# Damage Accumulation by Arsenic Ion Implantation and Its Impact on Transient Enhanced Diffusion of As and B

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## Abstract

*Utilizing buried layer substrates into which As was ion implanted at the surface, we evaluated the damage factor associated with As ion implantation, and succeeded in explaining the transient enhanced diffusion of buried layer B as well as the surface As redistribution.*

## I. Introduction

While As itself exhibits no significant transient enhanced diffusion (TED), the ion implantation of As in the source/drain region of a short channel nMOSFETs causes B TED in the channel region, ultimately leading to reverse short channel effects. In this contribution, we investigated the generation of interstitial Si, *I*, through As implantation and their influence on B TED.

## II. Results and Discussion

Our approach is based on one dimensional profile analysis from experimental secondary ion mass spectrometry (SIMS) data using a process simulator TESIM [1].

For the generation of *I*, we apply the same methodology in the case of B ion implantation [2]. We assume that each ion implanted As generates the same amount of *I* at low doses, and that the whole As identically contribute to the generation of *I*. Once the damage level has reached a certain value, *I* cannot be generated anymore. Therefore, $C_I^{tot}$ is expressed by

$$C_I^{tot}(x) = \begin{cases} f_D \Phi\, g(x) & for\, \Phi < \Phi_c \\ f_D \Phi_c\, g_c(x) & for\, \Phi > \Phi_c \end{cases} \tag{1}$$

where the damage factor, $f_D$, has a fixed value independent of the As dose, g(x) is the ion implanted As concentration normalized by the dose $\Phi$, and $g_c(x)$ is g(x) at the critical dose, $\Phi_c$, for TED saturation. The effective dose $\Phi_{eff}$ for *I* generation is

$$\Phi_{eff} = \min\left[\Phi, \Phi_c\right] \tag{2}$$

and Eq. 1 is simply expressed by

$$C_I^{tot}(x) = f_D \Phi_{eff}\, g(x) \tag{3}$$

The sensitivity of the impurity to the diffusion associated with the interstitial Si paring diffusion is empirically expressed with the factor $f_{Ieff}$, and the diffusion flux is schematically expressed as

$$f = (1 - f_{Ieff}) D_V \frac{dC}{dx} + f_{Ieff} D_I \frac{dC}{dx} \tag{4}$$

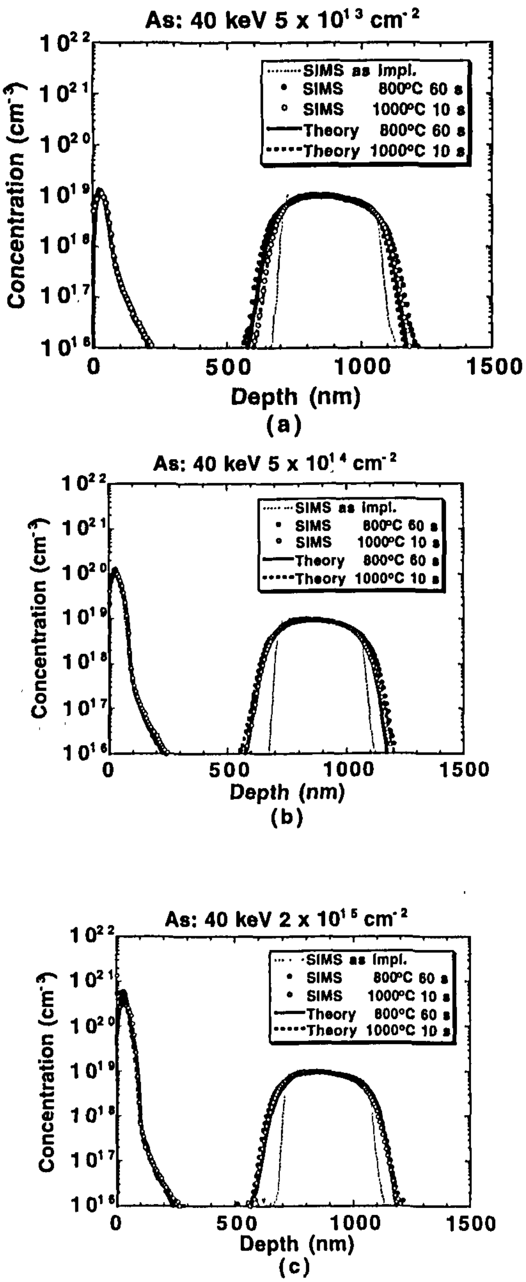

**Fig. 1.** Comparisonexperimental(SIMS) and calculated data illustrating dose dependence of diffusion profiles. (a) 5 x $10^{13}$ cm$^{-2}$, (b) 5 x $10^{14}$ cm$^{-2}$, (c) 2 x $10^{15}$ cm$^{-2}$.

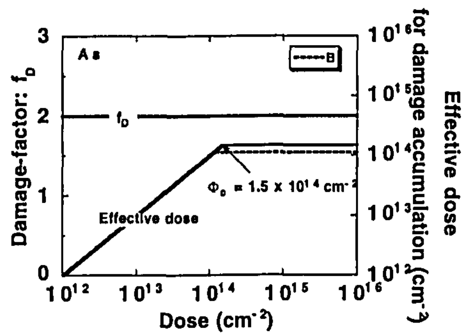

Fig. 2. Effective dose and damage factor $f_D$. $f_D$ is always 2 and $\Phi_c$ is 1.5 x $10^{14}$ cm$^{-2}$ independent of ion implanted energy. The dashed lines correspond to those for B ion implantation evaluated in [2].

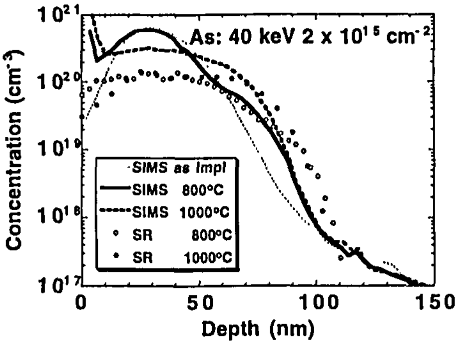

Fig. 3. The chemical B (SIMS) and carrier concentration (spreading resistance, SR) profiles.

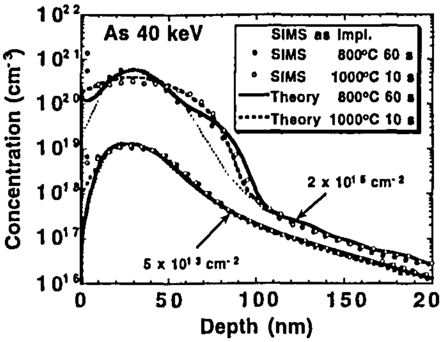

Fig. 4. Comparison of experimental (SIMS) and calculated surface As profiles with doses of 5 x $10^{13}$ cm$^{-2}$ and 2 x $10^{15}$ cm$^{-2}$.

where $D_V$ is the diffusivity associated with vacancy-impurity pair diffusion, and $D_I$ is the diffusivity associated with the *I*-impurity pair diffusion. (In the simulation, we used a more complex formula considering charge states and drift flux).

Figure 1a-c shows the As dose dependence of diffusion profiles. While the As diffusion is quite small as was expected, the TED of buried layer B is significant. For a damage $f_D = 2$ and a critical dose of $1.5 \times 10^{14}$ cm$^{-2}$, excellent agreement is obtained between SIMS and the simulated profiles. It is noteworthy that the extracted $f_D$ and $\Phi_c$ are almost the same as those for B ($f_D = 2$ and $\Phi_c = 1.125 \times 10^{14}$ cm$^{-2}$ ) [2]. All the other parameters associated with B and point defect kinetics are the exactly the same as in [2].

For the 1000°C , 10 s anneal, the displacement of the buried layer B increases with an increase in dose from $5 \times 10^{13}$ to $5 \times 10^{14}$ cm$^{-2}$, and then saturates. In our model, we can explain this result through the dependence of the effective dose.

For the 800°C , 60 s anneal, the displacement of the buried B layer is insensitive to the As dose. For this annealing condition, TED is only beginning. During the TED time period, the constant *I* concentration is supplied continuously from *I* clusters [2], and the displacement only depends on time and not on the total amount of *I* (i.e. dose).

Although the TED of As is not significant, the redistribution was observed as shown in Fig. 3. It should also be noted that the activation of As is not sufficient especially at 800°C as shown in Fig. 3, resulting in the kink profile. Therefore, we also introduce an As cluster model in which we assume

$$As_m \Leftrightarrow mAs^{(+)} + me^{(-)} \tag{5}$$

which leads to the time evolution of the As cluster as

$$m\frac{\partial C_{Asm}}{\partial t} = k_f\left(\frac{n}{n_i}\right)\left[C^m_{As(+)} - k_{eq}C_{Asm}\left(\frac{n}{n_i}\right)^{-m}\right] \tag{6}$$

where m is the amount of As in one cluster (we used 3 in this study), and n and $n_i$ are the electron and the intrinsic carrier concentrations, respectively. In contrast to the TED of the ion implanted B, the maximum diffusion concentration has no relationship to $n_i$. This is expressed with a larger activation speed (i.e., larger $k_f$). Furthermore, we tuned $f_{Ieff}$ to express the insignificant TED of As, and succeeded in explaining the redistribution of As at the surface region with an $f_{Ieff}$ of 0.03 as shown in Fig. 4. This means that the contribution of the As-*I* pair diffusion to the total As diffusion is quite small.

## III. Summary

We extended the damage calibration concept, which was proposed for B ion implantation, to the case of As ion implantation. According to our evaluation, the interstitial Si is generated linearly with the As dose with a factor of 2, and saturates at an As dose of $1.5 \times 10^{14}$ cm$^{-2}$. Using this damage factor combined with the As-*I* pair diffusion mechanism factor $f_{Ieff}$ of 0.03 and the As cluster model, we successfully explained the diffusion profiles of buried layer B and surface As at 800°C and 1000°C with the dose range between $5 \times 10^{13}$ and $5 \times 10^{15}$ cm$^{-2}$.

## Acknowledgments

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## References

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[2] K. Suzuki et al., IEDM Technical Digest, p. 502, 1997.