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Modeling of Ultra Shallow Junctions and Hybrid Source/Drain Profiles Annealed by Soak and Spike RTA

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Abstract – This paper discusses the 1D/2D modeling of arsenic profiles under soak and spike anneal conditions at both shallow extension and high concentration Source/Drain areas. This work also addresses the calibration of phosphorus profile in a hybrid (Arsenic + Phosphorus) Source/Drain with various anneal temperatures. It is shown that "+1" or modified "+n" model is not necessary for shallow arsenic profile modeling under spike anneal conditions. Finally, it is also shown that modeling of hybrid Source/Drain profile can be achieved by optimization of the dopant's Fermi level dependent diffusivity, initial value of point defects concentration at equilibrium state, and neglect of implant induced damage.

I. Introduction

Both USJ (Ultra-Shallow Junction) extension and hybrid (Arsenic + Phosphorus) Source/Drain are necessary for constant device scaling in aggressive CMOS technologies. The implant dosage at ultra-shallow extension area is increased in order to keep low sheet resistance while junction depth is scaled. That seems to make implant damage to play a more important role in dopant diffusion compared to convention LDD. The conventional approach to shallow junction modeling in the presence of implant damage is to use a "+1" or modified "+n" model to tune the diffusivity [1]. However, we have found that it does not work for USJ modeling under spike anneal condition.

Hybrid (Arsenic + Phosphorus) Source/Drain is very useful for reducing junction capacitance [2] and for alleviating polysilicon depletion [3] under tight thermal budget processes. The profile near the arsenic junction becomes graded because of the rapid diffusion of phosphorus inside the highly doped arsenic region. This effect also makes the hybrid junction a sensitive test structure for investigating Fermi level effects on phosphorus diffusion. Phosphorus diffusion modeling is notoriously difficult and embedding the phosphorus profile in a high concentration arsenic layer further complicates the problems. More sophisticated models included a vacancy rich surface region and an interstitial rich deeper region [4] was also introduced to model arsenic profile only. We have found that none of these models give a good global calibration for hybrid doping profiles subjected to very low thermal budget processes. Instead, optimum global profile fitting at different anneal temperature by optimization of the dopant's Fermi level dependent diffusivity, point defects concentration, and neglect of implant induced damage. We propose that the effects of implant damage are negligible for short soak or spike anneals and instead Fermi level dependent effects dominate the doping profile shapes. All of these ideas were implemented into 120nm and 75nm NMOSFET simulations and verified with silicon data.

II. Experimental

One-dimensional doping profile were obtained by SIMS from un-patterned wafers with same implant conditions and annealed by spike or soak RTA. The one-dimensional profile calibration results were verified with two kinds of NMOS transistors fabricated based on two different technologies. One has 20 Å oxide, soak anneal and a nominal gate length of 110nm [2] (technology A). Another has 17 Å oxide, spike anneal and a nominal gate length of 80nm [3] (technology B).

III. Profile annealed by soak RTA for Technology A

TSUPREM4 simulations with a plus-one model for ion implant damage and a fully coupled model for diffusion simulate well ultra shallow arsenic profile in the extension region (Fig. 1). However, it fails to capture the arsenic/phosphorus profile in the deep S/D region (Fig. 2), especially for phosphorus profile. A more sophisticated damage model with vacancies created at silicon surface and deeper interstitials from TRIM [4] was implemented in TSUPREM4 and the results shown in Fig.3. However, this approach succeeds in modeling arsenic but fails to model the hybrid implant profile. If we disable the plus-one model during implantation and optimize the equilibrium damage distribution prior to the soak RTA, only a vacancy-rich surface is observed due to the effect of the Fermi level on native point defects (Fig.3). This is effectively a concentration dependent profile, because the Fermi level will change during annealing as the dopant activation level changes. The optimized TSUPREM4 parameters of interstitial, vacancy, arsenic and phosphorus are listed at table 1. With this approach, we can properly model both arsenic and phosphorus profiles as shown in Fig. 2. The polysilicon depletion and quantum mechanism effects were also calibrated with C-V curve fitting of MOS capacitor (Fig. 4). And then, the result is implemented into two dimensional NMOSFET simulation for threshold voltage roll-off fitting as shown in Fig. 5. The good global fitting means correct profile modeling, especially at extension profile. Figure 6 show the excellent output characteristics Id-Vd global fitting that was attained by implementing the proposed model to technology A.

IV. Profile annealed by spike RTA for Technology B

The diffusion parameters obtained from soak RTA calibration were used to simulate the profile annealed by the spike RTA. Figures 7 and 8 show the simulation results in the extension and deep S/D region respectively. Obviously, the diffusion is overestimated for ultra shallow arsenic in the extension region. Arsenic profiles at the deep S/D region are reasonable, but the phosphorus profile needs further optimization. For a spike anneal process with a high ramp rate, the anneal time at low temperature is very short. Once again, enhanced diffusion caused by implant damage is not observed and in order to reflect this phenomena in simulation, we disabled the plus-one model for the implant damage. The point defect distribution is kept at its equilibrium value prior to the spike RTA simulation. The corresponding results for the arsenic ultra-shallow extensions are also shown in Fig. 7 after optimization of the intrinsic diffusivity and dose loss parameters at silicon/oxide interface [5]. Furthermore, good fitting of the phosphorus profile could then be obtained by minor tuning of the diffusivity. Figure 8 shows the final fitting result at different anneal temperatures for the deep S/D profiles. The methodology was also implemented into full process/device simulation. As like what we did at 0.15μm technology, polysilicon depletion and quantum mechanism effects were calibrated with C-V curve fitting. (Fig. 9) Figures 10 and 11 show the excellent threshold voltage roll-off and output characteristics Id-Vd global fitting that was attained by implementing the proposed model to technology B.

V. Conclusion

This work showed that spike-annealed ultra-shallow extension profiles could be properly modeled by optimization of diffusivity with negligible the plus-one model effect. However, in the case of implants annealed by soak RTA process, the plus-one model phenomenon was modeled for accuracy. The high concentration hybrid S/D profiles under both soak and spike anneal conditions were accurately modeled by ignoring the plus-one model and optimizing the equilibrium damage distribution prior to RTA. Global fitting was also obtained for spike samples with different anneal temperatures. These models were implemented into a full process/device simulation environment to demonstrate its validity for both device designs in two technologies.

References

[1] Avanti's TSUPREM-4, ver. 2000.2.0, 2000

[2] Carlos H. Diaz,, *et al.*, "A 0.15 μm CMOS Foundry Technology with 0.1 μm Devices for High Performance Applications", VLSI Tech. Symp., p. 146-147, 2000

[3] K.K.Young, *et al.*, "A 0.13μm CMOS Technology with 193nm Lithography and Cu/Low-k for High Performance Applications", IEDM Tech. Dig., p. 563-566, 2000

[4] P. Fastenko, S.T. Dunham, B. Murphy, " Modeling of Initial Stages of Annealing for Amorphizing Arsenic Implants", SISPAD, p. 171-174, 2000

[5] Y. Oh, D.E. Ward, "A calibrated Model for Trapping of Implanted Dopants at Material Interface During Thermal Annealing", IEDM Tech. Dig., p. 509-512, 1998

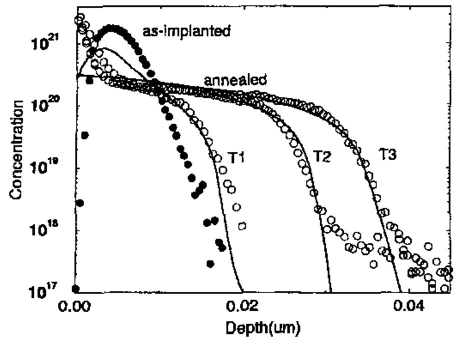

Fig.1. Simulation of low energy arsenic implant annealed at three temperatures of soak RTA compared to SIMS data (symbol).

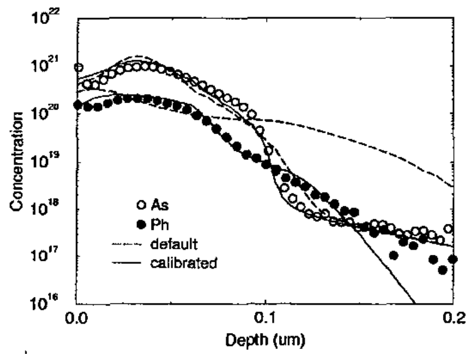

Fig.2. Simulation of arsenic followed by phosphorus implant annealed by 10 seconds soak RTA compared to SIMS data (symbol).

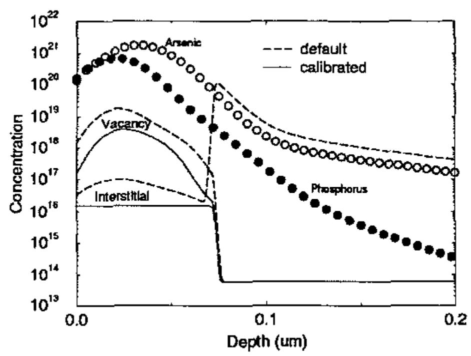

Fig.3. The distribution of arsenic, phosphorus, interstitial and vacancy after implant with default and calibrated parameters.

I	V	Ar		Ph	
neu.0	**neu.0**	dix.0	**dvx.0**	**dix.0**	dvx.0
neu.e	neu.e	dix.e	dvx.e	**dix.e**	dvx.e
neg.0	neg.0	dim.0	**dvm.0**	dim.0	dvm.0
neg.e	neg.e	dim.e	dvm.e	dim.e	dvm.e
dneg.0	**dneg.0**	dimm.0	dvmm.0	dimm.0	**dvmm.0**
dneg.e	**dneg.e**	dimm.e	dvmm.e	dimm.e	**dvmm.e**

Table 1. Important TSUPREM4 parameters for point defects and hybrid Source/Drain dopants are shown in bold. The other parameters are the default values or zero.

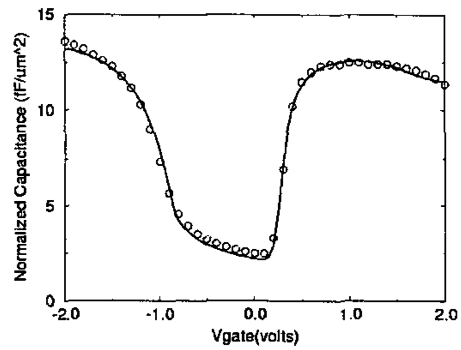

Fig.4. Calibration of polysilicon depletion and quantum mechanism effects with T_{OX} = 20Å C-V curves. (symbol : silicon data)

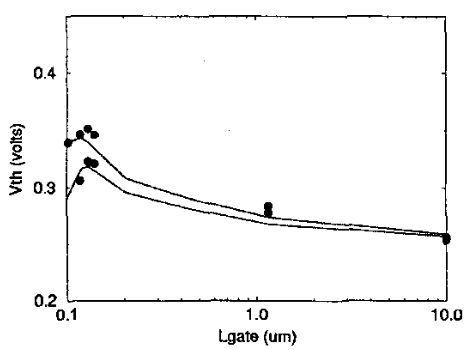

Fig.5. The simulated characteristics of threshold voltage versus channel length with Vds=0.1 and 1.2 volts compared to silicon data (symbol) for technology A.

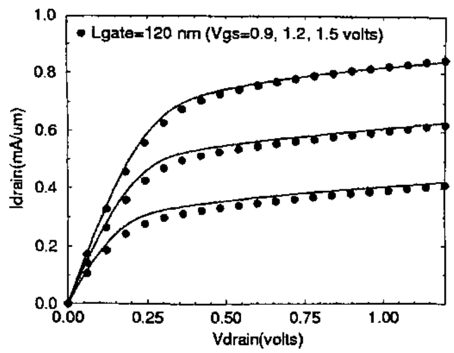

Fig.6. The simulated Id-Vd curves compared to silicon data (symbol) with Lgate= 120.

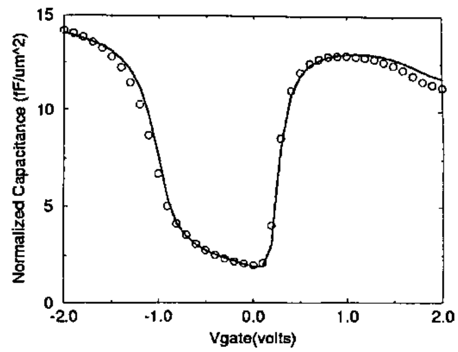

Fig.9. Calibration of polysilicon depletion and quantum mechanism effects with T_{OX} = 17Å C-V curves. (symbol : silicon data)

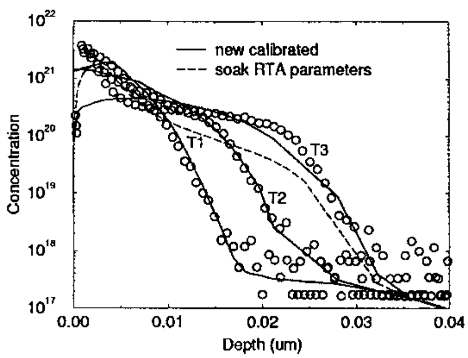

Fig.7. Simulation of low energy arsenic implant annealed at three temperatures of spike RTA compared to SIMS data (symbol). Dash line means simulated with parameters used in soak RTA case at temperature T1. Solid lines means simulated with new calibrated parameters.

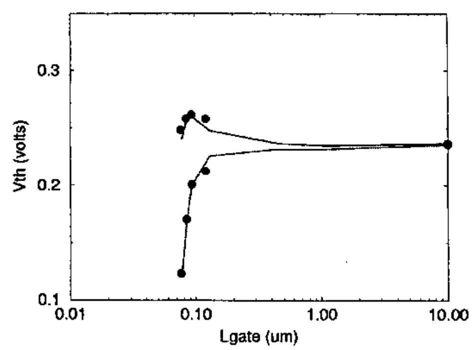

Fig.10. The simulated characteristics of threshold voltage versus channel length with Vds=0.1 and 1.0 volts compared to silicon data (symbol) for technology B.

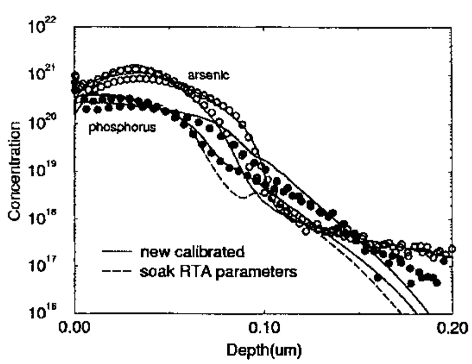

Fig.8. Simulation of arsenic followed by phosphorus implant annealed at two temperatures of spike RTA compared to SIMS data (symbol). Dash line means simulated with parameters used in soak RTA case. Solid lines means simulated with new calibrated parameters.

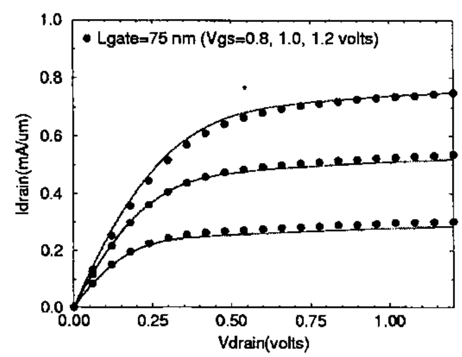

Fig.11. The simulated Id-Vd curves compared to silicon data (symbol) with Lgate= 75 nm.