Extended Abstracts of the 2000 International Conference on Solid State Devices and Materials, Sendai, 2000, pp. 290-291

C-6-1

Characteristics of Tunneling Nitride Grown by Electron Cyclotron Resonance Nitrogen Plasma Nitridation and Its Application to Low Voltage EEPROM

Kyeong-Sik Min and Kwyro Lee[1]
Memory Design Dept. 4, Hyundai Electronics Industries Co., Ltd.
1, Hyangjeong-dong, Hungduk-gu, Cheongju-si, 361-725, Korea
fax)+82-431-2704861 tel)+82-431-2703775 email) ksmin@hmec.co.kr
[1]Department of Electrical Engineering, Korea Advanced Institute of Science and Technology
373-1 Kusong-dong, Yusong-gu, Taejon, 305-701, Korea

1. Introduction

For many years, nitride-tunneling insulators have been investigated for the benefits of its low barrier height [1]. Compared with the silicon dioxide with the barrier height, ϕ_B of 3.1 [eV], nitride has the lower barrier height, ϕ_B of 2.1 [eV] [2], enabling low voltage programming and erasing EEPROM, as shown in Fig. 1. Low voltage alterable EEPROM composed of nitride tunneling insulator is very desirable, because it can eliminate the burden of on-chip high voltage generator and the programming and erasing can be done very fast. Thermal ammonia nitridation has been studied to grow high quality nitride film [1]. However, its growth rate is too low to be useful for VLSI technology and moreover, the process temperature is too high. Maximum thickness of the thermal nitride at 1200 °C is saturated at around 55 Å [1]. In this paper, we will propose a low temperature ECR plasma nitridation for low voltage alterable EEPROM. ECR nitride insulator shows better tunneling efficiency and stronger endurance characteristics than the tunneling thermal-oxide one, addressing that it will be favorable for future low voltage alterable EEPROM applications.

2. Physical characteristics of ECR nitride

We grow ECR nitride on the starting wafer of p-type (100) Si wafers. After removing native oxide, nitride films are grown at the wafer surface by ECR N_2 plasma nitridation. The process temperature is 400 °C and the microwave power is 600 W. Nitrogen and argon gases flow in the chamber during the nitridation with the process pressure of 2 mTorr. The thickness of ECR nitride (T_N) is measured by the ellipsometry. The refractive indexes of ECR nitride are measured in the range from 1.7 to 1.8, which are slightly less than the reported index of 2.05 for LPCVD nitride [3]. Assuming that the relative permittivity of ECR nitride is 6.0, which is obtained from the refractive index of 1.8, T_N calculated from C-V measurements are consistent with the result from the ellipsometry. The growth rates of ECR nitrogen-plasma and thermal ammonia nitridation [1] are compared in Fig. 2. It is worth noting that ECR nitridation at 400 °C shows higher growth rate than the thermal nitridation at 1200 °C, and that its thickness is proportional to the growth time without showing the saturation.

The atomic concentration of ECR nitride is analyzed by Auger electron spectroscopy, as shown in Fig. 3. The grown thickness of ECR nitride is 16 nm. One should note here that oxygen contamination occurred in the bulk as well as at the surface of ECR nitride. The contamination in the bulk might be caused by initial native oxide and residual oxidant impurities in the chamber. In addition, partial oxidant in nitrogen gas can diffuse into the bulk during the nitridation.

3. Tunneling characteristics of ECR nitride

Fig. 4 compares the insulator tunneling currents of nMOSFET's with ECR nitride and the thermal oxide as the gate dielectric at both the inversion and accumulation modes. The nMOSFET's have n+ poly-Si gate with the gate area of 550 μm^2 on ECR-nitride insulator. Much higher conduction efficiency is observed at ECR nitride than the thermal oxide in Fig. 4, due to its lower barrier height. From Ln(J/E^2) vs. 1/E plot shown in Fig. 5, the barrier heights of ECR nitride at the inversion and accumulation modes are 2.3 and 1.4 eV, respectively, while that of the thermal oxide at the inversion is 3.1 eV. The barrier height of 2.3 eV is very similar with the previously reported value of 2.1 eV for the nitride insulator [2]. Especially for the accumulation mode, Poole-Frenkel emission mechanism is suggested, in addition to F-N tunneling. In contrast, F-N tunneling characteristics are shown at the inversion modes of ECR nitride and the thermal oxide. To see how ECR nitride is strong against the electrical stress, we injected the constant current at the gate of MIS capacitor. ECR nitride exhibits suppressed trapping rate than the thermal oxide at both polarities of injection currents, as was also shown in case of thermal nitride [1].

4. EEPROM with ECR-nitride tunneling insulator

We have fabricated double-gate EEPROM, where the inter-poly insulator is formed by the thermal oxide with the thickness of 60 nm and the tunneling one is ECR nitride with the thickness of 10 nm. Fig. 6 shows the programming characteristics of EEPROM cell with W/L of 30/10 μm. Tunneling occurs at the control gate voltage of as low as 16 V. This voltage can be lowered if the coupling ratio is improved more. In this experiment, thick inter-poly oxide degraded the coupling ratio severely. The threshold voltage moves from -2.5 V (Erased State) to 2.0 V (Programmed State). One should note here that this threshold voltage window is comparable with conventional NAND-type EEPROM. Compared with the programming characteristics, the erasing requires much lower control-gate voltage, below 10 V. This is attributed to lower barrier height at the accumulation mode than the inversion mode, as shown in Fig. 4. Fig. 7 demonstrates the endurance characteristics of EEPROM with ECR-nitride tunneling insulator. For both programming and erasing, F-N tunneling method is used.

Surprisingly, any V_{TH} degradation is not observed even after $1x10^5$ cycles of the programming and erasing. This result is very comparable to the EEPROM with the thermal-nitride tunneling insulator [4]. For reference, NAND-type EEPROM with thermal-oxide tunneling insulator shows V_{TH} degradation at the erased state after $1x10^5$ cycles [5]. This is attributed to the net electron trapping during the programming and erasing. In contrast to this, negligible trapping at ECR nitride illustrates constant V_{TH}, as expected from the result of the constant current stress.

5. Conclusions

In this paper, we have proposed low temperature ECR-nitride tunneling insulator for low voltage alterable EEPROM. ECR nitridation shows much higher growth rate at lower temperature than the previously developed thermal nitridation. The measured characteristics of fabricated device show that it is a viable candidate for very fast low voltage high density EEPROM.

References

[1] M. Moslehi et al., *IEEE T-ED.* 32, 106 (1985).
[2] A. Goodman, *Appl. Phys. Lett.* 13, 275 (1968).
[3] S. M. Sze, Physics of semiconductor devices, (1981).
[4] T. Ito et al., *IEEE T-ED.* 26, 906 (1979).
[5] M. Momodomi et al., *IEEE JSSC. 26*, 492 (1991).

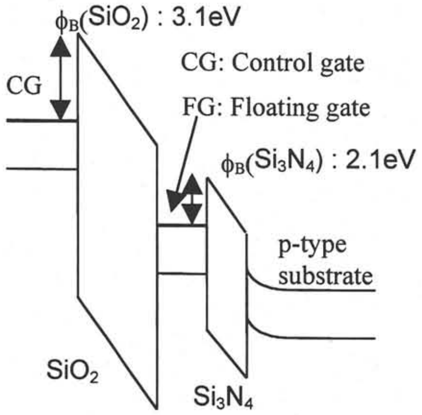

Fig. 1. The energy band diagram of the stack-gate EEPROM with the nitride tunneling insulator and the inter-poly oxide one when $V_{CG}(-)$ is applied.

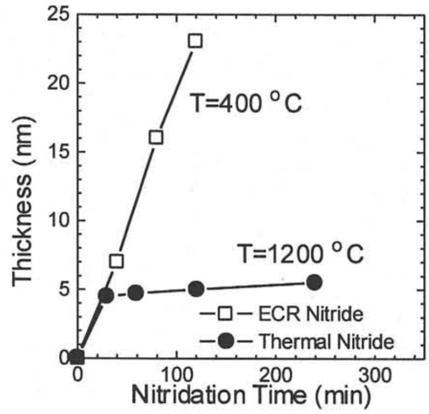

Fig. 2. The comparison of the growth rate between ECR nitride and the thermal nitride [1]. Here, ECR nitride does not show any saturation with increasing the process time.

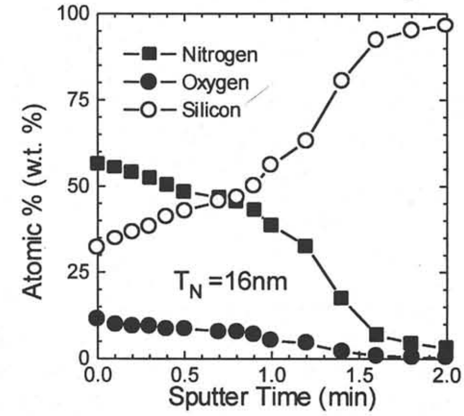

Fig. 3. Auger depth profile of ECR nitride with the thickness of 16 nm.

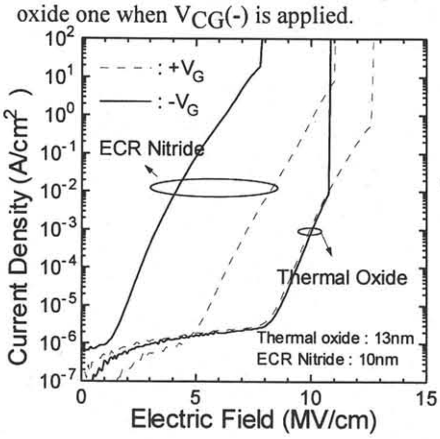

Fig. 4. The tunneling current characteristic of nMOSFET's with ECR nitride and the thermal oxide.

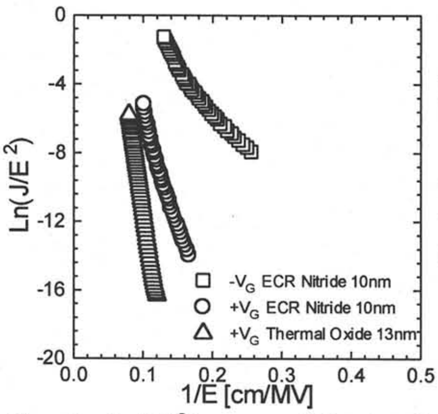

Fig. 5. Ln(J/E^2) versus 1/E plot for MOSFET's with the ECR nitride and the thermal oxide.

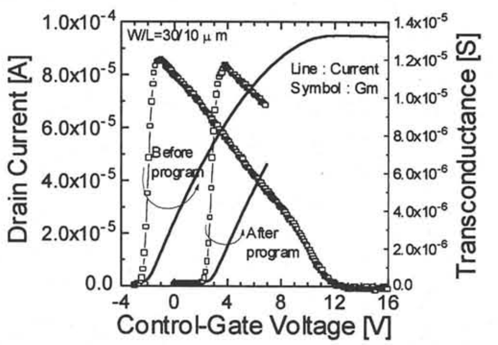

Fig. 6. Programming characteristics of EEPROM with ECR nitride as the tunneling insulator.

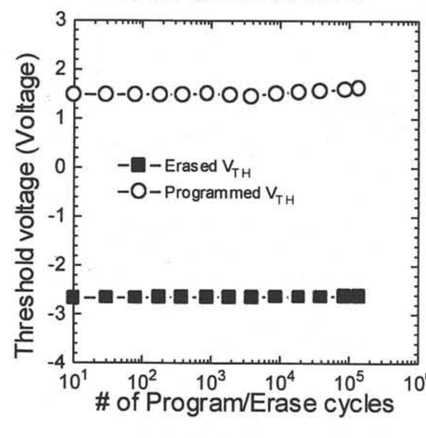

Fig. 7

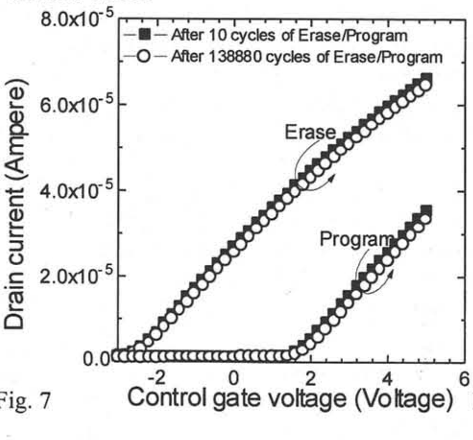

Fig. 8

Fig. 7. The endurance characteristics of EEPROM with ECR nitride as the tunneling insulator. Here, this does not show V_t degradation even after $1x10^5$ cycles.

Fig. 8. Drain current versus Control-gate voltage plot of EEPROM with the ECR nitride. Solid symbols are to the drain current after 10 cycles of program /erase and open symbols are to the current after 138880 cycles