Accurate Characterization of Dose and Shape of Ultra Low Energy Arsenic (1keV and 2keV) Implants by SIMS.

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Abstract- **During the past two to three years there have been several papers published on how to accurately measure the dose and shape of ultra low energy boron implants using Secondary Ion Mass Spectrometry (SIMS). In general, oxygen primary ion beam bombardment has been employed either using oxygen leak and 45° bombardment angle or normal incidence bombardment without oxygen leak. These methodologies have been employed to avoid problems from the pre-equilibrium issues encountered during SIMS measurements.**

The accurate dose and profile shape of ultra low energy arsenic implants unfortunately cannot employ the methodologies established for low energy boron measurements, due to the fact that arsenic segregates to the front of the oxygen beam when sputtering employing an oxygen ion beam and therefore the true shape of the arsenic implant profile can not be established.

In this paper, we employ Cesium primary ion beam bombardment using various sub-keV energies, various angles of bombardment and normalisation routines to establish the true shape and dose of 1 keV and 2 keV arsenic implants. The normalization of the arsenic profile to various silicon isotopes and combinations of its dimers are considered along with low temperature Chemical Vapour Deposited (CVD) silicon capped 1 keV and 2 keV arsenic implants. This is employed to avoid the pre-equilibrium transients in the SIMS profile of the arsenic at the surface of the silicon. The results lead to a methodology for obtaining the correct arsenic implanted dose and the correct arsenic implant shape using specific normalisation routines. The arsenic doses calculated from SIMS have been compared with Rutherford Backscattering (RBS) measured dose values.

INTRODUCTION

The production of 0.1µm complementary metal-oxide semiconductor (CMOS) devices requires the formation of very abrupt shallow junctions.

These junctions are expected to be as shallow as 20 nm with extremely high dopant concentrations for this technology node. These are the pre-requisites for the required low sheet resistance values in these advanced devices. Ultimately, it is necessary that the electrical junction values be measured very accurately using techniques such as Spreading Resistance Profiling (SRP). The inherent difficulties to accurately measure such shallow junctions using SRP easily and also its inability to measure non-activated dopants have meant that Secondary Ion Mass Spectrometry (SIMS) has been used extensively in the characterization of these Ultra Low Energy (ULE) junctions. To obtain the correct dose, profile shape and the correct junction depth using SIMS is, however, a non-trivial task.

Boron (p-type) and Arsenic (n-type) are the two dopants being used today for the formation of these ULE, p++ and n++ junctions in PMOS and NMOS transistors, respectively. During the past two to three years there have been several papers published [1, 2, 3, 4] on how to accurately measure the dose and shape of ultra low energy boron implants using SIMS. In general, oxygen primary ion beam bombardment has been employed either using oxygen leak and 45° bombardment angle or using normal incidence bombardment without oxygen leak. These methodologies have been employed to avoid problems from the pre-equilibrium issues encountered during SIMS measurements. Care has been taken to eliminate surface transient effects, crater bottom roughening and minimization of SIMS knock on effects by using appropriately low enough energies of O_2^+ bombardment with oxygen leak.

It has been shown [3] that not using appropriately low enough energies or appropriate angles will result in measuring a smaller dose compared to the implanted dose. In general it is accepted that the primary ion energy used for measurement of ULE boron implants should be 50% of the implanted energy (normal to the wafer surface). Other issues affect inaccuracies in the measured dose. Point-To-Point (P-T-P) normalization to the Si matrix exaggerates the surface peak for 45° bombardment with oxygen leak and results in the wrong (higher) dose values. This surface peak gets larger as a function of increased SIMS primary energy because the surface transient is longer and the matrix signal turns over lower.

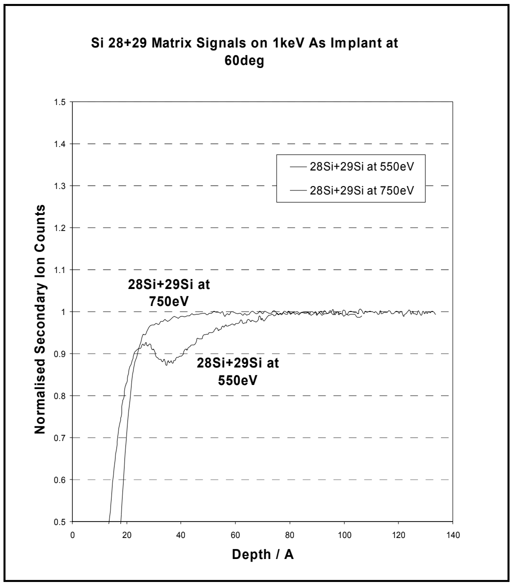

Fig.1 Normalized ^{28}Si + ^{29}Si counts at 60° angle of bombardment for Cs^+ ions at 550 eV and 750 eV energy.

In this study we try to establish the correct SIMS profiling parameters for the analysis of ULE arsenic implants. The accurate dose and profile shape of ultra low energy arsenic implants unfortunately cannot employ the methodologies established for low energy boron measurements, due to the fact that arsenic segregates to the front of the oxygen beam during the sputtering process employing oxygen ion beam and therefore the true shape of the arsenic implant profile can not be established using the methodologies established above for ULE boron measurement. Also the lack of sensitivity does not allow the junction depth to be measured accurately [4].

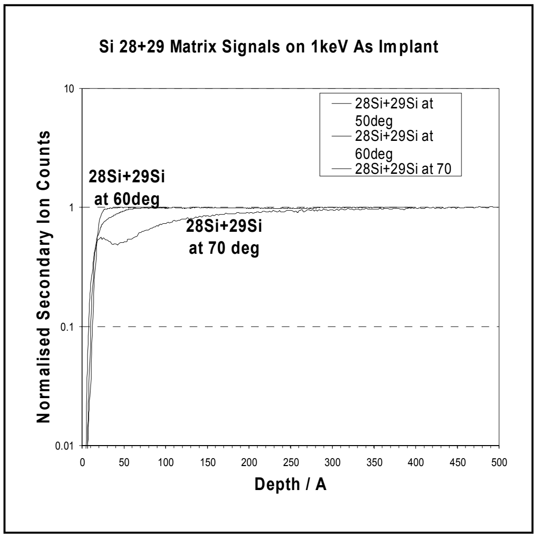

Fig.2 Normalized ^{28}Si + ^{29}Si counts for angles of bombardment 50°, 60°and 70° using 750 eV Cs^+ ions.

EXPERIMENTAL AND RESULTS

In this study we have employed cesium primary ion beam bombardment using *various sub keV energies*, *various angles of bombardment* and *normalisation routines* [5] to establish the true shape and dose of 1 keV and 2 keV arsenic implants. The normalization of the arsenic profile to various silicon isotopes and various combinations of its dimers are considered in a similar manner to Tomita et.al. [5]. Two silicon wafers implanted with 1 keV and 2 keV arsenic were also capped using low temperature chemical vapour deposited (CVD) silicon. This was employed to avoid the pre-equilibrium transients in the SIMS profile. The profiles obtained from the capped wafers were also used to compare our methodology used in the non-CVD silicon coated wafers. Finally the arsenic doses calculated from SIMS have been compared to RBS measured dose values.

The implants were carried out in an Applied Materials LEAP implanter. The CVD coatings were made with an Applied Materials CVD tool on an identical wafer. All the SIMS profiles were carried out using a PHI ADEPT 1010 SIMS instrument.

The R_p of a 1 keV arsenic implant is 3.2 nm from TRIM calculations. Therefore, to accurately measure the arsenic profile using SIMS, our measurement parameters must try to ensure that the matrix signal we wish to use for normalization purposes is at equilibrium below this depth (3.2 nm).

It has been suggested that the $^{28}Si + ^{29}Si$ dimer has similar energy distribution to the SiAs ion [6]. We evaluated the $^{28}Si + ^{29}Si$ dimer using different angles and energies of bombardment. It can be seen from figures 1 and 2 that the $^{28}Si + ^{29}Si$ dimer reaches equilibrium at a shallower depth when implementing 750 eV, 60° ion bombardment compared with other bombardment conditions. Although we are uncertain as to why the matrix oscillations seen are reduced under these conditions, obtaining a shallow equilibrium in the matrix signal used for normalisation is essential for the protocol suggested to achieve the correct dose and shape of the arsenic implant.

We also evaluated the trailing edge values of the SiAs dimer at different beam angles using 750 eV primary ion energy. The decay lengths are shown in Table 1.

TABLE I

Decay lengths of As 1 keV implants as a function of primary beam angles.

Beam Angle	**Trailing edge / nm (1/e decay)**
50°	1.7 nm
60°	1.0 nm
70°	1.1 nm

Therefore from our studies we arrive at the following parameters for the analysis of the 1 keV and 2 keV arsenic implants: 750 eV Cs^+, 60° angle of bombardment, following SiAs and using $^{28}Si+^{29}Si$ as the matrix signal.

TABLE II

Comparing implanted dose to SIMS and RBS Dose

Implant Dose (At/cm^2) And Energy (keV)	**SIMS Dose (At/cm^2)**	**RBS Dose (At/cm^2)**
1E15, 1keV	1.08E15	0.92E15
1E15, 1 keV, Capped	1.07E15	0.91E15
1E15, 2 keV	1.07E15	0.89E15
1E15, 2keV, Capped	1.01E15	0.88E15
1E15, 10 keV	0.86E15	0.90e15

All that remains is the quantification of the measured arsenic profile. Tomita et al. [5] reported that P-T-P normalization ($SiAs/Si_2$) normally overestimated the measured dose by 40 %, using SiAs/Si underestimated the dose by 9 % and the SiAS/bulk Si_2 value also overestimated the dose. Our procedure does not fully agree with the above findings.

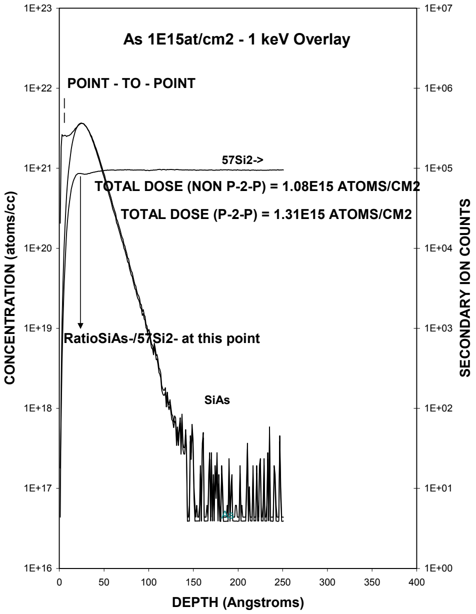

Fig.3. Overlay of a 1 keV arsenic implant quantified using P-T-P normalisation and overlaid with $SiAs/^{57}Si_2$ at the peak depth of the arsenic profile as indicated.

We found that SiAs/bulk Si_2 underestimates the dose slightly. When using the $SiAs/^{57}Si_2$ value at the same depth where the peak of the arsenic implant is for normalisation (see Fig. 3), we observed the best possible dose agreements.

Figures 4 and 5 are overlay profiles through the capping layer with normalization to the $^{57}Si_2$ value at the peak of the arsenic implant profile and P-T-P normalisation, respectively.

A range of 1 keV (capped and un-capped), 2 keV (capped and un-capped) and 10 keV arsenic implants were measured using the above protocol and the results are compared with those obtained using RBS of the same samples. Table 2 shows the SIMS and RBS measured doses. The correlation is found to be excellent within experimental error.

SUMMARY

In summary, SIMS is an excellent tool for precision dose measurement together with providing the correct implant shape and hence the junction depth values of low energy Arsenic implants. Nevertheless, great care must be taken when measuring such low implant energies using SIMS. The correct protocol - i.e. 60°, 750 eV Cs^+ bombardment and normalisation using the $SiAs/^{57}Si_2$ value at the depth where the peak arsenic concentration value lies - must be adhered to in order to obtain the correct arsenic implant dose and shape. RBS is also a very useful tool for measuring the arsenic dose accurately (provided the dose is high for such ULE implants) with the dose value correlation to SIMS being excellent.

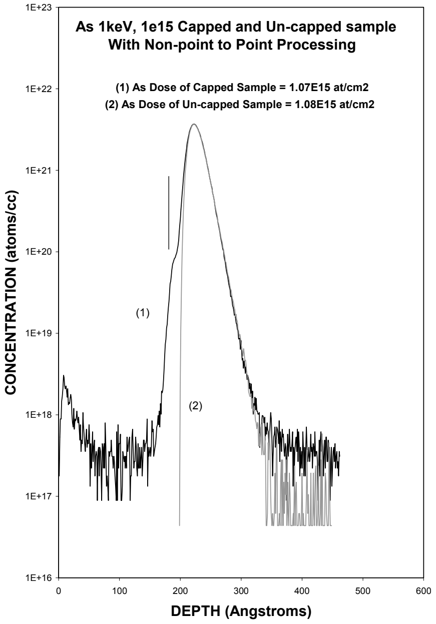

Fig.4. Comparison between SIMS profiles of capped and uncapped arsenic implants (1 keV, 1E15 at/cm^2). The un-capped profile has *not* been P-T-P normalized. The shoulder observed at the cap interface indicated by a vertical dash is due to the presence of interfacial arsenic and has been verified by measuring the arsenic content in a boron implanted wafer with capping layer.

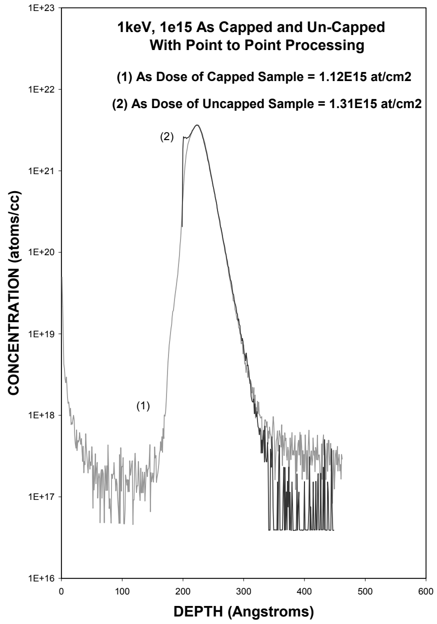

Fig.5 Comparison between SIMS profiles of capped and uncapped arsenic implants (1 keV, 1E15 at/cm^2). The un-capped profile has been quantified using P-T-P normalisation.

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