Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 90-91

Gate Voltage Dependence of Reliability for Ultra-Thin Oxides

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1. Introduction

A strong asymmetry in the Q_{BD} of ultra-thin oxides, determined using constant current stressing, has been observed for gate and substrate injection. A general consensus has been arrived at for some of the issues related to this. 1, A certain critical number of generated electron traps are needed for the destructive breakdown of the oxide [1]. 2, The difference in charge to breakdown for positive and negative polarity is due to the difference in the trap generation rate for the different polarities [2]. In this work we show that charge to breakdown determined using constant current stressing is not a good parameter anymore to study time dependent dielectric breakdown for the ultra-thin tunnel oxides. The differences observed for different polarities and processing conditions disappear if time dependent dielectric breakdown is correlated with gate voltage instead of oxide field. A unique relationship between time to breakdown and gate voltage is obtained for a fixed oxide thickness.

2. Experimental Details

Planar MOS capacitor structures with oxide thickness ranging from 3.2 nm to 6.5 nm were fabricated on n-type and p-type substrate. As^+ (70KeV) implantation was used for doping 250nm poly-Si gates. Four different implants for n^+-gates were used to study the influence of cathode/oxide and/or anode/oxide interface on the degradation of ultra-thin oxides. The doses used were 5.10^{14} cm^{-2}, 1.10^{15} cm^{-2}, $5.10^{15}cm^{-2}$, $1.10^{16}cm^{-2}$. The post implantation anneal used for activation of dopant was 10 sec RTA @1100°C.

3. Results

Electrical Characteristics

The tunnel current characteristics for 3.5 nm oxide with different gate doping are shown in Fig. 1(a), for gate injection (closed symbols) and 1(b) for substrate injection (open symbols). There is a spread in gate voltage (V_G) at high current density for positive polarity as the dopant concentration changes in poly-Si gate. For a current correponding to 0.1 A/cm^2 the difference in gate voltage is around 1V. The shift towards higher gate voltage for the same current implies that there is a difference in electrical thickness as a function of doping. This was confirmed by doing High Frequency (100Khz) Capacitance-Voltage measurement. For the n-type substrate (positive polarity) the thickness increases from 4.25 nm to 10nm as the dopant concentration decreases. For the case of negative polarity the spread in V_G is smaller for the same stress current and almost no influence was seen on thickness as measured by HFCV.

Reliability

The reliability of these ultra-thin oxides was studied using constant current stressing on $7.85x10^{-5}$ cm^2 area capacitors. Fig. 3 shows the influence of gate doping on charge-to-breakdown (Q_{BD}). For the case of substrate injection the open symbols with a dot correspond to stress current 0.5 A/cm^2 while for gate injection (closed symbol) and for substrate injection with lower doping concentration (open symbols) the stress current was $0.1A/cm^2$. For substrate injection a strong increase in Q_{BD} is observed with gate doping whereas the change in gate doping has no influence on gate injection. This confirms earlier results [4] that the injecting interface or cathode/oxide interface doesn't play an important role in oxide degradation, instead it is the anode/oxide interface which determines the charge-to-breakdown.

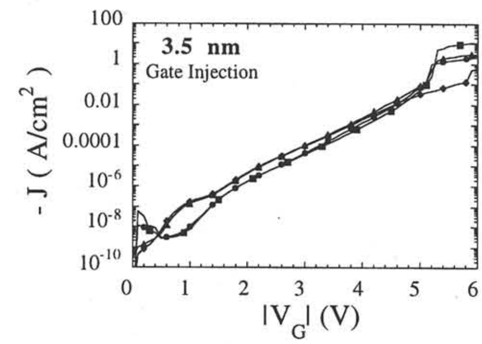

Fig. 1(a) Tunnel characteristics for 3.5 nm oxides for gate(closed symbols). The highest doping is shown by squares while the lowest by diamonds.

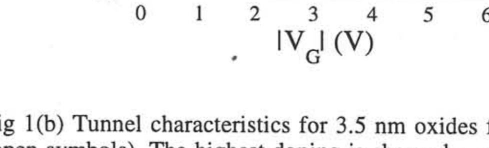

Fig 1(b) Tunnel characteristics for 3.5 nm oxides for substrate (open symbols). The highest doping is shown by squares while the lowest by diamonds.

For oxides above 5nm to 6nm in Fowler-Nordheim Tunneling (FNT) the time-to-breakdown (t_{BD}) has a strong correlation with the electrical field across the oxide(E_{OX}). Fig. 4 shows the 50% t_{BD} as a function of E_{OX} (V_{OX}/d_{OX}) [3], for the same data shown in Fig. 3. For these thin gate oxides we don't see such a correlation.

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Instead an anomalous increase in t_{BD} is observed for the gate with highest dopant concentration.

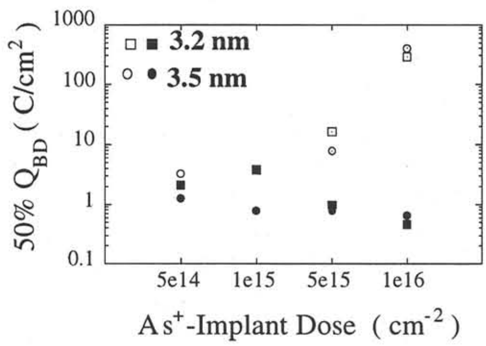

Fig. 3 50% Q_{BD} for two different oxide thickness on $7.85*10^{-5}$ cm^2 capacitors. The stress current for open symbols with a dot is 0.5 A/cm^2 while for all the other conditions the stress current was 0.1 A/cm^2. Open symbols are for substrate injection while closed symbols for gate injection.

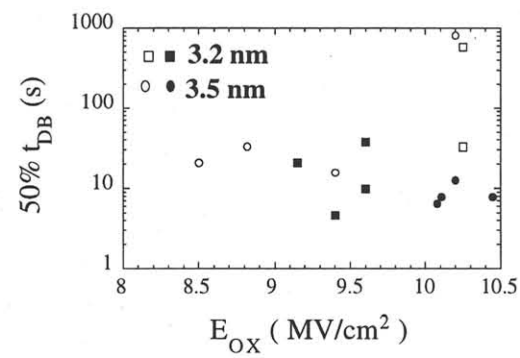

Fig. 4 50% t_{BD} as a function E_{ox} for gate (closed symbols) and substrate injection (open symbol).

In Fig. 5 the t_{BD} data for different oxide thickness and different processes has been plotted as a function of the start gate voltage (V_G) obtained from constant current stressing. The open symbols are for substrate injection while closed symbols are for gate injection for the same thickness. For ultra-thin tunnel oxides the t_{BD} is independent of the polarity of the gate voltage (as both the open symbols and closed symbols follow one curve for a fixed oxide thickness, Fig. 5), and also there is no influence of the different processing's on the intrinsic t_{BD}. The difference in processing for a single thickness changes the V_G for the same stress as can be seen from Fig. 1(b). Therefore, the increase in Q_{BD} for substrate injection seen in Fig. 3 for highest doping is due to the lower gate voltage. Also for the same stress current the difference in polarity is due to the fact that V_G for gate injection is higher as compared to substrate injection. This indicates that the degradation rate or the trap generation rate for the ultra-thin oxides depends on the gate voltage instead of the stress current for ultra-thin oxides.

The correlation with gate voltage is believed to be due to a correlation of the trap generation with the energy of the electron arriving at the anode. This energy is directly determined by the applied gate as the electron travels ballasticaly through the oxide [5]. This also means that the dependence of t_{BD} on polarity [6] and on gate doping is only apparent, and has nothing to do with different qualities of both interfaces.

The decrease in t_{BD} with decrease in thickness is attributed to the fact that for thinner oxide the critical number of traps needed for a destructive breakdown decreases. Since same number of traps are generated for a fixed gate voltage, the time-to-breakdown for thinner oxides is lower.

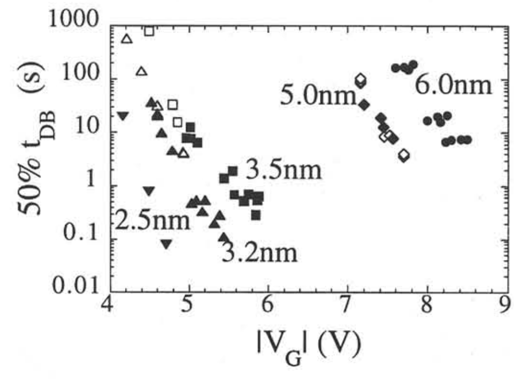

Fig. 5 50% t_{BD} as a function of gate voltage for oxides with different thickness. The open symbols are for substrate injection while closed symbols are for gate injection.

4. Conclusions

The strong asymmetry in t_{BD} with different gate doping for the two stress polarities is shown to be due to the difference in gate voltage. The degradation rate for the creation of electron traps or defects depends very strongly on the gate voltage for these ultra-thin oxides. The t_{BD} is shown to have a unique relationship with the gate voltage with a strong dependence on thickness for the ultra-thin tunnel oxides. Therefore, for these ultra-thin oxides time-dependent-dielectric-breakdown (TDDB) should be measured as a function of constant voltage stressing instead of constant current stressing.

Acknowledgments

This work was supported by ESPRIT Basic Research Action ASPYR.

Reference

1. R. Degraeve, G. Groeseneken, R. Bellens, M. Depas, H.E. Maes : IEDM Tech. Dig. (1995)863.
2. M. Depas, M.M. Heyns : INFOS'97, to be published.
3. M. Depas, B Vermeire, P.W. Mertens, R. L. Vanmeiraeghe, M. M. Heyns : Solid State Electronics Vol 38, No. 8 (1995)1465.
4. D. Wristers, H. H. Wang, L. K. HAN et al : ECS Proceedings Vol. 96-1 (1996)733.
5. D. J. Dimaria : Appl. Phys. Lett. 68 (21), (1996)3004.
6. L.K. Hans et al : IEDM Tech. Dig., (1994) 617.