Recent Developments on Information and Communication Technology (ICT) Engineering- Meen, Yang & Zhao
ISBN: 978-981-14-2136-5

Total-ionizing-dose-induced body shielding effect in 130 nm T-gate PDSOI I/O nMOSFETs

Xin Xie[1,2,*], Dawei Bi[1], Zhiuyuan Hu[1], Zhengxuan Zhang[1], Shichang Zou[1]

[1] State Key Laboratory of Functional Materials for Informatics, Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences
865 Changning Road
Shanghai, China

[2] University of Chinese Academy of Sciences
No.19(A) Yuquan Road, Shijingshan District
Beijing, China

[*]17740838540, xiexin@mail.sim.ac.cn

Abstract

This paper investigates total-ionizing-dose-induced body shielding effect in 130 nm T-gate partially-depleted SOI I/O nMOSFETs. As total ionizing dose increases, the body effect is useless to control the threshold voltage. A body neck pinch-off model is proposed to interpret that phenomenon. During irradiation under PG bias, high electric field is built in the buried oxide under the body neck region. Hence, more radiation-induced positive charges are trapped in the buried oxide under the body neck region. Then, the body neck region will be fully depleted. That is to say, the body neck will be pinched off as total ionizing dose increases. As a result, the body contact is shield. And the method using body voltage to control the threshold voltage does not work.

Key words: body effect, shielding effect, silicon on insulator, total ionizing dose

Introduction

In harsh radiation environment, there are many kinds of high energy particles, such as heavy ions, high energy protons, α particles. The high energy particles influence the devices and induce total ionizing dose (TID) effect, single event effect (SEE), and dose rate effect [1]. Silicon-on-insulator (SOI) technology, due to its good immunity to single event and dose rate effect, was proposed to radiation-hardened applications [2]. However, SOI technology are more sensitivity to the total ionizing dose effect due to the thick buried oxide layer (BOX).

Body effect is known as a threshold voltage change induced by body voltage [3]. In nMOSFETs, the maximum thickness of the depletion layer increases as the body voltage decreases, hence the threshold voltage increases as the body voltage decreases. In bulk technology, body effect is utilized to radiation harden and circuit reliability harden sometimes [4]-[6].

In this paper, we studied the influence of total ionizing dose on body effect in 130 nm partially-depleted (PD) SOI technology. We compared devices with different lengths and different widths, and found total-ionizing-dose-induced body shielding effect. We proposed a new model called body neck pinch-off model to interpret those phenomena.

Experimental details

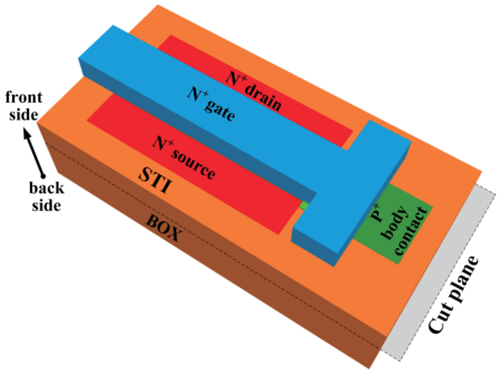
All devices in this paper are fabricated in 130 nm process partially-depleted (PD) SOI technology. The SOI wafer is 200 mm diameter UNIBOND® wafer from SOITEC corporation. The thickness of top Si film and BOX are 100 nm and 145 nm, respectively. Shallow trench isolation (STI) is applied for isolation. Body contacts of all devices are introduced by T-Gate layout as shown in Fig. 1. The average body doping concentration N_a is about $4.7 \times 10^{17}\ \mathrm{cm}^{-3}$. The thickness of gate oxide is 6 nm and operating voltage (VDD) is 3.3 V. The input/output (I/O) NMOS devices with different widths and different lengths are selected. All samples are 24-pin DIP ceramic packaged. Radiation experiments were carried out in Xinjiang Technical Institute of Physics and Chemistry, Chinese Academy of Sciences. The radiation source is $^{60}\mathrm{Co}$ γ-ray with a 100 rad(Si)/s dose rate. Pass-Gate (PG) bias (when source and drain are biased at 3.63 V, others are grounded) was used during radiation exposure. Characteristics of devices were all measured by Keithley 4200B parameter analyzer at room temperature before irradiation and after irradiation up to 30 krad(Si), 50 krad(Si), 100 krad(Si). All measures were taken within half an hour to avoid the anneal effect.

Results and Discussion

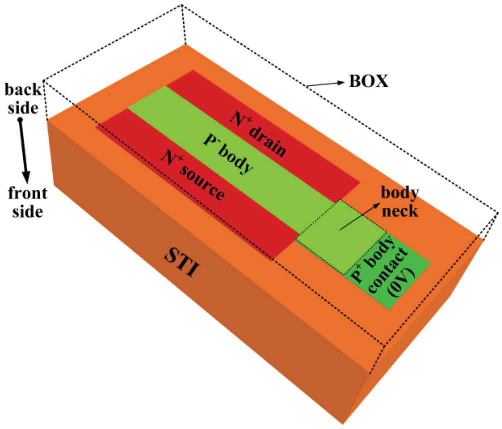
Fig. 2 is the transmission characteristic curve of device with width/length (W/L) =10 μm/0.35 μm. Before irradiation, the transmission characteristic curve shifts right by applying a negative body voltage. This is a regular phenomenon of body effect. According to previous studies [3], the threshold voltage (V_{th}) of PDSOI NMOS can expressed by

$$V_{th} = \Phi_{MS} + 2\Phi_f - \frac{Q_{ox}}{C_{ox}} + \frac{Q_B}{C_{ox}}$$
$$= \Phi_{MS} + 2\Phi_f - \frac{Q_{ox}}{C_{ox}} + \frac{\sqrt{2\epsilon_{si} q N_a (2\Phi_f - V_{bs})}}{C_{ox}} \quad (1)$$

where Φ_{MS} is the work function difference between gate poly and body silicon; Φ_f is the Fermi potential; Q_{ox} is the fixed charge density at the gate oxide; C_{ox} is the gate oxide capacitance; $Q_B = \sqrt{2\epsilon_{si} q N_a (2\Phi_f - V_{bs})}$ is the depletion charge density. Here, ϵ_{si} is the permittivity of silicon.



(a)



(b)

Fig. 1 The 3D layout of T-gate PDSOI I/O nMOSFET. (a) font side view, (b) back side view. The substrate silicon film is not shown in this figure. We call the body silicon film between source/drain and body contact as the body neck region.

According to (1), when the body is biased at a negative voltage ($V_{bs} < 0$), the threshold voltage increases ($\Delta V_{th} > 0$). Hence, the transmission characteristic curve shifts right. However, in Fig. 2, the transmission characteristic curves under different body biases are more close to etch other as total ionizing dose increases. It seems that the body voltage does not change the threshold voltage anymore as total ionizing dose increases.

Devices with different lengths are compared. Fig. 3 is the body-effect-induced threshold voltage variations of devices with different lengths at different TID levels under PG bias. The threshold voltages are all extracted by the maximum transconductance method [7]. As we can see, before irradiation, long devices surfer larger body-effect-induced threshold voltage variations than short devices. This may be induced by short channel effect which influences the effective depletion charges controlled by gate [3], [8]. As total ionizing dose increases, the body-effect-induced threshold voltage variations all decreases. At 100 krad(Si) TID level, the body-effect-induced threshold voltage variations are close to zero. These reveal that the body is shielded and the method using body effect to control threshold voltage does not work anymore as total dose increases.

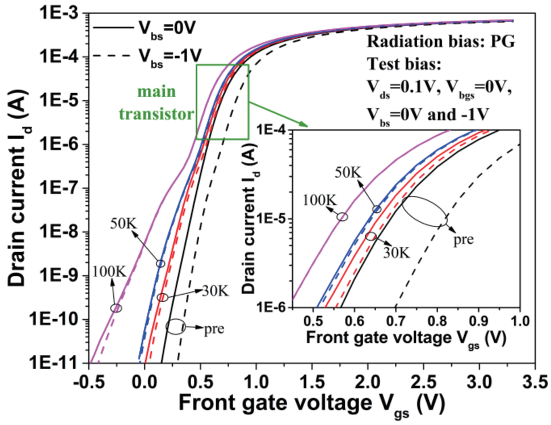


Fig. 2 The transmission characteristics of PDSOI I/O NMOS with W/L=10 μm/0.35 μm at different TID levels under PG bias. Test bias: V_{ds}= 0.1 V, V_{bgs}=0 V, V_{bs}=0 and -1 V. The solid lines are the transmission characteristics at V_{bs}=0 V, and the dash lines are the transmission characteristics at V_{bs}=-1 V.

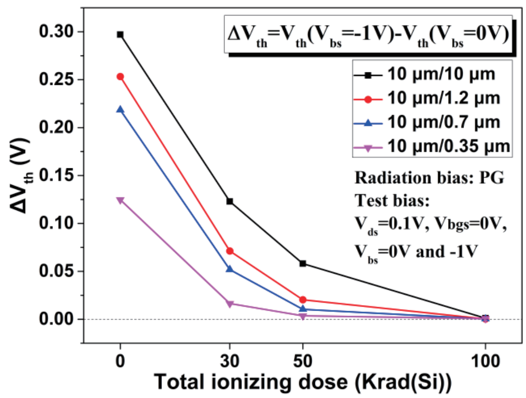


Fig. 3 The body-effect-induced threshold voltage variations of PDSOI I/O NMOS with different lengths at different TID levels. Test bias: V_{ds}=0.1 V, V_{bgs}=0 V, V_{bs}=0 and -1 V.

One interpretation which is easy to be thought of may describe those phenomena. As total ionizing dose increases, more and more radiation-induced positive charges are trapped in the BOX layer. Hence, the body silicon film near BOX is depleted. And the thickness of depletion region near BOX increases as total ionizing dose increases. It narrows the body region and increases the resistance of body. Then, the body region which is far away from the body contact is not controlled by the body contact and more close to be floating. Hence, the devices are not sensitive to body voltage anymore. We call this interpretation as body narrowing model. It seems to be reasonable. However, this interpretation infers that the wider devices are more sensitive to be floating as total ionizing dose increases.

To check the rationality of the interpretation above, we compared body-effect-induced threshold voltage variations of devices with different widths at different TID levels. As shown in Fig. 4, the body-effect-induced threshold voltage variations of devices with different widths are all decreases as total ionizing dose increases. This demonstrates that the body of devices with different widths all suffer shielding effect as total ionizing dose increases. However, the decrements of body-effect-induced threshold voltage variations are almost no differences between devices with different widths. This is not in agreement with the inference above. Hence, the body narrowing model is not appropriate to describe those phenomena.

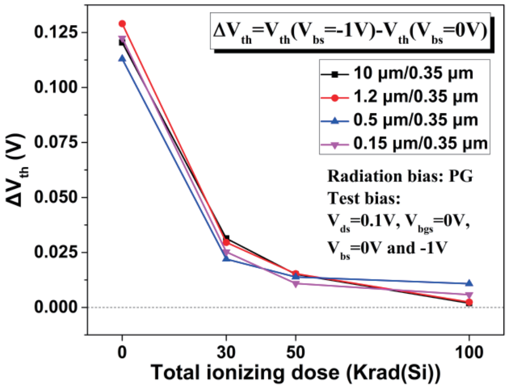


Fig. 4 The body-effect-induced threshold voltage variations of PDSOI I/O NMOS with different widths at different TID levels. Test bias: V_{ds}=0.1 V, V_{bgs}=0 V, V_{bs}=0 and -1 V.

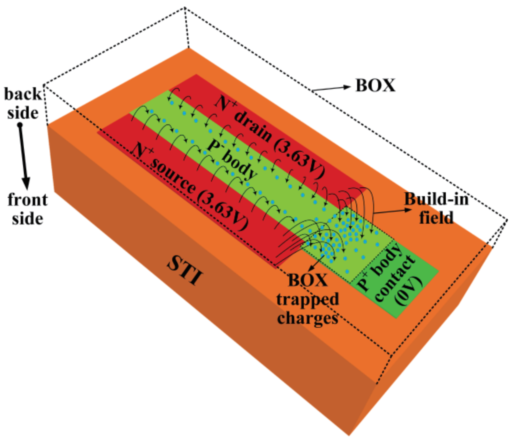


Fig. 5 The build-in field and the distribution of radiation-induced positive trapped charges in the BOX under PG bias.

To interpret the phenomena better, we proposed a new model called body neck pinch-off model. The body neck is the body silicon film between source/drain and body contact, as shown in Fig. 1b. Under PG bias, the source and drain are biased at 3.63 V, and the body contact is biased at 0 V. There is a high difference of potential between the source/drain and body contact. Then, high field is built in the BOX under the body neck region, as shown in Fig. 5. When devices is irradiated under PG bias, more radiation-induced positive charges are trapped in the BOX under the body neck region. The numerous positive trapped charges deplete the silicon film in the body neck region. Hence, the thickness of depletion layer in the body neck region is much larger than in the body region. When we apply a positive voltage at gate to measure $I_d - V_{gs}$ curves, the top maximum depletion layer connects with the bottom depletion layer in body neck region. That is to say, as total ionizing dose increases, the body neck region is pinched off. Hence, the body contact is opened to body region, and the body region is not controlled by body contact voltage. This interprets why the body is shielded as the total ionizing dose increases. The body neck pinch-off model is not influenced by the width of devices, because all devices with different widths but same length have the same body neck region.

Conclusion

Total-ionizing-dose-induced body shielding effect is found in this paper. As total ionizing dose increases, the body voltage does not control the threshold voltage anymore. We compare devices with different lengths and different widths. All of them suffer the total-ionizing-dose-induced body shielding effect. And the body-effect-induced threshold voltage variations of wide devices is the same as the narrow devices. A body narrowing model can interpret the body-effect-induced threshold voltage variations of devices with different lengths, however it can not interpret the body-effect-induced threshold voltage variations of devices with different widths. We proposed a new model called body neck pinch-off model to interpret all of the phenomena better. In this model, high field is build in the buried oxide under the body neck region. Hence, irradiation induces more positive trapped charges in the buried oxide under the body neck region. As a result, the body neck region is more easy to be fully depleted. When the body neck region is fully depleted, the body neck will be pinched off. Hence, the body voltage biased on the body contact is shielded as total ionizing dose increases. Because the body neck regions of devices with different widths are the same. The body neck pinch-off model can accord with the body-effect-induced threshold voltage variations of devices with different widths.

Acknowledgment

We are particularly grateful to the Xinjiang Technical Institute of Physics and Chemistry, Chinese Academy of Sciences for the experiment and support.

References

[1] P. E. Dodd, et al., "Current and future challenges in radiation effects on CMOS electronics," *IEEE Transactions on Nuclear Science*, vol. 57, no. 4, pp. 1747-1763, Aug 2010.

[2] J. R. Schwank, et al., "Radiation effects in SOI technologies," *IEEE Transactions on Nuclear Science*, vol. 50, no. 3, pp. 522-538, Jun 2003.

[3] J.-P. Colinge, *Silicon-on-insulator technology: Materials to VLSI*, 3rd ed. New York, Kluwer Academic Publishers, 2004, pp.164-169.

[4] G. Niu, et al., "Total dose effects on the shallow-trench isolation leakage current characteristics in a 0.35 um SiGe BiCMOS technology," *IEEE Transactions on Nuclear Science*, vol. 46, no. 6, pp. 1841-1847, Dec 1999.

[5] Z. Y. Hu, et al., "Radiation hardening by applying substrate bias," *IEEE Transactions on Nuclear Science*, vol. 58, no. 3, pp. 1355-1360, Jun 2011.

ISBN: 978-981-14-2136-5

[6] Z. Y. Hu, et al., "Impact of substrate bias on radiation-induced edge effects in MOSFETs," *Chinese Physics B*, vol. 20, no. 12, pp. 120702-120702, Dec 2011.
[7] A. Ortiz-Conde, et al., "A review of recent MOSFET threshold voltage extraction methods," *Microelectronics Reliability*, vol. 42, no. 4-5, pp. 583-596, Apr-May 2002.
[8] S. M. Sze and M.-K. Lee, *Semiconductor devices physics and technology*, 3rd ed. America, John Wiley & Sons, 2012. pp.195-197.