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Time Dependent Dielectric Breakdown of Thin SiO_2 Films

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Time dependent dielectric breakdowns (TDDB) of thin SiO_2 films are described. The breakdowns are composed of two logarithmic normal distributions having different mean time to breakdown. One is area dependent and the other is independent. With increasing the area of capacitors the distribution of dielectric breakdowns shifts toward only one logarithmic normal distribution dominated by the area dependent breakdown having the shorter mean time to breakdown. The results are compared with usual voltage ramping method. In addition, electric field acceleration factor is measured $10^{2.7}$/MV/cm for the area dependent mode and 10^5/MV/cm for area independent mode. The thickness dependence is also described.

§1. Introduction

Advances in MOS LSI fabrication technology continue to make ever smaller IGFET device dimensions possible. Reductions in lateral demensions must be accompanied by some combinations of increased surface impurity concentration, decreased insulator thickness, and decreased junction depth. In the development of a new technology, it is necessary to maintain device reliability. Particularly, dielectric breakdowns of oxide films must be carefully taken into considerations since this breakdown has been major factor among the failure modes of MOS LSIs. Therefore, the breakdown characteristics of oxide films have been studied extensively. A bias voltage ramping is one of the methods for evaluating the breakdown of oxide films.[1–5] However, it has been reported that the dielectric breakdown characteristics had a strong dependence on the time during which a bias voltage is applied on the gate insulator.[6] Thus, the usual voltage ramping method seems insufficient to examine the time dependent dielectric breakdown characteristics.

The measurement of time dependent dielectric breakdown (TDDB) is more straightforward in the relation to the device reliability.[7–11] By this evaluation method, Crook showed that the TDDB are normally distributed with the logarithm of time, and that the time to breakdowns is shortened by high electric field.[9]

In this letter, the TDDB is described in terms of two logarithmic normal distributions having different mean times to breakdowns. The electric field accelaration factors for each mode are described.

§2. Experimental

MOS capacitors having several dimensions were fabricated on P type ⟨100⟩ oriented silicon wafers with resistivity of 20 Ω-cm by using conventional n channel Si-gate MOS process. Gate oxide films were formed in dry oxygen containing HCl of 4 mole% at 1050°C. Polysilicon electrodes were deposited at 650°C by low pressure CVD method and phosphorous was doped. The samples were overcoated with the phosphosilicate glass films deposited by the CVD method.

The measurement of TDDB was performed by the repetition of the applied pulses with constant pulse width of 1 μs. In order to apply the electric field only on the gate oxide films, the test capacitors were stressed in accumulation mode. By monitoring the gate voltage of the capacitor, the dielectric breakdown was detected as a slight drop of the applied pulse voltage. The drops occured at abrupt change of the conductance by the dielectric breakdown.

§3. Results and Discussion

In Fig. 1, cumulative percent breakdowns

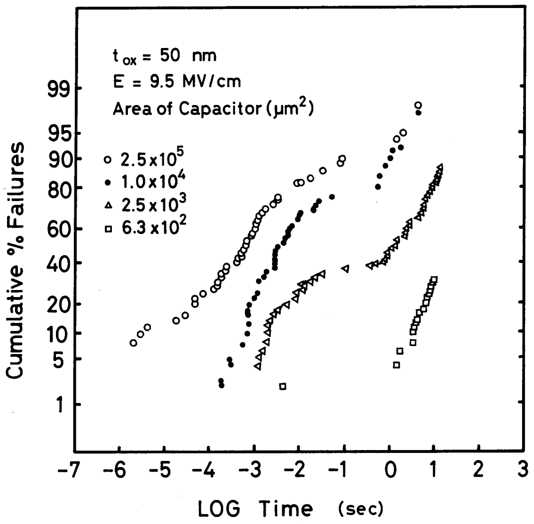

Fig. 1. Time dependent dielectric breakdown data for different capacitors area.

versus effective stress time are plotted for various capacitor area. The data obviously show that the breakdowns are composed of two lognormal distributions. With increasing the capacitor area, the number of breakdowns observed in the range of short time increases and the mean time to breakdown decreases. Such an area effect can be explained by considering that the weak points which limit the time to breakdown are randomly distributed over the gate oxide films, and that the probability of incorporating weak points increases with capacitor area. Therefore, this area dependent behavior seems to relate to defects. On the other hand, for the distributions observed in the range of long time, both the mean time to breakdown and its statistical variance (σ) are roughly unchanged for various capacitor area. These results indicate that these distributions are independent of area. Therefore, the latter breakdowns seem to be induced by the different origins in oxide films.

The edge effect of TDDB is also shown in Fig. 2. The measured capacitors have various periphery length which ranges from 400 to 4000 micrometers for a fixed capacitor area of $10^4\ \mu m^2$. This figure indicates that the distributions are not affected by the edge length of capacitors. Therefore, it is concluded that the nucleuses of defects inducing breakdowns are not localized along the edge but randomly located within the oxide films.

To determine the electric field acceleration factor for TDDB, breakdown data were taken at several stress field. Plots of the time to 5% and 95% cumulative breakdowns versus electric field strength are shown in Fig. 3. The electric field acceleration factor of area dependent mode and area independent mode are $10^{2.7}$ and 10^5/MV/cm, respectively. The former mode is not so accelarated as the latter one. For 16 Kbits dynamic RAMs, the electric field acceleration factor obtained from the points of the time to 2% cumulative breakdown is also shown in Fig. 3. The value is about $10^{2.7}$/MV/cm and the dielectric breakdowns of 16 K bits RAM are considered to be dominated by the area dependent mode.

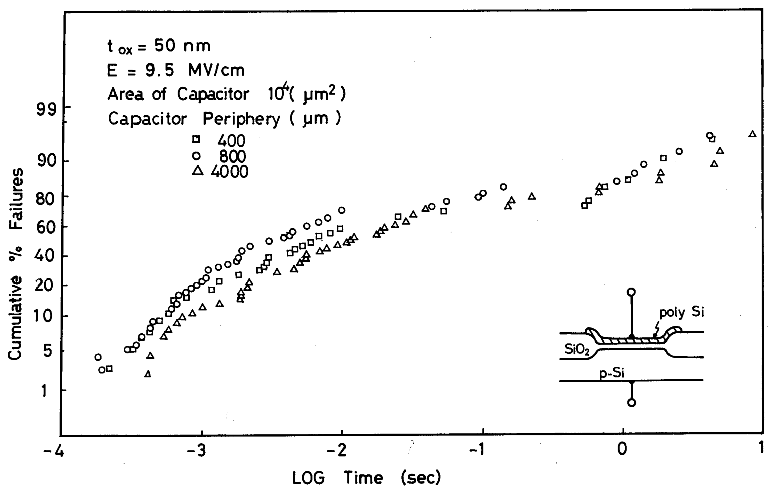

Fig. 2. TDDB dependence on the capacitor periphery.

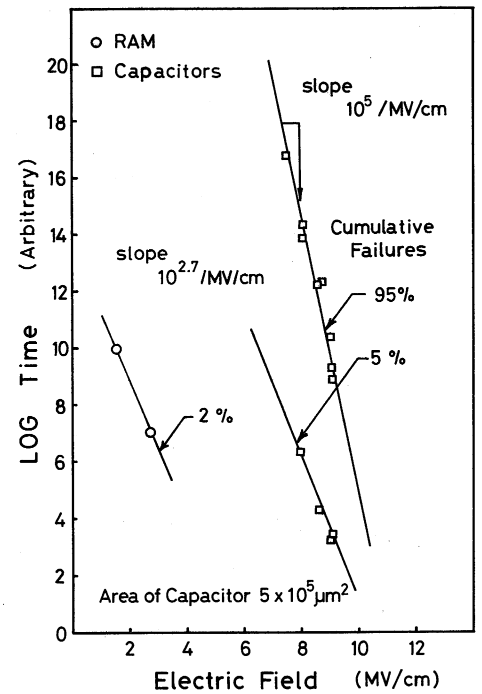

Fig. 3. Log time to reach 5% and 95% cumulative failures versus electric field.

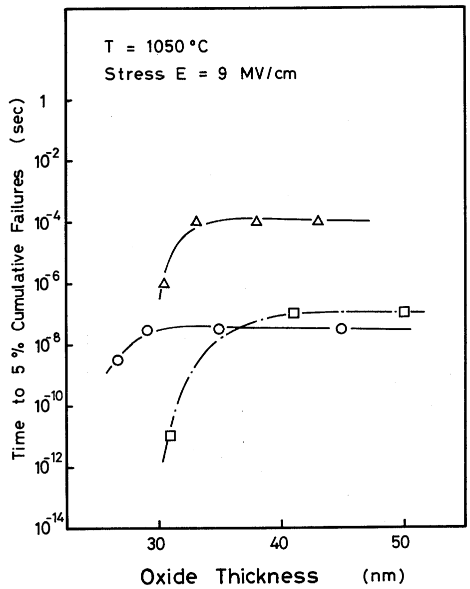

Fig. 4. Log time to reach 5% cumulative failures versus oxide thickness for three lots of test capacitors (○, △, □).

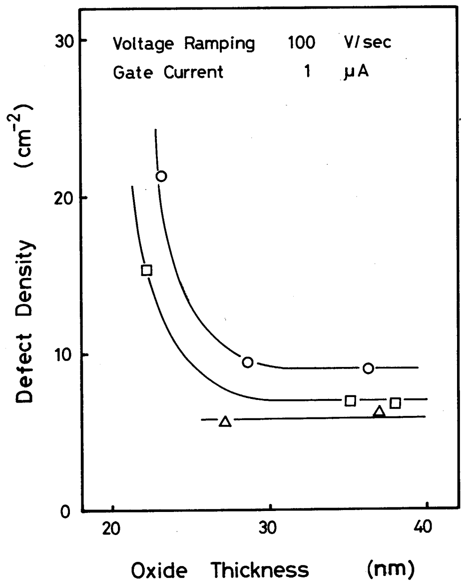

Fig. 5. Defect density at 8 MV/cm versus oxide thickness for three lots of test capacitors (○, △, □) with the capacitor area of 2 mm^2.

TDDB of the capacitors with the oxide thickness of 50, 40, and 30 nm were also measure. The time to 5% cumulative breakdowns versus gate oxide thickness is shown in Fig. 4. The results show the differences among the measured samples which were oxidized separately. However, the time to breakdown abruptly decrease below 30 nm. Oxide films thinner than 30 nm seem to have higher defect density. On the other hand, the defect density measured by the usual voltage ramping methode is not so high at the oxide film thickness of 30 nm. If the dielectric breakdowns are induced by these defects, the defect density ρ is calculated by the equation of $-\ln P(E)=\rho A$, where $P(E)$ is the probability that a capacitor of area A has breakdown greater than E. Figure 5 shows the thickness dependence of the defect density. It is clear that TDDB can sensitively detect the dielectric breakdowns in comparison with the voltage ramping method.

§4. Summary

Time dependent dielectric breakdown of oxide films is composed of two lognormal distributions. The breakdown seen in the range of short time has area dependence. The behaviour seems to be related to the defects in the oxide films. The other breakdown shown in the range of long time is not dependent on the area and seems to originate from an intrinsic characteristics of oxide films. The area dependent breakdowns are not localized at the edge but distributed randomly in the area of oxide films. The electric field acceleration factor is $10^{2.7}$/MV/cm for the area dependent mode and 10^5/MV/cm for area independent mode. The oxide thickness dependence of TDDB shows that the defect density in the oxide films extremely increases below the thickness of 30 nm.

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