Total dose radiation induced changes of the floating body effects in the partially depleted SOI NMOS with ultrathin gate oxide

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Abstract: In this paper, the impacts of total dose radiation on the low-frequency noise and gate induced floating body effects (GIFBEs) for the 130 nm partially depleted silicon-on-insulator N-type metal-oxide semiconductors transistor with an ultrathin gate oxide have been investigated. It is shown that the second transconductance $g_m$ peak becomes smaller after irradiation when the Lorentzian-like excess noise is more pronounced. The traps induced by irradiation at shallow trench isolation/body and buried-oxide/body interface can act as the recombination centers to increase the source-body diode current, which results in the changes in the excess noise and GIFBEs.

Keywords: total dose radiation, silicon-on-insulator, low-frequency noise, floating body effects

Classification: Electron devices, circuits and modules

References


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1 Introduction

Due to the hardness advantages of silicon-on-insulator (SOI) technology over bulk-silicon technologies, such as latch-up effect immunity and less sensitivity to single-event upset from energetic cosmic particles, the SOI technology has been widely used for military and space applications [1, 2]. However, the total dose radiation responses of SOI devices are more complex than the conventional bulk-silicon devices. For the radiation will introduce oxide trapped charges and interface traps not only in conventional oxide layer, gate oxide and shallow trench isolation (STI), but also in thick buried oxide (BOX), which results in that the devices cannot operate properly and even fail [3, 4].

The gate oxide thickness of the deep submicron complementary metal-oxide semiconductor (CMOS) devices is ultrathin, which makes itself have more advantages in radiation environments due to less radiation-induced traps in the gate oxide. Whereas the aggressive shrinking of gate oxide thickness in partially-depleted (PD) SOI MOSFETs leads to the gate-induced floating body effects (GIFBEs) in the linear operation region [5, 6], which have many similarities to the conventional drain-induced floating body effects (DIFBEs) at high drain bias [7]. Once the GIFBEs happen, a Lorentzian-like noise component will superimpose to the low-frequency (LF) noise due to the appearance of the excess noise [8, 9], which is similar to the phenomenon that the DIFBEs in PDSOI devices give rise to the Kink-related excess noise [10, 11].
However, a limited number of literatures investigated the impact of total dose radiation on the GIFBEs, and the specific mechanisms still remain controversial. From results in [12], after 500 krad(Si) total dose radiation the second transconductance induced by the GIFBEs decreased. The degradation was thought to result from the interface traps and oxide traps charge, which enhanced carrier recombination. But in the work by C. Peng et al. [13], attenuation of the second $g_m$ after radiation was ascribed to the subthreshold leakage. At present there is no a recognized explanation. In this research, the influences of the total ionizing dose irradiation on the GIFBEs in 130 nm PDSOI core nMOSFETs are investigated. Based on the connection between the excess low-frequency (LF) noise and the GIFBEs, a new interpretation of the changes in the two effects before and after radiation is proposed through mutual verification.

2 Experimental details

The SOI material of the PDSOI devices employed in this work was from SOITEC Corporation’s 200 mm diameter UNIBOND wafer with a 100 nm thick top Si film and a 145 nm thick BOX. The 130 nm PDSOI technology with the shallow trench isolation (STI) isolation was used. The devices were 24-pin DIP ceramic packaged. The gate oxide thickness of core devices was 1.8 nm and the operating voltage ($V_{DD}$) was 1.2 V. The floating body devices with $W/L = 10\mu m/10\mu m$ were used.

We carried out this experiment in Xinjiang Technical Institute of Physics and Chemistry, the Chinese Academy of Sciences. The radiation source was $^{60}$Co γ-ray and the dose rate was about 200 rad(Si)/s. During radiation exposure, the devices were under Transfer-Gate (TG) bias condition that the drain and source terminals were biased at 1.2 V and other terminals were grounded, which is the worst radiation bias condition for BOX [14]. Before and shortly after the irradiation, the direct-current (DC) and LF noise characteristics were measured at room temperature by the $1/f$ noise Measurement System which is composed of E4725AK01 Controller, E4725AK02 Resistor and E4725AK03 Dut.

3 Experimental results and discussion

Fig. 1 illustrates the drain current $I_{ds}$ and transconductance $g_m$ in the linear region for a PDSOI floating core device with $W/L = 10\mu m/10\mu m$ before and after 500 krad(Si) irradiation under TG bias. The positive charges trapped in the field oxide and buried oxide are not sufficient enough to produce an inversion layer, so that there is no radiation-induced leakage and threshold voltage shift to be observed. Before irradiation, a second hump in the transconductance characteristic is noticeable close to $V_g = 1.2$–1.3 V, and the value of the second transconductance $g_m$ peak exceeds the normal peak due to the electron-valence-band (EVB) tunneling [5]. The electrons in the body region can tunnel from the valence band to the ploysilicon under a sufficient vertical electric field, when the gate oxide thickness is less than 2 nm [13]. As a result, excess holes are left in the body region which is neutral originally, leading to the floating-body effect and resulting in a second $g_m$ peak. After 500 krad(Si) irradiation, the second $g_m$ peak
occurs at $V_{gs} = 1.2$ V, in common with the preirradiation behavior, but the magnitude of the second $g_m$ peak decreases and the attenuation of normal $g_m$ peak is not observed. Meanwhile, there is no change in the gate current before and after irradiation, as shown in Fig. 2.

The attenuation of the second $g_m$ peak implies that fewer holes are stored in the body of SOI MOSFETs after irradiation [5]. There are two possibilities for the decline of the second $g_m$ peak: (1) the EVB tunneling is suppressed after irradiation, with fewer holes generated in the floating body, because more traps generated in the gate oxide and interface between the gate oxide and the silicon; (2) the excess holes remove more quickly from the body after radiation so that there are less excess holes stored in the body region. The first possibility can be excluded due to no change of the gate current before and after irradiation under TG bias, as shown in Fig. 2. So how did the excess recombine quickly after radiation? In order to analyze this phenomenon, the $1/f$ noise before and irradiation were measured.
Fig. 3 shows the drain current power spectral density before irradiation. The effective gate voltage \((V_g-V_t)\), in which \(V_t\) is the threshold voltage, was positively swept from 0.85 V to 1.1 V, corresponding to the region where the second \(g_m\) peak appears. The threshold voltage of this core device is 0.27 V. Once the \(V_g\) value exceeds the GIFBEs beginning gate voltage (about 1.2–1.3 V), an excess noise (shot noise) takes place obviously, which is characterized by the superposition of a Lorentzian-like component on the conventional \(1/f\) noise spectrum. The behavior of this excess noise which happens in the linear region for PDSOI devices is same as the Kink-related excess noise previously observed in the saturation region [6, 7, 8, 9].

![Fig. 3. Drain current power spectral density before irradiation. Effective gate voltage is swept from 0.85 up to 1.1 V.](image)

Fig. 4 reports the drain current power spectral density after 500 krad(Si) irradiation under TG bias condition. The effective gate voltage was positively swept from 0.85 up to 1.1 V.

![Fig. 4. Drain current power spectral density after 500 krad(Si) irradiation under TG bias condition. Effective gate voltage is swept from 0.85 up to 1.1 V.](image)
Fig. 5 shows the behavior of the Lorentzian noise overshoot normalized drain current spectral density ($S_{id}/I_d^2$) as a function of the effective front gate voltage before and after irradiation, and corresponds to a frequency $f = 10$ HZ. As shown here, until the EVB tunneling happens, the magnitude of the normalized drain current power spectral density is similar regardless of irradiation. Nevertheless, after irradiation the excess Lorentzian-like noise induced by the EVB tunneling is obviously higher than the preirradiation. On the basis of the experimental results, we found that the second transconductance $g_m$ peak becomes smaller after irradiation when the Lorentzian-like excess noise is more pronounced.

Fig. 6 illustrates the input voltage power spectral density ($S_{vg}$) as a function of frequency at the effective gate voltage is 0.65 V and 0.7 V respectively when electron valence band tunneling doesn’t happen. Fig. 6 illustrates the input voltage power spectral density ($S_{vg}$) as a function of frequency at the effective gate voltage is 0.65 V and 0.7 V respectively when electron valence band tunneling doesn’t happen. Fig. 6 illustrates the input voltage power spectral density ($S_{vg}$) as a function of frequency at the effective gate voltage is 0.65 V and 0.7 V respectively when electron valence band tunneling doesn’t happen.

Fig. 6. Input voltage power spectral density before and after 500 krad(Si). Effective gate voltage is at 0.65 V and 0.7 V respectively, when electron valence band tunneling doesn’t happen.

The trap density at the front gate oxide can be estimated with the following formula [10]:
\[ S_{\text{vg}} = \frac{\lambda q^2 kT N_t}{WLC_{\text{ox}}^2 f}, \]

where \( N_t \) is the interface trap density (traps/cm\(^3\)/eV), \( C_{\text{ox}} \) is the gate oxide capacitance, \( \lambda \) is the tunneling constant (\( \lambda = 0.1 \text{ nm} \)), \( T \) is the temperature, and \( f \) is the frequency (HZ). It can be concluded that few interface traps at the front gate oxide are induced by the irradiation, which is consistent with the DC characteristic.

The conventional \( 1/f \) noise is associated with the conducting channel, and the excess noise is related to the floating-body effect. For the excess noise, the excess carriers in the body discharge through the body-source junction, which gives rise to the fluctuation of the body voltage and leads to the excess noise finally. The GIFBEs induced excess noise has two sources, and one is the gate-body tunneling current and the other is the body-source junction current [11]. After irradiation, there is no obvious change in the gate-to-body current. It is concluded that the body-source junction current is the major potential source of the incremental noise spectral density. Numerous researches have reported that irradiation will induce interface traps at the STI/body and BOX/body interfaces, which can act as the recombination centers [12]. On one hand the number of excess holes left in the body reduces through the recombination centers, which suppresses the second \( g_m \) peak; on the other hand the interface traps accelerate the fluctuation of the body potential as another access to discharge the left holes with source-body junction, and that induces a more pronounced Lorentzian-like excess noise.

### 4 Conclusion

In this paper, the impact of the total ionizing dose on the excess LF noise induced by the GIFBEs in PD floating core NMOS is discussed in details. The traps induced by irradiation at STI/body and BOX/body interfaces can act as the recombination centers to increase the source-body diode current, which results in the more pronounced Lorentzian-like excess noise and the attenuation of the second \( g_m \) peak.

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