

Hydrogen-Enhancing Boron Penetration in P-MOS Devices during SiO₂ Chemical Vapor Deposition

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Abstract

We demonstrated that boron penetration through gate oxides is more significant in a SiO₂ chemical vapor deposition ambient than in a N₂ ambient. We clarified that enhanced boron diffusion through gate oxides was attributable to hydrogen in the SiO₂ chemical vapor deposition source gas.

1. Introduction

Because surface channel pMOSFETs are required to suppress the short channel effect in scaled devices, p+-polysilicon electrodes have been used instead of n+-polysilicon. However, boron penetration from p+-polysilicon gate electrodes through thin gate oxides to the substrate is a serious problem in these MOSFETs. It is well known that H₂ enhances boron diffusion in SiO₂ [1-3]. Therefore, the H₂ gas in SiO₂ chemical vapor deposition (CVD) may enhance the penetration, a subject on which little study has been done. We evaluated H₂-enhanced boron penetration during SiO₂ CVD.

2. Experiments

We fabricated pMOS structures before SiO₂ CVD. CVD SiO₂ was deposited using a SiH₄-N₂O gas system at 780 to 820°C at a pressure of 40 to 400 Pa. For comparison, we annealed pMOS structures in N₂ ambient used in the same CVD chamber without the source gas. After CVD, we measured the boron penetration profiles in the substrate using secondary ion mass spectroscopy (SIMS) or fabricated MOS diodes to measure flat-band voltage (V_{FB}) shifts. We analyzed SIMS and V_{FB} data on boron diffusion in gate oxides using device and process simulators [4, 5]. To relate the CVD process data to more fundamental one, we annealed the pMOS structures in various levels of H₂ concentration ([H₂]) and performed SIMS measurements, and evaluated [H₂] dependence on boron diffusivity in gate oxides. [H₂] was expressed as the percentage of H₂ partial pressure to the atmospheric pressure.

3. Results and Discussion

Boron penetration into the substrate is much more significant in a SiO₂ CVD ambient than in N₂ without deposition (Fig. 1). We can explain the penetration profiles when boron diffusivities in SiO₂ gate dielectrics 2 times larger than those annealed in pure N₂ were used. Using the same factor of increase, the simulation can readily explain the V_{FB} shift experimental data, as shown in Fig. 2.

To relate the enhanced diffusion to hydrogen in the CVD ambient, we evaluated [H₂] dependence on boron diffusivity in gate oxides. Figure 3 shows an Arrhenius plot of boron

diffusivities in gate SiO₂ for various levels of [H₂]. The diffusivities increased with [H₂] and are proportional to [H₂]^{1/2} in high [H₂] levels (Fig. 4). The activation energy (E_a) for all [H₂] levels is almost the same. In low [H₂] levels, D_{ox}([H₂]) asymptotes D_{ox}(0), which is the boron diffusivity in SiO₂ annealed in N₂. Therefore, we can formulate the boron diffusivities in SiO₂ for various [H₂] levels as:

$$D_{ox}([H_2]) = D_{ox}(0)\{1 + 4.1[H_2]^{1/2}\}. \quad (1)$$

This relationship is independent of the gate polysilicon thickness (not shown). We also evaluated boron diffusivities in 4%-nitrogen-concentration oxynitride for various [H₂] [6], and found that the oxynitride has less effect on the H₂ enhancement (Fig. 4).

Figure 5 shows the [H₂] dependence on boron diffusivities at 800°C. The solid line was calculated from Eq. (1), and the circles are measurements during SiO₂ CVD. Boron diffusivities during SiO₂ CVD increased with [H₂]. Thus, rapid boron diffusion during SiO₂ CVD can be said to have contributed to the H₂ in the ambient. However, the H₂ effect cannot explain all of the enhancement effect of boron penetration during CVD. Other factors may also enhance boron diffusion during CVD.

Figure 6 shows the CVD temperature dependence on the critical CVD SiO₂ thickness for preventing boron penetration. We assumed in the calculation that D_{ox}([H₂](CVD))/D_{ox}(0) = 2. When BF₂⁺ ion implantation is used, the critical thickness is extremely thin. If it is needed to deposit 50-nm-thick CVD SiO₂ without boron penetration, we must lower the CVD temperature to temperatures below 760°C for 2-nm gate SiO₂.

4. Conclusion

We showed that the boron diffusivities in gate oxides are proportional to [H₂]^{1/2}, and that the E_a is constant for all levels of [H₂]. We found that the enhancement of boron penetration during SiO₂ CVD can be explained with this relationship. Considering the boron penetration problem in future devices, we must pay attention to the CVD process as well as the higher-temperature carrier activation process.

References

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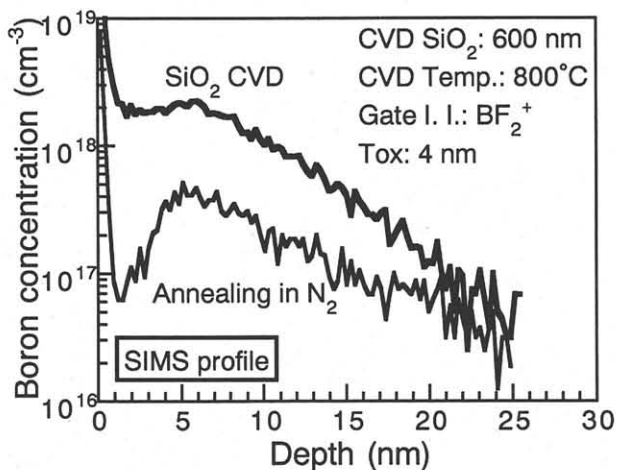


Fig. 1. Boron penetration profile in substrate after CVD. Boron penetrates more during CVD than annealing in N_2 .

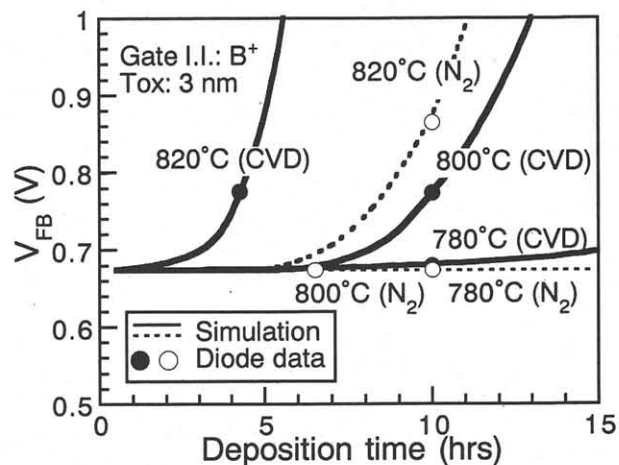


Fig. 2. V_{FB} shifts in p-MOS diodes after CVD. V_{FB} shifts after CVD are larger than those after annealing in N_2 without deposition.

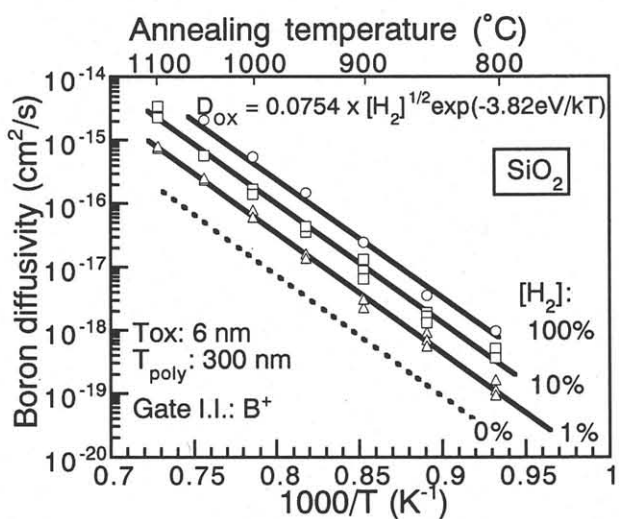


Fig. 3. Arrhenius plot of boron diffusivities in SiO_2 for various H_2 concentrations. The activation energies were the same for all $[H_2]$ levels.

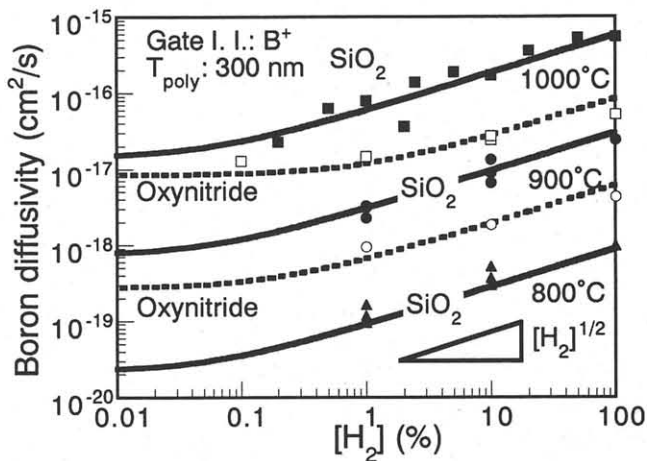


Fig. 4. H_2 concentration dependence on boron diffusivities in SiO_2 and 4%-nitrogen-concentrated oxynitride. The diffusivities were proportional to $[H_2]^{1/2}$.

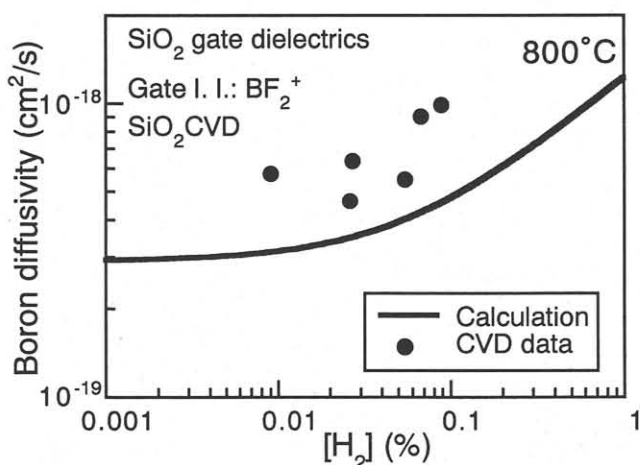


Fig. 5. Boron diffusivities in gate SiO_2 during CVD at $800^\circ C$. The diffusivities increased with $[H_2]$.

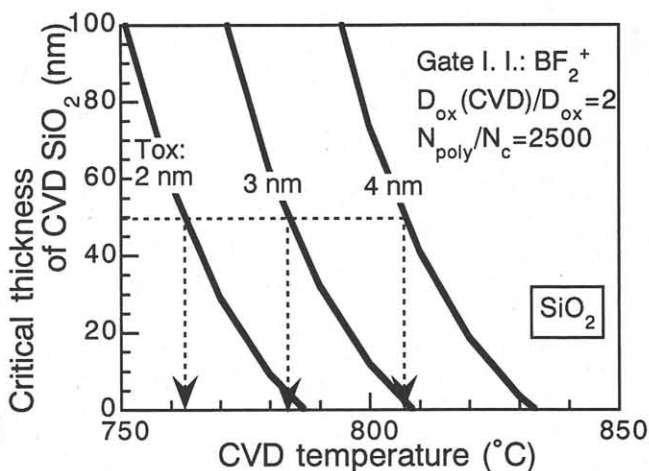


Fig. 6. Deposition temperature dependence on critical CVD- SiO_2 thickness for preventing boron penetration.