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Novel Nitrogen Profile Control Technology in Ultra Thin Gate Oxide for Deep Submicron CMOS

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Abstract

Nitrogen profile control in ultra thin gate-dielectric-film was successfully realized using a hydrogen deoxidation surface (HDS) treatment before NH_3 nitridation. The HDS treatment can make nitrogen concentration in the gate-electrode/insulator interface side (surface side) increase and simultaneously restrict nitrogen segregation in the insulator/substrate interface during nitridation. The HDS treatment realized the increase of 11% for gate capacitance and the reduction of 50% for flat band voltage shift as compared to the no-HDS sample before NH_3 nitridation. Therefore, the HDS can make a significant contribution to control boron penetration, to realize thinner effective thickness (high dielectric constant) and to obtain excellent interface in a gate-dielectric-film.

1. Introduction

Nitrided oxide is one of the most promising candidates to prevent boron penetration in a surface channel deep-submicron pMOSFET [1]. As gate-dielectric-film thickness is scaled down, more amount of nitrogen into the gate-dielectric-film is necessary in order to prevent boron penetration [2]. However, heavily nitridation makes insulator/substrate interface deteriorate because of segregation of nitrogen in the interface. As a result, drive current and Gm were reduced [3]. Therefore, nitrogen profile control is one of the most important subjects in the nitrided oxide. In this paper, a novel nitrogen profile control technology using hydrogen deoxidation surface (HDS) treatment before NH_3 nitridation is presented to get a excellent insulator/substrate interface and enough amount of nitrogen in the gate insulator.

2. Experiments

To examine the hydrogen deoxidation effect, three different gate dielectric samples were fabricated. Fabrication procedures are shown in Fig.1. Sample "A" was a conventional pure oxide. Sample "B" was a oxynitride using NH_3 nitridation at 900°C for 60min. after oxidation. Sample "C" was a nitrogen profile controlled sample using the HDS treatment after oxidation. To estimate the HDS effect, enhanced deoxidation was carried out in this study. The HDS treatment was performed at 900°C for 60min. in He-H_2(2%) atmosphere. Oxide film (initial thickness = 8nm) was reduced to 3.4nm by the hydrogen treatment. As a result, oxides thickness before nitridation were almost equal between samples "A", "B" and "C". In sample "C", nitridation process was carried out in NH_3 atmosphere under the same condition of sample "B" after the HDS treatment. Film thickness in this experiment was measured using the ellipsometry.

3. Results and Discussion

The important findings in this study are; (1) introduction of enough amount of nitrogen into the gate insulator, (2) improvement of the insulator/substrate interface under the heavy nitridation condition. Therefore we examined and discussed these points. Figure 2 shows XPS spectra of N1s. Nitrogen concentration was about 9% in sample "B". In sample "C", 1.5 times larger amount of nitrogen (about 13.5%) as compared with sample "B" was observed. It was clarified that the more amount of nitrogen could be introduced using HDS treatment. This result indicates that the nitridation is accelerated by the HDS treatment because of the formation of large number of Si-dangling-bond in the oxide surface. Figure 3 shows the SIMS profiles of N, O, and Si. In the gate-electrode/insulator interface side (surface side), the nitride concentration of sample "C" was higher than that of sample "B". Contrary to the surface side, the nitride concentration of sample "C" was lower than that of sample "B" in the insulator/substrate interface side. On the other hand, oxygen concentration of sample "C" was lower than that of sample "B" especially in the surface side. These results indicate that a more silicon-nitride-like film is formed in the surface side of sample "C" as compared to sample "B". Figure 4 shows high frequency capacitance on accumulation mode and flat band voltage (Vfb) of samples "A", "B" and "C". The HDS treatment realized the increase of 11% for gate capacitance and the reduction of 50% for flat band voltage shift as compared with sample "B". These results offer strong evidence that the HDS treatment has an advanced effect of increasing the total nitrogen concentration in the gate-dielectric-film without nitrogen segregation in the insulator/substrate interface. The gate-dielectric-film with a high dielectric constant and a good insulator/substrate interface was obtained using the HDS treatment.

The current density of sample "C" in a high electric field was one order of magnitude lower than that of sample "B". Furthermore, sample "C" exhibits a higher breakdown field than sample "B" as shown in Fig. 5. On the other hand, the current density of sample "C" in a low electric field was one order of magnitude higher than that of sample "B" in this enhanced experiment. However, this issue which was probably caused by the defects in silicon-nitride-like layer may be overcome using the post oxidation after NH_3 annealing [4]. Figure 6 shows a TDDB characteristics of samples "A" and "C". The early stage time to failure was remarkably improved in sample "C".

Figures 7 (a) and (b) show the proposed model and mechanism of high breakdown-resistance in the nitrided oxide gate-dielectric-film using the HDS treatment. From the Figs.2, 3 and 4, the gate electrode/insulator interface of sample "C" may be like a silicon nitride, and the insulator/substrate interface may be like a silicon oxide as shown in Fig. 7 (a). Therefore, P-F electron injected to the silicon-nitride-like film from the gate electrode recombined with F-N hole injected to the silicon-oxide-like film from the substrate, as shown in Fig. 7 (b). As a results, hot-electron is hard to generate and easy to recombine with the hole. In this model, the electron current is changed to the hole current in the gate-dielectric film.

4. Conclusion

We demonstrated the nitrogen profile control in an ultra thin gate-dielectric-film. Nitrogen profile control was successfully realized using the HDS treatment. The HDS treatment realized to increase nitrogen concentration (to prevent a boron penetration) in a gate dielectric film and to restrict nitrogen segregation in the insulator/substrate interface (to obtain a good insulator/substrate interface) simultaneously, during a nitridation of a gate oxide film. This new technology can make a significant contribution to realize an ultra thin gate dielectric film.

References

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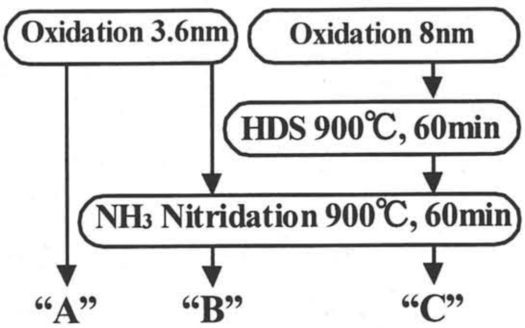

Fig.1 Fabrication procedure of dielectric film in each samples.

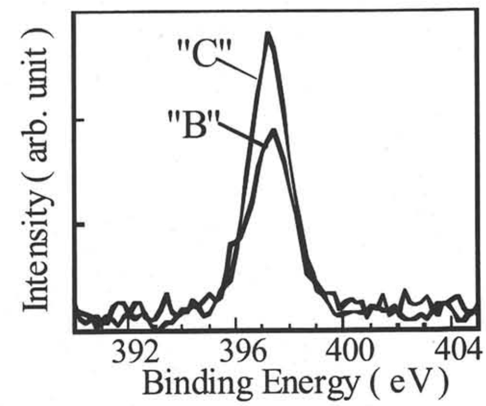

Fig.2 XPS spectra of N1s in sample "B" and "C".

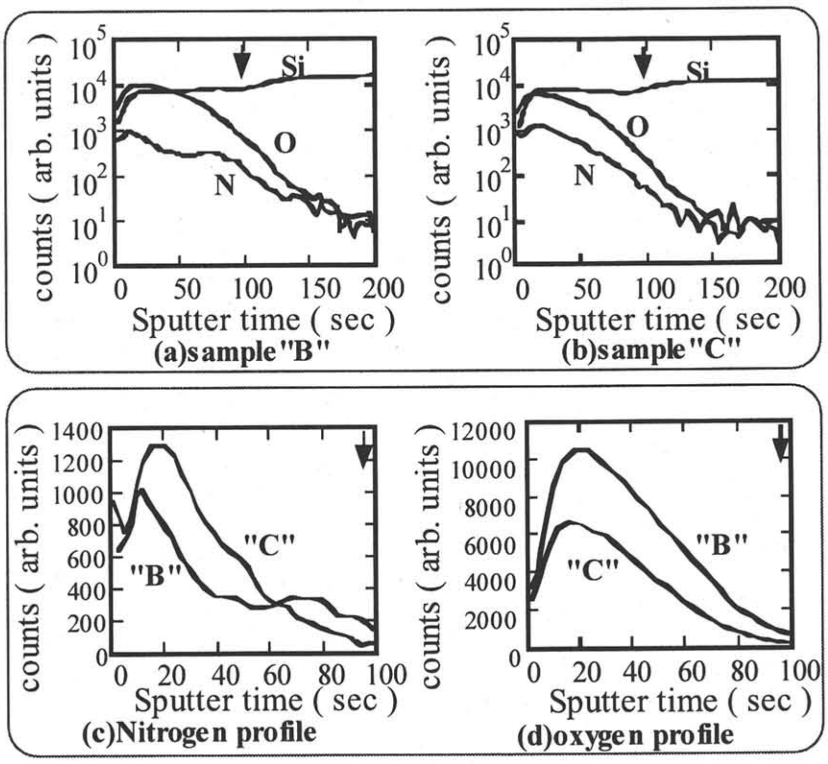

Fig.3 SIMS profiles of (a) sample"B" and (b) sample"C". Linear plot of (c) Nitrogen and (d) Oxygen are also shown. The arrows indicate the position of the insulator/Si interface .

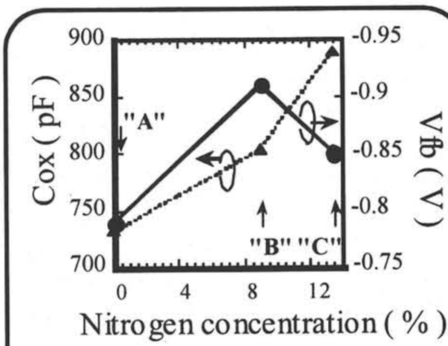

Fig.4 Gate capacitance and flat band voltage of sample "A", "B" and "C".

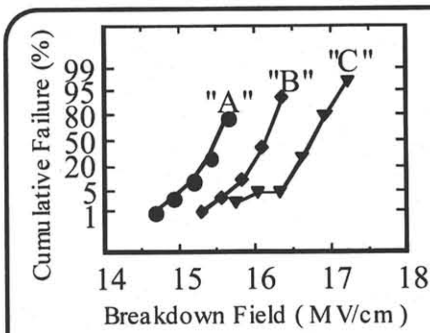

Fig.5 TZDB characteristics in sample"A" , "B" and "C".

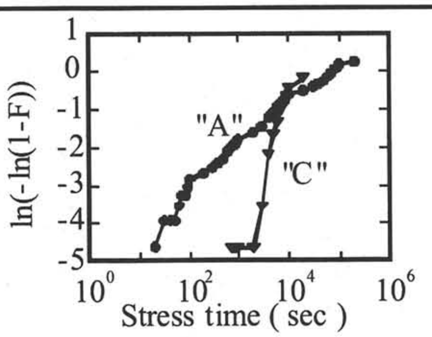

Fig.6 TDDB characteristics in sample "A" and "C".

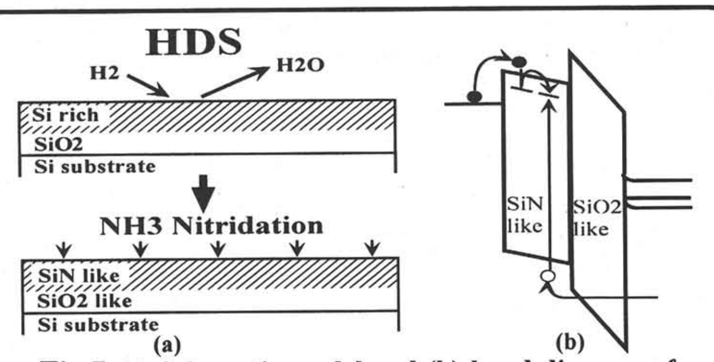

Fig.7 (a) Schematic model and (b) band diagram of high breakdown-resistance.