Correlations between Plasma Induced Damage and Negative Bias Temperature Instability in 65 nm Bulk and Thin-BOX FDSOI Processes

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***Abstract*— We evaluate Plasma Induced Damage (PID) and Negative Bias Temperature Instability (NBTI) by measuring frequency of Ring Oscillators (ROs). Initial frequency degradation by PID from Antenna Ratio (AR) of 500 to 1k are 2.1% and 1.9% in the bulk and thin-BOX FDSOI, respectively. NBTI is accelerated by PID in less than 500 AR which is the upper limit of the antenna rule. NBTI correlates with PID and also with initial frequency. The correlation coefficient (CC) between NBTI-induced degradations and the initial frequency is 0.68 in FDSOI, while there is few correlation in bulk (CC = 0.24) because random dopant fluctuation is dominant.**

I. Introduction

PID is an inevitable reliability issue by multilayer wiring and miniaturizing a device size in semiconductor chips [1]. Chip designers have to avoid PID with small antenna ratio (AR) because threshold voltages (V_{th}) are increased and oscillating frequencies are decreased. In the worst case, MOSFETs are broken by PID. Moreover, previous researches reveal that PID accelerates degradation of Bias Temperature Instability (BTI) which is an aging degradation[2-4]. There are NBTI (Negative BTI) and PBTI (Positive BTI). NBTI occurs in PMOS when gate-source voltage (V_{gs}) is negative. PBTI is the opposite of NBTI. PBTI appears in less than 45 nm with high-k gate dielectrics [5]. However, NBTI does even in 65 nm gate length. Chip designers have to consider NBTI caused by PID and measurements and evaluations are important to estimate these degradations. However, they are not evaluated in a thin Buried OXide (BOX) Fully-Depleted Silicon On Insulator (FDSOI) process. We evaluate the correlations by measuring frequency of ROs fabricated in 65 nm bulk and thin-BOX FDSOI processes.

II. Degradation by PID

An antenna is a metal wire which collects charge during the production of MOSFETs. Charge is induced in metal wires during interlayer dielectric processes around metal wires are processed. They become antennas to collect charge. When the antenna is connected to a gate of MOSFETs, charge in the antenna flows through gate oxides and generate defects as shown in Fig. 1. This charging damage is called PID. When a defect traps a carrier, V_{th} increases and oscillation frequency decreases. NBTI is also induced when the defect traps the carrier. There are correlations between PID and NBTI.

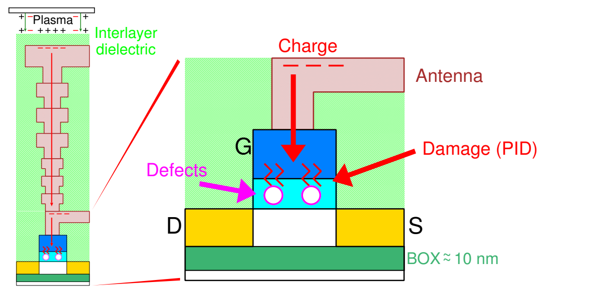

Fig. 1: PID by interlayer dielectric processes. Charge is induced in metal wires during plasma etching process.

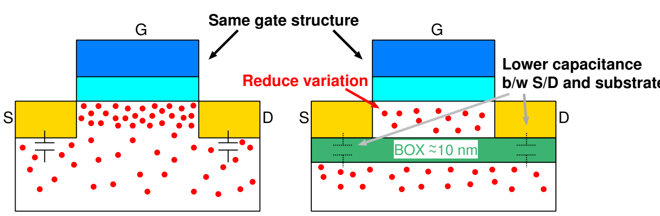

Fig. 2: Bulk and thin-BOX FDSOI processes. FDSOI has several advantages compared with bulk.

III. Measurement Cicuit and Setup

We compare PID and NBTI in bulk with in thin-BOX FDSOI processes [6]. Fig. 2 shows these two structures. They are fabricated in 65 nm process and have same gate structures. FDSOI has smaller stray capacitance and Random Dopant Fluctuation (RDF) than the bulk. The thickness of the BOX layer is 10 nm. It can control transistor performance through the back gate bias.

We fabricated 11-stage ROs composed of NORs as shown in Fig. 3. The NOR gate N11 at the last stage beside the antenna suffers from PID. The other stages (N1-N10) are composed of NORs without suffering NBTI as shown in Fig. 4 (a). The NOR with NBTI (N11) is placed beside the antenna as shown in Fig. 4 (b) in order to induce only NBTI in N11. We call the PMOSFET in the NOR gate near VDD $\mathrm{PMOS_A}$ and the opposite one $\mathrm{PMOS_B}$. The RO stops when the enable signal ENB is high. $\mathrm{PMOS_A}$ is stressed by NBTI when the RO stops. There is no NBTI in $\mathrm{PMOS_B}$ since A is

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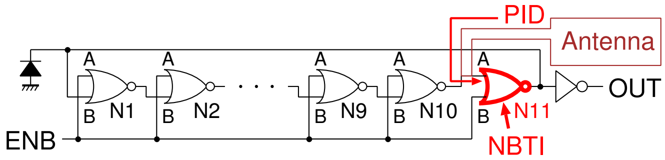
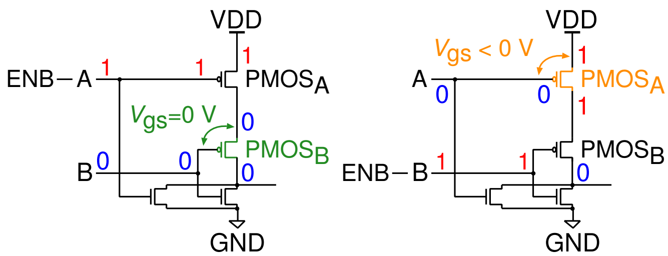


Fig. 3: 11-stage RO to measure degradations caused by PID. Only N11 suffers from PID.



(a) (b)

Fig. 4: (a) NOR without NBTI (N1-N10) and (b) NOR with NBTI (N11).

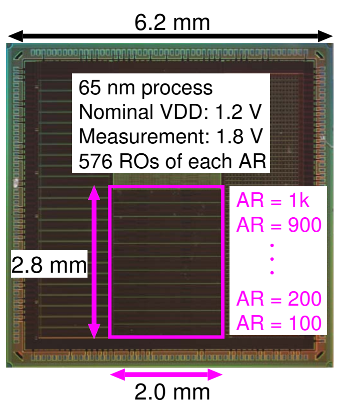
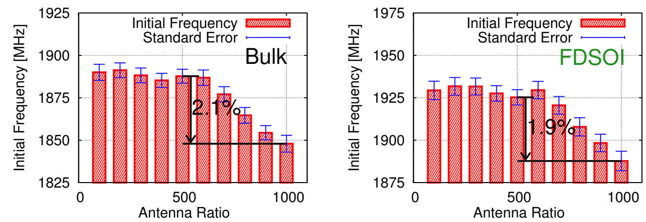


Fig. 5: Test chip fabricated in 65 nm process.

connected ENB as shown in Fig. 4 (a). The reason is that V_{gs} of the PMOS$_B$ is 0 V. Conversely, PMOS$_A$ suffers from NBTI because V_{gs} of PMOS$_A$ is negative as shown in Fig. 4 (b). It is stressed by NBTI when ENB is high. When we measure frequencies, ENB becomes low only for 28 μs to suppress NBTI stress on N1-N10.

The antenna ratio (AR), which is the area of an antenna divided by the area of a gate, indicates the strength of PID. The damage due to PID is increased by the AR. The upper limit of the AR is defined as 500. We prepare ROs with ARs from 100 to 1k every AR of 100 to evaluate PID around the upper limit of AR.

Fig. 5 shows the chip micrograph. There are 576 ROs of each AR. Supply voltage and temperature are 1.8 V and 80 °C to accelerate NBTI-induced degradations.



(a) (b)

Fig. 6: Measurement results of f_0 by PID in bulk (a) and FDSOI (b).

IV. Results and Discussions

A. Initial Frequency

Fig. 6 (a) and (b) show measurement results of initial oscillation frequencies (f_0) in bulk and FDSOI, respectively. f_0 is almost constant below the upper limit of AR (500). However, it starts to decrease as AR from 600. The differences between f_0 at 500 and 1k are 2.1% in the bulk. No MOSFET is broken even when violating the antenna rule over the AR of 500. However, defects are generated in the gate oxide and f_0 decreases caused by PID. Initial frequencies in FDSOI decrease 1.9% from AR of 500 to 1k. Degradation of f_0 by AR is almost equivalent between bulk and FDSOI to have the same gate structures. Thin-BOX FDSOI is caused by PID as same as bulk.

B. NBTI-induced Degradation

NBTI is induced when a defect traps a carrier as shown in Fig. 7 explained by the Atomistic Trap-based BTI (ATB) model [7]. $V_{\rm th}$ increases while defects trap carriers because carriers and drain current decrease.

Fig. 8 shows NBTI measurement results. Dots represent average of measurement data and line is drawn by the fitting function $f(t)$ of Eq. (1).

$$f(t) = S_{\rm NBTI} \log(t+1) + f_0 \qquad (1)$$

$S_{\rm NBTI}$ is a fitting parameter indicating degradations caused by NBTI and f_0 is an initial frequency $t = 0$. This function comes from the ATB model since defects have a time constant (τ) distributed uniformly on the log scale from 10^{-9} to 10^{9} s. Fitting functions are drawn along the measurements as shown in Fig. 8. The ATB model replicates NBTI-induced degradations. Then, we evaluate degradation factor $S_{\rm NBTI}$.

Fig. 9 (a) and (b) show the degradation factor $S_{\rm NBTI}$ in bulk and FDSOI. They are normalized by $S_{\rm NBTI}$ in AR of 500. Tendencies of $S_{\rm NBTI}$ in bulk and FDSOI are same. Chip designers may just estimate NBTI caused by PID in thin-BOX FDSOI as same as that in the bulk. $S_{\rm NBTI}$ increases as AR below 600. NBTI is accelerated by PID even if keeping the rule. Chip designers should consider NBTI caused by PID. However, $S_{\rm NBTI}$ decreases from the AR of 600 in both bulk and FDSOI. This is opposite result to the ATB model. We assume that NBTI has some correlations to the initial frequency f_0. It is evaluated in the next section.

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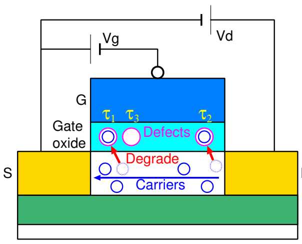


Fig. 7: Atomistic trap-based BTI model. V_{th} increases by trapping carries.

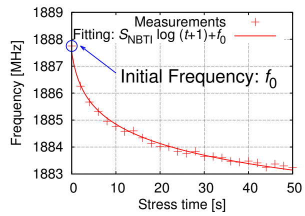
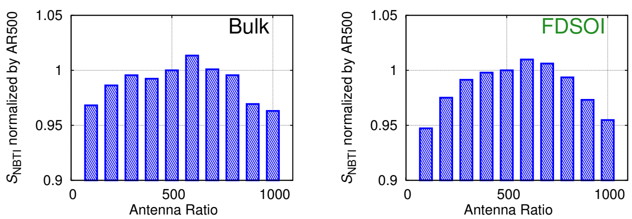
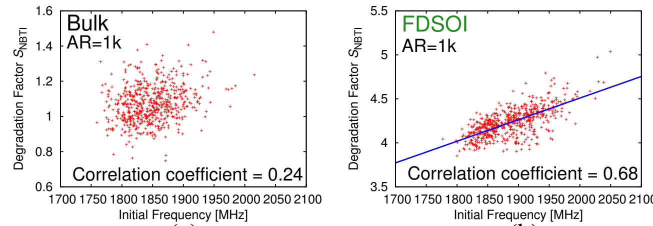


Fig. 8: NBTI measurement results. S_{NBTI}: fitting parameter indicating NBTI degradations.



(a) (b)

Fig. 9: Degradation factor S_{NBTI} by PID in bulk (a) and FDSOI (b).



(a) (b)

Fig. 10: Correlations between S_{NBTI} and f_0 in bulk (a) and FDSOI (b).

C. Correlation between NBTI and Initial Frequency

Correlation coefficient (CC) is used to evaluate how two parameters have correlation. CC is calculated by Eq. (2).

$$\mathrm{CC} = \frac{\sum_{i=1}^{n}(f_i - \overline{f})(S_{\mathrm{NBTI}i} - \overline{S_{\mathrm{NBTI}}})}{\sqrt{\sum_{i=1}^{n}(f_i - \overline{f})^2}\sqrt{\sum_{i=1}^{n}(S_{\mathrm{NBTI}i} - \overline{S_{\mathrm{NBTI}}})^2}} \quad (2)$$

Variables $\overline{f}$ and $\overline{S_{\mathrm{NBTI}}}$ are averages of f_0 and S_{NBTI}, respectively. n is number of ROs ($= 576$).

Fig. 10 (a) and (b) show correlations between S_{NBTI} and f_0 in bulk and FDSOI, respectively. The CC of bulk is 0.24. S_{NBTI} in bulk has few correlation to f_0. However, S_{NBTI} in FDSOI has strong correlation to f_0 for CC of 0.68. The correlation between NBTI and f_0 comes from variations of defects in the gate oxide [4]. In bulk, RDF in channel regions is more dominant than gate variations in process variations [8]. Thus, NBTI in bulk has few correlation to f_0. On the other hand, variation of gate work function is more dominant than RDF in FDSOI. V_{th} in bulk are controlled by dopant concentration, while those in FDSOI are by the gate work function which results in smaller variations. In FDSOI, slower ROs with higher-V_{th} transistors have smaller electric fields in gate dielectic. Thus, NBTI-induced degradations are highly correlated to the frequencies of ROs in FDSOI.

V. Conclusion

We fabricated ROs with various antenna ratios (ARs) in 65 nm bulk and thin-BOX FDSOI processes. Initial frequencies decrease by PID and their tendency are equivalent between bulk and FDSOI to have same the gate structures. NBTI is accelerated by PID below the upper limit of AR. However, it is opposite to previous researches in more than AR of 600 to have correlation with the initial frequency. There is few correlation between the NBTI and the initial frequency in bulk because random dopant fluctuation is dominant, while in FDSOI, NBTI is highly correlated with the initial frequency caused by PID. Correlation coefficient between these two parameters is 0.68.

Acknowledgment

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