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High Pressure H_2/D_2 Annealed SONOS Nonvolatile Memory Devices

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1. Introduction

The poly-Si-oxide-nitride-oxide-silicon (SONOS) nonvolatile memory (NVM) device based on localized charge storage in charge trapping layer has received much attention due to lower program/erase (P/E) voltage, better scalability and endurance characteristics.[1] However, we need to achieve a fast P/E speed as well as long data retention time. In the retention loss model, there are several mechanisms, such as the direct back tunneling and thermal excitation of trapped charges.[2] Therefore, the decay rate of trapped charges could be reduced by increasing the tunnel oxide thickness and the energy level of the trap.[3] Also, the generation of interface state density (D_{it}) under the P/E cycles which causes charge loss through tunneling oxide should be minimized to obtain the lower decay rate of trapped charges.[4][5] Especially, the decay rate of trapped charges in erase mode very much depends on D_{it} due to the relatively deeper hole trap than electron trap in the nitride band gap. Therefore, in order to improve the endurance and retention characteristics of SONOS NVM devices, we have proposed and investigated the new post-metallization annealing at high pressure (HP) in H_2 or D_2 ambient since HP annealing can effectively passivate D_{it} and decrease the generation of D_{it} under the P/E cycles. [6]

2. Device Fabrication

A 2-nm-thick SiO_2 was thermally grown as a tunnel oxide, followed by deposition of 6-nm-thick Si_xN_y on tunnel SiO_2. Next, 6.5-nm-thick SiO_2 blocking layer was deposited by LPCVD. After fabrication of n^+ poly-Si gated SONOS capacitors, post-metallization annealing in HP pure H_2 or D_2 ambient was performed at 400°C for 30min. For comparison, control device was annealed in a conventional atmospheric pressure hydrogen (H_2/N_2=4%/96%) forming gas (FG).

3. Results & Discussion

In order to investigate the effect of HP post-metallization annealing on P/E speed, memory window (MW) after biasing P/E voltages at 1ms was extracted as shown in Fig. 1. It is known that high pressure post-metallization annealing has no significant effect on P/E speed.

Figure 2 shows the retention characteristics of SONOS devices annealed in HP-D_2 ambient at 10 atm. Compared with control samples annealed in FG ambient at 1atm (Fig. 3), HP-D_2 annealed SONOS devices show the lower charge decay rates both before and after 10^3 P/E cycles (±12V, 1ms). In addition, the better endurance characteristics were obtained as shown in Fig. 4. It could be explained by the reduced generation of D_{it} under P/E cycles.

To confirm the variation of D_{it}, quasi-static capacitance versus voltage (QSCV) curves of fabricated SONOS devices annealed in each ambient were obtained under the P/E cycles. Compared with control devices (Fig. 5), FG annealed devices at 10 atm showed a smaller D_{it} both before and after P/E cycles. Also, HP-D_2 annealed devices at 10 atm (Fig. 7) showed a lower generation of D_{it} under the P/E cycles than HP-H_2 annealed devices at 10atm (Fig. 8) due to the kinetic isotope effect of deuterium. Therefore, it is known that HP annealing is very efficient to passivate D_{it} and Si-D bonds reduce the generation of D_{it} under the P/E cycles which in turn, make the better endurance and retention characteristics of SONOS devices.

Consistently, the decay rate of trapped charges as a function of post-metallization annealing conditions was investigated as shown in Fig. 9. It was confirmed that lower charge loss rate was obtained with the decreased D_{it} and charge loss rate of excess hole state depended on the D_{it} more significantly than charge loss rate of excess electron state.

Figure 10 shows the SIMS depth profiles of hydrogen and deuterium ions in SONOS devices annealed in HP-H_2 or D_2 as well as conventional FG ambient. With increasing annealing pressure, the higher concentration of hydrogen was observed. SONOS devices annealed in HP-D_2 ambient clearly showed a deuterium SIMS peak. In contrast, deuterium peak was not observed in the other devices annealed in hydrogen ambient.

4. Summary

The effect of post-metallization annealing at HP in H_2 or D_2 ambient on reliability characteristics of SONOS devices has been investigated. Compared with control devices annealed in FG ambient at 1atm, SONOS devices annealed in HP pure H_2 or D_2 ambient show improved endurance and retention characteristics without the significant degradation of P/E speed. It can be explained by significantly improved D_{it} and a large kinetic isotope effect of deuterium that reduces the generation of D_{it} under the P/E electrical stress.

Acknowledgments

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References

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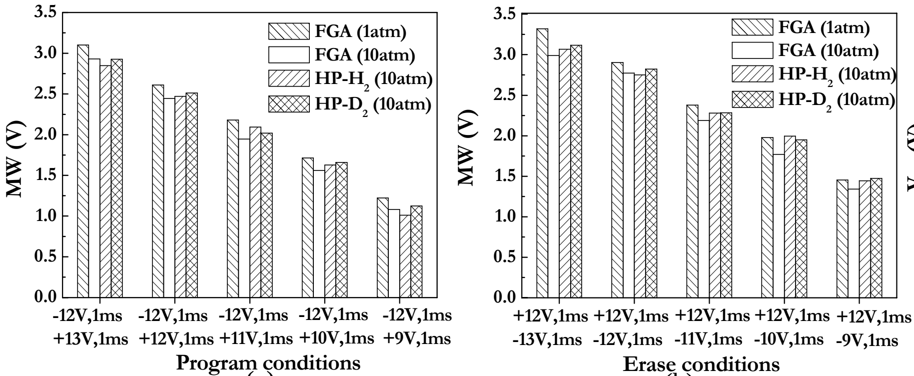


(a) (b)

Fig 1. (a) Program and (b) erase characteristics of fabricated SONOS devices annealed in each ambient.

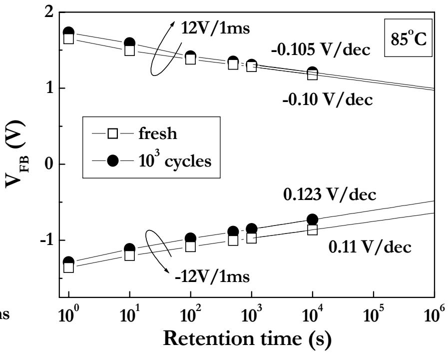


Fig 2. Retention Characteristics of SONOS devices annealed in HP-D_2 (10atm).

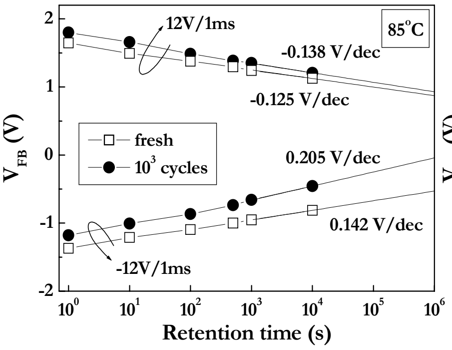


Fig 3. Retention Characteristics of SONOS devices annealed in FG (1atm).

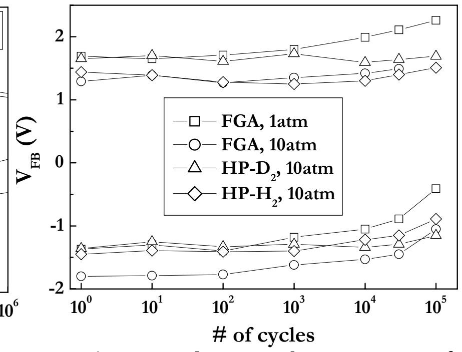


Fig 4. Endurance characteristics of SONOS devices.

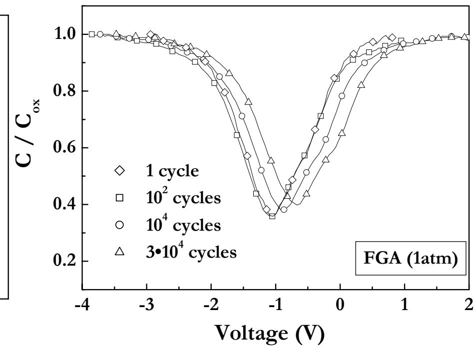


Fig 5. QSCV curves of SONOS devices annealed in FG (1atm) as a function of P/E cycles.

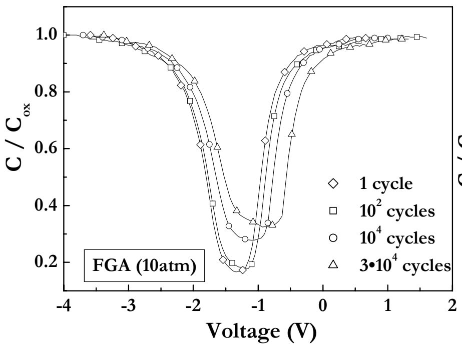


Fig 6. QSCV curves of SONOS devices annealed in FG (10atm) as a function of P/E cycles.

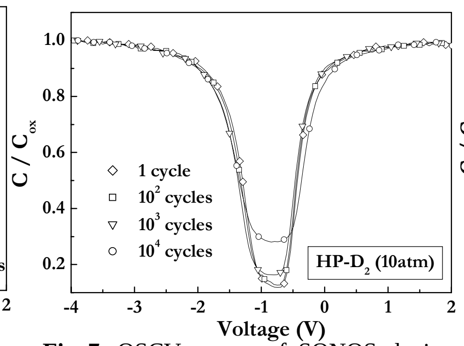


Fig 7. QSCV curves of SONOS devices annealed in HP-D_2 (10atm) as a function of P/E cycles.

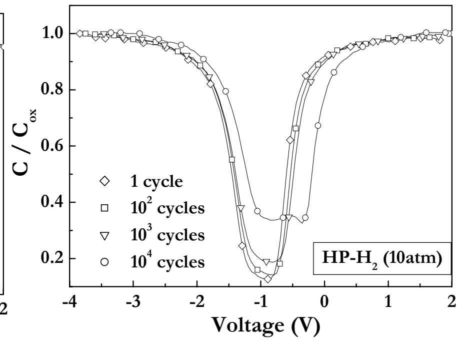


Fig 8. QSCV curves of SONOS devices annealed in HP-H_2 (10atm) as a function of P/E cycles.

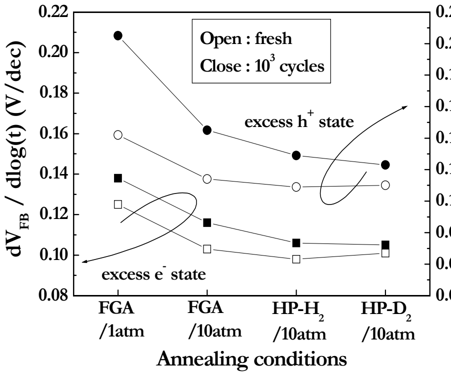
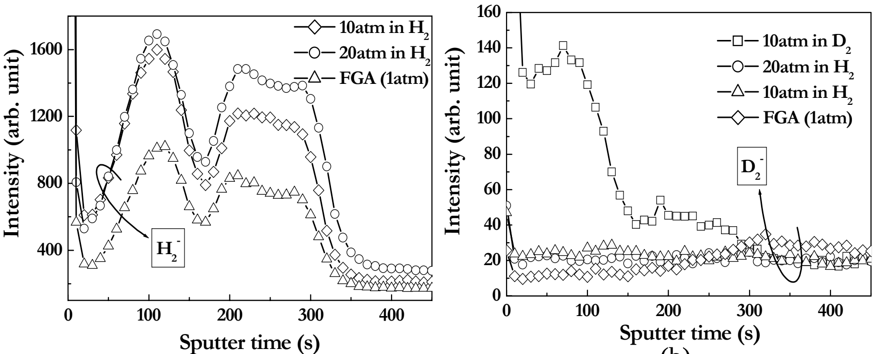


Fig 9. Charge decay rate of fabricated SONOS devices annealed in each ambient.



(a) (b)

Fig 10. SIMS depth profiles of ONO stack annealed in H_2 or D_2 ambients. (a) Hydrogen profiles, (b) Deuterium profiles.