Ultra-High-Vacuum Secondary Ion Mass Spectrometer*

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1 Introduction

Compared with all other surface analyzing techniques, secondary ion mass spectrometry (SIMS) has prominent features, including an extremely high sensitivity, a detecting capability of all elements, and a high precision depth profiling capability.[1] This technique was accepted as a method of a steel analysis in the 1970s in Japan. At Kawasaki Steel Corp., an ion microprobe mass analyzer (IMMA) made by ARL in the U.S.A. was installed in 1973. After investigating the optimum conditions for steel analysis and establishing a method of quantitative analysis, this instrument was put to practical use.[2] The method of quantitative analysis was extended to high alloys, and an original analytical method for the coated layers of steels was developed.[3,4] These methods of quantitative analysis have been utilized widely; studies for improving the hardenability of steel with grain segregation, the behavior of surface segregation under heat treatment, characterization of the various coated steels, and so on.

In the semiconductor industries, strict studies have been continued to improve the integrity, speed, and reliability of these devices. Various analytical techniques have been utilized to characterize the products and processes. The trace impurities in semiconductor materials affect the devices' characteristics and reliabilities. SIMS is known as one of the most effective analytical techniques for production processes of wafers and devices.[1] These days this technique is indispensable for the study and development of semiconductors. At Kawasaki Steel, studies have been made on highly reliable products using the consistent techniques including the growing of Si ingots, wafer processing, and developing necessary devices. For this reason, a new secondary ion mass spectrometer IX-70S made by VG-IONEX of the U.K. was installed. The new instrument has several features compared with conventional instruments. This article introduces the new instrument.

2 Main Features and Specifications

In secondary ion mass spectrometry, secondary ions ejected from the surface of a specimen by a bombardment of accelerated primary ions are led to a mass analysis system by an electric field. These ions are separated according to their mass/charge ratios and then detected. The instrument consists of:
(1) a primary ion beam system,
(2) a secondary ion mass analysis system,
(3) a detection and data processing system, and
(4) an analysis chamber and vacuum system.

The main specifications of the instrument are listed in **Table 1**. A schematic diagram and a photograph of the instrument are shown in **Fig. 1** and **Photo 1**. The main features are explained and compaired with conven-

Table 1 Specifications of IX 70S

Ion sources	O_2^+	C_s^+	G_a^+
Source voltage	1-20 kV	1-10 kV	30 kV
Min. spot size	2 μm	2 μm	0.1 μm
Scanning area	1×1 mm	1×1 mm	0.5×0.5 mm
Current range	2 μA-3 nA	2 μA-3 nA	25 nA-50 pA
Secondary ion mass spectrometer	Sector mass		Q-mass
Mass range	1-500 amu		1-800 amu
Mass resolution	$M/\Delta M$=500-10,000		ΔM=1/2 amu
Detector	Channeltron Faraday cup		Channeltron
Electron gun			
Source voltage	1-10 kV		
Spot size	50 μm		
Optical microscope magnification	×120		
Analysis chamber base pressure	$<7\times10^{-11}$ mbar		

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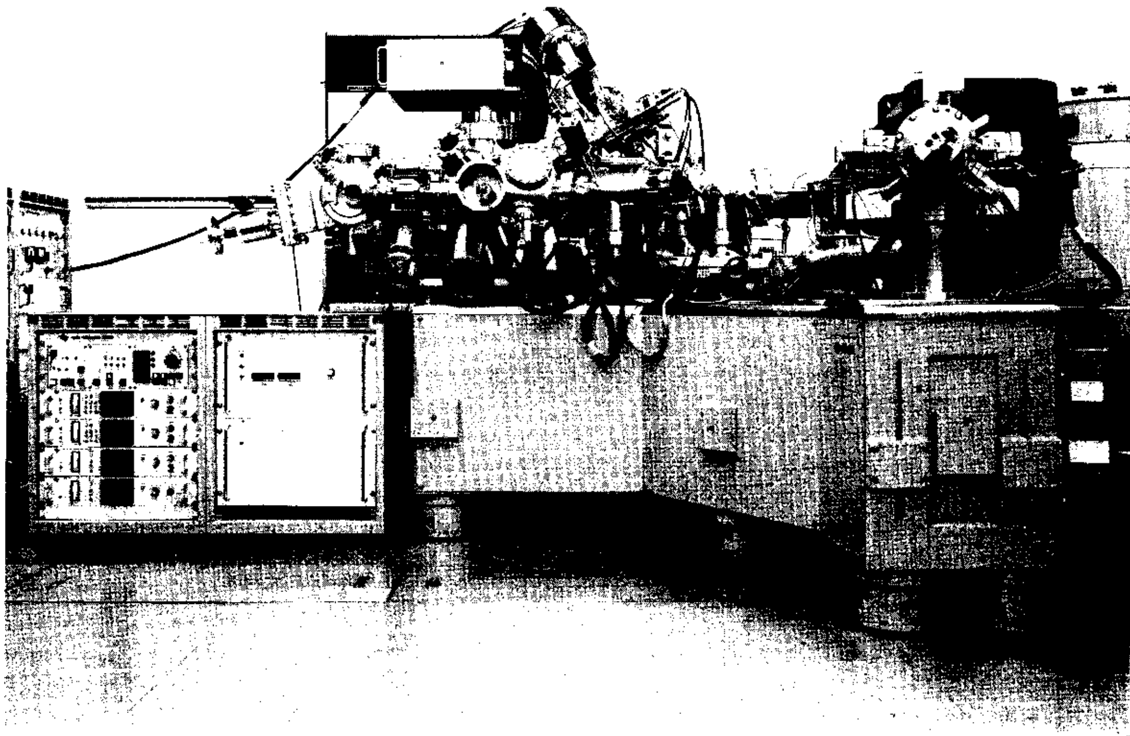

Photo 1 Secondary ion mass spectrometer made by VG-IONEX

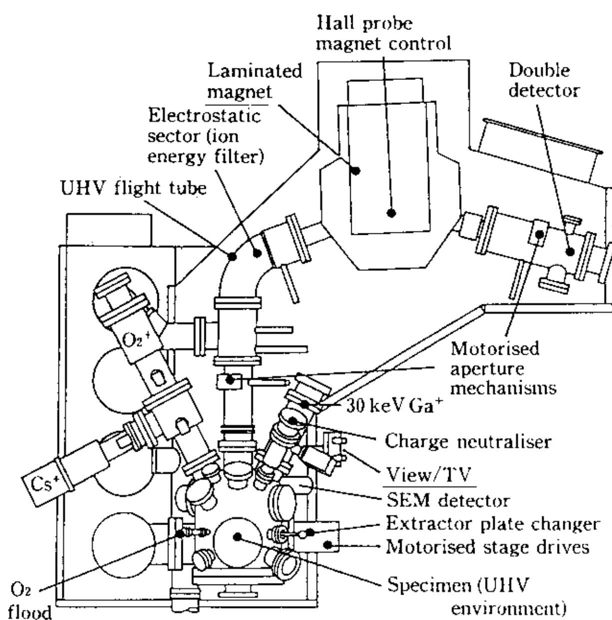

Fig. 1 Schematic diagram of IX 70S

tional methods.

2.1 Primary Ion Beam System

Secondary ion yields vary drastically from element to element, and depend on primary ion species. Therefore, in order to achieve the measurement with high sensitivity, primary ion species should be selected for every element to be measured. In general, O_2^+ ions are used for electro-positive elements like B, and Cs^+ ions are used for electro-negative elements like P.[5] Both types of ion sources are installed in the new instrument. The ions from the ion sources are mass-purified by the wine-filters. Cs^+ ions are bent 45° and enter the lens system which is also used for O_2^+ ions. The ion beams focused there are off-centered to remove the neutral particles at the end of the primary beam column, and then scanned over a specimen surface. Almost all of the elements can be detected with high sensitivity by selecting the O_2^+ or Cs^+ ions. Since both ion sources are designed to produce high ion currents to improve sensitivity, lateral resolution is not necessarily sufficient for an analysis of a small area. The Ga^+ liquid metal ion source, which can easily offer a fine focused beam, is equipped in another port of the instrument. The same area can be measured with O_2^+ or Cs^+ ion beam. For analysis of a small area less than 1 μm, Auger electron spectroscopy is usually applied. Using the Ga^+ ion source together with O_2 gas flood makes it possible to directly analyze smaller devices.[6] Another wine-filter is connected to the Ga^+ ion source, then the primary mass can be selected in order of the masses to be

measured. Other liquid metal ions can be applied by changing the chips of the ion source. The lens columns for O_2^+, Cs^+ and Ga^+ are controlled by the same controller.

Neutral particles are produced in a primary ion beam column by colliding ions into residual gases. In order to depress the background from the neutral particles, all of the lens columns are pumped down differentially to keep the whole system at ultra-high-vacuum (UHV) during the measurement in addition to off-centering the ion beam at the end of the primary beam column.

2.2 Secondary Ion Mass Spectrometer System

Secondary ions ejected from the specimen surface by primary ion bombardment are separated owing to the mass/charge ratios in the mass spectrometer system. In general, two types of mass spectrometer are used. One is a double-focused mass spectrometer which consists of an electric field and a magnetic one, and the other one is a quadrupole mass spectrometer. They each have different features. The former has high sensitivity resulting from a greater efficiency in collecting secondary ions since the specimen is subjected to a high electric field, and is very useful for meauring a specimen in which masses are interfer with each other because of the higher mass resolution. But it also has disadvantages: The whole system is huge and expensive; keeping the system in UHV is very difficult; and the sweep rate of the magnetic field is not as quick as the electric field. On the other hand, the latter one has economic advantages and many other features: rapid mass control, compact system, compatibility with UHV, and easier measurement of non-conductive materials. But it is difficult to apply to specimens whose masses interfer with each other because of its low mass resolution. Therefore, the features and disadvantages of each method supplement each other and using both types of analyzers is desirable for measuring various materials. In the new instrument, which is basically a magnetic sector type, by using the specimen chamber effectively, both types of mass analyzers are installed without a deterioration of either's performance. This makes it possible to select the optimum analytical conditions for each specimen, for example, to select a sector type for a specimen which needs high mass resolution or a quadrupole type for one which requires quick mass sweep. Therefore the new instrument can be widely applied.

2.3 Vacuum System

Compared to other surface analytical instruments, it is difficult to maintain a magnetic type SIMS instrument in UHV because it has complicated and long ion paths, the system is not bakable and gasses are used. In general, UHV is not necessary for SIMS due to the high sputtering rate of the specimen by the primary beam. But for the measurement of C, O, P, H, etc., the background from the residual gases deteriorates their detection limits.[1] These are the most important elements in Si. Therefore it is necessary to analyze these elements with high precision. Adopting the slider of the magnet, which makes the whole system (except the magnet) bakable, and connecting the differential lines make the system UHV. Backpressure is 7×10^{-11} mbar. Accordingly the backgrounds of these elements were depressed and their detection limits improved.

2.4 Additional Features

The SIMS technique is intrinsically destructive because a sputtering phenomena is used. For semiconductor materials like Si, a depth profiling analysis of trace elements, in which this phenomena is used actively, is most popular. Each instrument was devised to have a high sensitivity and a superior depth resolution.[1] In the new instrument, depth resolution is improved by combining the projective lens to the secondary ion optics. A higher sensitivity is achieved by improving the transmittance efficiency of the secondary mass analysis system by decreasing the vacuum and by improving the collection efficiency of secondary ions by controlling the electric field to collect all ions ejected from a specific area. Besides the depth profiling, a two- and three-dimensional analysis are also another feature of the analysis mode. These operate by either projective or scanning method. In the new instrument, primary ion scanning is controlled digitally and the corresponding secondary ion intensities are processed in each frame to give a two- or three-dimensional distribution of a specified element. The Ga^+ primary ion provides a two- or three-dimensional distribution with superior spatial resolution.

3 Application

It is very important to control the concentrations of trace elements because the characteristics and reliability of semiconductor devices are strongly influenced by them. As explained previously, the SIMS method has been used widely for the depth-profiling analysis of trace elements in semiconductors. In our laboratories the new instrument is mostly used for the depth-distribution analysis of dopants in Si. Some of the results obtained with O_2^+ ions are shown below. **Figure 2** is the result of a B distribution in Si substrate after thermal treatment. B is implanted in Si substrate through the oxide layer. The uniform layer of B concentration with $3 \times 10^{17}/cm^3$ was formed from the surface to about $0.2 \mu m$ in depth and the diffusion layer reached about $0.6 \mu m$ in depth. **Figure 3** is the result of TEG processed in the LSI Research Center of Kawasaki Steel Laboratories. Figure 3 (a) and (b) are both B distributions for the drain in PMOS and the well of NMOS respectively. These consist of the results by spread resistivity measurements. This fact shows the high accuracy of the measurement with the new SIMS.

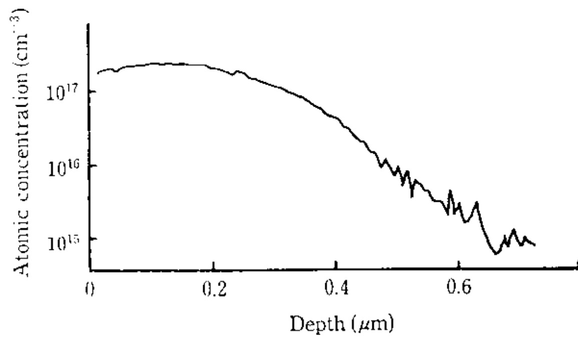

Fig. 2 Depth profile of B implanted in Si after thermal treatment

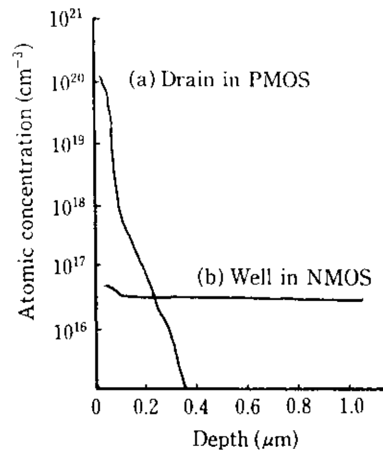

Fig.3 Depth profiles of B

4 Concluding Remarks

The newly introduced SIMS instrument has both sector and quadrupole functions. Various materials can be measured with high sensitivity. It is expected to be applied effectively for the development of semiconductor materials and characterization of products.

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