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Ultra-thin Oxide Lifetime Projection and Comparison of nFET and pFET for 90nm/65nm Application

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1. Introduction

When oxide thickness is scaling down to ultra-thin regime (oxide thickness < 20Å), gate oxide breakdown (BD) has been considered as one of the most critical reliability issue in integrated circuits. Recently, 90nm and/or 65nm process is the main stream for advance product application. In ultra-thin oxide, the BD behavior is different from that in thicker oxides [1,2]. In addition, the time to breakdown (TBD) in time dependent dielectric breakdown (TDDB) testing is closely related to the device type, gate voltage polarity [3,4], and the substrate back-gate bias (Vbs) [5-7]. But the relationship of lifetime projection, TBD distribution, and breakdown degradation mechanism on ultra-thin (core) and thick (IO) oxides between n and p FET are still not well understood. In this work, we study the lifetime and TBD for core and IO oxide on n and p FET devices. The breakdown mechanism and the lifetime of core pFET oxide with Vbs are also investigated.

2. Experiment

The core (16Å) and IO (52Å) oxides of n and p FET were manufactured by the standard 90nm CMOS process. There are at least 24 samples were used for each type oxide. We used the constant voltage stress (CVS) method to proceed the time depend dielectric breakdown (TDDB) testing [8,9]. Three to four stress voltages and three stress temperatures were used to extrapolate the voltage acceleration factor (AF) and activation energy (Ea). TBD is defined as the time of the first breakdown event occurrence in CVS testing. In order to precisely detect oxide breakdown for ultra-thin oxide, the stress induced leakage current (SILC) method at low voltage was used [10].

3. Results and Discussion

Fig. 1 and Fig. 2 show the initial stress leakage current versus sample sizes for core and IO oxides respectively. The oxide leakage current of core nFET is slightly larger than that of core pFET, but the leakage of IO nFET is greatly larger than that of IO pFET. Fig. 3 and Fig. 4 show the stress leakage current versus time plot for core and IO oxide respectively. The core nFET oxide reveals clear hard breakdown phenomenon no matter what the oxide at stress or at SILC current detection. But the core pFET oxide reveals progressive breakdown behavior both at stress and SILC current detection. Both IO thick nFET and pFET oxides reveal clear hard breakdown phenomenon.

The low failure percentage of 0.01 in TBD cumulative distribution and temperature of 125°C are used to calculate the oxide lifetime under operation voltage 1.1V and 2.75V for core and IO oxide respectively. In addition the voltage lifetime projection model of power-law (TBD ~ Vg^{-n}) and E-model (TBD ~ exp (-γEox) were used for core and IO oxides respectively [11]. Fig. 5 shows the TBD Weibull distribution and TBD (63.2%) value for core oxide. The pFET Weibull distribution and TBD value are all lower than those of nFET. Fig. 6 shows the core oxide lifetime projection, the prediction line of pFET is crossed with nFET at around Vg 2V. Although the TBD (0.01%) of pFET is higher than that of nFET at stress voltage, lifetime projection at operation voltage is lower than that of nFET. This because the Weibull slope of pFET is larger than that of nFET (1.6 vs 1.32). We use the same Weibull slope 1.6 for both core n and p FET, and re-plot the prediction line to examine the lifetime projection, as shown in Fig. 7. It is obviously that the n value of pFET is smaller than that of nFET, resulting in the pFET reveals lower lifetime prediction. Fig. 8 shows the TBD Weibull distribution and TBD (63.2%) value of IO oxide. It shows the TBD of nFET is greatly smaller than that of pFET. Fig. 9 shows the lifetime projection of IO n and p FET, it displays the nFET lifetime is smaller than pFET lifetime. This result is consistent with the result of the leakage current trend (Fig. 2). Table I summarizes the lifetime projection results and parameters for core and IO oxides. We observe the lifetime comparison of n and p FET, it reveals opposite trend between the core and IO oxides under inversion mode stress.

From Fig. 1 and Fig. 5(a) for core oxide, the stress leakage current of pFET is smaller than that of nFET, but the pFET TBD is smaller than nFET TBD. The smaller stress leakage current doesn't get the better lifetime projection. Fig. 10 shows the comparison of hole current in anode hole injection (AHI) effect for core n and p FET oxides [7,12]. The anode hole current of pFET is larger than that of nFET due to the larger Ene energy, this degraded the pFET oxide hardness more than that of nFET [13]. In addition, anode hydrogen release (AHR) is another effect to degrade core pFET oxide lifetime at inversion mode stress, it would generate trap states and hydrogen protons release in SiO_x at SiO_2/Si interface [14,15]. From Table I, the exponent n value of core pFET is smaller than that of core nFET (n=35.26 vs. 44.18). In order to clarify the degradation reason of core pFET n value, we set up an experiment of pFET with Vbs to study the exponent n value variation and to prove our proposed mechanism. Fig. 11 shows the magnitude of electron energy dissipation and the anode hole current generated by the Vbs for pFET. Large Vbs increases the magnitude of electron energy dissipation and leads to the larger probability of AHR effect, and increases the anode hole current simultaneously. Fig. 12 shows the lifetime projection of core pFET with oxide thickness 14Å under various Vbs, the n value and lifetime prediction are decreasing with increasing Vbs. Presumably the larger anode hole current and hydrogen proton release result in the lower TBD and the lower exponent n value for core pFET, and leads to the core pFET oxide BD revealing progressive BD behavior in current-time plot [Fig. 3(c) and (d)]. For IO oxide lifetime projection (Fig. 9), the lifetime is consistent with the stress leakage current trend, and the AHI and AHR effects less degrade the IO pFET oxide.

4. Conclusion

In this work, the core (16Å) and IO (52Å) oxide lifetime projections for n and p FET at inversion mode stress were investigated. For n and p FET with core oxide thickness, the lifetime predictions are opposite to the behavior of their stress leakage current trend. However, the lifetimes of IO thick n and p FET oxides are consistent with their stress leakage current trend. Presumably due to the larger anode hole current and more hydrogen proton release events result in the core pFET oxide revealing smaller exponent n value, smaller TBD, smaller lifetime prediction and more progressive BD phenomenon than those of core nFET oxide at inversion mode stress.

Acknowledgements

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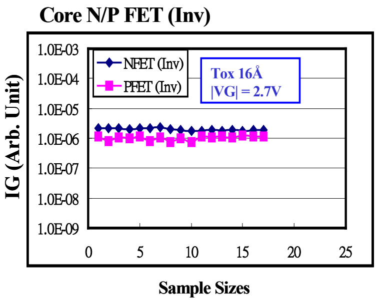

Fig.1 Initial stress leakage current vs sample sizes for core oxide.

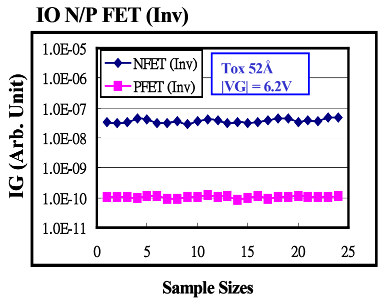

Fig. 2 Initial stress leakage current vs sample sizes for IO oxide.

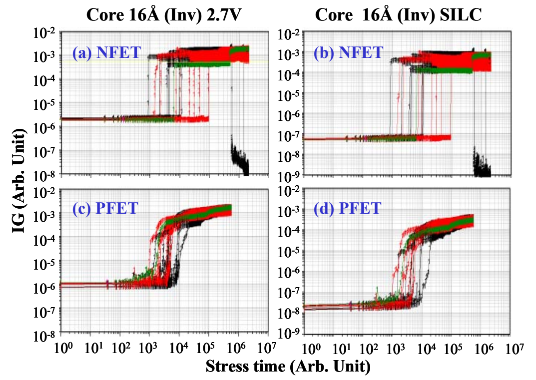

Fig. 3 Leakage current vs time plot for nFET at (a) stress voltage 2.7V and (b) SILC voltage 1.2V; for pFET at (c) stress voltage 2.7V and (d) SILC voltage 1.2V.

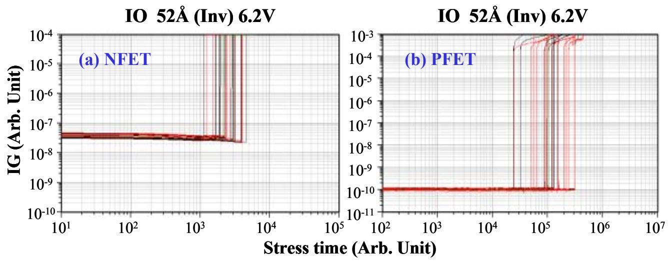

Fig. 4 Leakage current vs time plot of (a) nFET and (b) pFET at stress voltage 6.2V for IO oxide.

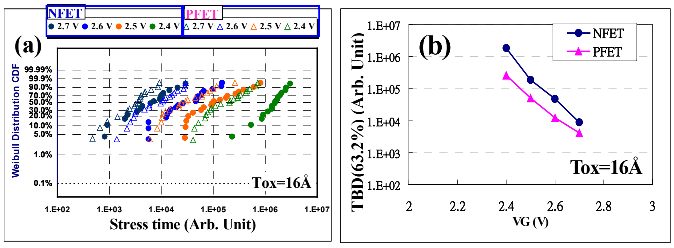

Fig. 5 (a) TBD Weibull distribution for nFET and pFET, and (b) TBD (63.2%) value of nFET and pFET at various stress voltages for core oxide.

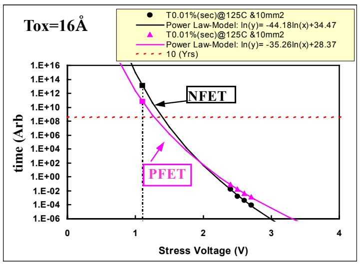

Fig. 6 Lifetime prediction of nFET and pFET at Vg 1.1V for core oxide.

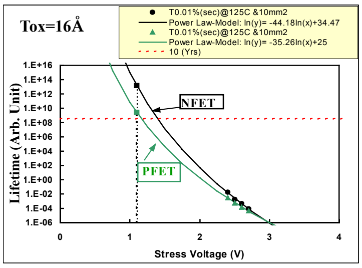

Fig. 7 Lifetime prediction of nFET and pFET at Vg 1.1V for core oxide. The Weibull slope of nFET is set same as the value 1.6 of pFET.

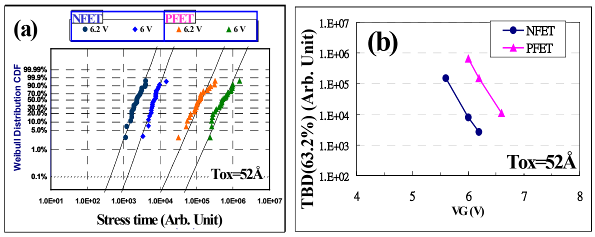

Fig. 8 (a) TBD Weibull distribution for nFET and pFET, and (b) TBD (63.2%) value of nFET and pFET at various stress voltages for IO oxide.

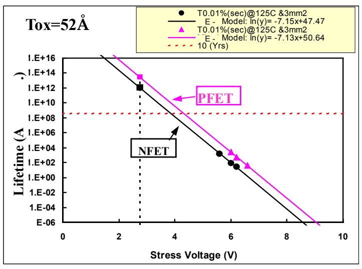

Fig. 9 Lifetime prediction of nFET and pFET at Vg 2.75V for IO oxide.

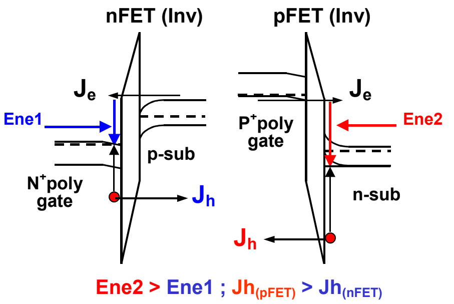

Fig. 10 The electron energy release magnitude of AHI for nFET and pFET

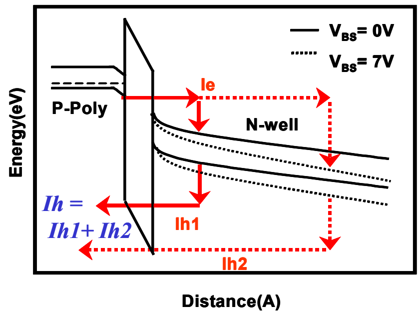

Fig. 11 Schematic band diagram of pFET with Vbs for electron energy dissipation and anode hole current generation.

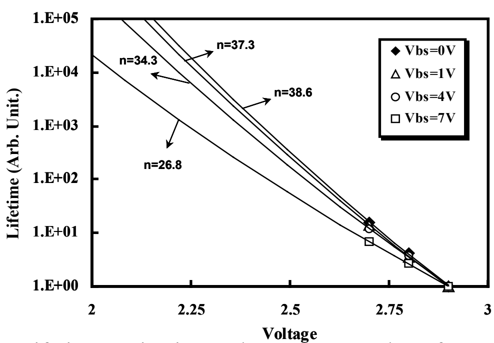

Fig. 12 Lifetime projection and exponent n value of pFET at inversion mode stress with Vbs is 0, 1, 4, and 7V for power law model.

Table 1 Lifetime prediction and reliability parameters of nFET and pFET for core and IO oxide.

Oxide	Device	Lifetime[a]	AF[b]	Weibull Slope
Core 16Å	nFET	~10^5	44.18	1.32
	pFET	~10^3	35.26	1.60
IO 52Å	nFET	~10^4	7.15	3.76
	pFET	~10^5	7.13	3.07

a: lifetime (years) projection at Vcc = 1.1V for core oxide, Vcc=2.75V for IO, and CDF=0.01%.

b: AF is the voltage acceleration factor; n of power-law model for core oxide, γ of E-model for IO oxide.