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Device Characteristics and Reliability of Thin Gate Dielectrics Grown by Light Wet Oxynitridation(LWO)

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For future thin gate dielectrics, we have developed Light Wet Oxynitridation (LWO) technology where oxynitride grows in diluted NH_3 in N_2O ambient. The oxynitride film is highly reliable under Fowler-Nordheim electron stress and avalanche hot electron stress due to nitrogen incorporation both at Si/SiO_2 interface and in SiO_2 bulk. The film also shows good as-grown device characteristics. These results suggest that LWO is one of the promising technology for future MOS ULSI.

Introduction

For highly reliable thin gate dielectrics for deep sub-micron CMOS and Flash EEPROM, many studies have been carried out on N_2O grown and nitrided oxides. It is well known, however, that N_2O grown oxide thickness is self-limited due to the blocking of oxidant diffusion by nitrogen incorporation at Si/SiO_2 interface [1]. Both N_2O grown and nitrided oxides are unable to improve the time-dependent-dielectric-breakdown (TDDB) characteristics under gate side injection. They also exhibit inferior as-grown characteristics such as Gm peak reduction and large initial fixed oxide charge [2,3].

We have developed Light Wet Oxynitridation (LWO) technology, where oxynitride grows in NH_3 gas diluted in N_2O, for new gate dielectrics. The LWO dielectrics grow faster than N_2O grown oxide and show improved TDDB characteristics even under gate side injection [4]. In this study, as-grown device performance and reliability of LWO dielectrics are presented and compared with thermal oxide (TH-OX) and N_2O nitrided oxide (N_2O-NO).

Sample Fabrication

Three different gate dielectrics (LWO, TH-OX, and N_2O-NO) were fabricated at the same process temperature of 900°C in different ambient. LWO dielectrics were grown in 3% diluted NH_3 in N_2O ambient at reduced pressure of 40 torr. N_2O-NO dielectrics were fabricated by N_2O nitridation of conventional O_2 grown (TH-OX) oxide. Initial device performances were evaluated using N+ poly gate n-MOSFET with 70 Å thick gate oxide. Reliability of the gate oxides were measured using MOS capacitors fabricated on both p- and n-well using LOCOS isolation.

Results and Discussion

Thickness dependence of TDDB characteristics under constant current stress is shown in Fig. 1. TH-OX shows rapid Qbd decrease under 70 Å, consistent with a previous result [5], whereas LWO exhibits slow Qbd decrease down to 55 Å and two times larger Qbd value than that of TH-OX in all thickness range. TDDB characteristics under gate side and substrate side electron injections are shown in Fig. 2 (a) and (b), respectively. LWO shows greatly improved TDDB characteristics compared with TH-OX and N_2O-NO under gate side injection. In case of substrate side injection, LWO also shows greatly improved TDDB characteristics in both BF_2 implanted poly gate (p+Poly) and $POCl_3$ doped poly gate(n+Poly). These results imply that LWO process is effective to incorporate nitrogen both at Si/SiO_2 interface and in SiO_2 bulk.

Generally, nitridation of thermal oxide increases fixed oxide charge (Qf) at Si/SiO_2 interface and thereby reduces low field transconductance (Gm) in n-MOSFET because of increased Coulombic scattering. Fig. 3 shows the Qf at Si/SiO_2 interface measured using high frequency C-V technique. N_2O-NO shows much large increase of Qf at Si/SiO_2 interface, whereas LWO shows small increase of Qf compared with TH-OX. This can be attributed to less nitrogen incorporation in LWO process. The enhanced growth rate of LWO due to H_2O generation by NH_3 and N_2O reaction leads to less nitrogen incorporation than N_2O-NO at Si/SiO_2 interface.

Smaller incorporation of nitrogen in LWO than N_2O-NO at Si/SiO_2 interface leads to quite different Gm and current drivability characteristics from those of N_2O-NO. In Fig. 4 (a) and (b), Gm characteristics of thermal oxide and nitrided oxide are shown. Short channel devices using LWO show slightly decreased Gm peak, which is consistent with Qf data, whereas long channel devices show Gm peak similar to TH-OX and larger Gm value at high gate field than that of TH-OX. This can be attributed to residual mechanical stresses [6]. Fig. 5 shows the current drivability of short channel (a) and long channel (b) devices. At the short channel, the current drivability of LWO is slightly decreased due to Gm peak decrease, whereas at the long channel, the current drivability is better than TH-OX case due to large Gm value at high gate voltage.

Fig. 6 shows Gm peak degradation during avalanche hot electron stressing at the gate voltage where substrate current is maximum. In case of LWO, because of nitrogen incorporation, Gm peak degrades less than TH-OX case as stress time increases. This result implies that LWO process improves hot carrier immunity and Si/SiO2 interface compared with TH-OX.

Conclusion

We have demonstrated that oxynitride gate dielectrics grown by LWO technology have highly reliable characteristics in MOS and device level, which can be attributed to the nitrogen incorporation both at Si/SiO_2 interface and in SiO_2 bulk. Smaller incorporation of nitrogen at Si/SiO_2 interface in LWO leads to better as-grown device performance than N_2O nitrided oxide even at long channel device. These results suggest that LWO is one of the promising technologies for future gate dielectric applications.

Reference

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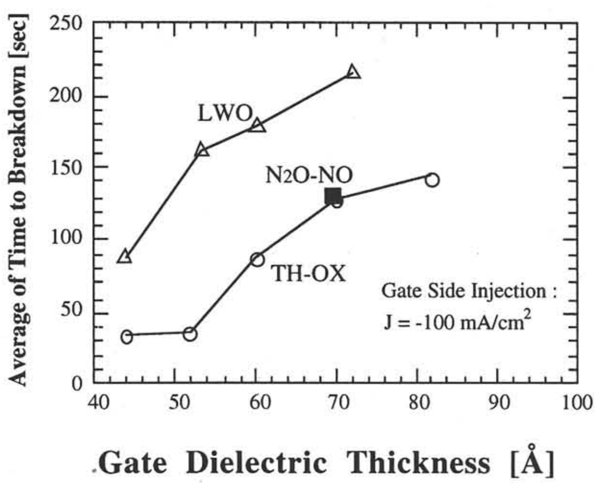


Fig.1. TDDB characteristics of thin thermal oxides and nitrided oxides under gate side injection

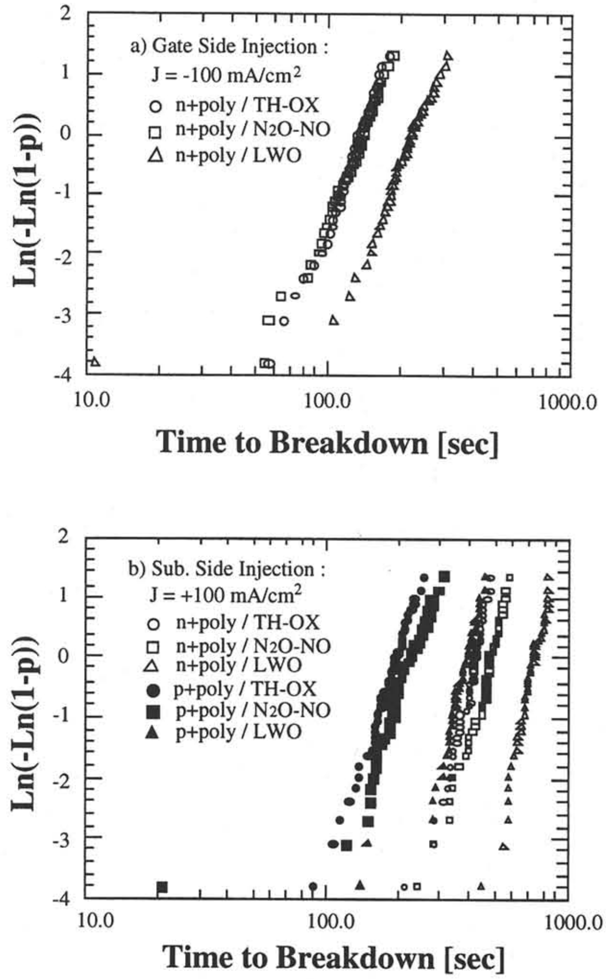


Fig.2. TDDB characteristics for 70 Å thermal oxide and nitrided oxides under gate side (a) and substrate side injection (b)
(n+poly : $POCl_3$ doped poly
p+poly : BF_2 implanted poly)

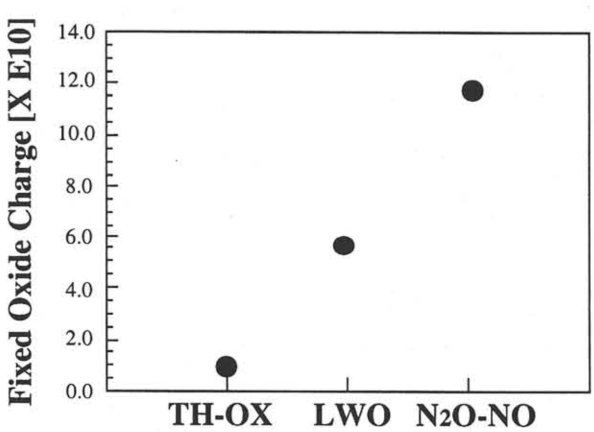
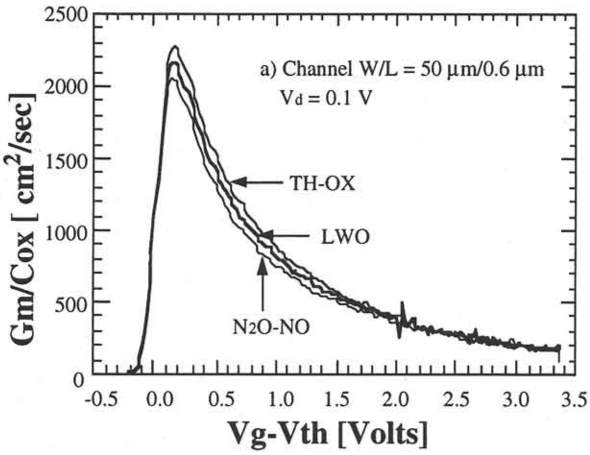
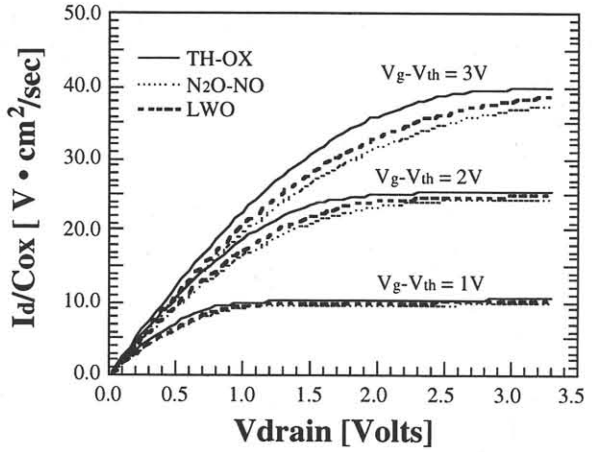


Fig.3. Fixed oxide charges of various oxidation conditions





(a) Short Channel nMOSFET (W/L = 50 μm/0.6 μm)

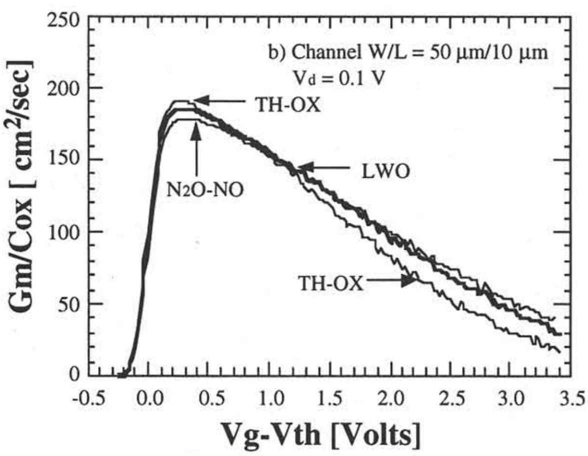
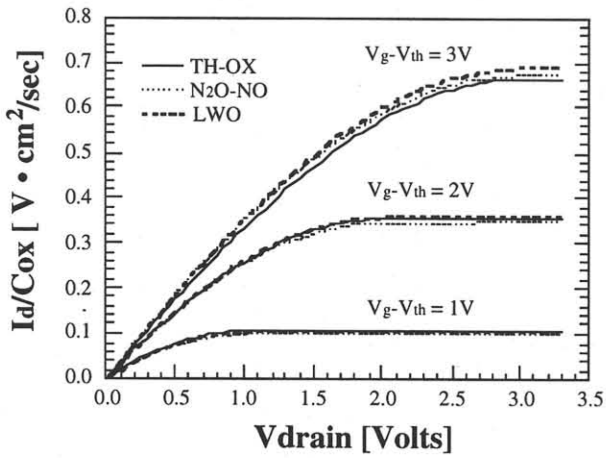


Fig.4. Gm characteristics of short channel (a) and long channel (b) nMOSFETs using thermal oxide and nitrided oxides



(b) Long Channel nMOSFET (W/L = 50 μm/10 μm)

Fig.5. Current drivability of short channel (a) and long channel (b) nMOSFETs using thermal oxide and nitrided oxides

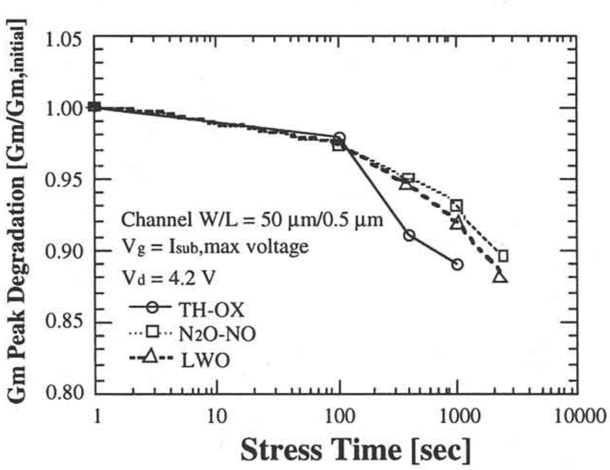


Fig.6. Gm peak degradation of nMOSFET under avalanche hot electron stress