

Field and Temperature Acceleration of Time-Dependent Dielectric Breakdown for Reoxidized-Nitrided and Fluorinated Oxides

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Abstract—The effects of injection current density and temperature on time-dependent dielectric breakdown (TDDB) of low-pressure thermally reoxidized-nitrided oxides (RNO's) and fluorinated oxides (FO's) with equivalent oxide thicknesses of 100 Å were examined. Time to breakdown for RNO was found to be improved over that for thermal oxide while both the impact ionization coefficient and the activation energy of lifetime are comparable to those of control oxide. On the other hand, no obvious TDDB improvement was observed for FO. This observation, in conjunction with the results for charge trapping measurements at different temperatures, indicates that the lifetime improvement for RNO's might be due to the reduced charge traps in these films. I - V ramp tests have shown that RNO has a comparable defect density to that of control oxide.

I. INTRODUCTION

THE RECENT finding that thermally reoxidized-nitrided oxide (RNO) and fluorinated oxide (FO) films possess improved high-field stability [1]–[4] has raised the interest in using these films in future ULSI technology. However, there is not much known about the reliability of RNO and FO under variable stressing parameters, e.g., injection field strength and temperature. In this work, the injection field and temperature acceleration of time-dependent dielectric breakdown (TDDB) for low-pressure RNO and fluorinated oxide were studied. It is found that both the field and temperature dependences of TDDB lifetime for RNO and FO are comparable to those of control oxide, though the lifetime for RNO's is increased by 3–6 times. I - V ramp measurements also

suggest that there is no significant defect reduction for these RNO and FO films.

II. EXPERIMENTAL

The devices used in this study were polysilicon-gate, field-isolated MOS capacitors. The substrate material was 10 ~ 20 $\Omega \cdot \text{cm}$ (100) n-type Si. The 100-Å oxide was grown at 850 to 950°C in atmospheric-pressure O_2 . Low-pressure nitridation and reoxidation [2] were then performed to form RNO films. Measured by Auger electron spectroscopy, the concentration of nitrogen incorporated in the RNO films is ~ 5 atm% at the oxide surface and ~ 8 atm% at the oxide/Si interface. Estimated by CV measurement, the equivalent thickness of the RNO's was increased by < 5% compared with the control oxide. The fluorinated oxide was grown by an HF-immersion process [4], [5] and the estimated F concentration incorporated through this process was about $10^{13}/\text{cm}^2$. All samples were then annealed in N_2 for 20 min. A polysilicon gate of 3000 Å was deposited at 650°C and *in-situ* phosphorus doped at 950°C. A post-poly annealing of 30 min at 450°C in forming gas completed the process. Process conditions for the gate oxides have been listed in Table I. Note that since there were no substantial differences for the control oxide grown at 850 and 900°C, only the data for 850°C control oxide were presented. Unless specified, the gate area used in this work is 100 m^2 and the constant current injection technique was used for stressing the devices. For all injection experiments, positive voltage was applied to the gate.

III. RESULTS AND DISCUSSION

In Fig. 1, charge to breakdown Q_{bd} is shown as a function of both injection current density and reciprocal cathode electric field, $1/E$. It can be seen that the Q_{bd} for RNO is higher over the whole measured current density range than that of FO and control oxide but the slopes of these curves are similar. According to [6], the slope of the plot $\log(Q_{bd})$ versus $1/E$ is proportional to the impact-ionization coefficient H and independent of injection current density and, hence, independent of injection barrier height which may be affected by nitridation/reoxidation procedures [3], [7].

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TABLE I
PROCESS CONDITIONS FOR GATE OXIDES

Sample	Oxidation Temp.	Nitridation Temp./Time	Nitridation NH ₃ Pressure	Reoxidation Temp./Time	Reoxidation O ₂ Pressure
RNO1	850°C	850°C/60 min	0.1 atm	850°C/180 min	1 atm
RNO2	950°C	950°C/60 min	0.01 atm	950°C/180 min	0.1 atm
FO	900°C				
Control Oxide	850/950°C				

(rinsed in 2% HF for 5 min before oxidation)

Therefore, the data in Fig. 1 suggest that the impact-ionization coefficient is not changed appreciably by the reoxidation/nitridation process. On the other hand, Q_{bd} for FO is increased by 20–70% over that of the control oxide. A best fit of the Q_{bd} versus $1/E$ data gives the H values listed in Fig. 1. It can be seen that these values are within the error limit of previously reported data for thermal oxides (70–80 MV/cm) [6], [8].

The effects of temperature on TDDB are illustrated in Fig. 2 where t_{bd} is plotted against the reciprocal of absolute temperature, $1/T$. Two distinct temperature regimes which have been previously observed for conventional oxide [8] can also be identified in RNO and FO. In each regime, the activation energy of the lifetime E_a can be extracted from the slope of the plot $\log(t_{bd}) \sim 1/T$. It can be seen that the RNO and FO have similar E_a values (0.18 eV, 0.26 eV) to those of control oxide (0.18 eV, 0.24 eV) in both temperature regimes. As a result, both RNO and FO maintain improvement in t_{bd} over that of control oxide at all temperatures studied.

It has been previously reported that at room temperature and an injection level of 10–20 mA/cm², the improved TDDB for RNO is accompanied by reduced charge trapping [1]–[3]. To examine the effects of charge trapping on the acceleration of TDDB, the gate voltage shift (ΔV_G) is shown in Fig. 3 as a function of injected charge at two elevated temperatures. It can be seen that both the rate of change and the amplitude of ΔV_G for RNO2 are lower than for control oxide, which suggests less electron trapping in RNO2. This observation agrees with previous observations at room temperature [1], [2]. For sample FO, the charge trapping rate is almost identical to that in the control oxide. This is expected based on Fig. 2. The fact that at higher temperature the electron trapping will increase agrees with the results of the temperature acceleration of TDDB, i.e., the stronger the electron trapping, the shorter the lifetime will be. It has been shown that the RNO films have very little positive charge trapping [13]. The well-known fact that both the shift and the distortion of the quasi-static CV curve for RNO are much smaller than those of the control oxide also confirms that the initial negative ΔV_G for RNO is not due to stronger hole trapping but is due to weaker electron trapping since hole trapping will increase interface state density [3].

Defect density was evaluated by the cumulative failure rate-ramping voltage technique [12] and is shown in Fig. 4. Since there are no appreciable differences between the two types of RNO samples, only the data for RNO1 are presented. No significant defect density reduction is observed for the RNO, although nitridation has been reported to reduce

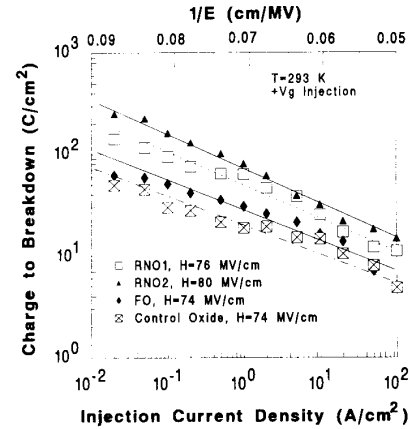


Fig. 1. Charge to breakdown Q_{bd} as a function of injection current density and reciprocal cathode electric field at 293 K. Each data point is an average of several measurements. The straight lines are fitted by $Q_{bd} = Q_{bd0} \exp(H/E)$ [6], where H is the impact ionization coefficient. Note that Q_{bd} versus $1/E$ and Q_{bd} versus $\log J$ can be expressed by the same curve since axis $1/E$ is approximately proportional to axis $\log J$ [6], [8].

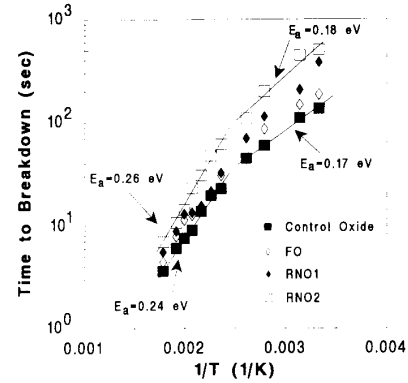


Fig. 2. The effect of temperature acceleration on time to breakdown t_{bd} . The temperature is from 300 to 565 K. Activation energy of lifetime E_a is also given by calculating the slope of the t_{bd} versus $1/T$. The injection current density is 200 mA/cm² and the relevant cathode field is about 12.5 MV/cm.

defect density [3], [11]. This contradiction may be due to the fact that a much lower nitridation level has been used in this study and only ~5-atm% nitrogen is incorporated into the oxide [2]. On the other hand, the defect density for sample FO is reduced by a factor of 2–3. Such a small defect density reduction is within the error limit of defect density for conventional oxide [12] and needs to be further investigated.

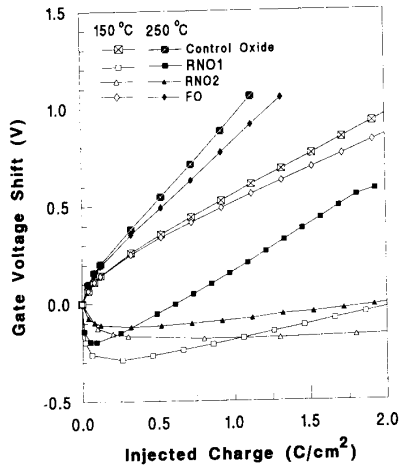


Fig. 3. Gate voltage shift versus injected charge at 150 and 250°C. The injection current density is 200 mA/cm² with a cathode field of 12.5 MV/cm.

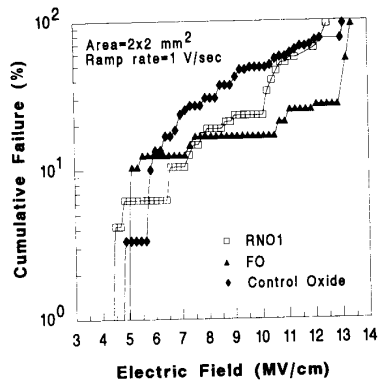


Fig. 4. Cumulative failure rate under ramping gate voltage at 293 K. The ramping rate is 1 V/s and a positive gate voltage was applied.

IV. SUMMARY

In conclusion, the TDDB characteristics for RNO and FO films have field and temperature dependences similar to those of control oxide, although RNO has a longer lifetime than

conventional oxide. Therefore, one may use the same acceleration factor as for conventional oxide to predict the lifetimes of RNO and FO films. Typically, at a stressing condition of 125°C and 10 MV/cm, the lifetime for sample RNO is 3–5 times longer than that of control oxide. The charge trapping reduction may be responsible for the increased lifetime of the RNO films. Also, nitridation/reoxidation does not have significant impact on oxide defects responsible for early breakdown.

REFERENCES

- [1] T. Hori and H. Iwasaki, "Ultra-thin re-oxidized nitrided-oxides prepared by rapid thermal processing," in *IEDM Tech. Dig.*, 1987, p. 570.
- [2] W. Yang, R. Jayaraman, and C. G. Sodini, "Optimization of low-pressure nitridation/reoxidation of SiO₂ for scaled MOS devices," *IEEE Trans. Electron Devices*, vol. 35, p. 935, 1988.
- [3] Z. H. Liu, P. T. Lai, and Y. C. Cheng, "Characterization of charge trapping and high-field endurance for 15-nm thermally nitrided oxides," *IEEE Trans. Electron Devices*, vol. 38, p. 344, 1991.
- [4] Y. Nishioka, E. F. Da Silva, Jr., Y. Wang, and T. P. Ma, "Dramatic improvement of hot-electron-induced interface degradation in MOS structures containing F or Cl in SiO₂," *IEEE Electron Device Lett.*, vol. 9, p. 38, 1988.
- [5] B. Y. Yu *et al.*, "Investigation of fluorine in SiO₂ and on Si surface by the ¹⁹F(ρ , α)¹⁶O reaction, secondary-ion mass spectrometry, and x-ray photoelectron spectroscopy," *Appl. Phys. Lett.*, vol. 56, p. 1430, 1990.
- [6] I. C. Chen and C. Hu, "Accelerated testing of time-dependent breakdown of SiO₂," *IEEE Electron Device Lett.*, vol. EDL-8, p. 140, 1987.
- [7] M. M. Moslehi, K. C. Saraswat, and S. C. Shatas, "Rapid thermal nitridation of SiO₂ for nitroxide thin dielectrics," *Appl. Phys. Lett.*, vol. 47, p. 1113, 1985.
- [8] J. Lee, I. C. Chen, and C. Hu, "Modeling and characterization of gate oxide reliability," *IEEE Trans. Electron Device*, vol. 35, p. 2268, 1988.
- [9] R. Moazzami, J. C. Lee, and C. Hu, "Temperature acceleration of time-dependent dielectric breakdown," *IEEE Trans. Electron Devices*, vol. 36, p. 2462, 1989.
- [10] M. S. Liang, C. Chang, Y. T. Yeow, and C. Hu, "MOSFET degradation due to stressing of thin oxide," *IEEE Trans. Electron Devices*, vol. ED-31, p. 1238, 1984.
- [11] T. Ito, H. Arakawa, T. Nozaki, and H. Ishikawa, "Retardation of destructive breakdown of SiO₂ films annealed in ammonia gas," *J. Electrochem. Soc.*, vol. 127, p. 2248, 1980.
- [12] R. Moazzami, J. C. Lee, and C. Hu, "Projecting gate oxide reliability and optimizing reliability screens," *IEEE Trans. Electron Devices*, vol. 37, p. 1643, 1990.
- [13] K. S. Krisch, B. J. Gross, and C. G. Sodini, "Positive charge trapping in nitrided oxide and reoxidized nitrided oxide gate dielectrics," *J. Appl. Phys.*, vol. 70, 1991.