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A Novel Transient Enhanced Diffusion Model of Phosphorus during Shallow Junction Formation

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1. Introduction

High-dose ion implantation and low temperature annealing are one of the key technologies for shallow junctions fabrication in quarter-micron CMOS VLSIs. It is well known that transient enhanced diffusion (TED) of implanted dopants dominates in diffusion mechanism at low temperature furnace annealing and RTA (Rapid Thermal Annealing) [1]-[8]. We reported an empirical compact model of TED which describes its dependency on implant doses and annealing temperature [6]. However, the model assumes effective diffusivity during the 10 minutes in furnace annealing, therefore it fails to describe time-dependent TED effect such as short-time RTA and ramping-effect in furnace annealing.

In this work, a new study on transient enhanced diffusion is discussed, which is focused on the RTA process for phosphorus diffusion. The dependency of annealing time on TED phenomenon is newly characterized as parameters of annealing temperature and implant dose in the new model.

2. A new universal TED model

We evaluated about forty samples of phosphorus doping-profile fabricated with various process conditions including RTA. Dopant depth-profiles are measured by SIMS analysis with CAMECA-ims4f. Analytical distribution model (Dual-Pearson IV) is used to analyze ion-implant profiles with calibrated parameters. In dopant-diffusion, a new TED model has been developed on the basis of the vacancy-assisted diffusion model. In the model, relaxation time approximation is utilized to formulate the point defect effects on impurity diffusion as shown in Figure 1. Here, Do is the normal diffusion constant and D is the TED diffusion constant. The model shows effective TED diffusivity which depends on the annealing time, annealing temperature and implant dose. The D-time (time dependent diffusivity) curves, shown in the Fig.1, are characterized with a new analytical model equation by introducing additional three semi-empirical parameters. The model parameters are extracted from the RTA experiments (SIMS profiles) and previous TED model data[6]. It is noted that the proposed model converges to previous empirical TED model equation when the annealing-time exceeds 10min in conventional furnace annealing. As the results, the effective TED diffusivity is determined as a parameter of annealing time for various annealing temperature as shown in the figure. The activation energy was approximately 2.0eV for the TED relaxation-time constants in our experiments.

3. Evaluation of TED model

As-implanted phosphorus profiles obtained from simulation and SIMS measurement are shown in Figure 2, for the implantation conditions of $1\times10^{14}/cm^2$ dose and 50keV acceleration-energy. As shown in the figure, both profiles coincide each other within an error of 0.8%. To demonstrate transient enhanced diffusion during phosphorous furnace annealing, simulation without TED effect is conducted and compared with experiment as shown in Figure 3 (a), showing a large discrepancy at the tail parts of profile after 10min furnace annealing at 900C. Figure 3 (b) shows the SIMS profile and simulation with TED parameter. TED parameter is verified in such a way that the both profiles get a good fit within error of less than 2% as shown in Figure 3 (b). The TED model is also applied to the RTA process as shown in Figures 4 (a) (b). In RTA, the TED phenomenon is observed during 1 sec. The experimental profile is coincident on the simulation with TED parameter.

4. Conclusion

The new compact universal TED model is proposed on the basis of the vacancy-assisted diffusion model. The model describes the relaxation-time of point defects which depends on the annealing temperature and implant dose. The model is verified both in the furnace and RTA processes.

References

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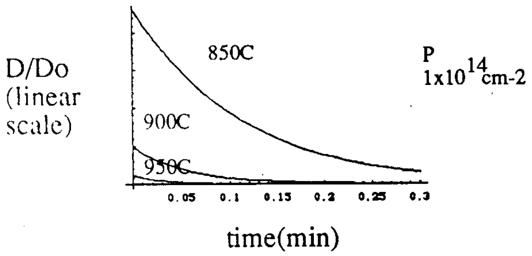


Figure 1 TED diffusivity

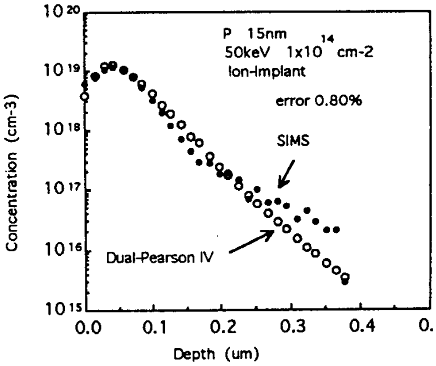
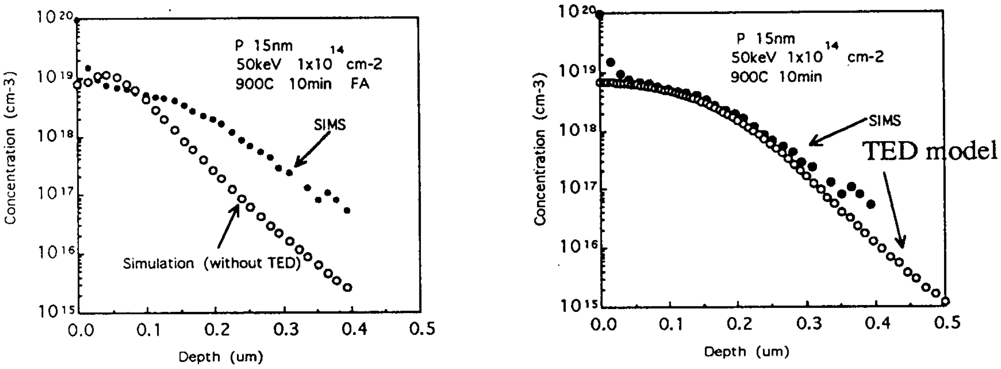


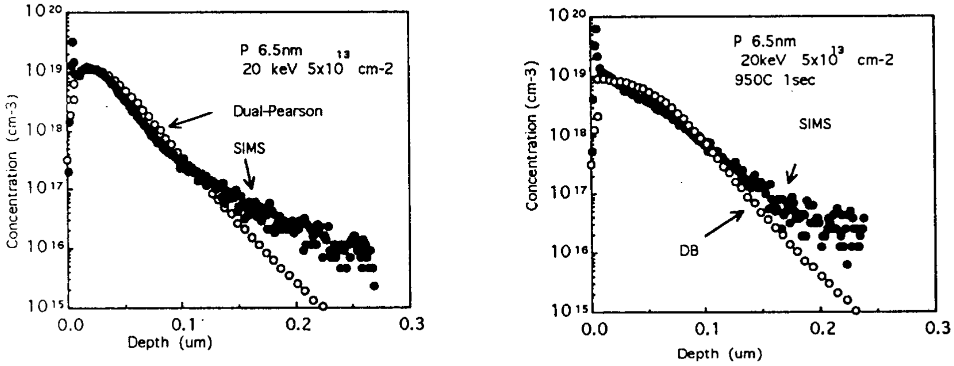
Figure 2 Phosphous profiles of SIMS and simualtion after ion-implant



(a) Without TED

(b) With TED

Figure 3 Comparison of phophorus porfiles between SIMS and simulation after furnace annealing



(a) Ion-implant

(b) RTA

Figure 4 Comparsion pf Phophorus profiles between SIMS and simulation during RTA process