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Impact of Nitrogen Distribution in Oxynitride Tunnel Film/Si on Band-to-Band Tunneling Current and Electron Injection in Flash Memory

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We discuss the impact of nitrogen distribution in oxynitride tunnel film/Si on band-to-band tunneling (BBT) current during electron ejection and an Fowler-Nordheim tunneling (FNT) current during electron injection in flash memories. During electron ejection from a floating gate, the BBT current is reduced by increasing nitridation of tunnel films, resulting in improvement of the endurance characteristics. However, higher nitrogen atom concentration in tunnel film/Si decreases the FNT current during electron injection into the floating gate.

1. INTRODUCTION

In certain types of FN (Fowler-Nordheim)-write/FN-erase flash memories, electrons are injected into a floating gate from a channel and ejected into a source or drain from the floating gate by FN tunneling (FNT) during write and erase operations. Since electrons are ejected from the floating gate by a high electric field, band-to-band tunneling (BBT), by which holes are injected into the tunnel film, occurs near the source or the drain[1,2]. Thus, the number of charge traps in the tunnel film increases, resulting in the degradation of the tunnel film reliability. This is a serious problem in the development of advanced flash memories. A graded junction was reported to reduce the lateral field, leading to a decrease in hole generation due to BBT[3].

Oxynitride films are appropriate for use as tunnel films in flash memories owing to their small increase in charge trap density and interface state density[4-7]. However, little information on the influence of tunnel-film oxynitridation on write and erase operations in flash memories has been obtained. We have studied the relationship between the nitrogen profile in oxynitride tunnel films and oxide reliability[8,9]. In this paper, we present the effect of nitrogen distribution in Si substrates with oxynitride tunnel films on BBT current during electron ejection and an FNT current during electron injection in flash memories.

2. EXPERIMENTAL

Fig. 1 shows the structure and write/erase conditions of a flash memory cell which was fabricated by a conventional self-aligned stacked gate process. Double-diffused drain structures were formed by As^+ and P^+ implantation in order to form a graded junction. Tunnel films were grown by rapid thermal processing, as shown in Table 1. The tunnel film thickness was approximately 9 nm, and the effective thickness of the inter poly-ONO film was approximately 20 nm. To investigate the electron conduction mechanism, the poly-crystalline silicon floating gates were shortened to the control gates. Write and erase operations were defined as electron ejection from the floating gate into the drain and injection from the channel into the floating gate, respectively.

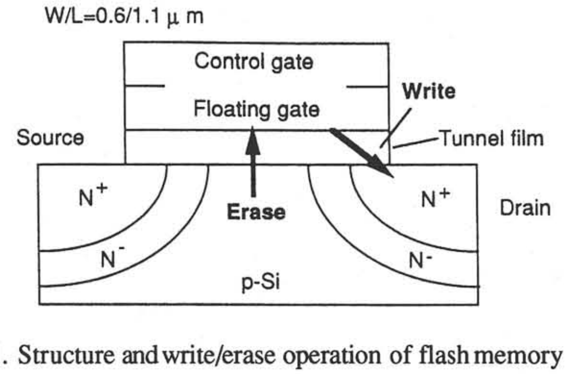

Fig. 1. Structure and write/erase operation of flash memory cells.

Table 1 Tunnel film formation conditions

	Process			
	RTO	RTN	RTO	RTON
Sample	O_2	NH_3(30 s)	O_2(30 s)	N_2O(30 s)
RTO	1100 ℃			
NO	1100 ℃			→ 1100 ℃
ONO	1100 ℃	→ 1000 ℃	→ 1100 ℃	
ONN4	1100 ℃	→ 1000 ℃		→ 900 ℃
ONN7	1100 ℃	→ 1000 ℃		→ 1000 ℃
ONN10	1100 ℃	→ 1000 ℃		→ 1100 ℃
ONN13	1100 ℃	→ 900 ℃		→ 1100 ℃

3. RESULTS and DISCUSSION

Fig. 2 shows the Vd-Id characteristics of flash memory cells with RTO tunnel film. Below 10^{-10} A, Id is independent of substrate bias (± 1 V). Moreover, at 340 K, Id below 10^{-10} A is equal to or slightly larger than that at 300 K. In addition, Id under the gate-open condition is sufficiently smaller than that under the Vg=0 V condition. These results indicate that below 10^{-10} A, Id is mainly due to BBT current, as shown by arrows inserted in Fig.2.

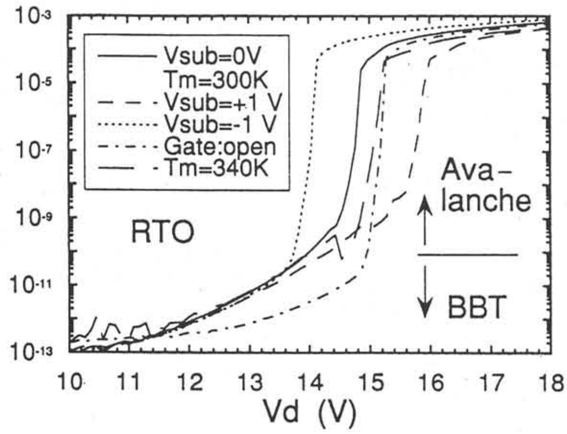

Fig. 2. Vd-Id characteristics of flash memory cells with RTO tunnel film. Solid line shows Vd-Id measured at 300K, Vg=Vsub=0 V.

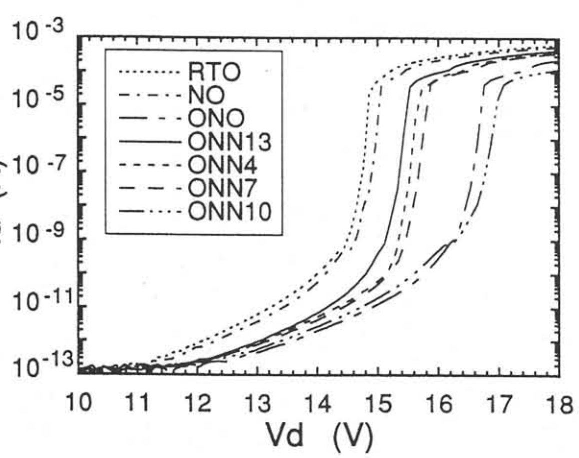

Fig. 3. Vd-Id characteristics of flash memory cells with RTO, NO, ONO and ONN tunnel films at 300 K, Vg=Vsub=0 V.

Fig. 3 shows the Id-Vd characteristics for memory cells with RTO, NO, ONO and ONN tunnel films. It should be noted that the BBT current in memory cells with ONO and ONN tunnel films is one to two orders of magnitude smaller than that in memory cells with RTO tunnel films.

Fig. 4 shows the nitrogen atom distribution in tunnel films/Si, determined by secondary ion mass spectroscopy using Cs^+ as primary ions and ^{147}NCs as detection ions in order to reduce the matrix effect. Secondary ion intensity of nitrogen atoms of more than 10^{-2} a.u. is observed in Si substrates. The nitrogen atoms near the surface of p-type Si wafers create a donor layer[10] which modifies the

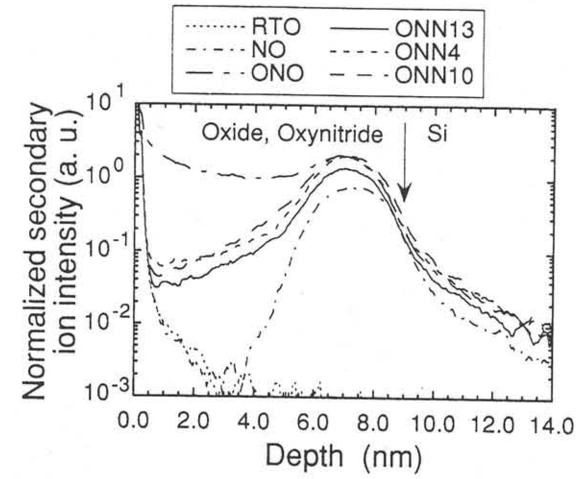

Fig. 4. Nitrogen distribution in RTO and oxynitride films/Si. Arrow indicates the films/Si interface.

electric field near the drain, thus, suppressing the BBT current. The BBT current decreases with increasing secondary ion intensity of nitrogen atoms in Si substrates, as shown in Fig. 5. Increasing the nitrogen concentration in Si (ONN, ONO) is found to reduce the BBT current. Thus, hole generation and injection into tunnel films are suppressed during write mode.

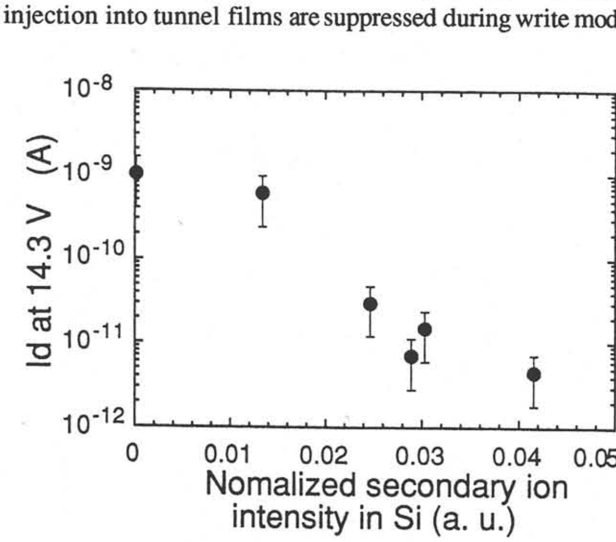

Fig. 5. Band-to-band tunneling current at 14.3 V as a function of secondary ion intensity of nitrogen atoms at a depth of 2 nm in Si substrates.

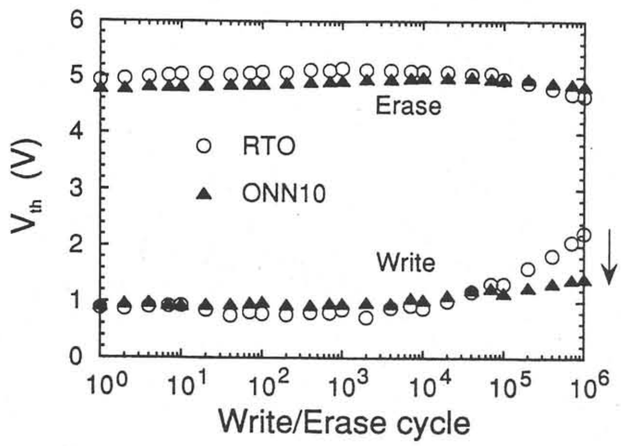

Fig. 6. Endurance characteristics of flash memory cells with RTO and ONN tunnel films. Erase condition: Vs=Vd=Vsub=-5 V, Vg=15 V, and Write condition: Vs=open, Vd=5 V, Vsub=0 V, Vg=-10 V.

Consequently, threshold voltage window narrowing in the endurance characteristics of flash memory is successfully decreased upon using oxynitride tunnel films due to the suppression of BBT current as well as the reduction in the number of charge traps[6-8] (Fig. 6).

However, in electron injection (erase mode), the FNT current flowing into the gate from the channel is decreased, as shown in Fig. 7. This is due to the modification of the electric field between the gate and the substrate due to the formation of the donor layer. Another possible reason is that the channels of memory cells with oxynitride tunnel films are deeper than those with RTO tunnel films because of the existense of the donor layer. Thus, the electron injection rate in the erase mode is reduced by using oxynitride tunnel films. Accordingly, the erasing time of flash memory cells with oxynitride tunnel films is two to three times longer than that of cells with RTO tunnel films.

4. SUMMARY

The process with greater nitridation, ONN and ONO, can be used to suppress BBT current during electron ejection into the source from the gate, however, decrease the FNT current during electron injection into the gate from channels. Consequently, although higher nitridation improves the endurance characteristics in writing, the erasing time is longer in flash memory cells. These results are explained by the formation of a donor layer due to nitrogen distribution into the Si which occurs during the formation of oxynitride tunnel films. Therefore, the nitrogen distribution profiles in oxynitride tunnel film/Si should be optimized from the viewpoint of not only charge traps, interface state formation, and dielectric breakdown characteristics, but also electron conduction for the development of advanced flash memories.

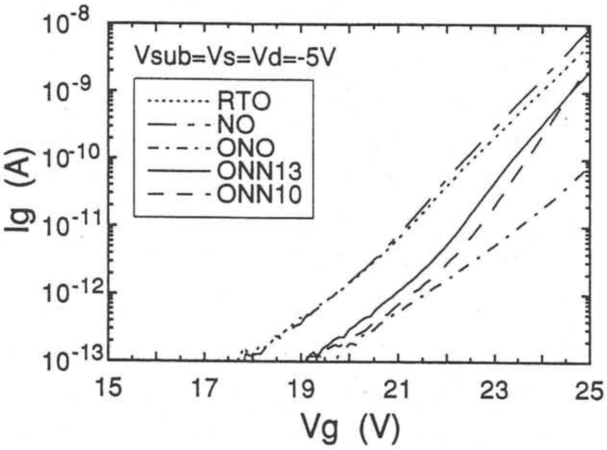

Fig. 7. Ig-Vg characteristics of flash memory cells with RTO and oxynitride tunnel films. Electrons were injected into the gate from the channel.

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