A Comparative Study of High-Field Endurance for Reoxidized-Nitrided and Fluorinated Oxides

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Time dependent dielectric breakdown (TDDB) characteristics of reoxidized-nitrided and fluorinated oxide thin films (110Å) were examined under electric field and temperature accelerations. Compared with conventional thermal oxides, these oxides have comparable impact ionization coefficients and activation energies, though the charge-to-breakdown are somewhat improved. This finding suggests that the established theory for projecting the minimum thickness of conventional oxide is still applicable to these films. Charge trapping experiments showed that both positive and negative charge trapping can be remarkably reduced by the reoxidation/nitridation process. However, no obvious defect density reduction has been observed for both oxides.

I. INTRODUCTION

Both reoxidized-nitrided oxides (RNOs) and fluorinated oxides (FOs) have been shown recently to possess improved hot-carrier integrity as the gate dielectrics of MOSFET's [1-5]. However, no detailed research has been reported for the high-field endurance of the RNO and FO films. For instance, how these films stand up to raised electric fields and temperatures, what their failure mechanism is and how it is connected with the defect density are still unknown. In this paper, the effects of electric field and temperature on time dependent dielectric breakdown (TDDB) of 110-Å RNO and FO films were investigated. Combined with the measurements of charge trapping and defect density, these results show that the mechanism for the improved TDDB of these two types of films may be due to the reduced charge trapping. The fact that both reoxidized-nitrided oxides and fluorinated oxides show an impact ionization coefficient comparable to that of the conventional oxide suggests that the established theory to project minimum acceptable thickness of conventional oxide [6] is still applicable to these oxide films.

II. SAMPLE PREPARATION

MOS capacitors with 110-Å gate oxide films were fabricated on 10~20 ohm-cm n-type <100> oriented silicon wafers by using a standard polysilicon-gate self-aligned LOCOS process, except for the growth of the gate oxides. Three type of gate oxide films were prepared: the control oxide that was grown at 850 °C in atmospheric pressure O2; the low-pressure reoxidized-nitrided oxide that was fabricated by the nitridation at 850 °C in 0.1 atm. NH3 or at 950 °C in 0.01 atm. NH3, followed by the reoxidation at 850 °C in 1 atm. O2 or at 950 °C in 0.1 atm. O2; the fluorinated oxide that was grown by a HF-immersed process [3,4]—the wafers were simply dipped in 2% HF solution for 5 min before the gate oxidation, and loaded into the oxidation furnace without further rinsing. Samples used in this study and their respective gate oxide processes are listed in Table I. All gate oxides have received an post-oxidation annealing in N2 for 20 min.

The thicknesses of the gate oxides and the flatband voltages of the MOS capacitors were determined by C-V technique. The thickness increase resulted from the reoxidation/nitridation process is less than 10% and the flatband voltage shift is less than 0.2 V.

Table I Gate Oxides Process Conditions

Sample	Oxidation Temp.	Nitridation Temp./Time	Nitridation NH3 Pressure	Reoxidation Temp./Time	Reoxidation O2 Pressure
RNO1	850 °C	850 °C/60 m	0.1 atm.	850 °C/180 m	1 atm.
RNO2	950 °C	950 °C/60 m	0.01 atm.	950 °C/180 m	0.1 atm.
FO	900 °C	Dipped in 50:1 HF for 5 min before oxidation)			
Control Oxide	850 °C				

III. RESULTS

To examine the electric field and temperature acceleration of TDDB, constant current injection was performed and the time to breakdown t_{bd} was recorded.
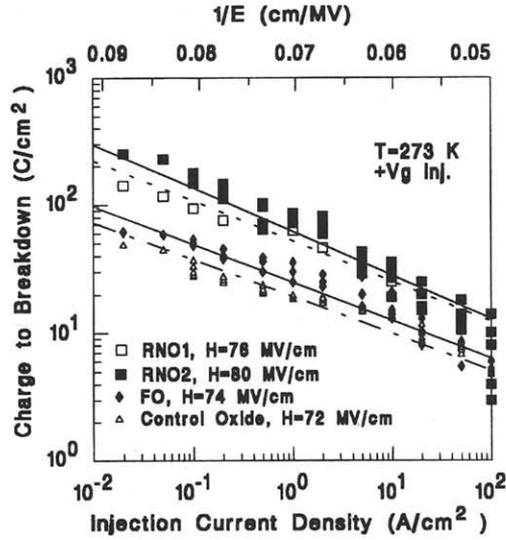
Fig. 1 The effects of injection current density and electrical field E on charge to breakdown Q_{bd}. The markers are experimental data and the straight lines are fitted by $Q_{bd} = Q_{bdo} \exp (H/E)$, where H is the impact ionization coefficient. The gate area is 10 mm by 10 mm.

Fig.1 shows the effects of electric field E or injection current density J on charge to breakdown Q_{bd} (= t_{bd} × J). Since the current conduction mechanism in lightly nitrided oxides is mainly of the *F-N* tunneling type[7], for these oxides E and J can be correlated by:

$$J = AE^2 \exp (-B/E), \quad (1)$$

where A and B are constants. It can be seen that, within the measured current density range, the Q_{bd} for RNOs is improved by a factor of 4 to 7 while the Q_{bd} for FO is increased by a factor of 2, as compared with that of control oxide. More importantly, Q_{bd}'s for these films depend linearly on the reciprocal of the electric field (1/E). It has been shown that the time to breakdown can be written as[8]:

$$T_{bd} = T_{bdo} \exp [(H+B)/E], \quad (2)$$

where H is impact ionization coefficient. According to (1) and (2), Q_{bd} can be expressed as

$$Q_{bd} = Q_{bdo} \exp (H/E). \quad (3)$$

Based on (3), the slope of the plot log (Q_{bd}) ~ 1/E gives the impact ionization coefficient which is shown in Fig. 1. One can see that no appreciable change has been induced by either nitridation/reoxidation or fluorinization. This observation suggests that one may

predict the lifetime of RNOs and FOs using the same acceleration factors as for control oxides after obtained the ratio of their Q_{bd} to that of control oxide.
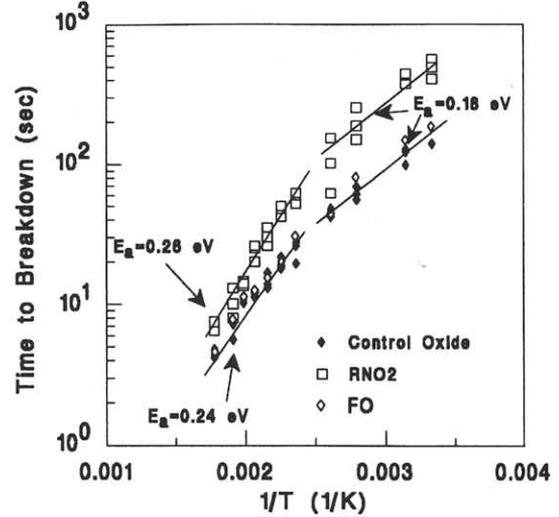
Fig. 2 The temperature acceleration of time to breakdown t_{bd}. The temperature T is from 300 K to 565 K and the activation energy of lifetime E_a is given by the slope of t_{bd} vs 1/T. The injection current density is 200 mA/cm2.

The temperature acceleration of TDDB is shown in Fig. 2. According to 9), the slope of the curves is proportional to the activation energy of lifetime (E_a). As one can see, both RNO and FO have the same temperature dependence as that of the control oxide. Not only do they have similar E_a values, but also the two temperature ranges within which the E_a value is extracted are identical [9].
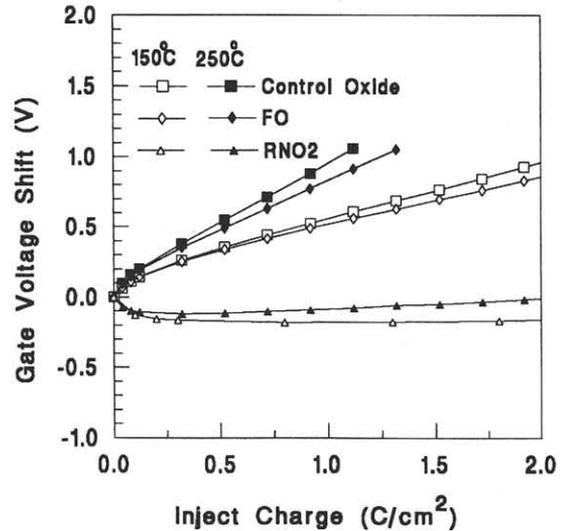
Fig. 3 Gate voltage shift vs injected charge. The injection current density is 200 mA/cm2 and the measuring temperature is 150 °C and 250 °C, respectively.

The charge trapping characteristics for RNO and FO films were examined by monitoring the gate voltage shift during constant current injection and the results are shown in Fig. 3 and Fig. 4. The data shown in Fig. 3 were measured at 150 °C and 250 °C, respectively,

with an injection current level at 200 mA/cm2. At both temperatures, sample RNO shows a much smaller positive V_g shift (due to electron trapping) than those of samples FO and control oxide. These results agree with previous obersvations taken at room temperature [1,2]. On the other hand, sample FO has an electron trapping rate comparable to that of control oxide. It is worth pointing out that the electron trapping rate at different temperatures seems to change reversely with TDDB lifetime, i.e., the higher the trapping rate is, the shorter the lifetime will be.
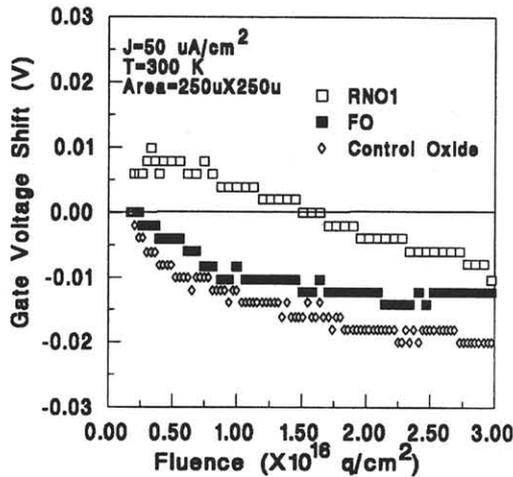
Fig. 4 Gate voltage shift vs injection charge at a lower current density (50 mA/cm2).

To enhance the observation of positive charge trapping, a lower injection current level (50 μA/cm2) is used for collecting the data in Fig. 4. The negative V_g shift for RNO and FO is less than that for the control oxide, suggesting that weaker positive charge trapping occurs. The initial negative charge trapping (positive V_g shift) for sample RNO1 may be due to new electron traps with larger capture cross section induced by nitridation[4] and needs to be studied further.
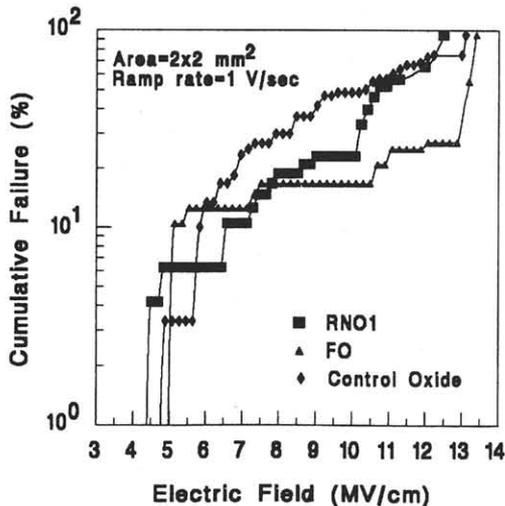
Fig. 5 Cumulative failure rate vs. ramping electric field. The ramping rate is 1 V/sec and the gate area is 2 mm by 2 mm.

In order to evaluate the defect density, the cumulative failure rate under ramping gate voltage is measured on large area device (4mm2) and shown in Fig. 5. Based on this result, the defect density which is proportional to the cumulative failure rate does not seem to improve significantly for RNO. On the other hand, although the defect density for fluorinated oxide FO appears to have been reduced by a factor of 3, it is still well within the limits caused by process fluctuation [9].

IV. SUMMARY

Based on the results presented here, we can conclude that the improved TDDB for RNO and FO is due to the modification of an intrinsic property of the films and not due to the reduction in defect density. The reduced charge trapping for these oxides may be responsible for the increased lifetime. The fact that RNOs and FO have field and temperature dependences comparable to those of the control oxide suggests that the failure mechanism for these oxides is similar and the present theory to predict the oxide lifetime is still applicable to the RNO and FO films.

ACKNOWLEDGEMENT

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