Depth Profiling Comparison between TOF-SIMS and Quadrupole SIMS at Near Surface Region

T.Hoshi, Li Zhanping, M.Tozu and R.Oiwa
ULVAC-PHI,Inc. 370Enzo, Chigasaki, 253-0084 Japan

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Using a shallowly doped boron into silicon wafer, the analytical performances were compared between TOF-SIMS with a dual beam approach and quadrupole SIMS combined with a low energy primary beam. The depth profile obtained by TOF-SIMS showed similar analytical performances with quadrupole SIMS, such as detection limit and stability of secondary ion signal. At pre-equilibrium region(0-3nm surface region), results of quantification had strong dependence on the bombardment condition of the primary beam. Below 4nm depth, the decay length became larger as the energy of primary beam increased. The results were compared and discussed with respect to the quantification(concentration / depth conversion), the detection limit and the decay length.

1.Introduction

Recently, the need for near-surface analysis in the Si semiconductor industry is increasing, such as analysis of ultra shallow dopants, analysis of <10nm thick gate dielectric films, analysis of surface contamination and so on. Traditional SIMS primary beam conditions,10-15kV beam energy, can not provide stable secondary ion signals within the top 10nm of the sample surface, because the sensitivity-enhancing effects caused by the implantation of the primary beam do not become apparent until the surface has been sputtered to the range of the implanted primary ions.

In this study, using a shallow implanted boron into silicon wafer, the analytical performances were compared between TOF-SIMS with a dual beam approach[1],[2] and quadrupole SIMS(Quad SIMS) combined with a low energy primary beam [3],[4], allowing us to obtain the accurate in-depth profile within the top 10nm of sample surface. The results were compared and discussed with respect to the quantification (concentration / depth conversion), the detection limit and the decay length.

2. Experimental

A depth profiling using TOF-SIMS is limited by its slow sputtering rate. The nano-second order pulsed primary beam and its kHz order repetition rate reduce the sputtering rate 10^4-10^5 times smaller than the those of dynamic SIMS. However, recent TOF-SIMS with the dual beam approach allows us to have a moderate sputtering rate. In this study, TOF-SIMS apparatus (Physical Electronics TRIFT II) was operated with a gallium primary beam for analysis;12kV beam energy and 41deg incident angle. For a sputtering gun, oxygen beam was operated with 1kV, 260nA, 700um raster and 42deg incident angle from the surface normal. A 10 second data acquisition with 25kHz and a 25 second sputtering was carried out alternately. In addition, positive ion yields were enhanced by flooding the sample with oxygen ($5x10^{-5}$Pa) during the TOF-SIMS depth profile.

A quad SIMS apparatus (Physical Electronics Model 6650) was operated with Oxygen primary beam ;250V and 500V beam energy, 15deg incident angle. Table 1 shows the detail condition of primary beam for both TOF-SIMS and Quad SIMS. The samples prepared for the evaluation of depth profiles were shallow doped boron into silicon wafer. Boron was doped by plasma doping and distributed within 10nm-surface region of the silicon wafer. $^{30}Si^+$ and $^{11}B^+$ were monitored down to 10^{16}atoms/cm^3 and about 30nm depth.

3.Results and discussion

3-1. Quantification (concentration / depth conversion)

For the quantification of near surface region, there are many difficulties; 1) the inaccurate measurement of a shallowly sputtered crater, 2) extremely long analysis time caused by the slow sputtering rate (0.1nm/min at 250V oxygen beam), and 3) the changes of the sputtering and secondary ionization yields[5]-[7] before the surface has been sputtered to the range of the implanted primary ions. In addition, the sputtered crater of TOF-SIMS measurement has a two step profile which created by oxygen sputtering and gallium analysis beam, so it is almost impossible to measure the two step crater accurately. In this study, the sputtering rates for the various primary beam conditions used in the profiles shown in Figures were estimated by measuring a BF_2 5kV $2.5x10^{14}$atoms/cm^2 implant profile for each of analysis conditions. No corrections for the changes of the initial sputtering rate have been applied. Furthermore, no corrections for the changes of sputtering rate between SiO_2 and silicon substrate were done. The boron concentration was calculated using a relative sensitivity factor (RSF) which obtained from the measurements of BF_2 5kV implants under the same analysis conditions. Because of the assumptions used in quantification, it is likely that none of the depth profiles represent the “true” implant distribution. However, for the first order approximation, it is useful to discuss the comparison between TOF-SIMS and Quad SIMS depth profiles under the assumptions used in quantification, especially from the practical point of view.

3-2. Boron profile obtained by TOF-SIMS

Figure 1 shows the depth profile obtained using dual beam TOF-SIMS. Total acquisition time down to 100nm depth was about 250min (430cycles). The stability of the $^{30}Si^+$ secondary ion was within +-1.3% during 250min acquiring time. The background level of boron was about $2x10^{16}$atoms/cm^3 and the dynamic range of boron was very close to 5 orders of magnitude. The obtained peak intensity of $^{11}B^+$ secondary ions was $2x10^4$counts/s, and its intensity was almost the same as the reputation rate of TOF analysis, $2.5x10^4$pluses/s. This means that one gallium pulse produced one $^{11}B^+$ secondary ion. From the point of analytical performance, the above numbers obtained by dual beam TOF-SIMS was comparable with those of Quad SIMS depth profile(see ref.[8]).

3-3. Boron profile shape and Pre-equilibration depth

Figure 2(a) is boron depth profiles obtained by dual beam TOF-SIMS and Quad SIMS. Figure 2(b) is silicon depth profiles normalized at 10nm depth. Table 2 summarizes the comparison of analytical performances between TOF-SIMS and Quad SIMS. From Figure 2(a), the shapes of boron profile below 3nm depth were very similar, but with progressive reduction in the decay length (1/e) of boron at $1x10^{20}$atoms/cm^3

concentration was observed, namely1.2nm (oxygen 250V Quad SIMS), 1.3nm (oxygen 500V Quad SIMS) and 1.5nm(oxygen 1kV sputter TOF-SIMS). At near surface region (0-3nm), the shape of boron profile had a strong dependence on the bombardment condition of the primary beam, namely boron concentration became higher as primary beam energy decreased. On the other hand, in Figure 2(b), the shape of silicon profiles obtained by TOF-SIMS (1kV oxygen sputter) coincided with the shape obtained by Quad SIMS(250V oxygen) after 0.5nm depth. This fact concludes that the pre-equilibration depth of boron is not equal to that of silicon and normalization using silicon signal has no meaning at near surface region.

4. Conclusion

TOF-SIMS and Quad SIMS depth profiles were compared using shallowly doped boron into silicon wafer. The analytical results by dual beam TOF-SIMS showed comparable with the results by Quad SIMS, such as stability of $^{30}Si^+$ secondary ion (+-1.3%), the background level of boron ($2x10^{16}$atoms /cm^3) and dynamic range of boron (5 orders of magnitude). The shapes of boron profiles below 3nm depth were very similar, but with progressive reduction in the decay length (1/e) as the energy of primary beam decreased. It was found that the pre-equilibration depth of boron is not equal to that of silicon and normalization using silicon signal has no meaning at near surface region.

Reference

[1]T.Hoshi and M.Tozu ;SIMS XI , ed by A.Benninghoven et al. Jhon Wiley & Sons(1997) 267
[2]K.Iltgen, C.Bendel, E.Niehuis and A.Benninghoven; SIMS IX , ed by A.Benninghoven et al. Jhon Wiley & Sons(1995) 374
[3] J.J.Lee,J.E.Fulghum,G.E.McGuire, M.A.Ray, C.M.Osburn and R.W.Linton, J. Vac. Sci. Technol. A8 (1990) 2287
[4] C.W.Magee and M.R.Frost, Int. J. Mass Spectrom. Ion Processes, 143 (1995) 29
[5] M.G.Dowsett; Atomic Layer Characterization ALC97 (1997) 18
[6] C.W.Magee, G.R.Mount, S.P.Smith, B. Herner and H.-J.Gossmann; XII international conference on Ion Implantation Technology, (1998) 1
[7] M.G.Dowsett; SIMS XI , ed by A.Benninghoven et al. Jhon Wiley & Sons(1997) 259
[8] T.Hoshi, R.Oiwa and M.Kudo, J.Surface Science Society of Japan V19 (1998) 527

Table 1 Analysis conditions

	TOF(Analysis)	TOF(Sputter)	Quad SIMS
Species	Ga^+	O_2^+	O_2^+
Energy	12kV	1kV	250V/500V
Incident angle	41deg	42deg	15deg
Current	20nA(DC)	260nA	50nA/160nA
Raster	20um	700um	500um/400um
Gate	100%	-	9%
Time/Cycle	10sec	25sec	-
O_2 flood	$5x10^{-5}$Pa	-	-

Table 2. Analysis performances

	TOF-SIMS	Q- SIMS
Sputter Energy	1kV	250/ 500V
Sputter Rate(nm/min)	0.5	0.1/ 1.6
Decay (nm at 1E20/cc)*	1.5	1.2/ 1.3
Equilibration (nm)	0.5	0.5/ 3
Dynamic Range	4.8	5/ 5
Background (atoms/cc)**	2E16	8E16/ 2E16
Analysis Time(min)***	75	300/ 18

* Decay length was defined by 1/e at 1E20atoms/cc concentration.

**Background Level was measured at 100nm depth(TOF and 500V Quad SIMS), and at 30nm (250V Quad SIMS)

*** Analysis time was measured at 30nm depth. TOF-SIMS included a data acquisition time.

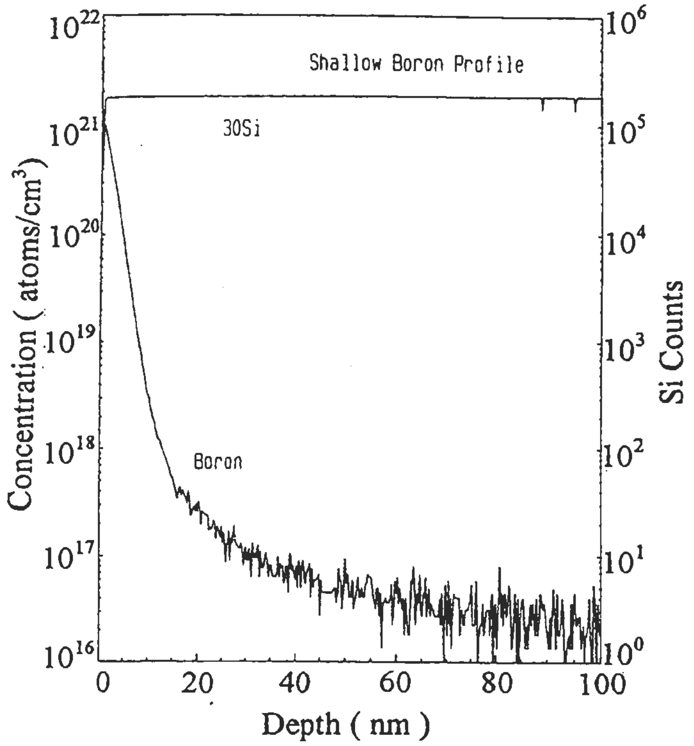

Figure1
Depth profile obtained using dual beam TOF-SIMS

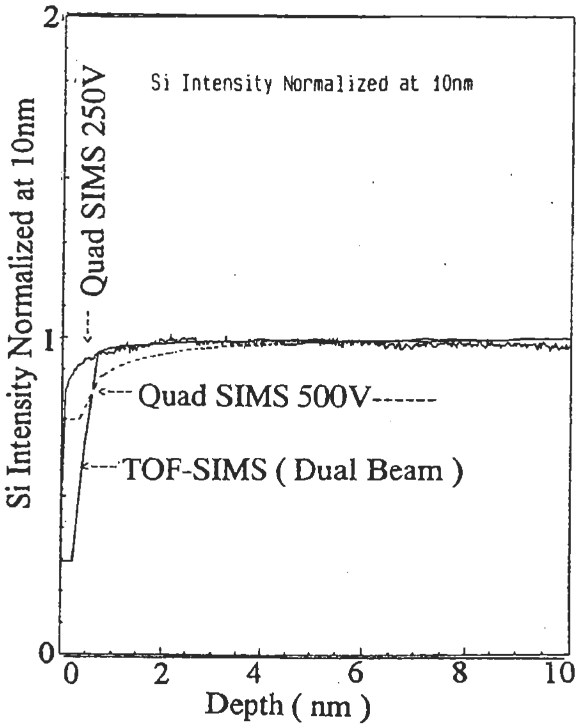

Figure 2(b)
Silicon depth profiles normalized at 10nm depth.

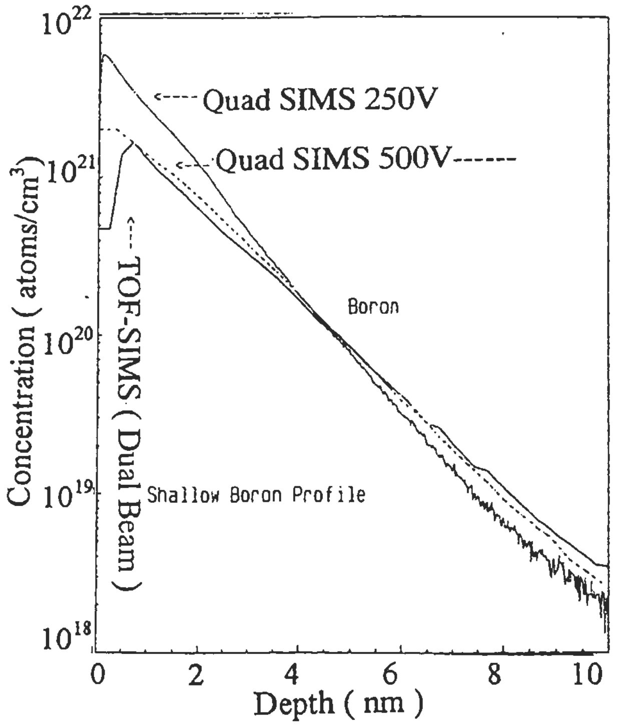

Figure 2(a)
Boron depth profiles obtained by dual beam TOF-SIMS and Quad SIMS