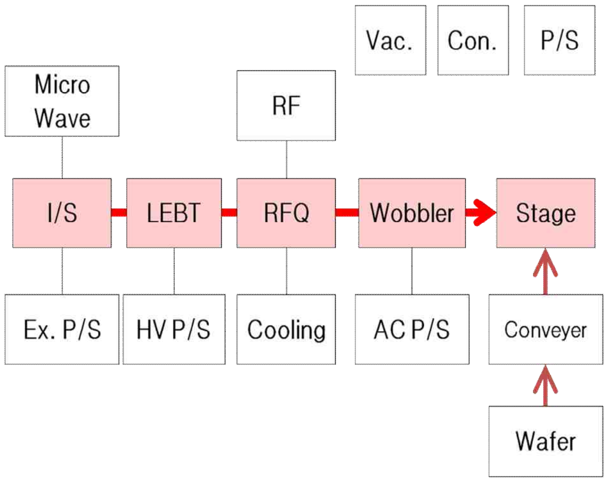


Fig. 4. Irradiation system with RFQ system.

## 4. Conclusions

We have designed a RFQ as a He accelerator for implantation. With the output beam from this accelerator, we have studied an irradiation system for circular targets such as silicon wafers for power semiconductors. In this study, we have used a Scott transformer for a simple and reliable irradiation device. The feasibility study with detail designs will be done.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] K. R. Crandall, T. P. Wangler, L. M. Young, J. H. Billen, G. H. Neuschaefer, D. L. Schrage, “RFQ Design Codes”, LA-UR-96-1836.