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Analysis of Gate Disturb Degradation by Nitridation of Flash Tunnel Oxide

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Introduction

Nitrided tunnel oxide is one of the key technologies to improve the reliability in flash EEPROMs. Several authors have shown that nitrided tunnel oxide had higher charge to breakdown (Q_{BD}), reduced interface states and improved endurance characteristic compared with conventional tunnel oxide [1],[2]. However, the disadvantages of nitrided tunnel oxide have not been studied sufficiently. In this work, the enhancement of gate disturb with negative bias stress caused by increased hole trapping at the surface of tunnel oxide was found. Based on gate disturb characteristics, the desirable conditions of nitridation were discussed.

Experimental

Nitrided oxide films were formed on n-type and p-type substrates by processes shown in Table 1. Final thickness of each nitrided oxide was adjusted to about 8nm. Q_{BD} and hole trapping was evaluated by constant current charge injection into tunnel oxide with accumulate mode in MOS capacitors. Flash memory cells were fabricated to evaluate gate disturb characteristics by a conventional stacked gate process. Gate disturb characteristics were measured by adjusting control gate voltage to have the same electric field at tunnel oxide after 1000 program/erase cycles.

Table 1 Nitridation parameters.

#Sample	SiO_2 8nm	SiO_2 7nm +N_2O 1nm	SiO_2 5nm +N_2O 3nm	SiO_2 8nm +NO 800℃	SiO_2 8nm +NO 950℃
Peak of Nitrogen Concentration [atmic%]		1.652	2.697	not measured	2.970
Base Oxide [nm]	8.01	6.81	4.86	8.01	8.01
Nitridation		N_2O 1050℃ 60s	N_2O 1050℃ 205s	NO 800℃ 60s	NO 950℃ 60s
Total Thickness [nm]	8.01	8.15	7.98	8.03	8.11

Results and Discussion

A. Gate Disturb Characteristics

Fig. 1 shows gate disturb characteristics with negative bias stress. The threshold voltage shifts ΔVtm- increase as increasing thermal budget for N_2O-nitrided oxide. On the other hands, the degradation of ΔVtm- is not observed for NO-nitrided oxide. Fig.2 shows gate disturb characteristics with positive bias stress. The threshold voltage shifts ΔVtm+ are greatly reduced for both N_2O-nitrided oxide and NO-nitrided oxide. In the conditions of both SiO_2 5nm+N_2O 3nm and SiO_2 8nm+NO 950°C, almost the same improvement of ΔVtm+ can be achieved.

B. Hole Trapping into Nitrided Tunnel Oxide

Fig. 3 shows comparison of 50% cumulative failure of Q_{BD} between positive gate bias and negative gate bias. In positive bias, Q_{BD} increases with the increase of thermal budget for both N_2O-nitrided oxide and NO-nitrided oxide. However, in negative bias, Q_{BD} is degraded with the increase of thermal budget for both N_2O-nitrided oxide and NO-nitrided oxide. Similar gate polarity dependence is observed in gate voltage shifts by hole trapping during Fowler-Nordheim (F-N) stresses defined in Fig.4. In positive bias, hole trapping increases with the increase of thermal budget for both N_2O-nitrided oxide and NO-nitrided oxide. Conversely, hole trapping is strongly suppressed in negative bias as shown in Fig. 5. It should be noted that little increase of hole trapping is achieved for NO-nitrided oxide compared with N_2O-nitrided oxide in positive bias. We now propose dual-quality-layer model, which can explain these results. In nitridation process, high quality layer is formed on the substrate side of tunnel oxide by nitrogen diffusion [3], but poor quality layer is concurrently formed on the region where nitrogen atoms do not exist as shown in Fig. 6. In positive bias, Q_{BD} increases because electrons pass through the high quality layer, but hole trapping increases because most holes are trapped at the poor quality layer. In negative bias, Q_{BD} is degraded because electrons pass through the poor quality layer, but hole trapping is suppressed because most holes are trapped at the high quality layer. One possible cause creating poor quality layer is diffusion of hydrogen atoms out of base oxide [4]. The little increase of hole trapping in positive bias for NO-nitrided oxide is explained by suppressed out-diffusion of hydrogen atoms due to the lower thermal budget.

C. Discussion

It is found that ΔVtm- depends on hole trapping at the surface of tunnel oxide as shown in Fig. 7. This result indicates that trapped holes at the surface of tunnel oxide enhance gate disturb with negative bias stress. On the other hands, gate disturb with positive bias stress is improved even if the trapped holes at the surface of tunnel oxide increase. This is due to the localized band modulation at the surface of tunnel oxide as shown in Fig. 8. In negative gate bias, electrons can easily tunnel through oxide because of the reduced barrier height at the surface of tunnel oxide. In positive gate bias, electron tunneling is not enhanced because the reduced barrier height at the surface of tunnel oxide never makes a contribution to enhancement of electron tunneling. Further, hole trapping at the bottom of tunnel oxide is suppressed by diffused nitrogen atoms, therefore, electron tunneling is extremely suppressed in positive gate bias as shown in Fig. 3. From these results, it is considered that ideal condition of nitridation should be lower thermal budget with higher nitrogen concentration. In conclusion, NO-nitridation at 950°C is the most applicable for flash tunnel oxide in this experiment because of the maximum suppression of gate disturb with positive bias and no degradation of gate disturb with negative bias.

Summary

The enhancement of gate disturb with negative bias stress caused by increased hole trapping at the surface of nitrided tunnel oxide was found. For NO-nitrided oxide, no degradation of gate disturb with negative bias stress and large improvement of gate disturb with positive bias stress were achieved because of its lower thermal budget with higher nitrogen concentration.

References

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2) M. Ushiyama et al., *Ext. Abs. SSDM*, 859 (1994).
3) Y. Okada et al., *Appl. Phys. Lett.*, **61**, 3163 (1992).
4) T. Hori et al., *IEEE Trans. Electron Devices*, **ED-36**, 340 (1989).

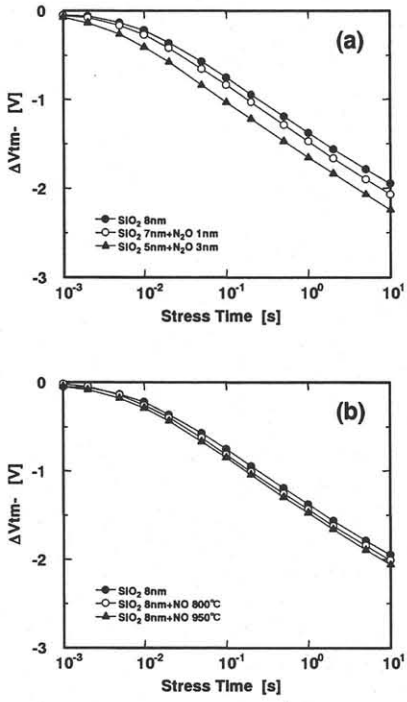


Fig.1 Gate disturb characteristics with negative bias stress.
(a) N_2O-nitrided oxide
(b) NO-nitrided oxide

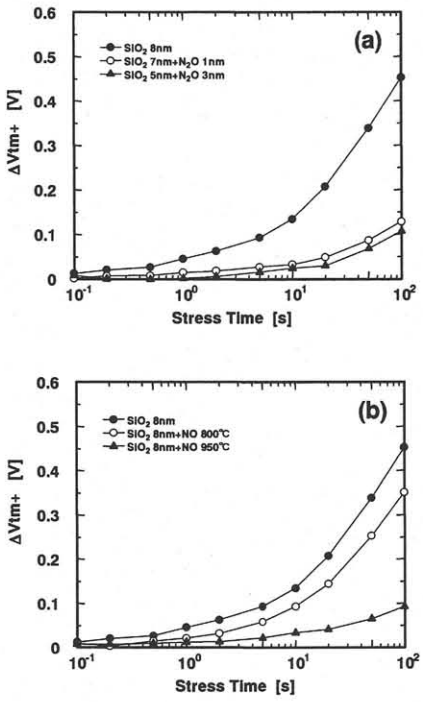


Fig.2 Gate disturb characteristics with positive bias stress.
(a) N_2O-nitrided oxide
(b) NO-nitrided oxide

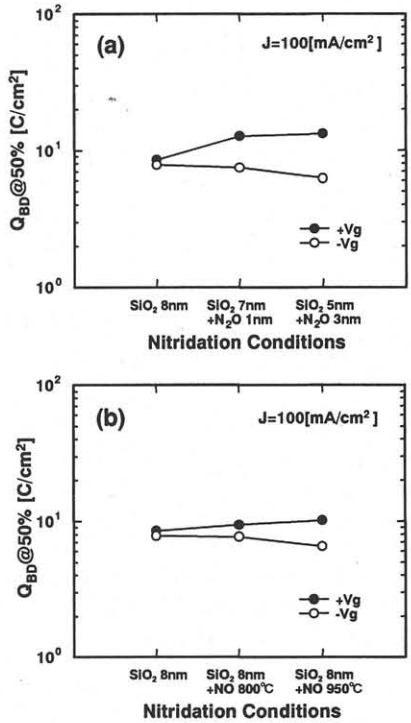


Fig.3 Comparison of charge to breakdown between positive gate bias and negative gate bias.
(a) N_2O-nitrided oxide
(b) NO-nitrided oxide

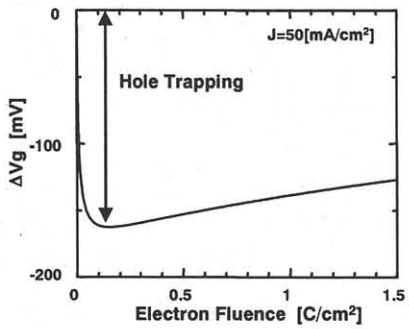
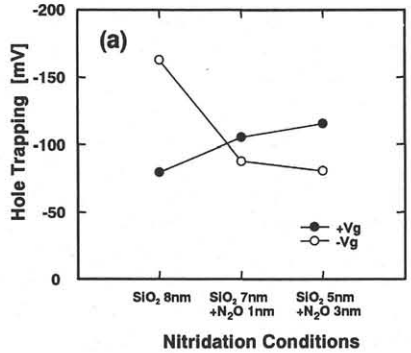


Fig.4 Gate voltage shifts by charge trapping during F-N constant current stresses.



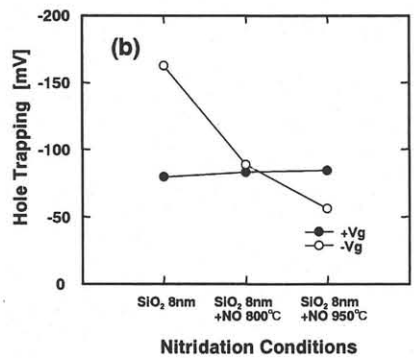


Fig.5 Comparison of hole trapping between positive gate bias and negative gate bias.
(a) N_2O-nitrided oxide
(b) NO-nitrided oxide

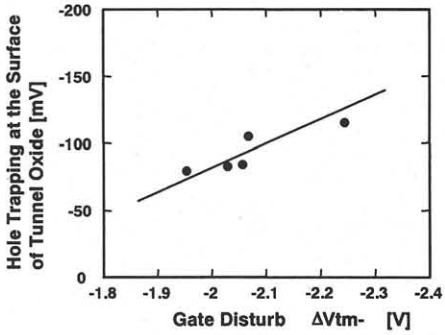


Fig.7 Relationship between hole trapping at the surface of tunnel oxide and ΔVtm- after 10 seconds stress.

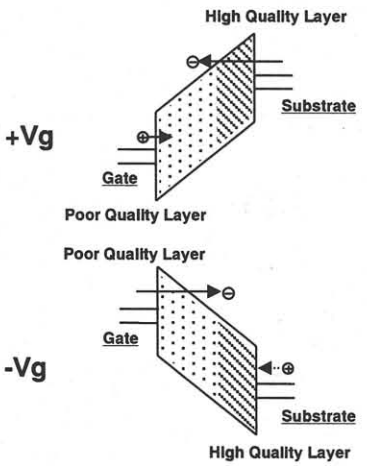


Fig.6 Schematic energy-band diagram showing hole trapping into poor quality layer.

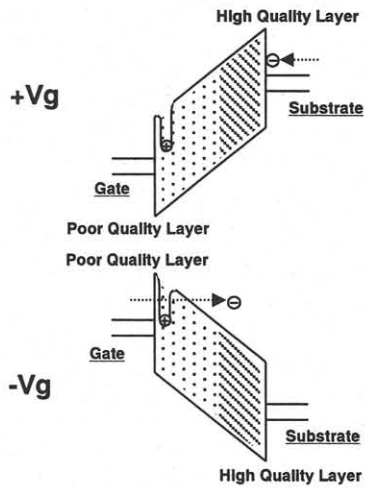


Fig.8 Schematic energy-band diagram showing enhancement of gate disturb with negative bias stress by hole trapping into poor quality layer.