Evaluation of Two-dimensional Transient Enhanced Diffusion 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. [1]-[5] However, dependence of transient diffusivity increase on implant doses remains unclear.

In this work, a new study on transient enhanced diffusion are described focused on phosphorus implant and furnace annealing process. We found the anomalous diffusion is implanted-dose dependent as well as annealing temperature dependent.[4] Critical doses for Phosphorous enhanced diffusion has been determined in 950C annealing condition, which might be a function of annealing temperature. Two-dimensional effect of the phenomena has been also verified, showing that the TED in phosphorous is close to isotropic.

2. Experiments and Simulation

We evaluated about forty samples of phosphorus doping-profile fabricated with various process conditions. Dopant depth-profiles are measured by SIMS analysis with CAMECA-ims4f. Lateral diffusion profile obtained by CV method [7] is refereed to verify 2D diffusion in Phosphorous shallow junction. Analytical distribution model (Dual-Pearson4) and Monte Carlo simulation are used to analyze ion-implant profiles. In dopant-diffusion simulation, vacancy-assisted diffusion model is adopted in which the TED diffusivity parameters were calibrated.[6] In order to compare between simulation and experiment, we introduced an RMS error defined in [6].

3. Results and Discussion

As-implanted phosphorus profiles obtained from simulation and SIMS measurement are shown in Figure 1, for the implantation conditions of $1\text{x}10^{14}/\text{cm}^2$ 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. 2, showing a large discrepancy at the tail parts of profile after 10min furnace annealing at 950C. TED parameter (transient effective diffusivity) is determined in such a way that the both profiles get a good fit within RMS error of less than 2%, as shown in Figure. 3. Dose dependency of the TED parameter is shown in Figure 4 for 50 minutes 950C annealing. As shown in the figure, the parameter shows a constant value of D/Do=16, when the total dose is higher than $1\text{x}10^{14}/\text{cm}^2$. On the other hand, no transient enhanced diffusion is observed when the implant dose is lower than $1\text{x}10^{13}/\text{cm}^2$. It is also proved that the TED parameter in Phosphorous diffusion is approximately independent of implant-energy and annealing time as shown in Figure 3 and 4, as an example. In Figure 5, we summarized the dependency of extracted enhanced diffusivity (normalized) on implant doses at 850-950C annealing. It is shown that diffusivity increases with dose between the dose of $1\text{x}10^{13}/\text{cm}^2$ and $1\text{x}10^{14}/\text{cm}^2$ at 950C, but it saturates at higher dose than $1\text{x}10^{14}/\text{cm}^2$. It is seen that the transient region of TED effect might be temperature dependent to a certain extent.

Two-dimensional Phosphorus shallow junction formation under $2\text{x}10^{13}/\text{cm}^2$ dose is investigated by Monte Carlo and diffusion simulations with TED parameter. It is shown in Figure 6. Lateral profile (at surface) and vertical (depth) profile are verified by comparing simulation and experimental results as shown in Figure 7. In the simulation, the TED parameter is assumed to be isotropic. Using the isotropic TED parameter, phosphors profiles along the silicon surface agrees well with experimental profile within an error of 0.5%.

4. Acknowledgement

The authors would like to thank Mr. K. Kubota of Semiconductor Design & Development Center, Hitachi, Ltd. and Mr. K. Ishikawa of Device Development center, Hitachi, Ltd. for providing experimental data and useful discussions.

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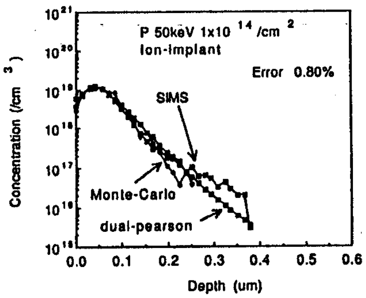

Figure 1 Phosphorus ion implant profiles of simulation and SIMS analysis

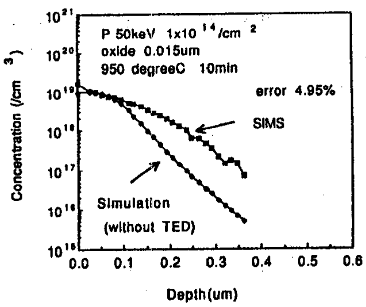

Figure 2. Phosphorus profiles of simulation and SIMS analysis

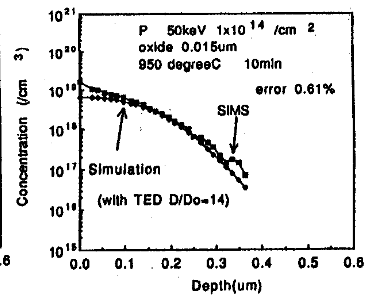

Figure 3. Phosphorus profiles with TED parameter

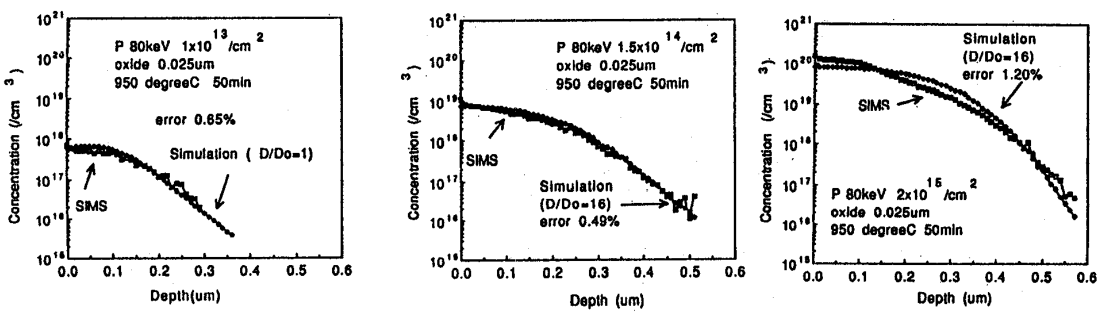

Figure 4. Phosphorus diffusion profiles at various doses

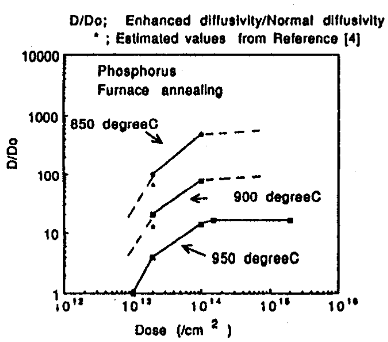

Figure 5. The dependence of calibrated diffusion constant of Phosphorus on implant dose

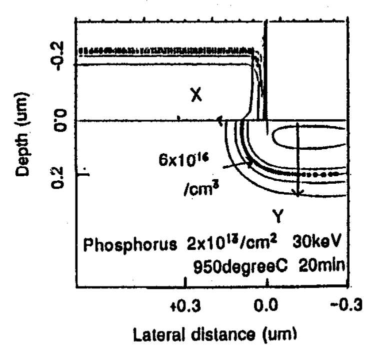

Figure 6. Simulation of two-dimensional phosphorus concentration contours of 950 degreeC annealing

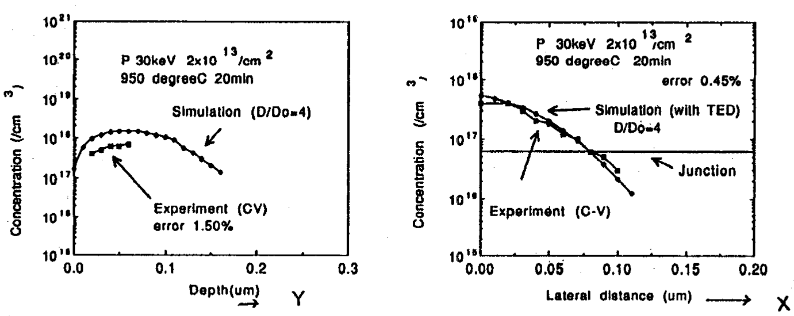

Figure 7. Phosphorus surface profiles of simulation compared with CV method
(a) depth profile (b) lateral profile