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Initial and Long-Term Frequency Degradation on Ring Oscillators from Plasma Induced Damage in 65 nm Bulk and Silicon On Thin BOX processes

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Abstract

Degradation of reliability caused by plasma induced damage (PID) has become a significant concern with miniaturizing a device size. In this paper, we measure frequencies of ring oscillators with an antenna structure on a single stage. In bulk, PID is relieved by connecting an antenna to a drain because electric charge flow to a substrate. The difference of initial frequencies is 0.79 % between structures which cause and relieve PID. A Silicon On Thin BOX (SOTB) which has a buried oxide of less than 10 nm also relieves PID. Initial frequencies are affected by PID but there is no effect of PID in a long-term degradation mainly caused by bias temperature instability (BTI).

1. Introduction

Degradation of reliability caused by plasma induced damage (PID) has become a significant concern with miniaturizing a device size [1]. PID generates defects into a gate oxide. Defects increase a threshold voltage ($V_{\rm th}$) and decrease an oscillating frequency. Defects cause bias temperature instability (BTI) [2]. We measure initial and long-term frequencies of ring oscillators with an antenna structure on a single stage of a ring oscillator.

2. Degradation Caused by Plasma Induced Damage

An antenna is a metal wire which collects electric charge at a plasma etching process on production of MOSFETs. PID appears when an antenna is connected to a gate of MOSFETs as shown in Fig. 1. PID generates defects into a gate oxide. $V_{\rm th}$ increases when defects trap carriers. It calls the trap-detrap model [3] as shown in Fig. 2. These defects have a time constant (τ) from 10^{-9} to 10^{9} seconds. Short time constants affect an initial frequency and long time constants affect aging degradations like BTI [2].

There are several ways to relieve PID. Fig. 3 shows one of those ways using the drain of bulk as a discharging path. By connecting an antenna to the drain, electric charge flow to a substrate through a drain in the bulk. But Silicon On Thin BOX (SOTB) does not relieve PID in the drain because SOTB has a buried oxide (BOX) embedded on a wafer between a body and a substrate as shown in Fig 4. SOTB is one of Fully Depleted Silicon On Insulator (FD SOI) processes [4]. SOTB reduces variations due to impurities because SOTB does not dope any dopant to a channel of MOSFETs. In SOTB, electric charge remains in the drain because of BOX layers between the drain and the substrate. But SOTB may relieve PID because electric charge flow the substrate by quantum tunneling because BOX is less than 10 nm [5]. We compare PID in the bulk with that in the SOTB.

3. Measurement Circuits

We fabricated a chip including 11 stage ring oscillators (ROs) which have different antenna structures in 65 nm bulk and SOTB processes. Note that the layout patterns are exactly same in both processes except for the BOX layer. Fig. 5 shows 11 stage ROs. The inverter next to the antenna is degraded by PID.

Fig. 6 shows connection structures of antennas. M1 and M2 are the first and second-level metal wires, respectively. M1 is processed earlier than M2. AG causes PID because all electric charge of the antenna flow to the gate. ADG relieves PID by some amount because of the drain connection. AD relieves PID at most because most of electric charge flow to the substrate through the drain. But in ADG and AD, SOTB may get PID because of BOX layers.

The antenna ratio (AR) which is the area of an antenna divided by the area of gate is correlated to the damages caused by PID. The upper limit of AR is 500 in the antenna rule. According to the antenna rule, ADG relieves PID by 0.08 times. The PID of AR 6250 ADG will be the same as the PID of AR 500 AG. We prepare that AR is 500 and 6250 based on that rule.

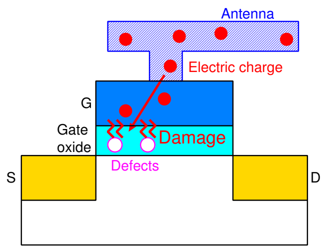

Fig. 1. PID to the Gate Oxide

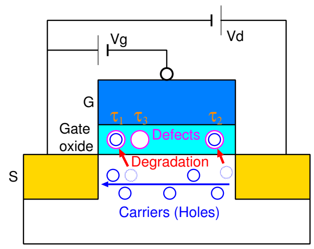

Fig. 2. Trap-Detrap Model

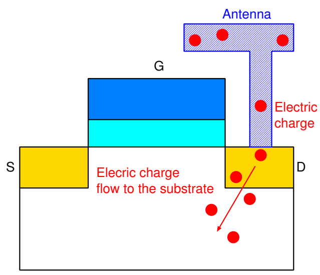

Fig. 3. Relieving PID in the Drain of Bulk

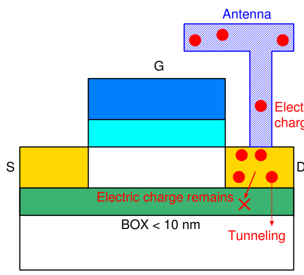

Fig. 4. Charge Remaining in the Drain of SOTB

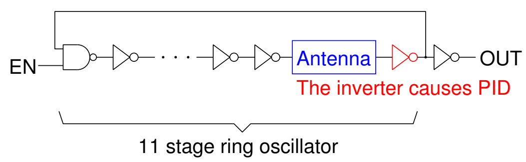

Fig. 5. 11 Stage Ring Oscillator for Measuring Frequencies

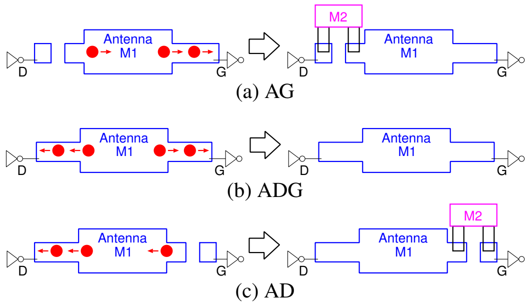

Fig. 6. Connection Structures of Antennas

4. Measurement Results

We measured average frequencies from both of bulk and SOTB chips. One chip contains 98 ROs of the same structure. We measured initial frequencies at 25 °C and 1.2 V. FR is frequency ratio which is based on the AG average frequency.

Fig. 7 shows comparison of initial frequencies with measurement and simulation results. We assume that simulation and measurement results are matched in the AG structures since they are damaged by the same amount both in the bulk and SOTB structures. The measured frequencies of ADG and AD are increased by 0.83 % and 0.79 % from the simulation results, respectively. By connecting an antenna to the drain (AD structure), PID are relieved in AR500.

Fig. 8 shows AR6250 results in bulks. The frequency of the ADG structure is relieved by 0.40 %. The ADG structure does not relieve PID enough in AR6250. But the AD structure relieves 1.05 %. The AD structure relieves PID more than the ADG one.

Fig. 9 and 10 show results of initial frequencies in SOTB chips. ADG and AD relieve 0.82 % and 0.75 % in AR500, respectively and they relieve 0.58 % and 1.08 % in AR6250, respectively. Both structures are almost same as the bulks. SOTB also relieve PID by connecting an antenna to a drain.

We measured BTI degradation of ROs. BTI measurement condition is at 80 °C and 1.5 V to accelerate BTI degradation by the temperature and the voltage. The inverter connected an antenna is stressed when EN is “0”. We keep EN to “0” except when measuring frequencies. Frequency degradation is based on the initial average frequency of each structure.

Fig. 11 and 12 show BTI degradations in the bulk process. Solid lines are fitting function of $a * \log(t) + b$. If the fitting parameter a is larger, degradation is larger. Table I shows the fitting parameter a of all structures. Frequency degradation rate and the fitting parameter a are not different with antenna structures in the bulk process. Fig. 13 and 14 show the BTI degradation in the SOTB process. These results are almost equivalent to those in the bulk process. There is no effect of PID in a long-term degradation rate. It might be supposed that defects which have long time constants are not generated by PID.

5. Conclusion

We fabricated ring oscillators with an antenna structure in 65 nm bulk and SOTB processes and measured their frequencies. The AD structure relieves 0.79 % in the bulk of AR500. In SOTB, the AD structure relieves 0.75 %. Both of the bulk and SOTB relieve PID by connecting an antenna to a drain. Electric charge pass through thin BOX layers less than 10 nm. As for the long-term stress, BTI, it is not different with antenna structures. Initial frequencies are affected by PID but there is no effect of PID in the long-term degradation. We assume that defects with short time constants are generated but those with long time constants are not generated by PID.

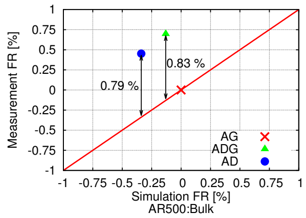

Fig. 7. Comparison of Initial Frequency Ratio with Bulk and Simulation in AR500

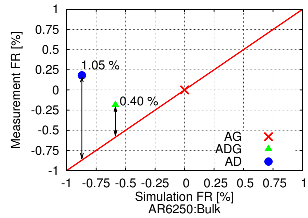

Fig. 8. Comparison of Initial Frequency Ratio with Bulk and Simulation in AR6250

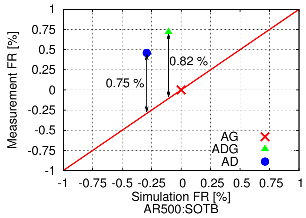

Fig. 9. Comparison of Initial Frequency Ratio with SOTB and Simulation in AR500

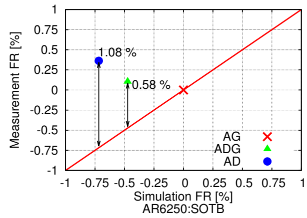

Fig. 10. Comparison of Initial Frequency Ratio with SOTB and Simulation in AR6250

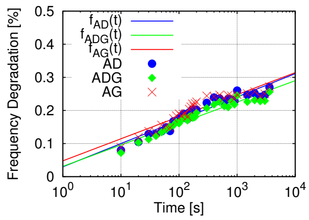

Fig. 11. BTI of AR500 in the Bulk Process

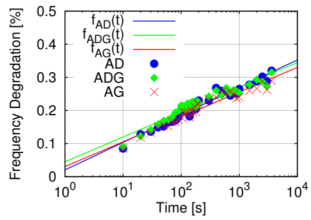

Fig. 12. BTI of AR6250 in the Bulk Process

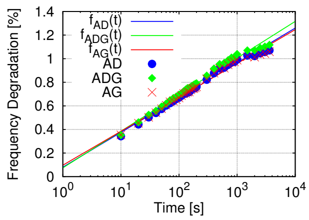

Fig. 13. BTI of AR500 in the SOTB Process

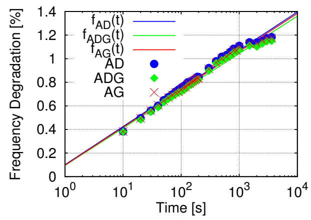

Fig. 14. BTI of AR6250 in the SOTB Process

Table I. The Fitting Parameter a of All Structures

	AG	ADG	AD
AR500:Bulk	0.0290	0.0281	0.0306
AR6250:Bulk	0.0326	0.0327	0.0361
AR500:SOTB	0.125	0.135	0.128
AR6250:SOTB	0.140	0.138	0.141

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