Initial Frequency Degradation and Variation on Ring Oscillators from Plasma Induced Damage in Fully-Depleted Silicon on Insulator Process

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Abstract

Degradations of reliability caused by plasma induced damage (PID) have 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. PID is relieved by connecting an antenna to a drain because charge flows to a substrate. The difference of initial frequencies is 0.64 % between structures which cause and relieve PID. Initial frequencies are degraded by PID. Standard deviations are almost equivalent among antenna structures. The variation from PID is smaller than the other variations such as random dopant fluctuation.

1. Introduction

Degradations of reliability caused by plasma induced damage (PID) have become a significant concern with miniaturizing a device size [1–3]. PID generates defects into a gate oxide. Defects increase a threshold voltage (V_{th}) and decrease an oscillating frequency. We measure initial 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 charge at the 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. An aluminum wire collects charge when it is processed by plasma etching directly. A copper wire collects static charge as shown in Fig. 2. Charge are induced into a metal wire when interlayer dielectric around metal wires is processed.

There are several ways to relieve PID. Fig. 3 shows one of those ways using the drain of bulk as a discharging path. Charge flows to a substrate through the drain in the bulk wafer by connecting the antenna to the drain. But Silicon On Insulator (SOI) does not relieve PID in the drain because it has buried oxide (BOX) layers embedded on a wafer between a body and a substrate. Charge remains in the drain and flows to another gate of MOSFETs. But Silicon On Thin BOX (SOTB) may relieve PID. SOTB is one of Fully Depleted Silicon On Insulator (FD-SOI) processes [6]. It reduces variations due to impurities because it does not dope any dopant to a channel of MOSFETs. A special feature of SOTB is that the BOX layer is less than 10 nm. SOTB may relieve PID because charge flows the substrate by quantum tunneling as shown in Fig. 4 as a similar manner as a flash memory [7].

3. Measurement Circuits

We fabricated a chip including 11 stage ring oscillators (ROs) which have different antenna structures in 65 nm SOTB processes. Fig. 5 shows 11 stage ROs. The inverter next to the antenna is damaged 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 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.

4. Measurement Results

We measure initial frequencies at 25 °C and 1.2 V. One chip contains 98 ROs of the same structure. We calculate average frequencies and standard deviations from the SOTB chip. FR

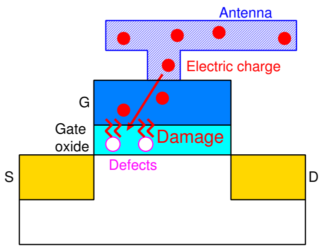

Fig. 1. PID to the gate oxide

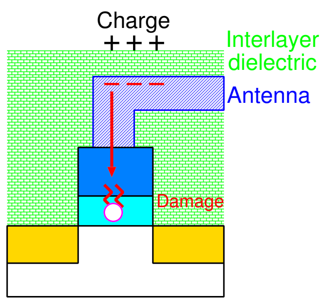

Fig. 2. PID by interlayer dielectric processes

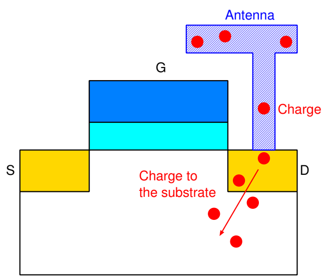

Fig. 3. Relieving PID in the drain of bulk

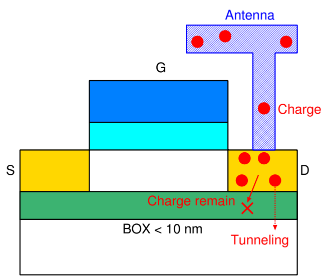

Fig. 4. Charge remaining in the drain of SOTB

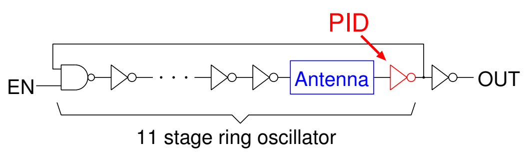

Fig. 5. 11 stage ring oscillator for measuring frequencies

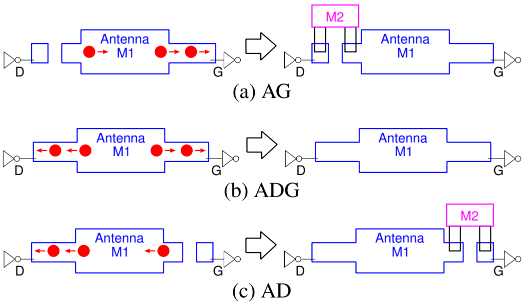

Fig. 6. Connection structures of antennas

is frequency ratio which is based on the AG average frequency by Eq. (1).

$$FR_{\mathrm{AG}} = \frac{F - F_{\mathrm{AG}}}{F_{\mathrm{AG}}} \tag{1}$$

FR_{AG} is the frequency ratio based on the frequency of AG. F is the frequency of AD or ADG. F_{AG} is the frequency of AG.

Fig. 7 shows relation ships between initial frequencies with measurement and simulation results. Its vertical axis is the measured FR_{AG} and horizontal axis is the simulated one. Frequencies of ROs before the inverter is damaged by PID are different among antenna structures. We simulate frequencies of ROs including only resistance and capacitance. If ADG or AD structures are damaged by the same amount, the points are located on the straight line of $y = x$. If they relieve PID larger than the AG, the points above $y = x$. The measured frequencies of ADG and AD are increased by 0.51 % and 0.64 % from the simulation results, respectively. PID are relieved by connecting the antenna to the drain first in AR500.

Fig. 8 shows AR6250 results. The frequency of the ADG structure is relieved by 0.61 %. The AD structure relieves 1.16 %. The AD structure relieves PID more than the ADG one. SOTB also relieves PID by connecting the antenna to the drain because charge flows the substrate by quantum tunneling as a similar manner as a flash memory. It has less than a 10 nm gate oxide [7]. It uses the quantum tunneling by applying high electric field into the gate oxide. During production of MOSFETs, high electric field is also applied into the BOX layer by charge collected in the antenna. We assume that charge flows to the substrate through the drain by quantum tunneling in the thin BOX layer as the same manner.

Fig. 9 and 10 show the average frequencies and standard deviations (σ) in AR500 and AR6250, respectively. Standard deviations are almost same among antenna structures. Some of AD structures are slower than that of AG structures. The variation caused by PID is smaller than the other variations.

5. Conclusion

We fabricated ring oscillators with an antenna structure in 65 nm SOTB process and measured their frequencies. The AD structure relieves PID by 0.64 %. SOTB relieves PID by connecting an antenna to a drain. Charge passes through thin BOX layers less than 10 nm. Initial average frequencies are affected by PID but standard deviations are almost equivalent among antenna structures. Some of AD structures is slower than that of AG structures. Variation from PID is smaller than the other variations such as random dopant fluctuation.

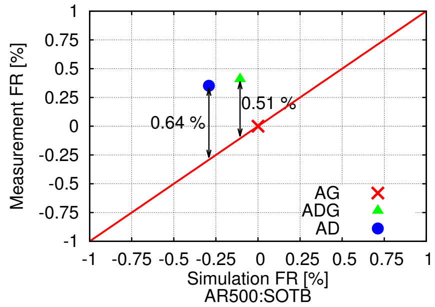

Fig. 7. Comparison of initial frequency ratio with measurements and simulations in AR500

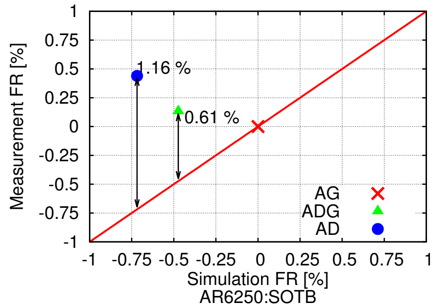

Fig. 8. Comparison of initial frequency ratio with measurements and simulation in AR6250

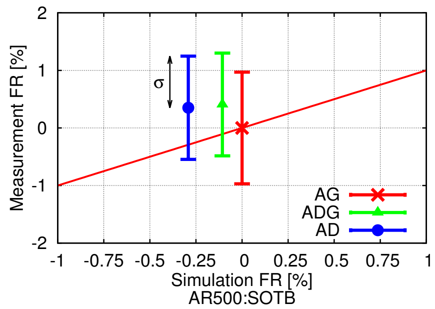

Fig. 9. Average frequencies and standard deviations in AR500

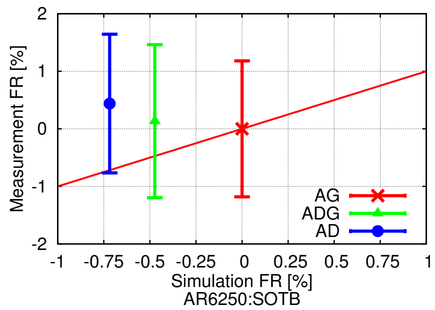

Fig. 10. Average frequencies and standard deviations in AR6250

Acknowledgment

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References

[1] R. Kishida et. al., *SSDM*, pp. 52-53, 2014.
[2] W. H. Choi et. al., *CICC*, p. 14-3, 2014.
[3] A. C. Mocuta et al., *American Vacuum Society*, pp. 104-107, 2001.
[4] V. Huard et al., *IRPS*, pp. 289-300, 2008.
[5] B. Kaczer et al., *IRPS*, pp. XT.3.1-XT.3.5, 2011.
[6] R. Tsuchiya et al., *IEDM*, pp. 631-634, 2004.
[7] T. Hori, *Springer Series in Electronics and Photonics*, Vol. 34, 1997.