Extended Abstracts of the 1995 International Conference on Solid State Devices and Materials, Osaka, 1995, pp. 461-463

Time-Dependent Dielectric Degradation (TDDD) Influenced by Ultrathin Oxidation Process

Mikihiro KIMURA[a] and Tadahiro OHMI

Department of Electronic Engineering, Tohoku University, Sendai 980

A completed hole-induced breakdown model suggests that the intrinsic oxide breakdown under an optimal low-field operation-lifetime is not so critical limitation in region of thin oxide films (30-180Å). Also, buildup of the oxide trapped charges during electrical stress, closely correlated with water-related thin oxide films, decreases in thinner oxide (~50Å). On the other hand, stress-induced leakage current (SILC) increases in the thinner oxide, and besides the SILC is dependent on oxidation processing and the origin of SILC cannot be explained by the water-related model but can be explained by the Si-O weak/strained bond model. Owing to establishment of a new wafer level reliability for the SILC, an evaluation technology of time-dependent dielectric degradation (TDDD) was developed, and leads that the TDDD is more important in the reliability of ultrathin oxides than the TDDB.

1. INTRODUCTION

Modern developing of ultra-large-scale integration (ULSI) has consequently demanded *scaling-down* of metal oxide semiconductor (MOS) structures and aggressively proceeds to reduce the oxide thickness from thin oxide films of ~100Å to ultrathin oxide films of ~50Å. Therefore, the reliability of ultrathin oxide films is of great importance to develop highly reliable ULSIs. In the present work, it is revealed that a lifetime to intrinsic oxide breakdown under a low-field operating-stress can be explicitly extrapolated from a completed hole-induced breakdown model in Fowler-Nordheim (F-N) tunneling regime and the intrinsic oxide breakdown is not so critical limitation in region of thinner oxide films. It becomes, however, more serious problem that the stress-induced leakage current (SILC) in the ultrathin oxide films conspicuously increases at the low-field region after stressing and is dependent on oxidation process as reported in our previous work [1], [2]. We demonstrate that the evaluation technology of time-dependent dielectric degradation (TDDD) is successfully developed as a new wafer level reliability for the SILC and the TDDD is very available to evaluate the SILC reliability before occuring the breakdown in the ultrathin oxides.

2. THEORETICAL

Owing to extrapolation of lifetime to breakdown at a device-operation field, there is need for exact knowledge on oxide breakdown mechanism. Two breakdown models have been competively developed in relation to the field-acceleration: one predicts a linear field dependence based on electro-chemical Eyring model, while the other predicts a reciprocal field dependence based on hole-induced breakdown model. Concerning the intrinsic oxide breakdown mechanism, it is worthwhile considering hole attribution inside of the oxide. Chen and Hu [3] proposed the hole-induced breakdown model as $Q_h \propto J\alpha t$ and derived the breakdown time as $t_{BD} \propto \exp(G/E_{ox})$. Shiono and Itsumi [4], however, pointed out the hole-induced breakdown model overestimates the lifetime extrapolation and more accurate derivation is given by $t_{BD} \propto \exp(G/E_{ox})/E_{ox}^2$. We here derive a completed hole-induced breakdown model in the F-N tunneling regime and prove the operation-lifetime can be extrapolated from one accelerated lifetime $t_{BD}(E_{st})$ and one acceleration factor $G(t_{ox})$ as follows:

$$t_{BD} = Q_h / J_e \gamma_h = g(t_{ox}) E_{ox}^{-2} \exp\left[G(t_{ox}) / E_{ox} \right] , \quad (1)$$

where

$$J_e = A E_{ox}^2 \exp\left[-B / E_{ox} \right] , \quad (2)$$

$$\gamma_h = J_h / J_e = \gamma_0(t_{ox}) \exp\left[-H(t_{ox}) / E_{ox} \right] , \quad (3)$$

$$g(t_{ox}) = Q_h(t_{ox}) / A\gamma_0(t_{ox}) . \quad (4)$$

Hence,

$$G(t_{ox}) = B + H(t_{ox}) , \quad (5)$$

$$g(t_{ox}) = t_{BD}(E_{st}) E_{st}^2 \exp\left[-G(t_{ox}) / E_{st} \right] . \quad (6)$$

3. EXPERIMENTAL

(n^+/p) structured MOS capacitors and n-channel MOS transistors (n-MOSFETs) were fabricated with an n^+-poly Si gate electrode and thermally grown thin gate oxide films isolated by local oxidation of silicon (LOCOS) processing on p-type (100) Si substrates with resistivity of 8.5-11.5 Ω cm. The thin gate oxide films were thermally grown to various oxide thicknesses between ~30Å-180Å in pyrogenic steam at 750 °C or 820 °C (wet oxides) and in a dry O_2 atmosphere at 900 °C (dry oxides). The thicknesses of thin oxide films were measured by both of ellipsometry and capacitance-voltage (C-V) technique, and both the measurements were consistent within ±2% error.

4. RESULTS

A. Time-Dependent Dielectric Breakdown (TDDB)

Figure 1 shows a *constant field stress* (-12MV/cm) TDDB characteristics with different wet oxide thicknesses of 30Å-180Å using n^+-poly Si gate/p-type substrate (n^+/p) MOS structures. As shown in Fig. 1, it is comfirmed that the oxide breakdown time is complicated variable in the thin oxide regime around 50Å in case of (n^+/p) MOS structure. It is, however, important to extrapolate the lifetime under a low-field stress for actual device operation.

Figure 2 shows the oxide thickness dependence of

[a]Permanently with:
ULSI Lab., Mitsubishi Electric Corp., 4-1 Mizuhara, Itami, Hyogo 664

intrinsic breakdown lifetime t_{BD} at an operation-field (e.g. -6.6MV/cm) with 10% margin, extrapolated by Eqs. (1)-(6). Although the accelerated breakdown time is complicated variable in ultrathin oxide regime around 50Å under the high-field stressing of -12MV/cm, the extrapolated breakdown time increases with decreasing the oxide thickness and is not serious problem in thinner oxide films if using an optimal scaling of the operation-field as shown in Fig. 2.

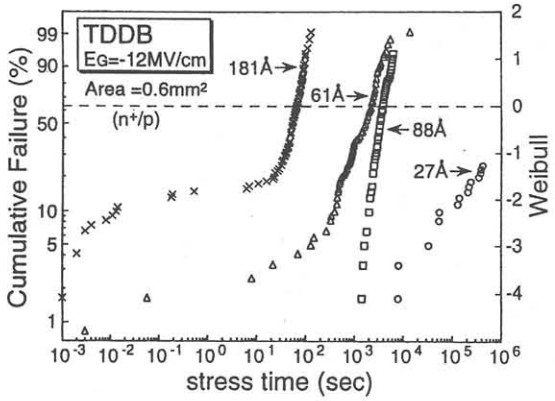

Fig.1. Constant field stress (-12MV/cm) TDDB characteristics with different wet oxide thicknesses of 30Å-180Å using (n^+/p) MOS structures.

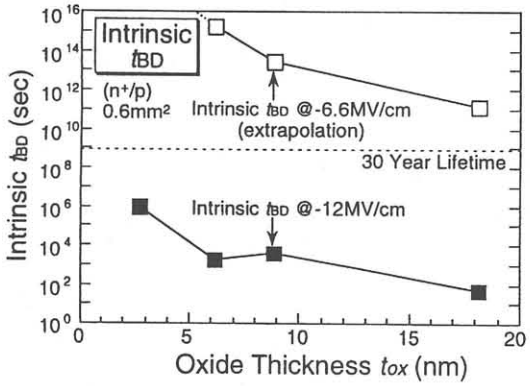

Fig.2. Oxide thickness dependence of intrinsic breakdown time t_{BD} at a stress-field of -12MV/cm and an operation-field with 10% margin of -6.6MV/cm, extrapolated by using the CHIB model.

B. Oxide Trapped Charges

As mentioned above, the intrinsic oxide breakdown is not critical in the thinner oxide, excepting the extrinsic oxide breakdown caused by the fabrication process damages and contaminations. Not only the oxide breakdown but also the oxide degradation such as oxide trapped charges and oxide leakage current is important for highly reliable ULSIs.

Figure 3 shows buildup of the oxide trapped charges inside of the wet oxide and the dry oxide during a constant current stress in the 86Å oxide (a) and the 50Å oxide (b). In the 86Å oxide (a), the buildup of oxide trapped positive charges inside of the wet oxide is larger than that inside of the dry oxide. This indicates the "water-related" model associated with H_2O, OH, and H species, as reported by many researchers. However, the buildup charges in the ultrathin oxide film of 50Å thick (b) are obviously small, compared to the 86Å oxide (a). This indicates that the oxide trapped charges decrease in thinner oxide; namely the buildup of oxide trapped charges is also no problem in thinner oxide.

C. Stress-Induced Leakage Current (SILC)

While, the SILC phenomenon is more important problem in thinner oxide since the SILC remarkably increases in the ultrathin oxide (~50Å), as reported in our previous work [1].

Figure 4 shows ultrathin oxidation process dependence on the SILC in wet oxide (a) and dry oxide (b), fresh and

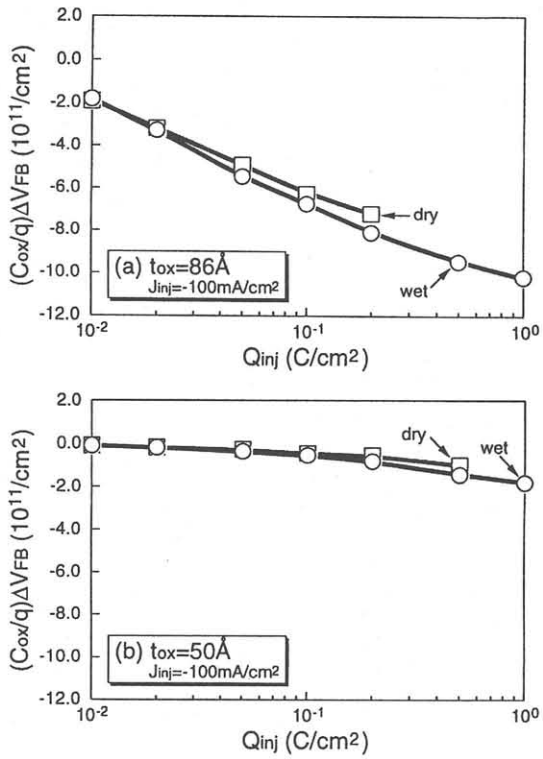

Fig.3. Correlations of oxide trapped charges in the 86Å oxide (a) and the 50Å oxide (b), during a constant current stress.

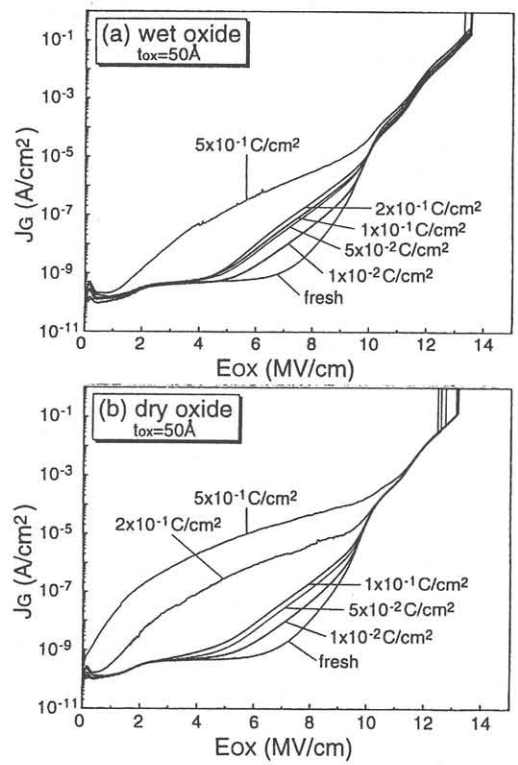

Fig.4. Oxidation process dependence on the SILC in wet oxide (a) and dry oxide (b), fresh and after stresses.

after stresses to Q_{inj} = 0.5C/cm². Both of the wet oxide and the dry oxide are thermally grown to acculately 50Å thick. As a result, the SILC after 0.2C/cm² is smaller in the wet oxide (a) than in the dry oxide (b). This intesively suggests that the SILC can be reduced by developing ultrathin oxidation technologies, and the *origin* of the SILC increasing is not due to the water-related model but is due to the weak and/or strained bond of≡Si---O—Si≡in the SiO_2 amorphous networking induced by the electrical stressing.

In addition, we have been investigated on F-N tunneling after the stresses. As shown in Fig. 5, it is verified that both of the wet oxide (a) and the dry oxide (b) also fit well with F-N lines after the stresses. This indicates that the *mechanism* of the SILC in ultrathin oxide is due to the neutral oxide trap-assisted tunneling [1], apart from the oxidation processing.

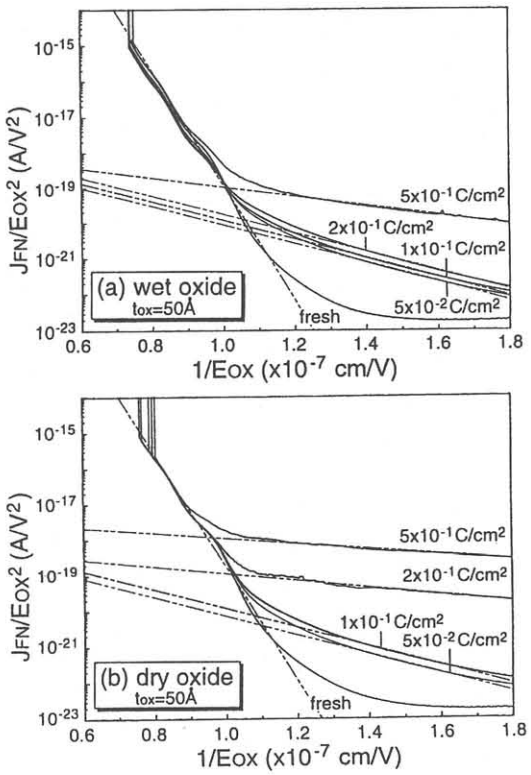

Fig.5. F-N tunneling after stress in wet oxide (a) and dry oxide (b), in order to confirm the neutral oxide trap-assisted tunneling model.

D. Time-Dependent Dielectric Degradation (TDDD)

Thus the SILC is dependent on the ultrathin oxidation process (~50Å) and seriously degrades the reliability before occurring the oxide breakdown. Therefore, it is greatly important to establish evaluation technologies of time-dependent dielectric leakage (TDDL) and time-dependent dielectric degradation (TDDD) as a wafer level reliability (WLR) for the SILC by simultaneous measuring with multi-chips on a wafer. An important feature is that stressing conditions and measuring conditons are independently variable in the system. Owing to the establishment, it is possible to evaluate the TDDL, the TDDB, and the TDDD influenced by the ultrathin oxidation process.

Figure 6 shows typical TDDL characteristics in the wet and the dry ultrathin oxides. Samples are used large area size of 3mm² near to an actual ULSI device, having the (n^+/p) MOS structures with accurate oxide thickness of 50Å. The TDDL evaluations were performed using the conditions of a stress-field of -12MV/cm and a measurement-field of -7MV/cm, independently. As a result, the leakage current for early stress time before the extrinsic breakdown does not increase in both the wet and the dry oxides, while the leakage current for long stress time before the intrinsic breakdown *abruptly* increases with depending on the ultrathin oxidation process.

In the TDDL characteristics as shown in Fig. 6, a TDDB distribution can be obtained by setting a higher fail-criterion and a TDDD distribution obtained by setting a lower-fail criterion. Figure 7 shows the distributions of TDDD and TDDB in the 50Å oxides of 120 chips. It is verified that the intrinsic TDDD is one order of magnitude as short as the intrinsic TDDB, in both of the wet and the dry oxides, and the TDDD in the wet oxide is longer than that in the dry oxide. This indicates that the TDDD is more important than the TDDB in thinner oxide and also influenced by the ultrathin oxidation process.

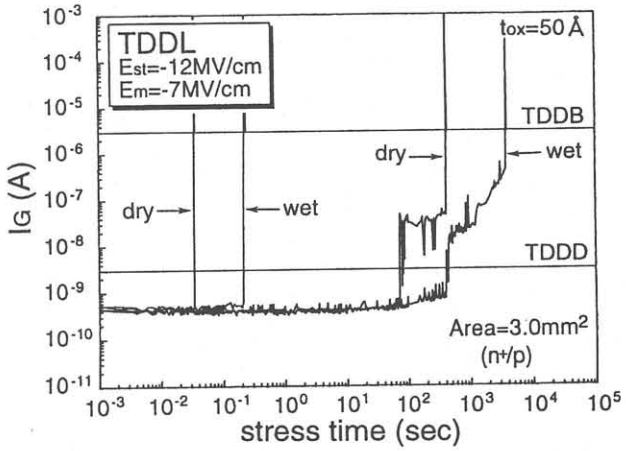

Fig.6. Typical TDDL characteristics in the wet and the dry ultrathin oxides. Samples are used large area size of 3mm², having the (n^+/p) MOS structure with accurate oxide thickness of 50Å

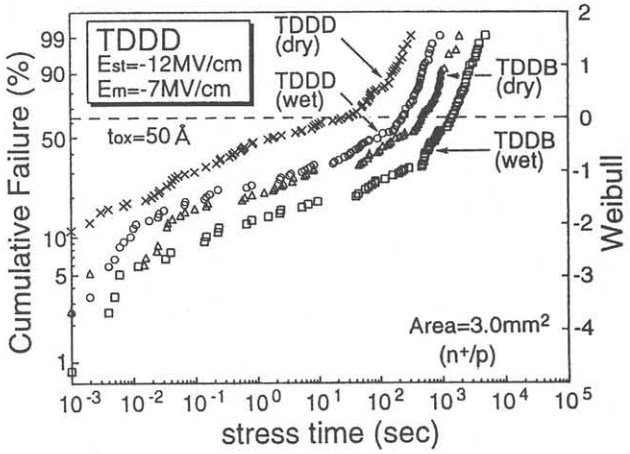

Fig.7. Distributions of TDDD and TDDB in the wet and the dry oxides of 120 chips obtained from the TDDL characteristics.

References

[1] M. Kimura and H. Koyama, IEEE *Proc. Int. Rel. Phys. Symp. (IRPS)*, p.167, 1994.

[2] T. Ohmi, K. Nakamura, K. Makihara, IEEE *Proc. Int. Rel. Phys. Symp. (IRPS)*, p.161, 1994.

[3] I. C. Chen and C. Hu, IEEE Electron Device Lett., **EDL-8**, p.140, 1987.

[4] N. Shiono and M. Itsumi, IEEE *Proc. Int. Rel. Phys. Symp. (IRPS)*, p.1, 1993.