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Latest developments for the CAMECA ULE-SIMS instruments: IMS Wf and SC-Ultra

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Abstract

SIMS depth profiles for full wafer analyses were carried out on the CAMECA IMS Wf instrument. Experiments have been performed in order to investigate the analytical performance of this SIMS instrument for shallow, medium and deep profiles in terms of measurement repeatability and sample throughput. First results using a cassette loader option implemented on the IMS Wf are presented.
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1. Introduction

The development of ultra shallow junctions for semiconductor devices technology requires SIMS tools capable of measuring in-depth distribution of dopants within the first tens of nanometers underneath the sample surface. Depth resolution performance of these tools has become of great importance for this application field. In order to address this analytical challenge, CAMECA has developed a next generation SIMS instrument (IMS Wf and SC-Ultra) simultaneously offering capabilities for ultra low energy primary ions, high mass resolution and high transmission [1].

The IMS Wf instrument is equipped with a large analysis chamber, compatible with 300 mm wafers, and with a new high precision, horizontal sample stage which allows full 300 mm × 300 mm *X* and *Y* travels. A *Z*-axis adjustment has also been implemented for high precision *Z*-sample positioning. Adjustment of the *Z*-axis allows one to keep constant the distance between the sample surface and the first electrode of the immersion lens, thus ensuring the best data reproducibility. The experiments were performed with an instrument equipped with a FOUP cassette loader, which enables the analysis of a batch of wafers loaded in a cassette in fully automated mode.

The goal of this work is to evaluate the measurement repeatability of the IMS Wf for full wafer analyses. Several configurations have been tested:

- load-to-load reproducibility and dose mapping for a 300 mm Si wafer with a B 10 keV implant, the wafer being loaded/analyzed/unloaded from the FOUP unit in a fully automated mode;
- load-to-load and cross wafer reproducibility for a series of 300 mm/200 mm Si wafers with shallow and deep B, P and As implants with the wafers manually introduced directly in the load-lock instead of using the FOUP system;

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- dose matching for a series of 200 mm Si wafers with a low dose B 10 keV implant, to check dose variations among wafers.

2. Experimental

For the 300 mm/B 10 keV implant, experiments were performed using a 50 nA O_2^+ primary ion beam rastered over an area of 200 μm × 200 μm. The impact energy was set to 4 keV, using a source accelerating voltage of 9 kV and a sample extraction voltage of 5 kV. The incidence angle was about 40° from normal. Laser interferometer data were used for the depth scale calibration [2,3]. The same experimental conditions were used to analyze the series of 200 mm/B 10 keV implant, but the primary current has been increased up to 140 nA and raster reduced down to 175 μm × 175 μm in order to increase the sputter rate and therefore the sample throughput.

For the load to load repeatability test with the FOUP, the wafer has been loaded into the analysis chamber twelve times, each load being followed by an analysis on the center of the wafer. The transfer of the wafer from the cassette into the analysis chamber is performed according to the sequence: cassette loader (air) → aligner (air) → load-lock (air/vacuum) → analysis chamber (vacuum). The full sequence lasts 8 min, which includes 7 min for the load-lock pumping after transferring the wafer from the aligner to the load-lock, and about 1 min for the robot-controlled movements. The unloading procedure consists on the reversed operation. The time required for unloading a wafer is about 4 min, consisting mostly in 3 min for the load-lock venting. Once the sample is introduced in the analysis chamber and before starting each analysis, the automated *Z*-positioning is performed using an optical autofocus routine which works for patterned and unpatterned wafers. The analysis recipe also includes a beam centering routine, which automatically performs a fine alignment of the primary ion beam with the field aperture axis. The acquisition time for each analysis was set to 15 mn. Thus, the total time per wafer (wafer loading + autofocus + analysis + wafer unloading) is 28 min, making a total of about 5.5 h for the twelve loads of the same wafer. Note that this a fully automated sequence, no operator attendance being required. It must also be emphasized that the throughput of the instrument is higher when measuring consecutively different wafers, which correspond to the most common measurement conditions. In this case, one can take advantage of the two wafer load-lock parking positions. The total time per wafer is shorter since the next wafer to be measured is loaded and pumped down in the load-lock while the previous wafer is being analyzed.

For the dose mapping test, a nine-site mapping has been performed across the wafer for two different orientations of the wafer loaded on the stage (90° rotation between the two loads). The nine spots were, at the center, and at 50 and 100 mm from the center to the east, north, west and south directions. The comparison of these mapping allows confirming if the dose variation is representative of a non-uniform implant or due to an instrumental effect.

3. Results and discussion

The $^{11}B^+$ profiles obtained for the load to load test with the FOUP in the sequence described above were quantified using a relative sensitive factor (RSF), determined by measuring a B bulk doped reference sample in the same conditions. The RSF value $^{11}B/^{28}Si$ was 7.88×10^{22}. This RSF value has been applied to calibrate the $^{11}B^+$ profiles, using for the reference signal the mean value of the Si curve computed over the last 200 nm. The profiles were depth calibrated using the laser interferometer data (the sputter rate was 3.3 Å/s). The 12 profiles are overlaid in Fig. 1. The profiles exhibit a dynamic range larger than four decades and a detection limit in the high 10^{15} atoms/cm^3. The dose value computed for each profile between 2.5 and 300 nm is given in Table 1. The average dose value is 1.01×10^{15} atoms/cm^2, very close to the expected value of 1×10^{15} atoms/cm^2. The maximum–minimum variation over the 12 loads is lower than 1%, and the standard deviation (S.D.) is 0.26%, indicating very good data reproducibility.

The 300 mm/B 10 keV wafer was also used for the nine-site mapping with the same experimental conditions. The results for the dose mapping series measurements are overlaid in Fig. 2. Since primary beam current was stable to within 0.2% over the mapping sequence, depth calibration of the profiles was performed using the same sputter rate value. This value is

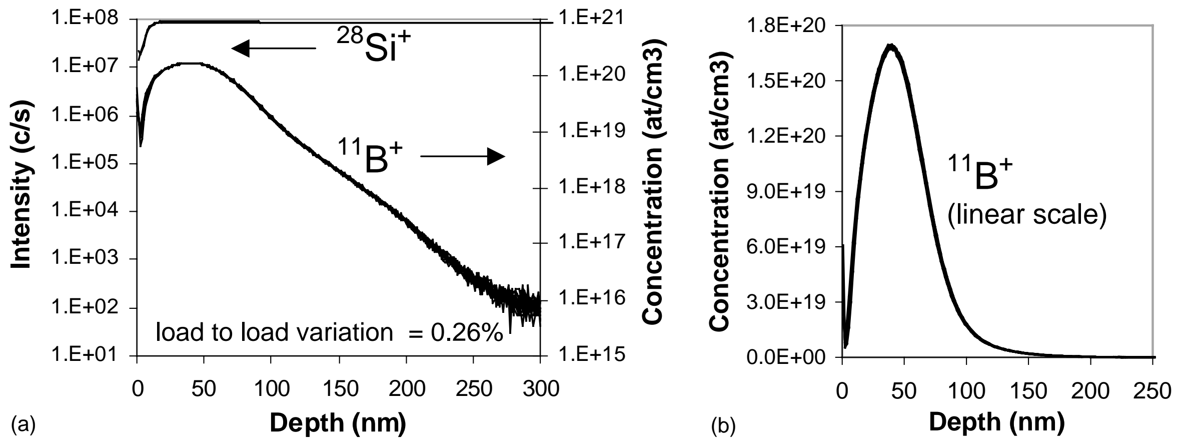


Fig. 1. Overlay of 12 quantified SIMS $^{11}B^+$ depth profiles, obtained for different loads of the same wafer: 10 keV B implant, measured under O_2^+ 4 keV impact energy. The scale is logarithmic in (a) and linear in (b). Matrix $^{28}Si^+$ profiles for the first and last measurements are also shown in inset (a). These results have been obtained in an automated sequence using the cassette loader.

the average over the mean sputter rate values given by the laser interferometer in the nine mapping analyses. Concentration quantification and dose computation of B^+ profiles has been performed as for the load to load test. Dose values across the wafer show significant differences, of about 4% between maximum and minimum value. The results after a 90° rotation of the wafer on the stage show dose variations relative to the wafer notch position in very good agreement with the first series and confirm a non-uniform B dose

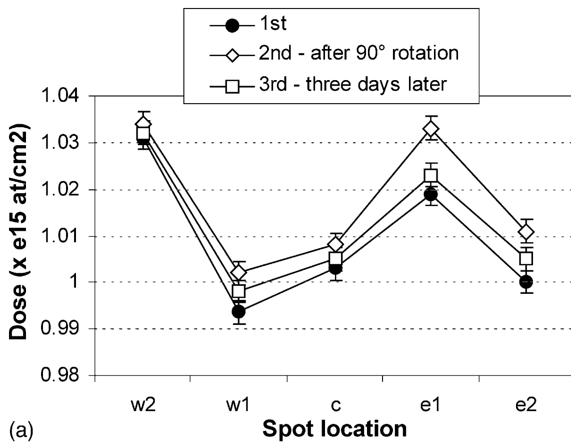
Table 1
Dose measurement repeatability for 12 load to load operations in an automated chained sequence using the cassette loader

Load	Dose ($\times 10^{15}$ atoms/cm^2)
1	1.005
2	1.008
3	1.010
4	1.007
5	1.009
6	1.009
7	1.008
8	1.014
9	1.011
10	1.011
11	1.010
12	1.014
Mean	1.010
Maximum–minimum	0.89%
S.D.	0.26%

Corresponding profiles are shown in Fig. 1.

across the wafer. A third series of measurements carried out three days later is also reported in Fig. 2. Note that the RSF value for the concentration calibration of this third series has been obtained from the profile from the center spot by imposing a dose value of 1.005×10^{22} atoms/cm^2 (average over the dose values obtained on the center spots for the two first mapping series). Again, the agreement of these results with the previous ones is remarkably good (see Fig. 2). These results show that the instrument can detect small dose variations across the wafer, allowing precise control of implant homogeneity across the wafer.

A set of eight 200 mm wafers with a low dose (5×10^{12} atoms/cm^2) 10 keV B implant have been analyzed under similar experimental conditions. The relative dose variation for the set of wafers has been measured and then compared to the scaling given by the implanter. The 200 mm wafers were manually introduced in the load-lock since a 200 mm cassette loader was not implemented on the instrument. A five-site mapping was performed on each wafer: a spot on the center and four spots at 70 mm from the center to the east, north, west and south directions. With a sputter rate of 10 Å/s, each analysis lasted 5 min to record a profile with three orders of magnitude dynamic range which is enough to get a dose value at better than 1% precision. This allowed the five-site mapping analyses to be completed in 25 min and therefore 42 min per wafer including load/unload operations and automatic routines (autofocus and



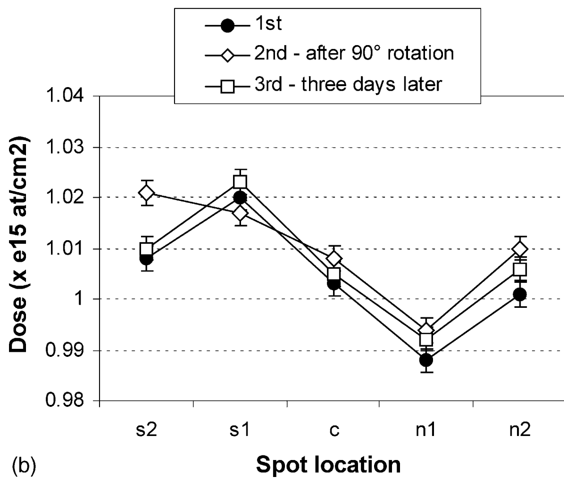


Fig. 2. Boron dose value obtained across the wafer (same wafer as for Fig. 1) for different wafer orientations and different days. Positions are relative to the wafer notch.

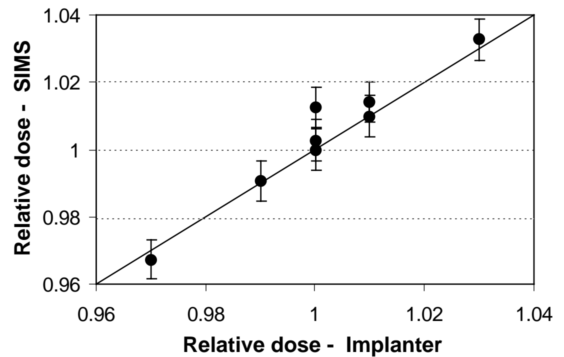


Fig. 3. Relative dose variation between eight wafers (B, 10 keV, 5×10^{12} atoms/cm^2): SIMS vs. implanter.

beam centering). Each five-site mapping sequence was performed in chained mode. The $^{11}B^+$ profiles were quantified using an RSF value $^{11}B^+/^{30}Si^+$ of 2.74×10^{21}, the value obtained on a reference B bulk doped sample. For each point measured on the wafers, the dose was computed between 10 and 220 nm. Since no significant variations have been obtained across each wafer, the dose values obtained for the five-site profiles have been averaged. The plot of the relative variation of the SIMS dose versus the relative variation of the implanter dose is shown in Fig. 3. For each wafer, the standard deviation for the dose values obtained on the five spots has been calculated. The error bars in Fig. 3 represent the average over the standard deviation values obtained for the eight wafers (0.62%). Very good agreement has been found between the SIMS dose and the implanter dose, demonstrating that the IMS Wf can detect 1% dose differences between wafers.

Repeatability performance of IMS Wf instrument has been tested extensively by performing full wafer analyses for shallow and deep implants of boron, phosphorus and arsenic in 200/300 mm wafers. The results are summarized in Tables 2 and 3. The load to load repeatability test results are reported in Table 2.

Table 2
Dose measurement repeatability for nine load to load operations of 200/300 mm wafers

300/200 mm wafer			Beam	Max–min (%)	S.D. (%)
As	4 keV	10^{15} atoms/cm^2	Cs^+, 1 keV	1.5	0.3
As	200 keV	5×10^{12} atoms/cm^2	Cs^+, 13 keV	3.2	0.9
P	30 keV	10^{15} atoms/cm^2	Cs^+, 13 keV	1.7	0.6
P	200 keV	5×10^{12} atoms/cm^2	Cs^+, 13 keV	0.9	0.35
B	2.2 keV	10^{15} atoms/cm^2	O_2^+, 500 eV	1.5	0.6
B	200 keV	10^{15} atoms/cm^2	O_2^+, 5 keV	1.7	0.32

ILSIMS SEA-project, courtesy of STMicroelectronics, Crolles, France.

Table 3
Dose measurement repeatability for nine spots across wafer

300/200 mm wafer			Beam	Maximum–minimum (%)	S.D. (%)
As	60 keV	10^{15} atoms/cm^2	Cs^+, 9 keV	0.52	0.25
As	4 keV	10^{15} atoms/cm^2	Cs^+, 500 eV	1.2	0.48
P	250 keV	5×10^{15} atoms/cm^2	Cs^+, 9 keV	2.3	0.88
B	225 keV	10^{13} atoms/cm^2	O_2^+, 7 keV	1.6	0.55
B	500 eV	5×10^{15} atoms/cm^2	O_2^+, 500 eV	2.3	0.78

ILSIMS SEA-project, courtesy of STMicroelectronics, Crolles, France.

In all cases, a standard deviation lower than 1% is obtained. Cross wafer repeatability test results (nine-site mapping) are reported in Table 3. Analyzed spots were at 0, 100 and 145 mm from wafer center. These results show standard deviation values of less than 1% also for wafer mapping measurements.

4. Summary and conclusion

The performance of the IMS Wf has been tested thoroughly by performing repeatability tests on full wafer samples. The analytical results presented in this article show that very good dose measurement repeatability (<1%) can be achieved for measurements of shallow, medium and deep profiles in the IMS Wf. This instrument can therefore detect very small dose variations among wafers or across a wafer. A special attention has been given to measurements performed using the cassette loader. Reproducibility of only 0.26% has been obtained for the sequential analysis of twelve loads of the same wafer performed in a fully automated sequence using the cassette loader configuration. In conclusion, the 300 mm stage of the IMS Wf instrument combined to the cassette loader capability and to a high automation level makes the full wafer analysis a routine application, this instrument being well adapted to perform high volume SIMS analyses.

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