Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 710-711

A-7-1

Investigation of Degradation model for Ultra-thin Gate Dielectrics

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1. Introduction

The Negative Bias Temperature Instability (NBTI) and the Time Dependent Dielectric Breakdown (TDDB) of the gate-dielectric films are serious problems in device scaling. Generally, we estimate device lifetime from temperature dependence and voltage dependence. Some voltage dependent models, such as V_G, $1/V_G$ and power-law, are reported [1]-[4]. These models have been constructed with only the data in high voltage region. In this study, we investigated the mechanism and the valid model which describing both NBTI and TDDB for ultra-thin gate dielectrics of 1.1 and 1.9nm thick, with taking low stress data into account. We have found that the voltage dependences of the TDDB and the NBTI lifetimes follow the power-law over a wide range of the temperature and the voltage. We also investigated the defect generation probability in NBTI and Stress Induced Leakage Current (SILC), and have found their voltage and temperature dependences are the same.

2. Experiments

The samples were fabricated in a standard CMOS process. We define the TDDB failure by Soft Breakdown (SBD), which is detected SILC increase at use voltages, *i.e.*, 20%. The transistor characteristics were measured in the NBTI test. We define the NBTI lifetime at the time when DI_D / I_{D0} = 3%. Here, I_{D0} and DI_D mean initial drain saturation current and degradation of I_D.

3. Results and Discussion

Figure 1(a), (b) show TDDB and NBTI results for PMOSFET with T_{OX} = 1.1nm, where T_{OX} means oxide thickness. Both of the lifetimes for TDDB and NBTI are well described with the power-law, that is, V_G^{-n}. The same results are obtained in the T_{OX} = 1.9nm case. The exponent n for the NBTI is 17. On the other hand, the n is 28 for TDDB. We think this difference is due to the followings: The degradation of the NBTI is saturated with the stress time. The TDDB occurs in this region. Therefore, each lifetime is defined in a different region. If we define the NBTI lifetime in the saturation region, for example at DI_D / I_{D0} = 20%, we obtain n = 24, which is closer to the value for the TDDB.

Suñé *et al*. suggested that the TDDB might be explained by hydrogen release model. In this model, the mechanism of the TDDB is described by the following reactions: 1) Electrons are injected from cathode. 2) The injected electrons release hydrogen atoms from interface of Poly-Si and oxide. 3) The released hydrogen atoms generate electron traps in oxide [5]. In this model, the lifetime T_{BD} is given by $T_{BD} = N_{BD} / (P_G \times J_G)$, where N_{BD} is the defect density at the breakdown, J_G is the gate current density, and P_G is the defect generation probability defined by [5].;

$$P_G = \partial(\Delta I_G / I_{G0}) / \partial Q_{INJ} \quad (1)$$

Then lifetime is depend on $V_G^{-n} \times [J_G (V_G)]^{-1}$, because P_G is approximated as $P_G \propto V_G^{n}$. Our result of TDDB lifetime shows the same dependence.

On the other hand, we examined the relation between the injected charge (Q_{INJ}) and the degradation rate in order to investigate whether the origins of TDDB and NBTI are the same or not. Fig. 2 shows the relation between the DI_D / I_{D0} and Q_{INJ}. The DI_D / I_{D0} is saturated with Q_{INJ}. Here, we introduce the concept of defect generation probability for the NBTI (P_{G_NBTI}) as the following equation (2) to examine the similarity of the SILC and the NBTI;

$$P_{G\_NBTI} = \partial(\Delta I_D / I_{D0}) / \partial Q_{INJ} \quad (2)$$

Fig. 3 shows the V_G dependence of the P_G and the P_{G_NBTI} at $Q_{INJ} = 5 \times 10^5$ [C / cm^2]. Both dependences are similar each other. Further, we obtain the same activation energy (E_a) for the P_G and the P_{G_NBTI} from the plot in Fig. 4. We investigate the P_{G_NBTI} over a wide range of the testing voltage. It is shown in Fig. 5. In only narrow voltage range, $P_{G\ NBTI}$ shows exponential dependence, but it shifts from the exponential and approaches the power-law when we include low voltage data. This leads to the power-law like behavior of the lifetime.

From these results, we consider that both TDDB and NBTI are dominated by the same reaction, which might be described with the hydrogen release model. This corresponds to the suggestion of Tujikawa *et al*. [6].

The shift of the P_{G_NBTI} from the exponential dependence means slope m varies with NBT stress, as shown in Fig. 6, where m is defined log (DI_D / I_{D0}) ~ m × (log t). Under higher NBT stress condition, degradation rate is larger than that which is measured in lower stress. This means the degradation in use condition is slower than that which is extrapolated from high stress conditions. Then, we investigated the E_a and the power exponent in the low stress regime. They become large for lower voltage or lower temperature as shown in Fig. 7 and 8. With the data over a wide range of stress, the lifetime of the NBTI is estimated more than an order magnitude longer than that extrapolated from high stress condition.

4. Conclusions

Taking the low stress data into account, we obtained following results about TDDB and NBTI in ultra-thin gate dielectrics of 1.1 and 1.9nm thick.

1) The voltage dependences of the TDDB and NBTI lifetimes follow power-law.

2) The defect generation probability, activation energy and power exponent are almost same for the SILC and the NBTI. These suggest that the same degradation mechanisms are dominant in both TDDB and NBTI.

3) We have improved the accuracy of lifetime estimation with the results which are obtained under low stress.

References

[1] E.Y.Wu *et al.*, *IEDM Tech. Digest*, pp.541-544, 2000

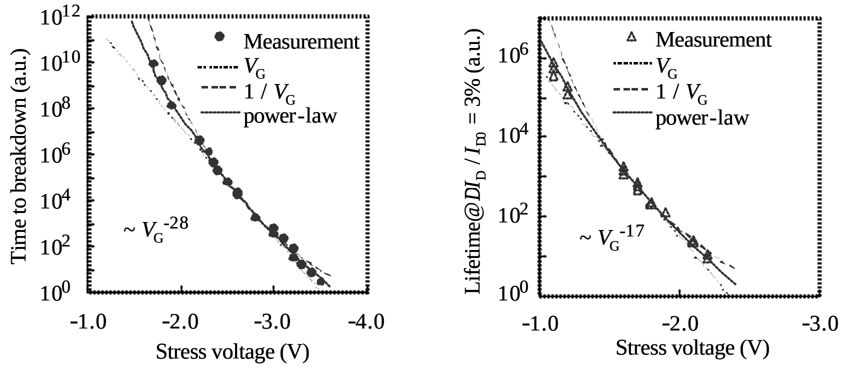
[2] P.Nicollian, *et al.*, *International Reliability Physics Symposium*, pp.7-15, 2000

[3] T.Nakajima *et al.*, *13th RCJ Reliability Symposium*, pp.85-90, 2003

[4] Kato *et al.*, *12th RCJ Reliability Symposium*, pp.65-70, 2002

[5] J. Suñé *et al.*, *2001 Symposium on VLSI Technology Tech. Dig.*

[6] S.Tsujikawa *et al.*, *2003 Symposium on VLSI Technology Tech. Dig.*



(a) TDDB (b) NBT

Fig.1 The voltage dependences of lifetimes for both TDDB and NBTI show the power-law. The junction temperature T_J = 125℃ for TDDB, and T_J = 150℃ for NBTI.

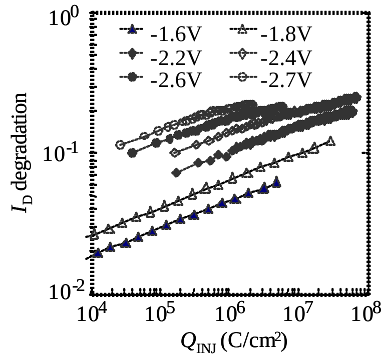


Fig. 2 Injected charge dependence of I_D degradation (T_J = 150 ℃, T_{OX} = 1.1 nm).

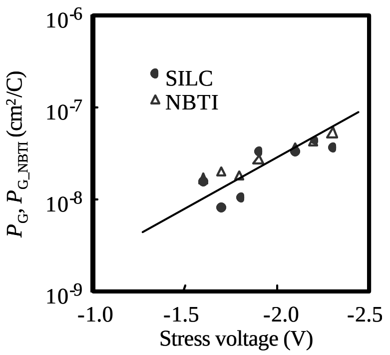


Fig. 3 The SILC and the NBTI have the same voltage dependence of P_G at Q_{INJ} = 5 × 10^5 [C / cm^2].

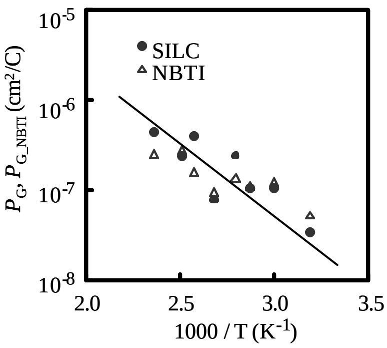


Fig. 4 The P_G and the P_{G_NBTI} have the same E_a at Q_{INJ} = 5 × 10^4 [C / cm^2].

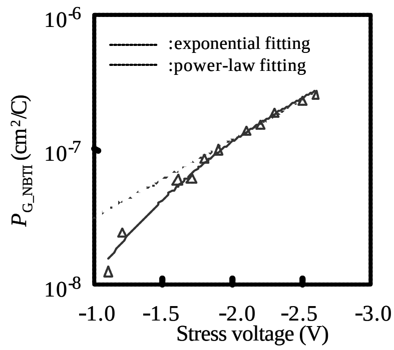


Fig. 5 Voltage dependence of P_{G_NBTI} shows the power-law dependence over a wide range.

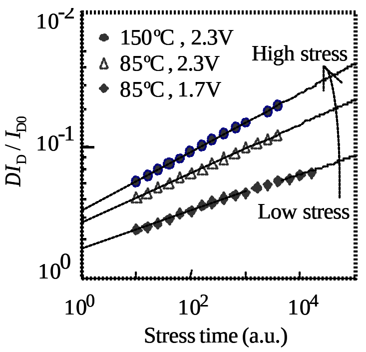


Fig. 6 I_D degradation at high and low NBT stresses (T_{OX} = 1.1 nm). The slope m increases with stress intensity.

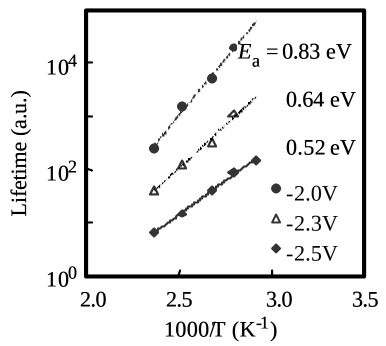


Fig. 7 The E_a at various voltages (T_{OX} = 1.1 nm). The E_a increases as the stress voltage decrease.

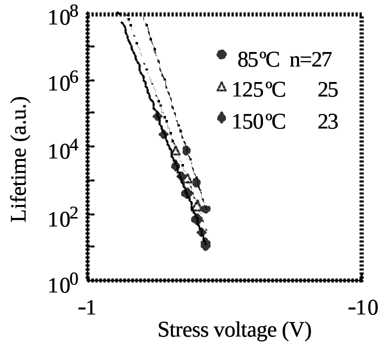


Fig. 8 The exponent n at various temperatures. The n becomes large as the temperature increases.