Dynamics of Arsenic dose loss at the SiO_2 interface during TED

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Abstract

The transient behavior of arsenic dose loss at the silicon-SiO_2 interface during transient enhanced diffusion has been studied. Careful sample preparation and high precision surface SIMS are successfully used to achieve highly reproducible and accurate dose measurements. Effects of different ion implantation and annealing conditions on dose loss are studied. A dopant trapping/detrapping model at the interface is used to simulate the experimental results.

I. Introduction

The silicon-oxide interface traps a significant amount of dopant dose during annealing [1,2]. The trapped dopants become immobile, electrically inactive and will be removed by an HF oxide etch. Experimental work shows that dose loss is related to TED [1] and also Solid Phase Epitaxy (SPE) which happens during annealing an amorphizing implant dose [3]. Also, it has been shown that dose loss is partially reversible [1]. In this work, we have studied the transient behavior of dose loss for arsenic implants. The correlation between TED and dose loss and the effect of SPE on dose loss are studied. Dynamics of reversibility of dose loss are examined. A trap model is implemented and used to simulate the experimental results.

II. Experimental Setup

A furnace dry oxidation at 800C was used to grow a 100A screen oxide on <100> p-type Czochralzki silicon wafers. Arsenic implants at 32 keV were done through the oxide. Implants were in two doses: 1×10^{15} /cm^2 which is an amorphizing dose and 2×10^{13} /cm^2 which is below the amorphous threshold.

A series of anneals at 1050C and 750C were done in an argon ambient. Table 1 summarizes the anneal times. All the anneals were done in an RTA except for the 750C 2-hour anneal which was done in a furnace. Additionally, for the amorphizing dose of 1×10^{15} /cm^2 a 600C 4-minute anneal was done to separate the effect of Solid Phase Epitaxy from TED. TED is minimal for this sample but solid phase epitaxial regrowth has occurred; any dose loss observed would be due to SPE only. After annealing, the oxide was removed by dilute HF. Samples were carefully monitored during the oxide etch to avoid over etching the surface of silicon.

High precision surface SIMS was used to measure dopant profiles and total dose. In this technique [4], an oxygen leak during the SIMS, a very low sputtering rate and a high tilt oxygen sputtering beam are used to achieve dopant profiles accurate to about 10A from the surface. We have used as-implanted samples during the SIMS as control samples for dose measurements and also to estimate the reproducibility of the SIMS dose measurements. One as-implanted sample was run in the beginning of each day of SIMS and the same sample was run towards the end of the day. These results were used to estimate the error in dose measurements in each day of SIMS. Also, calibration standards with grown arsenic layers were run in between samples to monitor and calibrate the machine drift.

III. Results and Discussion

Fig.1 shows the SIMS results for two different runs of the as-implanted 1×10^{15} /cm^2 sample at the beginning and end of a day of SIMS along with the profile of the sample annealed for 1 second at 1050C. The two as-implanted profiles lie almost exactly on top of each other while the 1-second anneal gives a 28% dose loss. Using this surface SIMS technique, we have achieved less than 1% error on dose measurements within each day of SIMS, and less than 2% error for 1×10^{15} /cm^2 samples between different days of SIMS. For 2×10^{13} /cm^2 samples, we are measuring low concentrations of arsenic and have an 8% error between different days of SIMS. Overall, we have achieved highly reproducible, accurate dose measurements.

In order to verify surface SIMS accuracy we looked at two different profiles: a monotonically increasing and a monotonically decreasing profile. As shown in Fig. 2, surface SIMS is indeed capable of distinguishing these two all the way up to the surface. We used the first 200A of as-implanted 1×10^{15} /cm^2 for the monotonically increasing profile. The monotonically decreasing sample was made by wet oxidation of the as-implanted sample at 750C for 1 hour. Growing 1100A of oxide and snow plow effect for arsenic would create a monotonically decreasing profile.

Fig. 3 shows the SIMS result for a 600C 4-minute anneal along with the as-implanted profile. The crystalline/amorphous interface is extracted from a UT Marlowe simulation of the implant. There is a small shift in the peak of the profile after the anneal. This is caused by Solid Phase Epitaxy. No dose loss is measured for this sample. This means that SPE does not cause dose loss for 32 keV arsenic implants.

A set of SIMS profiles for the high dose sample annealed for different times at 1050C are shown in Fig. 4. The percent arsenic dose loss for different anneal times at 1050C is shown in Fig. 5. For both low and high implant doses there is a significant amount of dose loss for a 1-second anneal. For a 1×10^{15} /cm^2 implant, dose loss increases with the anneal time up to 10 seconds, and then it drops and remains constant. This is possibly because TED is over and there is not a flux of silicon interstitials towards the surface, pushing dopants and keeping them in a super saturated state at the interface. Another possibility is that trap sites at the interface are annealed out and cannot hold as much dopant. For the 2×10^{13} /cm^2 implant, dose loss increases with time, or equivalently with total diffusion.

Fig. 6 shows the transient of arsenic dose loss at 750C. No dose loss is observed for anneal times less than 2 minutes. For both implant doses, dose loss increases with the anneal time up to 2 hours. The higher dose implant shows larger dose loss for each anneal time.

IV. Modeling and Simulation

A general interface trap model proposed by Lau et. al. [5], assumes trapping and emission fluxes into and out of the traps on each side of the boundary. Fig. 7 shows a schematic of this model. Dopant flux terms on each side of the interface are:

$$F_1 = t_1 T_0 C_1 - e_1 T_d$$

$$F_2 = t_2 T_0 C_2 - e_2 T_d$$

$$\frac{\partial T_d}{\partial t} = F_1 + F_2$$

where $T_d + T_0 = T$ is the total number of traps at the interface, T_d is the density of filled traps and T_0 is the density of the empty traps. F_1 and F_2 are dopant fluxes out of oxide and Si into the interface, respectively and t and e are trapping and emission coefficients on each side of the boundary. The equilibrium segregation will be eventually reached with this proportionality:

$$m = (e_1/t_1) \times (t_2/e_2)$$

We have used a partial differential equation solver for diffusion equations [6], and implemented this trap model along with fully coupled diffusion and 311 cluster growth/evaporation models [7]. A +1 model for the damage is used. Fig. 8 shows the simulated profiles for $1X10^{15}$ /cm^2 implant, annealed at 1050C. Fig.9 compares simulation and experimental results for the transient behavior of arsenic dose loss. As seen in these two figures, this model predicts the dose loss for anneal times longer than 30 seconds. However, it cannot predict the overshoot in the dose loss that happens at shorter anneal times.

Summary

Transient behavior of arsenic dose loss has been studied. Careful sample preparation and high precision surface SIMS are successfully used to obtain highly reproducible and accurate dose measurements. Correlation between TED and dose loss, and the effect of Solid Phase Epitaxy on dose loss are investigated. A trapping/emission model has been used to simulate the experimental results.

Acknowledgments

The authors wish to thank Eric Perozziello for his help in sample preparation and Dr. Martin Giles and Dr. Henry Chao for their insightful discussions. This work was supported by the Semiconductor Research Corporation and Intel.

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Temperature	Anneal Time							
1050 C	1 sec.	5 sec.	10 sec.	20 sec.	30 sec.	2 min.		
750 C	5 sec.	15 sec.	30 sec.	1 min.	2 min.	4 min.	8 min.	2 h
600 C	4 min.							

Table 1: Anneal times and temperatures

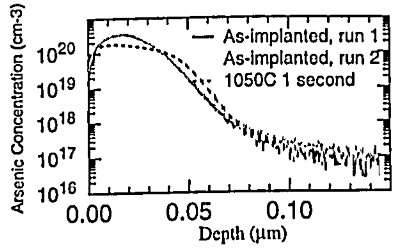

Fig. 1: SIMS profiles at the beginning and end of a day for as-implanted $1X10^{15}$ /cm^2 32keV arsenic implant along with a sample annealed for 1 second at 1050C which shows 28% dose loss.

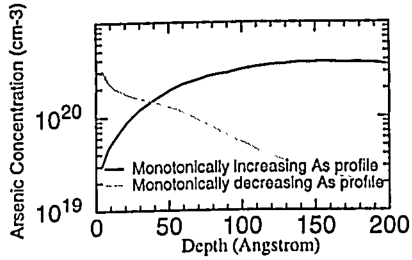

Fig. 2: Comparison of the SIMS results of two different arsenic profiles: monotonically increasing and decreasing with depth.

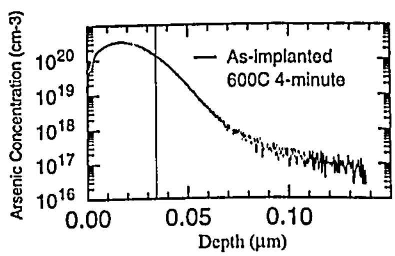

Fig. 3: SIMS profiles of as-implanted and 600C 4-minute anneal. No dose loss due to Solid Phase Epitaxy is observed.

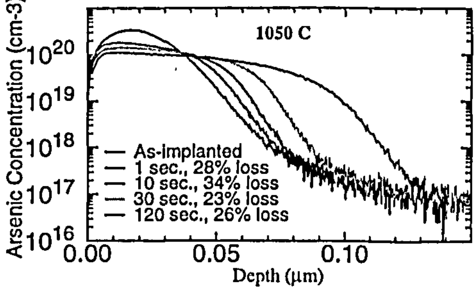

Fig. 4: A set of SIMS profiles of $1X10^{15}$ /cm^2 implant annealed for different times at 1050C along with the as-implanted profile.

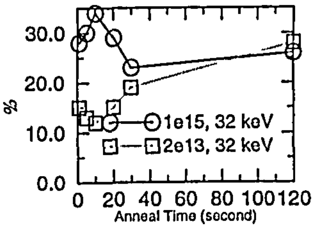

Fig. 5: Percent arsenic dose loss vs. anneal time for 1050C anneals.

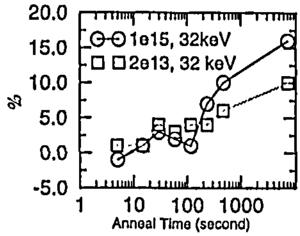

Fig. 6: Percent arsenic dose loss vs. anneal time for 750C anneals.

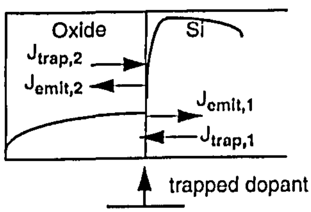

Fig. 7: A schematic of trapping/emission model

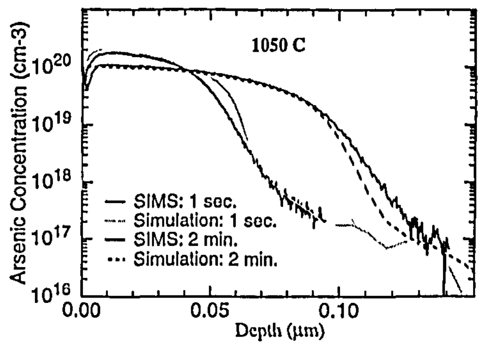

Fig. 8: SIMS and simulation results for $1X10^{15}$ /cm^2 32 keV arsenic implant annealed at 1050C.

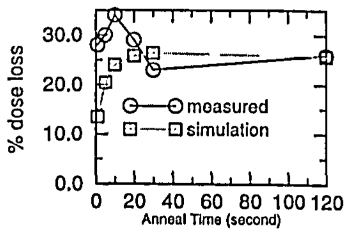

Fig. 9: Measured and simulated dose loss transient for $1X10^{15}$ /cm^2 32 keV arsenic implant annealed at 1050C.