# High-current Oxygen Ion Implanter for SIMOX

## — For volume production of SOI wafers that enable realization of high-speed, low-power LSIs —

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*OVERVIEW: SOI (silicon on insulator) technology* has attracted a lot of attention as a promising breakthrough technology for high-speed, low-power LSIs. Research and development aimed at its practical use are now being conducted over a wide range of fields, including circuit design, device, process, and SOI wafer manufacturing. The key to the practical use of SIMOX (separation by implanted oxygen) technology, an important SOI technology, depends on how satisfactory performance we can obtain in ion implanters which are used for implanting oxygen ions into Si to form a buried oxide layer. In ion implanters for SIMOX, practical productivity as well as wafer quality enabling manufacture of advanced LSIs must be ensured at the same time. This requirement leads to the necessity of higher performance implanters enabling high current (50 – 100 mA), high temperature (– 550°C), uniform, low contamination and low particle level implantation, exceeding the concept of conventional ion implantation. Hitachi, Ltd. has developed UI-5000, a high-current oxygen ion implanter for SIMOX. Its basic design concepts are the use of a microwave ion source and a mechanical scanning scheme. The implanter has already been applied to SIMOX wafer production and has shown good performance — it has an implant current of 70 mA during regular operation and an implantation uniformity of 2% or better (determined by film thickness uniformity). This implanter will potentially lead to volume production of SIMOX wafers.*

## INTRODUCTION

WITH the progress of information technology, typically Internet, the needs for higher performance network information processing systems and highly functional portable equipment are rapidly growing. To meet this demand, development of higher speed and lower power consumption LSIs as key components of these systems and equipment is necessary. This has brought about strong interest in SOI (silicon on insulator) technology as the technology that holds the key to this.

From a variety of possibilities, the promising methods of producing SOI wafers have been narrowed down to SIMOX (separation by implanted oxygen) technology$^{1)}$ and wafer bonding technologies. In SIMOX, the SOI structure is formed by oxygen-ion implantation in Si, followed by high-temperature annealing. This process forms the buried oxide (BOX) layer at a fixed depth below the surface, keeping a single-crystalline Si layer (SOI layer) on the top surface.

In response to customer demand, in 1993 Hitachi began developing an ion implanter dedicated to the manufacture of SIMOX wafers. In July 1995 the first implanter, the UI-5000, was delivered. The first system was developed in a relatively short time. This was mainly due to utilization of technologies built up over many years, including expertise in microwave ion source technology; high-voltage, high-current ion beam technology; and conventional ion implanter technology.

This paper outlines the features and system structure of UI-5000, describes the quality of the wafers manufactured, and discusses briefly the direction of future development.

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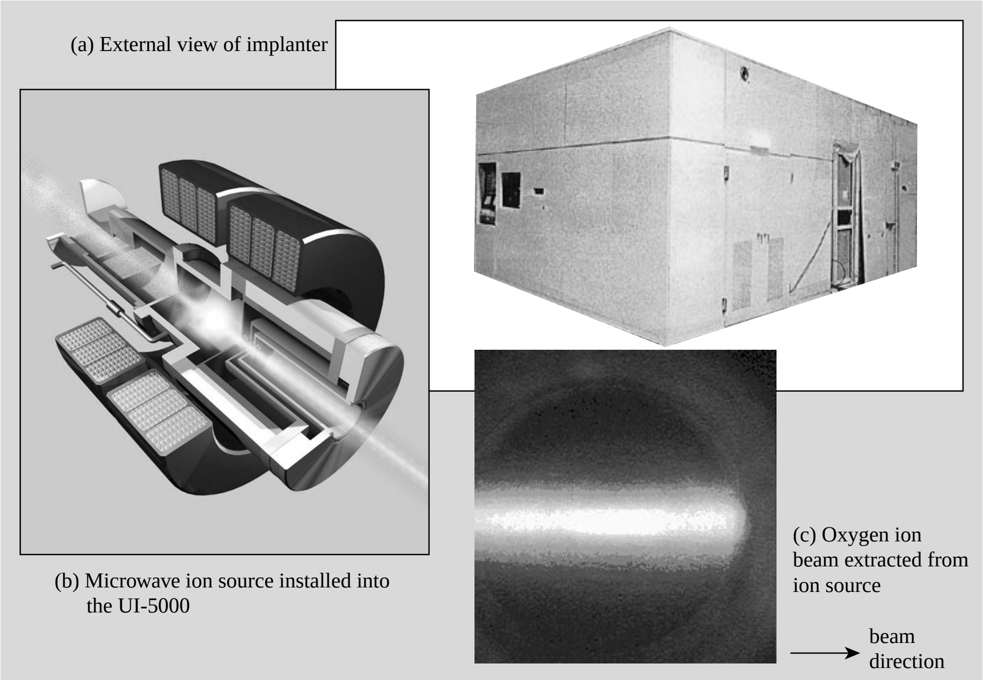
*SOI technology is a semiconductor technology in which the thin silicon layer formed on an insulating film is used as the device area. It is useful for making high-speed, low-power and highly integrated LSIs. SOI wafers are usually made up of three layers; a surface single crystalline layer, a buried oxide layer, and a Si substrate. To apply to CMOS LSIs, the surface single-crystalline layer must be 50 – 200 nm thick and of uniform thickness.



(a) External view of implanter

(b) Microwave ion source installed into the UI-5000

(c) Oxygen ion beam extracted from ion source

*Fig. 1—High-Current Oxygen Ion Implanter UI-5000 for Volume Production of SIMOX Wafers.*
*Hitachi's years of experience in microwave ion source technology have helped it develop an oxygen ion implantater with a practical implant current of 70 mA.*

## REQUIREMENTS FOR IMPLANTER

The requirements for the ion implanter for SIMOX are as follows:

### Productivity

The oxygen ion dose needed for 'low-dose' SIMOX is about $4 \times 10^{17}\text{cm}^{-2}$, which is 2 or 3 orders of magnitude larger than conventional implantation for impurity doping in semiconductors. The practical target for wafer productivity is about 20 - 30 thousand wafers (200 mm in diameter) per implanter per year. This target is equivalent to a throughput of 2.7 - 4 wafers per hour. For such a high-dose implantation, throughput is mainly determined by implantation time. To increase the throughput, we must increase the ion beam current. At least 50 mA and a maximum of 100 mA are required at usual operation of the implanter.

### Implantation Quality

Wafer heating: To maintain the single crystallinity of the Si surface, we have to keep the temperature of the wafer at around 550°C during implantation (hot-ion implantation).

Uniformity: To apply SOI wafers to device fabrication, we must ensure that the SOI and BOX layers have uniform thicknesses. The ITRS (International Technology Roadmap for Semiconductors) value for thickness uniformity is 5%, but current market requirements are more stringent at 2%. The target for the dose uniformity is around these values.

Contamination and particles: Although these requirements are common to all ion implanters, they are more strict for SIMOX ion implanters since in SIMOX implantation, the implantation time is 10 and 1,000 times longer than that of conventional ion implantation.

Table 1 shows the specifications of UI-5000 prescribed according to the above requirements.

## DEVELOPMENT CONCEPT AND IMPLANTER STRUCTURE

### Basic Concepts

In the development of an implanter satisfying the above requirements and specifications, the most important points are the selection of an ion source

TABLE 1. Specifications of UI-5000
*Specifications have been determined to ensure the levels required of both productivity and implantation quality.*

| Item | Specifications |
|---|---|
| Implant energy | 80 – 200 keV |
| Implant current | Normal: 70 mA (180 keV)<br>Maximum: 100 mA (200 keV) |
| Wafer temperature | 550 ± 50°C |
| Implant angle | 0 – 14° |
| Dose uniformity | Less than 3% ($\sigma$) |
| Metal contamination | Order of $10^{10}$ $\text{cm}^{-2}$ |
| Wafer mounted on the disc | 13 (200 mm in diameter),<br>17 (150 mm in diameter) |

| Item | | Method |
|---|---|---|
| High productivity | | Increase in ion beam current → Utilization of microwave ion source |
| High quality | Hot implantation | Lamp heater heating |
| | High uniformity implantation | Mechanical scanning method |
| | | Precise control of scanning speed |
| | | Stabilization of beam position and shape |
| | | Precise control of wafer temperature and its uniformity |
| | Low contamination, low particle | Covering of beam line inner wall with Si plate |
| | | Elimination of contaminants from wafer periphery |
| | | V-shaped beam dump |
| | | Fast cut-off of power supply |
| | | Beam deflection after post-acceleration |
| | | Optimization of wafer holder structure and limitation of holder materials to Si and $SiO_2$ |

TABLE 2. Design Concepts of UI-5000
*This table shows characteristic features of the system design for achieving the performance required.*

having high-current capability and the selection of a scanning scheme suitable for high-current, uniform implantation. Furthermore, careful measures to completely eliminate contamination and particles are required.

A microwave ion source is well-suited for installation into high-current oxygen implanters, because it does not have parts that deteriorate, such as filaments, and it has a long life, even if used in chemically active ions such as oxygen. Hitachi has a lot of experience in the research and practical use of microwave ion sources. Utilizing this technology and optimizing the design for high-current use, we installed these ion sources in the UI-5000.

A mechanical scan method was employed in which the beam position is fixed and a wafer mounted on the rotating disc is scanned by the fixed beam. The advantages of this method are that it ensures implantation uniformity and reduces contamination because the beam profile is unchanged.

Table 2 shows specific features of the implanter design, including the ion source and scanning method. The V-shaped beam dump and high-speed power supply cut-off technologies in the table originate from the technologies applied to the neutral beam injection system for nuclear fusion reactors. The V-shaped beam dump receives and measures high-current beams without causing sputtered particles to spread out. Moreover, a quick cut-off of the power supply when the electric break down takes place in the ion source or the post-acceleration tube minimizes the beam bombardment of the beam-line inner wall and reduces undesirable metal contamination.

## Implanter Structure[2)]

Fig. 2 shows a schematic diagram of the implanter.

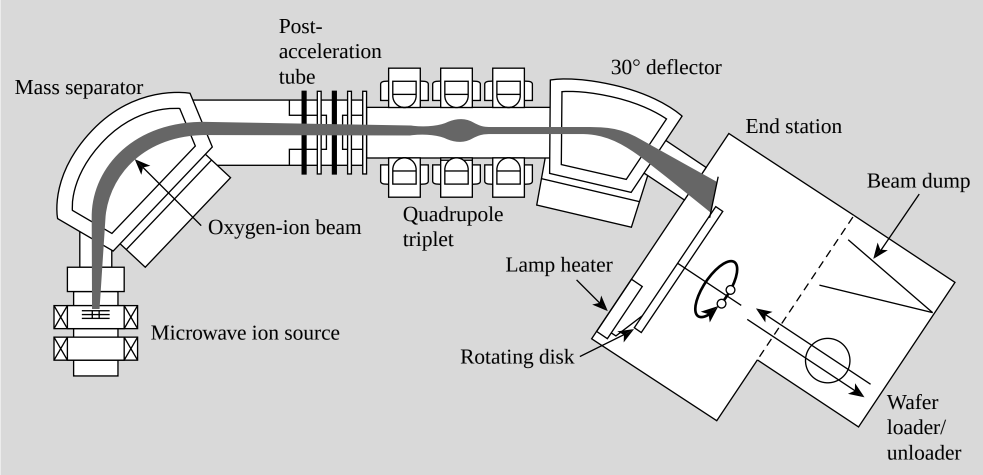


*Fig. 2— Schematic Diagram of UI-5000.*
*The beam size at the wafer position is 40 mm × 100 mm.*

(1) The mass separator selects $^{16}O^+$ from the ion beam extracted from the ion source; (2) the post acceleration tube accelerates $^{16}O^+$ until it has the required energy; (3) the magnetic quadrupole triplet adjusts the beam shape; (4) the 30° deflector removes neutral species and contaminant ions; and (5) the beam impinges on the wafer.

In usual operation, the extraction voltage from the ion source is fixed at around 50 kV and accelerated to the prescribed energy at the post-acceleration tube. The post-acceleration voltage varies from 30 to 150 kV, so, the final implantation voltage is 80 - 200 kV. In the implantation for SIMOX, the implant energy is usually 180 keV.

In the UI-5000, we employed a batch processing in which wafers are mounted on wafer holders arranged along the circumference of the rotating disc. The disc rotates at a maximum of 500 r/min and is mechanically scanned (max. 0.4 Hz). Thus, implantation is done for the whole wafer surface. The scanning speed is inversely proportional to the distance between the beam center and the disc center, which ensures uniform implantation. The beam current is at all times measured and the implant dose is accurately controlled by integrating the beam current value. The wafer is heated using a lamp heater installed in the end station wall, facing the wafer. The implanter uses a cassette-to-cassette wafer load/unload method, which makes it fully automated.

## IMPLANTER PERFORMANCE AND WAFER QUALITY

The implanter must have both high productivity and high quality. For high productivity, a high implant current is necessary. It is crucial for implanter productivity that the prescribed implant current be obtained. In contrast, implantation quality depends on the overall effects of the combination of approaches shown in Table 2. Therefore, rather than describe the performance of each part of the implanter, this section discusses the results of an evaluation of the implanted wafers.

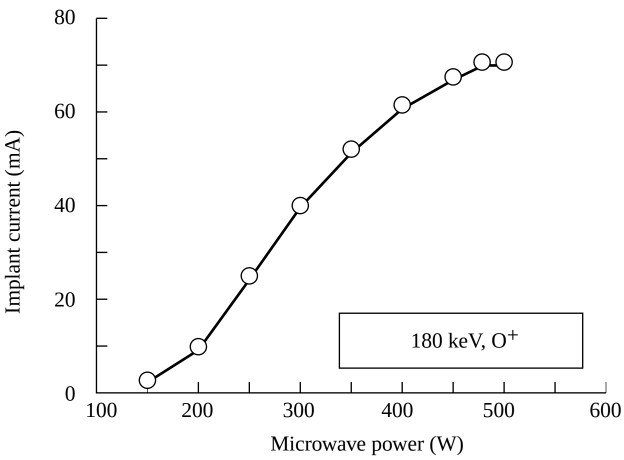


*Fig. 3—Dependence of Implant Current on Microwave Power. An implant current of 70 mA is obtained for a microwave power of 500 W.*

### Implant Current and Ion Source Properties

Fig. 2 shows measurement results of implant current. A current of 70 mA, which is assumed to be the normal operating current of the implanter, was stably obtained and a maximum current of 100 mA was also confirmed. Furthermore, stable beam extraction from the ion source was also confirmed in a 120-hour test run. These results indicate that the ion source is reliable for long-term operation and practical for use as a production tool.[2)]

### Wafer Quality

Table 3 shows evaluation data of SIMOX wafers manufactured using the UI-5000. Except for the number of BOX defects, which are leakage defects in the buried oxide layer, the data indicate that the wafer quality satisfies the level requested at the present stage. The main cause of BOX defects may be that the implanted ions are shielded by particles stuck on the wafer. Finding a way to reduce the number of particles

TABLE 3. Quality of SIMOX Wafers Manufactured by UI-5000

*Except for BOX defect density, wafer quality satisfies the level required at the present stage.*

| Property | Present values | Required level* |
|---|---|---|
| SOI thickness uniformity<br>(SOI thickness: 60 – 200 nm) | ≤ ± 2 nm<br>(200 mm-dia.) | ± 5% |
| BOX thickness uniformity<br>(BOX thickness: – 100 nm) | ≤ ± 2 nm<br>(200 mm -dia.) | ± 5% |
| Metal contamination | $\leq \pm 10^{10}$ cm$^{-2}$ | $\leq 1.3 \times 10^{10}$ cm$^{-2}$ |
| BOX defects | 0.5 – 2.0 cm$^{-2}$ | ≤ 0.12 cm$^{-2}$ |

*: ITRS 1998 range for 180 nm
Data provided by Komatsu Electronic Metals Co., Ltd. and Nippon Steel Corporation.

is an important subject for future work.

The featuers of SIMOX include the simple manufacturing process and the excellent thickness uniformity of SOI and BOX layers. Thickness is determined mainly by easily controllable factors such as the dosage and energy level of ion implantation. In addition, the UI-5000 incorporates many approaches for enhancing uniformity such as precise control of disc scanning speed, appropriate setting of scanning width, stabilization of beam shape, and uniform heating of wafers. As a result, we could achieve a uniformity of 2% or better for both the SOI layer and BOX layer for 200-mm diameter wafers.

Furthermore, the amount of metal contamination was confirmed to be at an acceptable level. Surface concentrations of Cr, Fe, Ni and Cu for as-implanted wafers under low-dose conditions were less than $2 \times 10^{10}$cm$^{-2}$, and concentrations of Cr, Fe, Ni and Cu for completed SIMOX wafers after cleaning and annealing were less than $10^{10}$cm$^{-2}$.

## CONCLUSIONS

This paper introduced UI-5000, a high-current oxygen ion implanter for manufacturing SIMOX wafers. The implanter has already been applied to the production of SIMOX wafers, and on the whole it has achieved the expected performance levels. However, the situation regarding SOI technology has changed considerably since we began developing the UI-5000, and requirements for wafer quality and prices have clearly shifted from those for R&D use to those for practical device fabrication. As a result, the required ion implanter performance levels are becoming more stringent. An urgent matter is the further reduction of the number of particles. In this respect, we are already applying a variety of approaches.

Our goal is to realize an implant current of 100 mA or more at normal operation and develop fully-fledged implanter that is capable of volume production with abailability and operability bearing in mind. Through the development of these implanters, we hope to contribute to large changes in semiconductor technology.

## ACKNOWLEDGMENTS

Finally, we would like to thank all those at Komatsu Electronic Metals Co., Ltd. and Nippon Steel Corporation for providing the data on wafer quality and related information. We would also like to express our appreciation to Professor Katsutoshi Izumi of Research Institute for Advanced Science and Technology, Osaka Prefecture University (former Executive Chief Researcher at Nippon Telegraph and Telephone Corp.) for his valuable advice on the development of this implanter.

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