

B-4-4**Analysis of Oxide Voltage and Field Dependence of Time-Dependent Dielectric Soft Breakdown in Ultrathin Gate Oxides**W. Mizubayashi, Y. Yoshida, S. Miyazaki and M. Hirose¹

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1-1-1 Higashi, Tsukuba, 305-8562, Japan**1. Introduction**

The lifetime prediction of MOS devices has been made by time-dependent dielectric hard breakdown (TDDDB) which are interpreted either by the thermochemical E model [1] or the anode hole injection model [2] including some modifications of these models. The accelerated TDDDB test has been performed at high temperatures, while the hard breakdown (HBD) and soft breakdown (SBD) activation energies are known to change in the range of 100 ~ 150°C [3, 4]. Recently, Wu et al. [5] have reported that the gate voltage dependence of the normalized time-to-hard breakdown (T_{BD}) for different gate areas S_{G2} with respect to the reference area S_{G1} is described by the relationship $T_{BD} \propto (S_{G1}/S_{G2})^{1/\beta}$ where β is the Weibull slope and the T_{BD} vs V_G plot follows the power law. However, the relationship $T_{BD} \propto S_G^m$, where m is a negative constant, does not hold at low oxide fields [6], while the time-to-soft breakdown (t_{SBD}) is proportional to S_G^m regardless of oxide fields [6]. It is shown that the transition time distribution from SBD to HBD is statistically spread [7] and hence particular care is necessary in measuring and determining t_{SBD} .

In this study, we have carefully analyzed the oxide voltage and field dependence of the time-to-soft breakdown t_{SBD} at different gate areas. The results have been discussed in connection with the thermochemical E model.

2. Experimental

MOS capacitors with phosphorus doped n⁺poly-Si gates were fabricated on p-type Si(100) substrates with LOCOS structures. Si wafers were cleaned by an NH₄OH:H₂O₂:H₂O = 0.15:3:7 solution at 80°C for 10 min and the surface were terminated with hydrogen in a 0.1% HF + 1.0% H₂O₂ solution to minimize the surface microroughness [8]. The gate oxides with $T_{ox} = 2.9$ and 4.1 nm were grown at 850°C in dry O₂. The t_{SBD} measurements were performed by the constant voltage stress (CVS) condition and constant current stress (CCS) method in which SBD and HBD are better discriminated with a higher probability. Since the gate voltage fluctuation during stress time was less than 0.7% with respect to the initial gate voltage until the onset of SBD, the CCS method simultaneously satisfies the CVS condition [9].

3. Results & Discussion

The Weibull plots as a function of t_{SBD} for 2.6 nm-thick gate oxides are shown in Fig. 1 for different oxide voltages. The value of 50% t_{SBD} measured as a function of gate area S_G gives the relation $t_{SBD} \propto S_G^m$ ($m < 0$) and the power law holds regardless oxide thicknesses as shown in Fig. 2, showing that the number of defects which trigger the oxide wearout increases as the gate area increases. It is considered that strained Si–O–Si bonds existing in SiO₂ within 1.5 nm from the SiO₂/Si(100) interface could be defect precursors which cause SBD. In this

model a localized conductive path is formed through Si–Si bond formation from strained SiO₂ near the interface [7, 9]. Also, this model can quantitatively explain the measured SBD current [9]. The thermochemical E model [1] assumes that the oxide breakdown occurs through the Si–Si bond formation from strained Si–O–Si bonds in oxides and the time-to-hard breakdown t_{BD} is expressed as $\exp(Ea/k_B T - \gamma Eox)$. Here, Ea is the activation energy of defect formation, γ the electric field acceleration factor and Eox the oxide electric field. This lifetime prediction model equation is well fitted to the measured t_{BD} over the wide electric field range of 5.5 ~ 9.0 MV/cm [10]. For 2.9 and 4.1 nm-thick oxides, the slope of t_{SBD} vs. oxide voltage slightly changes with oxide thickness (Fig. 3). From the relation $t_{SBD} \propto S_G^m$ in Fig. 2, the normalized 50% t_{SBD} with respect to the reference gate area of 1.3×10^{-7} cm² is plotted as functions of oxide voltage and field as indicated in Fig. 4 (a) and (b), respectively. The normalized t_{SBD} is proportional to $\exp(-\alpha Vox)$, where $\alpha = \partial \ln t_{SBD} / \partial Vox$ as shown in Fig. 4 (a). Also, slight increase in α with thinning oxide thickness is consistent with a previous report on t_{BD} vs. V_G data [5]. As shown in Fig. 4 (b), the value of normalized t_{SBD} is determined solely by oxide field strength and independent of oxide thicknesses. In fact the thermochemical E model gives the field acceleration factor $\gamma = \partial \ln t_{SBD} / \partial Eox$ which is independent of oxide thickness, and γ is expressed as $(1+L\chi)/p k_B T$, where L is the Lorentz factor, χ the electric susceptibility of the SiO₂ network and p the permanent dipole-moment of Si–O bond as shown in Fig. 5. The value γ obtained from Fig. 4(b) is consistent with reported values [11], where γ was evaluated by fitting t_{BD} data to the thermochemical E model. It is interesting to note that the mechanism of SBD is basically similar to that of HBD.

In summary, time-dependent dielectric soft breakdown in ultrathin gate oxides is considered to be controlled by a similar mechanism to that of hard breakdown, and t_{BD} and t_{SBD} data are consistently explained by the thermochemical E model, where the defect generation such as Si–Si bond formation is triggered by strained Si–O–Si bond in SiO₂ near the interface.

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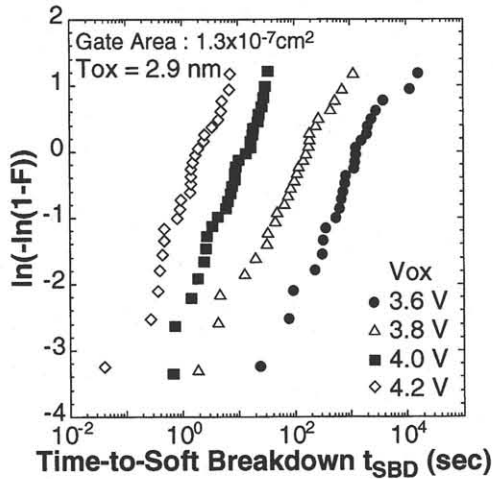


Fig. 1. The Weibull plots of t_{SBD} for 2.9-nm-thick gate oxides.

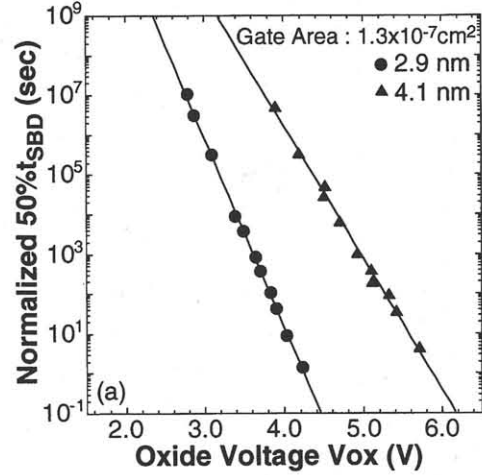


Fig. 4. The normalized t_{SBD} plotted as functions of oxide voltage (a) and field (b).

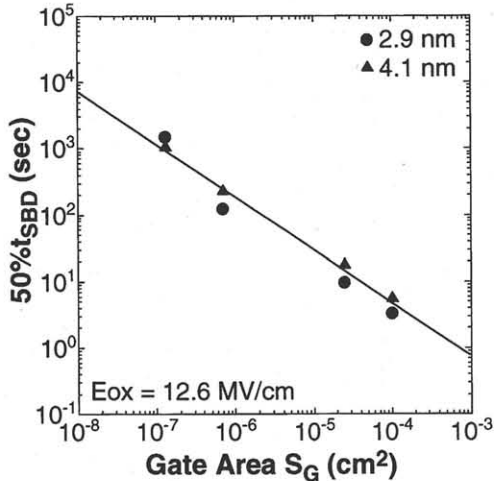


Fig. 2. The gate area dependence of 50% t_{SBD} for 2.9 and 4.1 nm-thick gate oxides

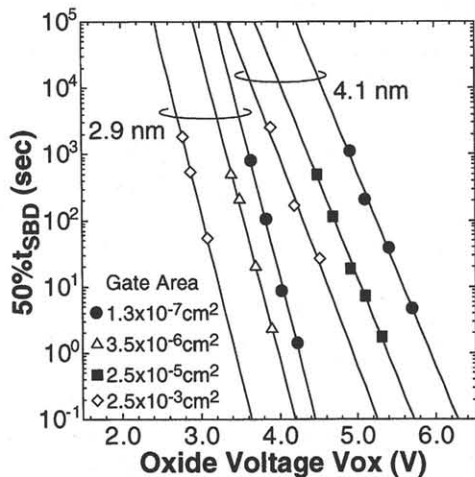
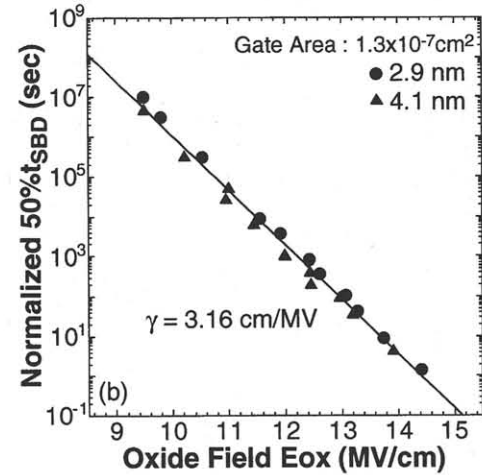


Fig. 3. 50% t_{SBD} for each gate area plotted as a function of oxide voltage.

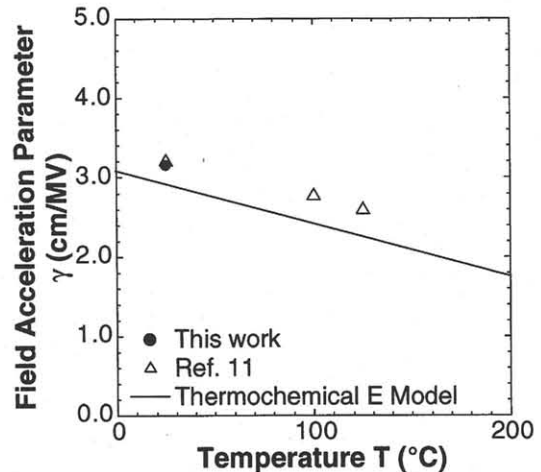


Fig. 5. Temperature dependence of electric field acceleration parameter γ .