Energy and Mass Analyses of Secondary Positive Ions from Silicon Wafer Surfaces

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The kinetic energy distribution of ions liberated from a silicon wafer surface was measured. The primary ion was 8 keV O^+ . The energy distribution was analyzed using an electric toroidal sector ($r_e=212\text{mm}$, $\phi_e=85^\circ$, $c=0.5$). Two new sharp energy peaks have been observed immediately below a giant sputtered ion peak.

These energetically discrete sputtered ions were analyzed with a double focusing mass spectrometer. From the results of SIMS analyses, ions of the lowest energy peak have been identified as the ambient gas ions, ions of the next higher energy peak as those from the top surface, and ions of the giant energy peak as those from the bulk.

1. Introduction

Recently, solid surface analyses have been risen progressively in importance in response to the demands of semi-conductor device and metalworking industries. Although there are many solid surface analysis methods, it may be said that the most advantageous analytical method is secondary ion mass spectroscopy (SIMS) from the points of analytical sensitivity and compound ion identification.

Sputtered secondary ions have relatively broad energy compared with ions from an electron impact ion source. Therefore, it is desirable to adopt some special ion optical devices in order to analyze these sputtered ions with a high mass resolution

and a high analytical sensitivity.

One ion optical device, a double focusing mass spectrometer which has radial, axial, velocity and second-order focusing properties, was examined and has been previously reported¹⁾. Incorporating a primary ion source in this mass spectrometer, a high mass resolution SIMS instrument was realized, and a maximum resolution of 11,000 was obtained²⁾. A comparative study of low energy ion scattering spectroscopy (ISS) and SIMS was carried out³⁾ using the electric sector of the double focusing mass spectrometer as an energy analyzer.

In the mass spectra of SIMS, it is often found that ambient gas ions and solid surface contamination ions are observed

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in addition to sputtered solid bulk ions. These ion mixtures make solid surface analyses complicated. It is well known that the energy of ambient gas phase ions are relatively lower than that of sputtered bulk ions⁴⁻⁹. Employing this fact, the gas phase ion mixture can be eliminated through energy selection. In this paper, experimental results of energy distribution of the sputtered ions from a silicon wafer are described using the previously reported SIMS instrument⁹, and the results of SIMS analyses are reported.

2. Instrument

Detail of the high resolution secondary ion mass spectrometer used for the present investigation has been reported elsewhere^{1,2,9}. Therefore, only a brief description of the instrument will be given here. A schematic diagram of the instrument is shown in Fig. 1. It is primarily composed

Fig. 1 Schematic diagram of the high resolution secondary ion mass spectrometer.

1. duo-plasmatron ion source, 2. sample holder, 3. variable object slit, 4. variable α -slit, 5. electric toroidal sector, 6. variable intermediate slit, 7. channel electron multiplier detector, 8. uniform magnet with non-zero angular entrance and exit pole edges, 9. variable collector slit, 10. electron multiplier detector.

of a primary ion source, a sample chamber and a double focusing mass spectrometer.

The primary ion source is a Hitachi IMA-2 duo-plasmatron. Eight keV oxygen ions bombard a silicon wafer sample at an angle of 45° to the surface plane. The sputtered secondary ions are extracted into the direction of 90° with respect to the direction of the primary ion beam, and accelerated to have 2.8 keV energy.

The kinetic energy distribution of the secondary ions is analyzed using the electric toroidal sector ($r_e = 212$ mm, $\Phi_e = 85^\circ$, $c = 0.5$), and the ion current is detected by a channel electron multiplier detector at the back of the intermediate focusing point (β -slit position). Combined a uniform magnetic sector of the non-zero angular entrance and exit ($r_m = 200$ mm, $\Phi_m = 90^\circ$, $\epsilon_1 = 32^\circ$, $\epsilon_2 = -10^\circ$) with the electric toroidal sector, the apparatus is used as a double focusing mass spectrometer.

The sample holder and the electric

Fig. 2 Schematic diagram of the sample holder lens system.

lens system are shown schematically in Fig. 2. The sample is covered with an equipotential box. The sputtered ions are extracted from the exit silt, and focused at the object slit position. The focus position is adjusted by a half plate lens.

Three pump systems composed of liquid nitrogen traps, oil diffusion pumps and rotary pumps are used at the ion source, sample and electric toroidal sector housings. The ultimate pressure is 2×10^{-7} Torr. During operation, the pressure increased up to 1×10^{-5} Torr due to the oxygen gas from the primary ion source.

3. Experimental Results

3.1. Energy distribution of sputtered ions

A silicon wafer of p-type $20 \Omega \text{ cm}$ was used as the sample. 8keV oxygen primary ions bombarded the sample surface, and the sputtered ions were accelerated to have the energy of 2.8 keV. The energy distribution of the secondary ions was measured by a rapid linear scanning of the electric sector field. One of the results is shown in Fig. 3.

The observed sputtered ions have approximately the same energy as the acceleration energy, 2.8 keV. The sputtered ion peak has a long tail on the higher energy side. While, the peak rises relatively sharply on the low energy side. A fine structure of the energy distribution could not be obtained from such a rapid scanning.

The energy distribution spectra were measured by a slow scanning of the electric field. The result is shown in Fig. 4. In this case, two sharp energy peaks, P_1 and

Fig. 3 Energy distribution of the accelerated sputtered ion beam. The straight line indicates the linear scanning electric sector field.

Fig. 4 Energy spectra of the accelerated sputtered ion beam.

P_2 , were observed on the lower side of the giant peak, P_3 . The upper line shows the constancy of the primary beam current. The relative energy difference between P_1

and P_2 was measured to be about 35 eV, and the difference between P_2 and P_3 to be 55 eV. The actual potential of the sample surface during the ion bombardment might be somewhat different from the sample holder box due to the charge up effect. So that the energy difference between P_1 and P_2 shown here, may include the energy shift. These energy peaks were stably reproduced in several repeated measurements.

The dependence of these secondary ion energy spectra on the energy of the primary ions, E_p , was examined, and the results are shown in Fig. 5. When the energy of the primary ions is increased from 6 keV to 10 keV, the peak height of P_3 is increased. However, the intensity of

the two lower energy peaks, P_1 and P_2 , do not change. It is found that the energy differences among the three peaks are independent of E_p .

3.2. Comparison between energy spectra and SIMS spectra

It is interesting to identify the separated energy peaks using SIMS. The analyses were made with the double focusing mass spectrometer setting the electric sector field to the tops of the energy peaks. In this case, the channel electron multiplier detector at the back of the β -slit was pulled out of the ion path.

The SIMS spectra at the lowest energy peak, P_1 , are shown in Fig. 6. The ion intensity sequence is as follows:

Fig. 5 Primary ion energy (E_p) dependence of the sputtered ion energy distributions.

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Fig. 6 SIMS spectra for the lowest energy peak (P_1).

Fig. 7 SIMS spectra for the second energy peak (P_2).

From these spectra, it is clear that the lowest energy peak, P_1 , corresponds to the gas phase atoms and molecules which are ionized by the primary ions, secondary electrons and secondary ions. The oxygen is considered to be supplied from the primary ion source.

The SIMS spectra at the next higher energy peak, P_2 , are shown in Fig. 7. In the figure, the sensitivity of the amplifier was reduced to 1/10 of that in Fig. 6. The ion intensity sequence is as follows:

Here, sputtered ions of silicon, silicon-compounds and many hydro-carbons appeared. Therefore, the second energy peak, P_2 , can be ascribed to the sputtered ions from the top surface of the silicon wafer.

The SIMS spectra at the giant peak, P_3 , are shown in Fig. 8. The sensitivity was reduced to 1/50 of that in Fig. 6. The ion intensity sequence is as follows:

As a result, it is clear that the giant peak, P_3 , corresponds to the sputtered ions of the silicon bulk. The observed SIMS results at the three energy peaks are summarized in Table 1. In this table, the identified ions

Fig. 8 SIMS spectra for the highest or giant energy peak (P_3).

and their relative ion current intensities are given.

Table 1. SIMS analyses of three discrete energy peaks

Mass Number	Identified Ion	Relative Ion Intensity for Three Energy Peaks		
		P ₁	P ₂	P ₃
12	C ⁺	0.007	0.15	1.7
13	CH ⁺		0.03	1.6
14	CH ₂ ⁺		0.07	0.9
15	CH ₃ ⁺		0.07	
16	O ⁺	0.097	0.37	0.17
17	OH ⁺		0.01	
18	H ₂ O ⁺	0.017		
26	C ₂ H ₂ ⁺		0.1	
27	C ₂ H ₃ ⁺		0.23	
28	Si ⁺	0.04	3.1	100.*
29	SiH ⁺		0.4	5.0
32	O ₂ ⁺	0.14		
39	C ₃ H ₃ ⁺		0.23	
41	C ₃ H ₅ ⁺		0.23	
44	SiO ⁺		0.3	0.23
45	SiOH ⁺		1.1	0.2

* All values are normalized from this peak intensity.

4. Conclusion

(1) Bombarding a silicon wafer by primary 8 keV oxygen ions, the energy distribution of the sputtered secondary ions was analyzed using an electric toroidal sector. From this experiment, two discrete energy peaks were resolved from the giant sputtered peak.

(2) Setting the electric sector field to each energy peak top, SIMS analyses were made using a double focusing mass spectr

ometer. From the SIMS analyses, the following identifications were clarified:

the lowest energy peak: O₂⁺, O⁺,
the second energy peak: Si⁺, SiOH⁺, SiH⁺,
O⁺, SiO⁺, C_mH_n⁺,
the highest energy peak: Si⁺, SiH⁺.

(3) From the analytical results, it is concluded that the lowest energy peak corresponds to the ambient gas ions, the second energy peak the sputtered surface ions, and the highest energy peak the sputtered bulk ions.

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Keywords

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