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Boron Diffusion in Nitrided Oxide Gate Dielectrics Leading to High Suppression of Boron Penetration in P-MOSFETs

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Abstract

Nitrided oxide gate dielectrics have been proposed to suppress boron penetration in deep submicron MOSFETs. However, there are few quantitative reports on how nitrided oxides enlarge the permissible thermal budget. We evaluated the diffusivities of a nitrided oxide formed by annealing SiO_2 in NO gas and demonstrated that this film enables us to use BF_2^+ for scaled devices. We also proposed a model depicting the boron penetration through the nitrided oxide layer.

1. Introduction

Surface channel pMOSFETs are required to suppress the short channel effect in scaled devices , and hence p+-polysilicon gate electrodes have been proposed instead of n+-polysilicon. Boron penetration from the p+-polysilicon gate electrodes through thin gate oxides to the substrate is a serious problem in these MOSFETs. P+-polysilicon gates are usually fabricated with BF_2^+ ion implantation into gate polysilicon electrodes. However, unintentionally introduced fluorine enhances boron diffusion in oxides [1]. When we use B^+ instead of BF_2^+, the boron penetration is substantially suppressed, but it is difficult to scale down the thickness of polysilicon.

Nitrided oxide gate dielectrics have been proposed to relax the thermal budget. However, there are few quantitative reports on boron diffusion in nitrided oxides, although the diffusivities of gate dielectrics play an essential role in boron penetration and are fundamental data for evaluating diffusion problems. We determined the effective boron diffusivity in nitrided oxide and clarified how this film widens the thermal budget.

2. Experiments

5-nm nitrided oxide was formed by annealing SiO_2 in NO gas at 900°C for 20 min. Figure 1 shows the nitrogen profile of the nitrided oxide measured by AES. The nitrogen was mostly located at the interface of the nitrided oxide and the substrate. The maximum concentration was 9 at%. The areal density measured by SIMS was 3×10^{14} cm^{-2}. Note that the thickness of the high nitrogen concentration region is thinner than observed in Fig. 1 because of the electron escape depth. From XTEM observations, the increment of thickness by the nitridation was 0.2 nm, which is considered to be the thickness of the high nitrogen concentration region. Subsequently, conventional MOS diode processing was carried out. We used BF_2^+ or B^+ for the gate ion implantation. The devices were subjected to various annealing conditions, and the concentration of B that penetrated the substrate was measured with SIMS.

We simulated the penetrated boron concentration profiles in substrates using the boron diffusivity of the nitrided oxide as a fitting parameter [2].

3. Results and Discussion

Although nitrided oxide is inhomogeneous in films, as shown in Fig. 1, we initially regard it as being homogenous for the sake of simplicity, and extract the effective diffusivities. Figure 2 shows the effective boron diffusivities of the nitrided oxide. When BF_2^+ was implanted into gate polysilicon (Fig. 2a), the diffusivities of the nitrided oxide samples below 950°C were 1 order of magnitude smaller than those in SiO_2. The activation energy (Ea) changed significantly at 950°C. When B^+ was implanted (Fig. 2b), the diffusivities in the nitrided oxide were 0.2 to 0.6 times smaller than in SiO_2.

Using these extracted diffusivities, we can calculate the available annealing conditions (Fig. 3) [3]. The nitrided oxide widens the thermal budget in comparison to the condition of B^+ with pure SiO_2 at temperature ranges of under 950°C. However, this improvement weakens in temperature ranges of over 950°C.

Next, we considered the nitrided oxide as double-layers, as is the actual case. Figure 4 shows the boron diffusivities in the high nitrogen concentration layer (second layer) of the nitrided oxide. The diffusivities were derived from a simulation in which the nitrided oxide was composed of two layers. The activation energy of the diffusivities in the second layer is lower than that in homogeneous 4%-nitrogen-concentration bulk oxynitride, though the diffusivities were much smaller. From these results, we hypothesized on the structure of the nitrided oxide (Fig. 5). There are low and high activation energy regions in the second layer, which correspond to low and high nitrogen concentrations, respectively. Boron diffused though low activation energy regions, but the area for diffusion is decreased by the higher nitrogen concentration region. Small values of boron diffusivity under the existence of fluorine might be caused by trapped fluorine in the high nitrogen concentration region.

4. Conclusion

We determined the effective boron diffusivities in nitrided oxide. We demonstrated that the nitrided oxide suppresses boron penetration significantly at a temperature range of under 950°C, and that the thermal budget of BF_2 is comparable with that of B^+ with pure SiO_2. However, this improvement weakens at temperatures over 950°C. We also proposed an empirical model of the nitride oxide film structure to explain the experimental data.

References

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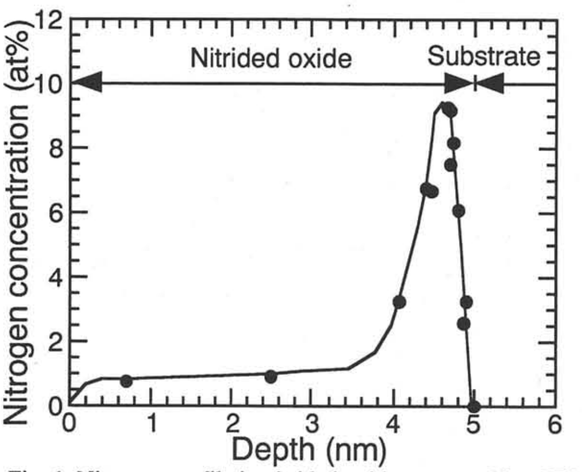

Fig. 1. Nitrogen profile in nitrided oxide measured by AES.

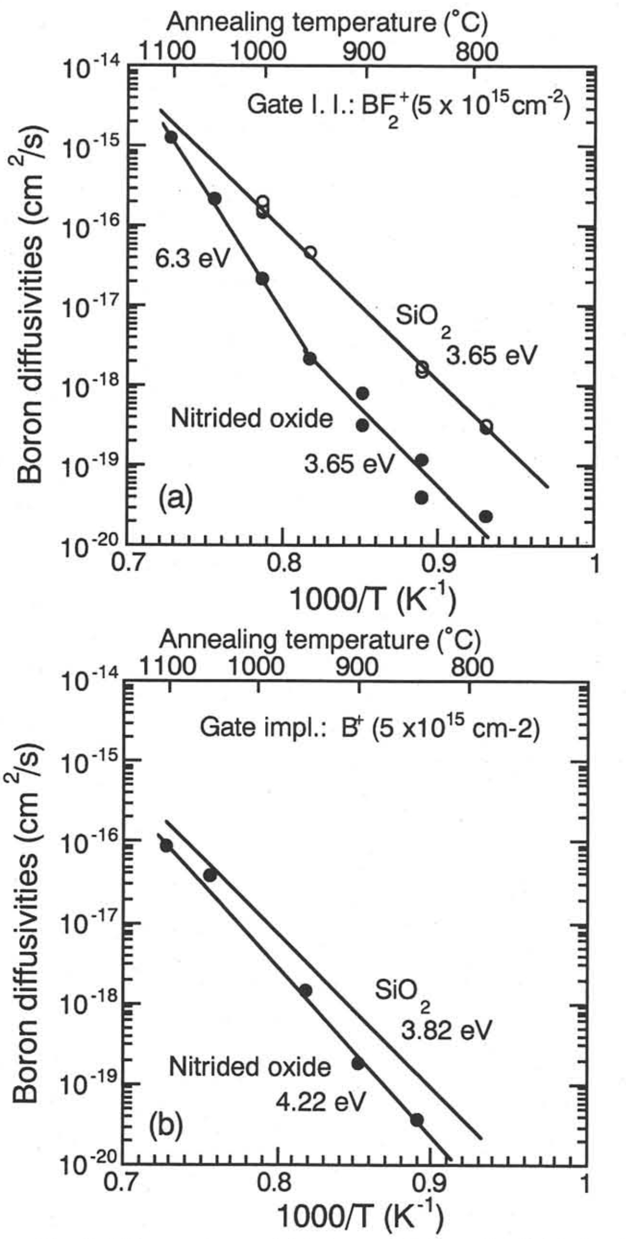

Fig. 2. Effective boron diffusion coefficients in nitrided oxide with (a) BF_2^+ and (b) B^+ used for gate ion implantation.

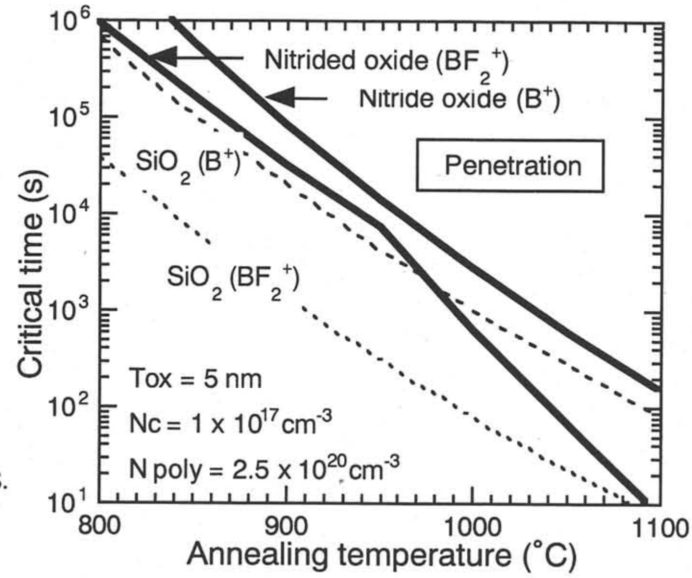

Fig. 3. Available annealing condition when nitrided oxide was used for gate dielectrics.

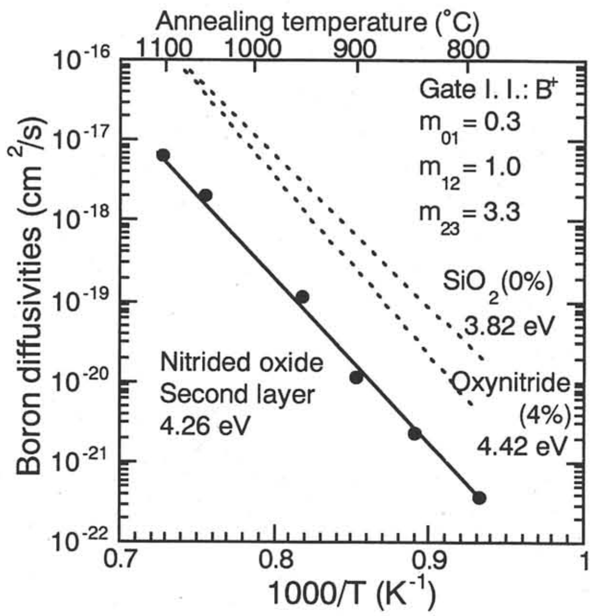

Fig. 4. Diffusivities in second layer of nitrided oxide.

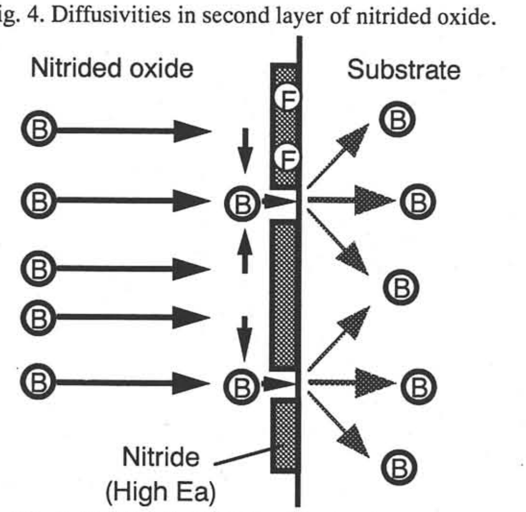

Fig. 5. Model of nitrided oxide structure.