EXTRACTION AND TRANSPORT OF THE HIGH CURRENT ION BEAM

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Abstract

Design and construction of the ion beam extraction and transport system of a high current ion implanter for industrial applications are described. A duoPIGatron ion source with a multi-beamlet has provided the nitrogen ions current about 100 mA. The beam divergence due to the space - charge effect during acceleration and transportation is surveyed, and the electrostatic suppression and the neutralization of space charge are discussed.

Introduction

Recent industrial applications of the high current ion beams, such as buried dielectric layer formation in silicon by oxygen ion implantation and surface modifications of the ferrous materials by nitrogen ion implantation, require very high implant doses in the range of $10^{17} \sim 10^{18}$ ions/cm^2 in view of the stoichiometric requirements. Hence, the commercial ion implanters must satisfy the performance conditions of the beam current of a few 100 mA and the energies $100 \sim 200$ keV for the high through-put.

A nitrogen ion implanter of very high current has been constructed to accomplish high dose implantation. It is well known that for the high current and low energy ion beam devices there exist fundamental and physical limitations on the extraction current density from the ion source and the divergence of the beam in the transport system. One of the important factors for the limitations is the space-charge effect on the plasma boundary of the beam extraction system in the ion source and on the way of beam transport system. Proper design of the beam extraction system and the beam transport system is essential to overcome and at least reduce these limitations.

In this paper the concepts of the space-charge compensation and neutralization by the electrons are applied to a design of the high current beam extraction and transport system.

Implanter Configuration

A schematic diagram of the nitrogen ion implanter is shown in Fig.1. The beam line without a mass

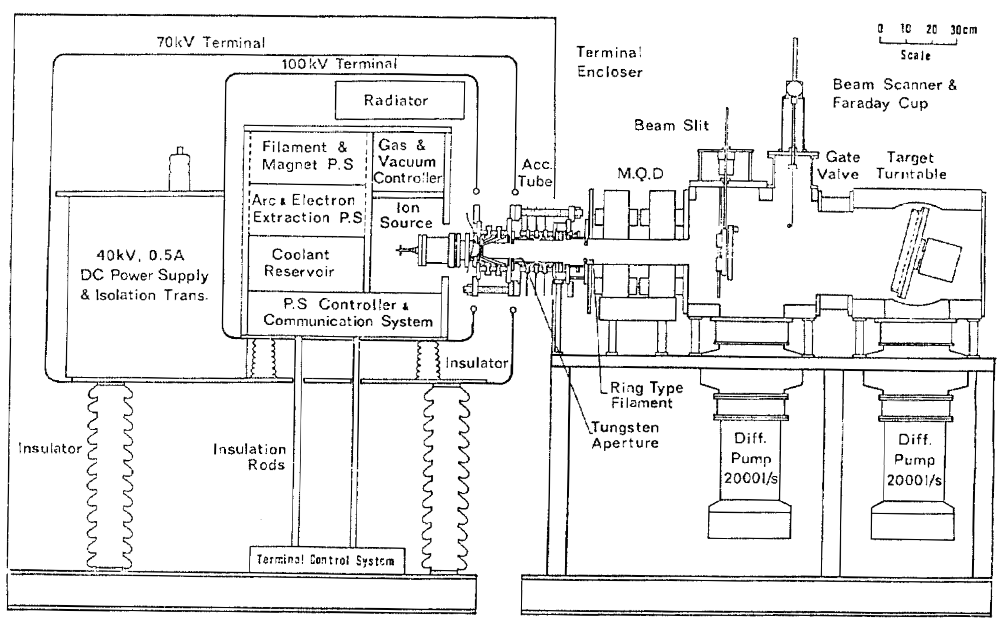

Fig.1. Schematic drawing of a high current nitrogen ion implanter.

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Table 1. Design parameters of the nitrogen ion implanter.

Beam Energy	100 kV
Beam Current	~ 100 mA
Ion Source	DuoPIGatron
Beam Current	≥ 100 mA
Extraction Voltage	30 kV
Filament	Th-W
Accelerator Tube	Single Gap
Accelerating Voltage	70 kV
Gap Distance	15~30 mm, Variable
Aperture Diameter	85mm
Beam Focusing & Shape Control	Magnetic Quadrupole Doublet, 2-D Control
Beam Diagnostics	Faraday Cup & Beam Scanner
Vacuum	Accelerator : 2000 ℓ/sec
	Target : 2000 ℓ/sec
Operation Pressure	1 x 10^{-5} Torr
Target	2-D Rotating
Turntable Dia.	310 mm
Workpieces Cooling	Ternary Eutectics
Irradiation Time(Plate)	~ 5 min.

analyzing system is composed of an ion source, an accelerator tube, quadrupole lenses, beam diagnostic system and target. Ions are extracted from the ion source at an energy of 30 keV and then accelerated further to 100 keV through the accelerator tube. Major design features are as follows ;

- Modification of the beam extraction system in the conventional duoPIGatron to improve the beam quality and to increase the beam current with principle of the space-charge compensation
- Design of the high current accelerator tube which makes it possible to control the ion optical properties and suppress the space-charge effect
- Development of the 2-D rotational turntable type target in order to provide a high density beam irradiation and the inner surface irradiation of workpieces
- Magnetic quadrupole doublet to control the two-dimensional beam size at the target
- Faraday cups and beam scanners which can monitor beam current density and profile in the horizontal and vertical planes
- Development of the beam transport system for the high beam current with the concepts of the space-charge neutralization by thermal electron

Design parameters of the implanter are listed in Table 1. Fig.2 is a photograph of the assembled implanter.

Ion Source and Beam Extraction System

In order to produce high current ion beam with good quality and reliability, a duoPIGatron ion source [1] is modified.

The source is designed for two different operational modes of plasma generation, the conventional hot-cathode reflex arc mode and modified reflex arc mode in which plasma generation is initiated by controlled electron beam emitted from the cathode.

The schematics for the modified reflex arc mode is shown in Fig.3. In difference with the conventional electron beam ion source(EBIS), electron beam is extracted from the cathode in the intermediate electrode as a same direction of the ion beam. Therefore, the beam electrons with a high energy are effectively used in order to reduce an ion space-charge effect due to a low velocity of the ions near the plasma surface of the extraction region.

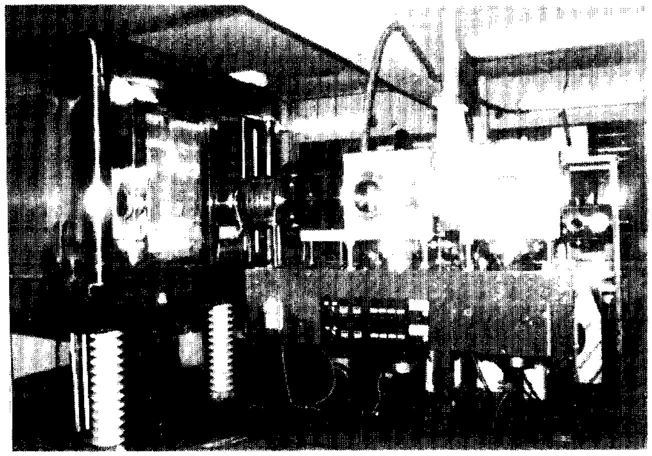

Fig.2. Photograph of the implanter

When the ion space-charge compensation by electron is effective, theoretically, the divergence of an ion beam is suppressed, the space-charge limitation of an extractable ion current is relaxed, and the shape of an ion-emission surface is improved [2].

Special attention is placed on the design of a radiation shielding electrode to protect the insulators from X-ray produced by the backstreaming electrons and to reduce the spark discharges in the high gradient potential.

Fig.4 shows the extracted ion current as a function of the magnet current in the conventional mode operation. The extraction currents are strongly dependent on the magnetic field in the plasma generation region, which is related to the density of the plasma generated by the confined electrons on the field line.

The results of the modified mode show that the extraction ion current is saturated on a few mA range caused by limitations of plasma density in the plasma generator. But high current beams are expected by means of improvement of the electron optics in the electron extraction system including the cathode shape.

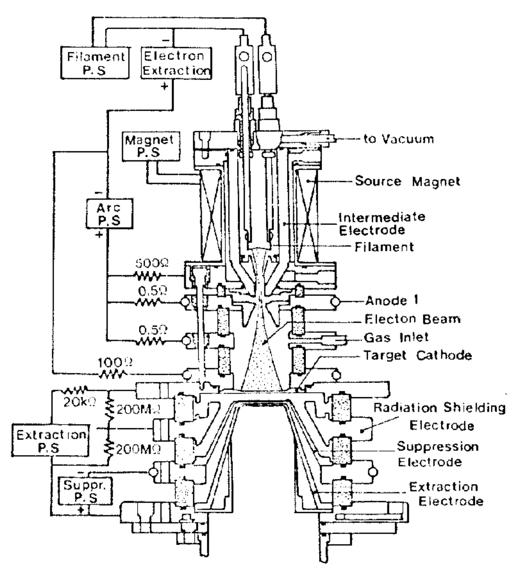

Fig.3. Schematics of the modified duoPIGatron.

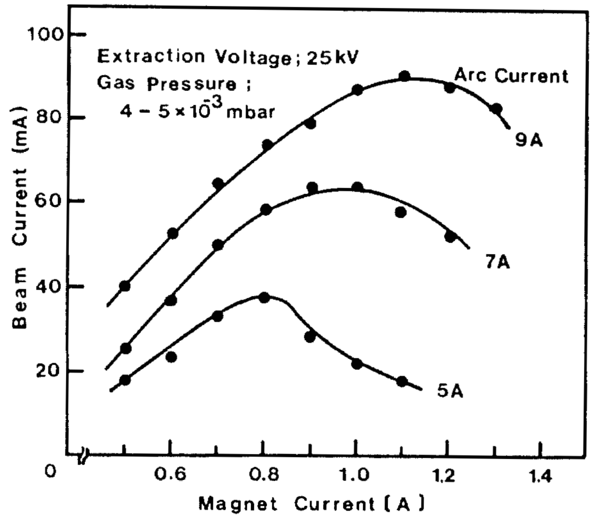

Fig.4. Beam current versus magnet current as a function of arc current for the conventional mode operation.

Accelerator Tube and Beam Transport System

The space-charge effect in a high current beam can exert a profound influence on the ion trajectories. Especially a non-neutralized ion beam is rapidly diverged by the transversal strong repulsive forces. In order to suppress the expansion effect due to the space-charge, the accelerator tube and beam transport system require an appropriate design.

Two concepts for the suppression of space-charge may be applied;

- The space-charge neutralization method in the axial electric field free region
- The electrostatic suppression method in the acceleration region

In the field free region between the beam extraction electrode and the accelerator tube, a tungsten aperture with a diameter of 70 mm is placed. When ions hit the rim of the aperture, secondary electrons are produced. These electron can be trapped by a biased potential of 1.5 kV on the extraction electrode and will effectively neutralize the extracted ions.

In the drift region after accelerator tube, it is usually found that the ion beam is always neutralized by the secondary electrons from the target. For effective trapping of the electrons, a negative electric potential of 1.5 kV is applied on the axis in the lower column of the accelerator tube. A ring type filament placed at the end of the accelerator column can supply thermal electrons for the space-charge neutralization.

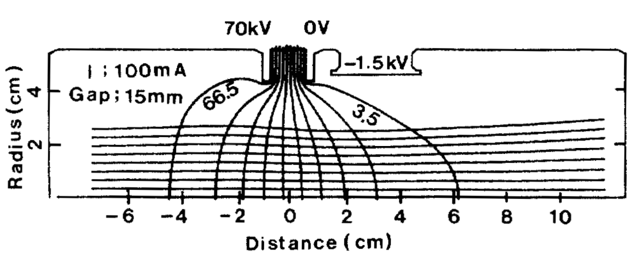

Fig.5. An example of the ray-tracing calculation used in the accelerator tube design. [ion species ; N^{+}(50%)+N_2^{+}(50%), initial energy : 30 keV]

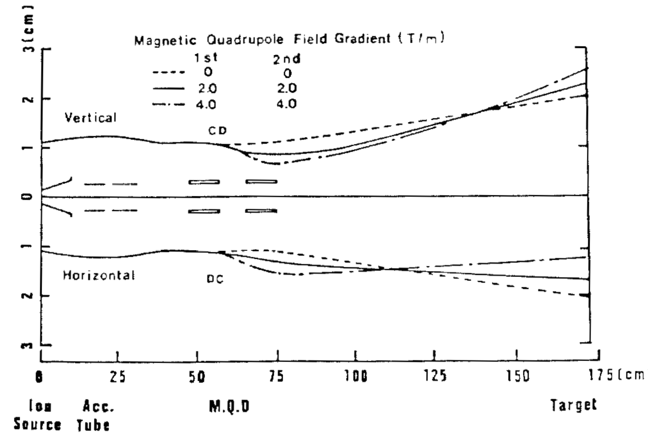

Fig.6. Calculated beam envelopes in the condition of complete neutralization in the beam transport system.

An accelerator tube is designed with a single gap of variable spacing to achieve a strong focusing in the electrostatic fringing field and to suppress the diverging effect from the space- charge expansion [3]. The gap spacing variation can adjust the optical properties of the accelerator tube for the compensation of the diverging effect in proportion to the beam current.

Ray-tracing calculations have shown that this method of suppression is effective over wide range of operating current. Fig.5 shows an example of the ray-tracing calculation. Fig.6 represents a beam envelope in the beam transport system which is calculated by the "BOTDM" computer code [4] assuming complete neutralization.

Conclusion

A nitrogen ion implanter with the ion beam current up to 100 mA and the energy of 100 keV providing much potential for engineering applications is designed and assembled, and now under the performance test. The duoPIGatron ion source is modified to improve the extractable ion current and beam quality using the concepts of the space- charge compensation in the beam extraction region by electron beam. Also two methods, the electrostatic suppression in the acceleration tube and the space-charge neutralization in the axial field free region, are studied to prevent the beam divergence due to the space-charge effect in the high current beam line.

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