第 26 卷 第 12 期
2005 年 12 月

半 导 体 学 报
CHINESE JOURNAL OF SEMICONDUCTORS

Vol. 26 No. 12
Dec. ,2005

One Method for Fast Gate Oxide TDDB Lifetime Prediction

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Abstract: A method for fast gate oxide TDDB lifetime prediction for process control monitors (PCM) is proposed. For normal TDDB lifetime prediction at operation voltage and temperature ,we must get three lifetimes at relative low stress voltages and operation temperature. Then we use these three lifetimes to project the TDDB lifetime at operation voltage and temperature via the E-model. This requires a very long time for measurement. With our new method ,it can be calculated quickly by projecting the TDDB lifetime at operation voltage and temperature with measurement data at relatively high stress voltages. Our test case indicates that this method is very effective. And the result with our new method is very close to that with the normal TDDB lifetime prediction method. But the measurement time is less than 50s for one sample ,less than 1/100000 of that with the normal prediction method. With this new method ,we can monitor gate oxide TDDB lifetime on-line.

Key words: TDDB; lifetime; prediction
EEACC: 2560
CLC number: TN304.2^{+}1 **Document code:** A **Article ID:** 0253-4177(2005)12-2271-04

1 Introduction

The gate oxide SiO_2 represents the very heart of reliability of a MOSFET device. SiO_2 has shown excellent reliability with thickness scaling ,which is one of the primary reasons that CMOS technology has enjoyed worldwide acceptance and great industrial success for many years. The reliability of the SiO_2 gate oxide has received much attention over the last 30 years[1]. Time-dependent dielectric breakdown (TDDB) is an important failure mechanism of the SiO_2 gate oxide. The dielectric fails when a conductive path forms in the dielectric, shorting the anode and cathode. The two models used for describing TDDB are the field-driven model (E-model)[2] and the current-driven model ($1/E$-model)[3].

In a mass production process ,it is necessary to monitor the process on line with a PCM to ensure the quality of the product to customers. For a gate oxide ,the TDDB lifetime must be available as soon as possible. With the current methods ,three TDDB lifetimes at low stress voltages are needed to project the lifetime at operation voltage and temperature. But this takes a long time. It is not feasible for a PCM test. Here ,we put forward a method for fast and effective TDDB lifetime prediction with high voltage stress TDDB measurement data which can be used for a gate oxide PCM. After applying these two methods to a test case ,we find that the result projected with our new method is credible and acceptable.

2 Method description

The observed time to failure (TF) depends on the electric field E_{ox} in the dielectric and the temperature ,with two models

$$E\text{-model}: TF = A_0 \exp(-\gamma E_{ox}) \exp(E_a / kT)$$

$$1/E\text{-model}: TF = \tau_0(T) \exp[G(T)/E_{ox}]$$

Received 15 June 2005 ,revised manuscript received 25 July 2005

where E_{ox} is the electric field across the dielectric, γ and $G(T)$ represent the field acceleration parameters in the two respective models, E_a represents the thermal activation energy, A_0 is the arbitrary scale factor, and $\tau_0(T)$ is a temperature dependent factor. The E-model is based on a dipolar field lowering of the activation energy required for thermal bond breakage while the $1/E$-model is based on current-induced hole injection into the oxide. The E versus $1/E$ controversy has continued for many years due to the fact that either model fits TDDB rather well over limited field ranges. In order to clearly differentiate the two models, TDDB data must be collected over a wide range of fields and, hopefully, even extending testing fields close to normal very large scale integrated-circuits (VLSI). Low-field TDDB data collection, however, requires very long test times. Fairly recently, however, there have been several long-term, low-field TDDB studies published with each showing that the E-model provides a superior fit to the TDDB data, especially at lower fields[4]. From the above discussion, it is obvious that the TDDB lifetime projected with high field condition data via the E-model or $1/E$ model is not credible because the TDDB lifetime fits different models (E model and $1/E$ model) at low and high fields. So we propose the following method to solve this problem.

Because the TDDB lifetime fits different models at low and high fields, there must exist a transition field region (Fig. 1). Firstly, three lifetimes at E_1, E_2, and E_3 in the transition field region were projected via the $1/E$ model with our measured TDDB lifetime at high field conditions. Then we use these three lifetimes at E_1, E_2, and E_3 to project the TDDB lifetime at operation field with the E model. Finally, we give a real case to support our method.

3 Experiments, results, and discussion

The test structure was a 1000μm ×1000μm nMOS capacitor. The oxide thickness was 8nm. At high stress voltage, TDDB tests were done with an HP 4071A Semiconductor Parametric Tester at wafer level, and at a low stress tests were made with a Qualitau System (Taiwan) at package level. The operation voltage and temperature for the device are 3.3V and 85 ℃.

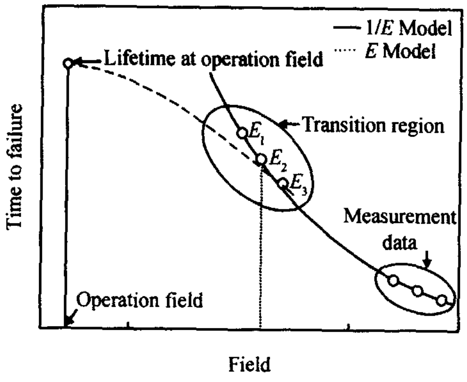

Fig. 1 Illustration of our new method for TDDB lifetime prediction

Three low stress TDDB times were measured (5.95, 6.3, 6.75V). The measurement data is shown in Fig. 2(a). In Fig. 2(a), $F(t)$ is the failure rate. With these three lifetimes, the TDDB lifetime at 3.3V can be extrapolated via the E-model (Fig. 2(b)). The lifetime is 1.3×10^5 years. In Fig. 2(b), $T_{63.2}$ is the lifetime when the failure rate is 63.2% (We defined this lifetime as the device's lifetime).

Figure 3(a) shows the TDDB test results at relatively high stress voltages (8.68, 8.96, 9.24V) under operation temperature (85 ℃). From the above description of our method, the $1/E$-model was first used to project three TDDB lifetimes at 7.1, 7.4, and 7.7V at the temperature of 85 ℃ (Fig. 3(b)). Then these three lifetimes were used to project the lifetime at 3.3V via the E-model (Fig. 4). The lifetime is 1.1×10^5 years. Compared with the above lifetime projected with the normal method, we see that the results are very close.

The most important issue is the selection of the above three voltages. Table 1 shows the different lifetimes projected with different voltages. From Table 1, it can be observed that the bigger the voltages used for lifetime projection, the shor-

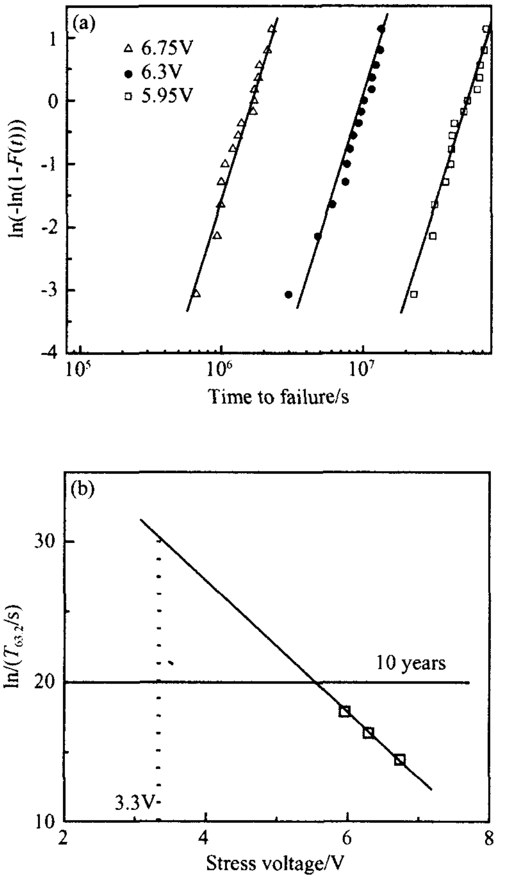

Fig. 2　TDDB data at 5.95, 6.3, and 6.75V (a) and prediction result with the *E* model (b)

ter the lifetime we get. But for PCM use it is better that the result is more pessimistic to some degree. We can confirm that our gate oxide TDDB property is good.

Table 1　Comparison of lifetimes projected with different voltage data

Voltages/ V	7.1, 7.4, 7.7	7.4, 7.7, 8	7.7, 8, 8.3	Normal method
Lifetime projected/ y	1.1×10^5	2.7×10^4	2.5×10^4	1.3×10^5

4　Conclusion

A method for fast gate oxide TDDB lifetime prediction is proposed forward in this paper. The TDDB evaluation time can be shortened greatly with this new method, which can be used for PCM gate oxide TDDB lifetime prediction. At the same time, the projected TDDB lifetime with our new method is credible compared with that projected with the normal method.

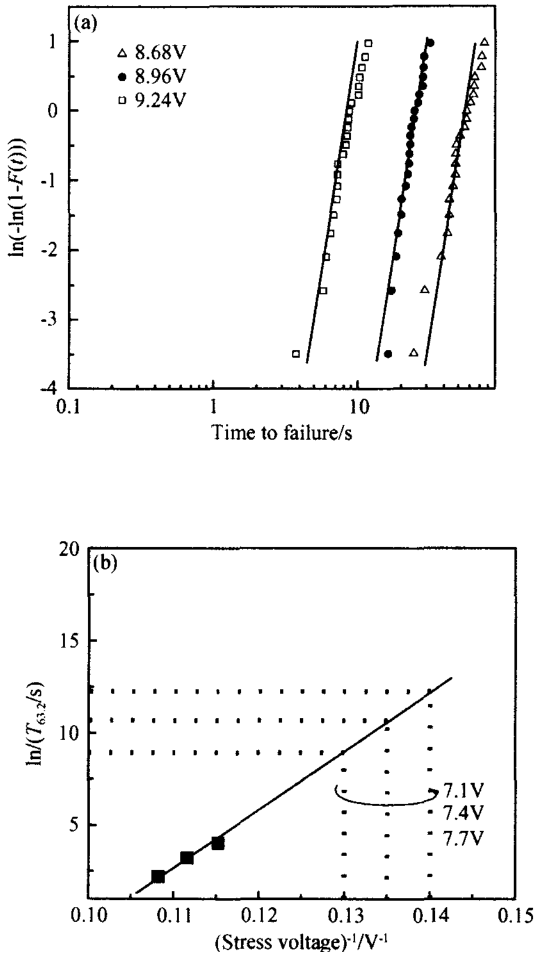

Fig. 3　TDDB data at 8.68, 8.96, and 9.24V (a) and prediction result for 7.1, 7.4, and 7.7V with the 1/ *E* model (b)

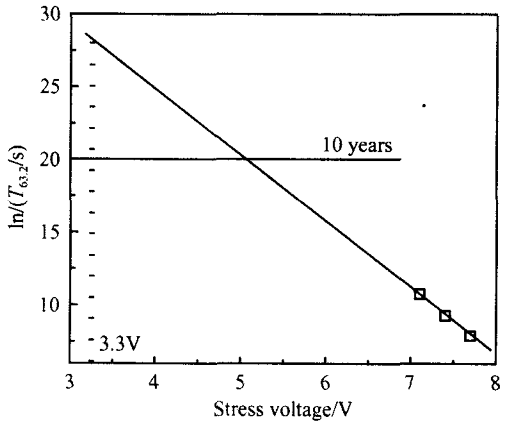

Fig. 4　TDDB lifetime at operation voltage of 7.1, 7.4, and 7.7V data via the *E* model

Acknowledgements　Most of all, we thank Mr. Jian Yang for his HP4071 auto test support.

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一种快速推算栅极氧化膜TDDB寿命的方法

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摘要: 提出了一种快速推算栅极氧化膜TDDB寿命的新方法. 该方法可以用于对工艺的实时监控. 通常情况下, 为了得到栅极氧化膜在器件使用温度下的TDDB寿命, 必须得到三个在一定温度下的不同电压下的TDDB寿命. 然后使用一定模型(*E*模型或者1/*E*模型)和这个三个寿命推算出氧化膜在器件使用温度下的寿命. 比较常用的是*E*模型. 但是为了保证使用*E*模型推得的寿命的准确性, 必须尽量使用较低电压下的寿命来推算想要的寿命. 显然, 为了获得低电压下的TDDB寿命, 必须花费相当长的测试时间(甚至1个月). 这对于工艺的实时监控来说, 是不能接受的. 文中提出一种新的推算栅氧化膜TDDB寿命的方法. 运用该方法, 可以快速、准确获得栅氧化膜的TDDB寿命, 而花费的测试时间不到普通方法的1/1000000. 在该方法中, 巧妙地同时利用了1/*E*模型和*E*模型.

关键词: TDDB; 寿命; 预测
EEACC: 2560
中图分类号: TN304.2$^+$1 **文献标识码**: A **文章编号**: 0253-4177(2005)12-2271-04

Received 15 June 2005, revised manuscript received 25 July 2005