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Film Thickness Dependence of TDDB Characteristics for Thermal Oxide

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Behavior of electric field acceleration factor, β, was investigated systematically over a wide range of oxide thickness from 9 to 50 nm. It was shown that β depends on both oxide thickness and oxide field strength. The observed β behavior was found to be explained by modified hole trapping model, in which shifts in injected electron current and hole generation efficiency during stress time are taken into account. By introducing modified acceleration factor, it is possible to project plausible gate oxide lifetime for a wide range of oxide thickness.

1. INTRODUCTION

Projecting gate oxide lifetime is one of the most important techniques for MOS integrated circuits. The concept of electric field acceleration factor, β, is widely used to deduce oxide lifetime under low operating fields from the high field accelerated test data.

Many β values have been reported in literature. Yamabe and Taniguchi pointed out that β value was a function of oxide thickness[1]. On the other hand, the U. C. Berkeley group showed oxide field strength dependence of β, based on the oxide breakdown model associated with hole trapping[2]. Therefore, it is necessary to clarify the oxide field strength dependence and/or oxide thickness dependence of β values in order to project accurate gate oxide lifetime. In this work, the β behavior is investigated systematically over a wide range of oxide thickness and oxide field strength. It is shown that β depends on both oxide thickness and oxide field strength. Furthermore a possible interpretation for the observed β behavior is presented.

2. EXPERIMENTAL

The samples used in this study were conventional n^+ poly-silicon gate capacitors. The gate oxides were grown on n-type substrate in a dry oxygen ambient at 900℃. Oxide thickness was varied from 9 to 50 nm. A small capacitor area, 0.015 mm^2, was used to investigate the intrinsic oxide property. TDDB tests were accomplished by constant voltage stress, to evaluate the oxide lifetime under actual stress conditions. 130 or 65 samples were tested for each stress condition, to decrease statistic error.

Figures 1 (a) and (b) show typical examples of stress current shifts during constant voltage stress. The time dependence of stress current density varies with changing oxide thickness or oxide field strength, because of different trapped charge density. On the assumption that oxide lifetime depends on the total number of electrons injected into the oxide or holes generated in the oxide, the electric field acceleration factor, deduced from time to breakdown, would be affected by the current shift behavior. In order to exclude the influence of the stress current shift, new parameter, modified acceleration factor, β^*, was introduced, which was derived from modified time to breakdown, Tbd*=Qbd/Jinit (Qbd: charge to breakdown, Jinit: current density at the initial stress point).

3. RESULTS AND DISCUSSION

Figure 2 shows the relationship between time to breakdown and stress field, for various oxide thicknesses. Note that time to breakdown increases as oxide thickness decreases, except for oxide thinner than 13.3 nm. This is due to the current shift during stress time. In Fig. 3, the modified time to breakdown is also shown as a function of stress field. Note that the modified time to breakdown depends more weakly on oxide field for thinner oxides or for lower stress field and the curves tend to merge into a single line. Such features resemble the hole substrate current behavior, which is observed when high fields are applied across gate oxides[3]. This fact suggests that dielectric breakdown occurs due to holes generated in oxides under high field stress.

Now, consider the electric field acceleration factor. The model for the acceleration factor has been proposed by the U. C. Berkeley group[2]. They assumed that the dielectric breakdown occurs when the total number of trapped holes, which are generated under high field stress, exceeds a critical value. According to their assumption, the electric field acceleration factor was expressed as $\beta=140/Eox^2$ [decade/MV/cm][2]. Note that, according to their hole trapping model, the acceleration factor is independent from oxide thickness. Figure 4 shows acceleration factors, deduced from the present data, for various oxide fields and various oxide thicknesses. It is shown that oxide thickness dependence exists in a complicated manner. The discrepancy between the model and the present experimental data will be attributed to two facts, which were not taken into account in the model. One is time dependence for the injected electron current during stress. The other is time dependence for the hole generation efficiency during stress. In order to take into account the time dependence for the injected electron current, the acceleration factor was deduced from the modified time to breakdown. The results are shown in Fig. 5. Note that the experimental data agree well with the hole trapping model in a thinner oxide region. However, there is discrepancy between the model and the experimental data, especially for thicker oxide or for higher field region. On the other hand, it was found that the deduced modified acceleration factors are always greater than the values estimated from the hole trapping model, when breakdown occurs during stress current increase, as illustrated in the inset of Fig. 6. The main figure for Fig. 6 shows the ratio of current density at the initial stress point and one at the breakdown point. For thicker oxides or for higher fields, the ratio is greater than unity, which means the field strength in the cathode region is greater than the initial value. Therefor, the discrepancy between the modified acceleration factor and the model can be explained by the time dependence of the hole generation efficiency during stress. Figure 7 shows a diagram to illustrate the situation. Namely, when the generated holes are trapped in the cathode region, the field strength in the region near the anode decreases. The field strength reduction leads to a decrease in the hole generation efficiency and, finally, to an increase in the acceleration factor.

4. CONCLUSION

To investigate the β behavior systematically, it was found that;

1. The electric field acceleration factor depends on both oxide electric field and oxide thickness in a complicated manner.

2. The behavior of acceleration factor is explained by the modified hole trapping model, in which shifts in injected electron current and hole generation efficiency during stress time are taken into account.

The modified acceleration factor was found to be described by the relationship, $\beta^*=140/Eox^2$ [decade/MV/cm], in fairly low field stress conditions, for example, lower than 12 MV/cm for 20 nm oxide. By measuring modified time to breakdown (or charge to breakdown), and using the modified acceleration factor, it is possible to predict plausible oxide lifetime for a wide range of oxide thickness.

1) K.Yamabe and K.Taniguchi: IEEE Trans. Electron Devices ED-32(1985)423.
2) I.C.Chen and C.Hu: IEEE Electron Device Lett. EDL-8(1987)140.
3) A.Toriumi and M.Iwase: Proc. 19th Conf. Solid State Devices and Materials, 1987, p.351.

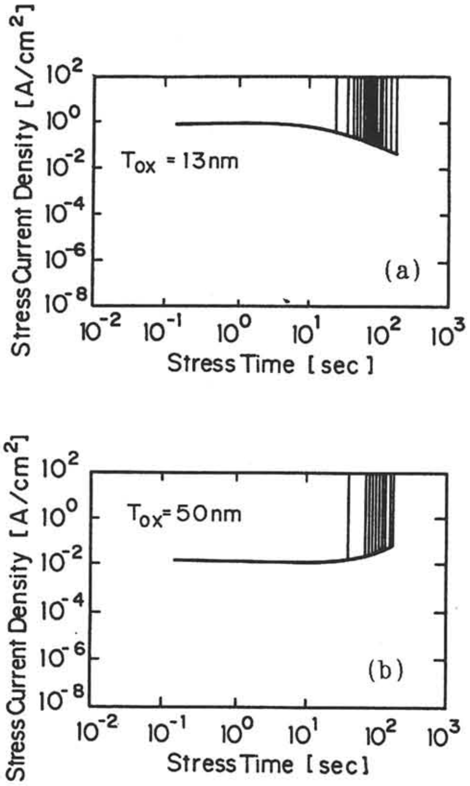

Fig.1 Stress current shift during constant voltage stress for (a) 13 nm and (b) 50 nm oxides

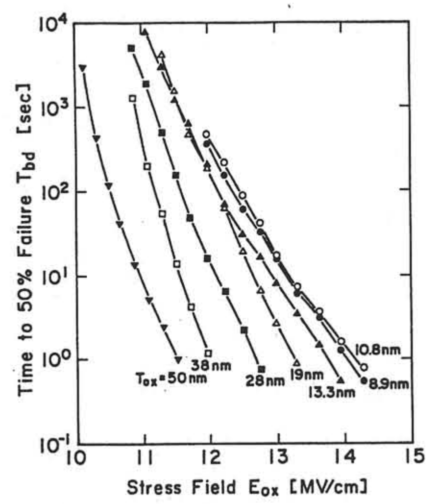

Fig.2 Time to breakdown versus stress field strength

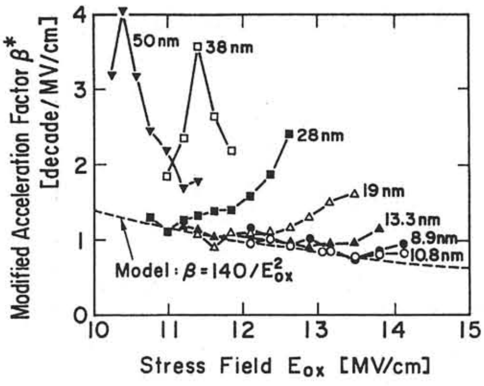

Fig.5 Acceleration factor, deduced from modified time to breakdown

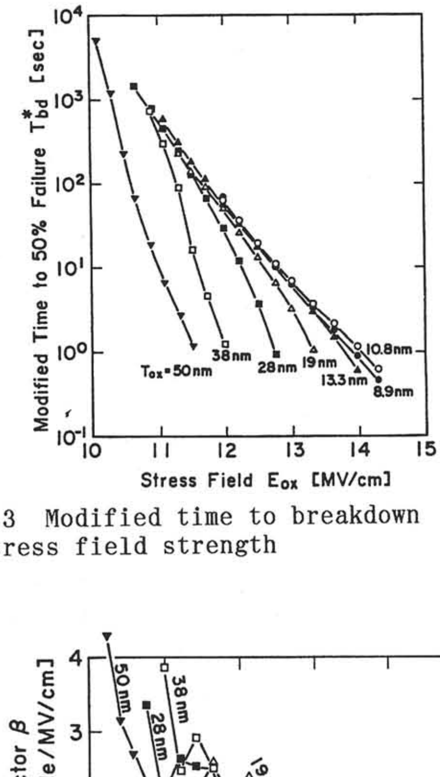

Fig.3 Modified time to breakdown versus stress field strength

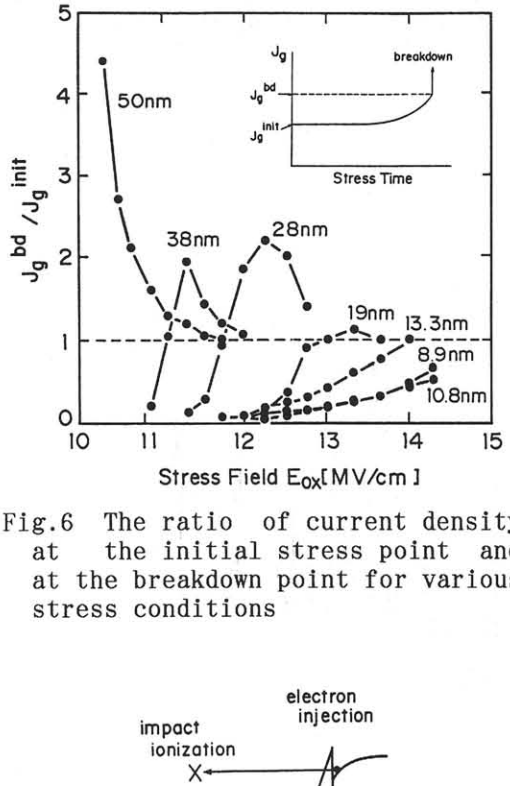

Fig.6 The ratio of current density at the initial stress point and at the breakdown point for various stress conditions

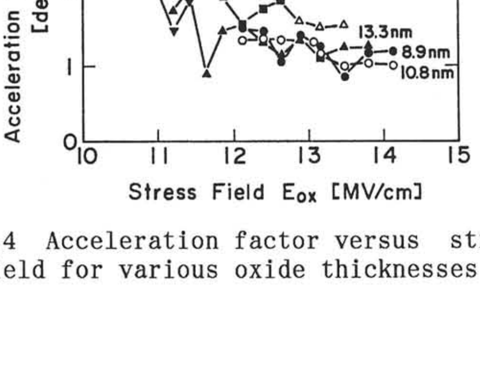

Fig.4 Acceleration factor versus stress field for various oxide thicknesses

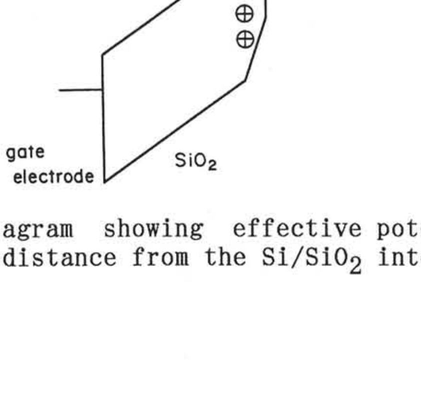

Fig.7 Diagram showing effective potential versus distance from the Si/SiO_2 interface