# Total ionizing dose induced single transistor latchup in 130-nm PDSOI input/output NMOSFETs*

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Total ionizing dose induced single transistor latchup effects for 130 nm partially depleted silicon-on-insulator (PDSOI) NMOSFETs with the bodies floating were studied in this work. The latchup phenomenon strongly correlates with the bias configuration during irradiation. It is found that the high body doping concentration can make the devices less sensitive to the single transistor latchup effect, and the onset drain voltage at which latchup occurs can degrade as the total dose level rises. The mechanism of band-to-band tunneling (BBT) has been discussed. Two-dimensional simulations were conducted to evaluate the BBT effect. It is demonstrated that BBT combined with the positive trapped charge in the buried oxide (BOX) contributes a lot to the latchup effect.

**Keywords:** total ionizing dose (TID), single transistor latchup (STL), band-to-band tunneling (BBT), partially depleted silicon-on-insulator (PDSOI)

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## 1. Introduction

In space or other harsh radiation environments, exposure to high energetic particles such as electrons and protons can significantly reduce the lifetime of integrated circuits (ICs) due to radiation effects.[1] When a material is exposed to total ionizing dose (TID) irradiation, the interface traps as well as the electron–hole pairs can be generated. The generated carriers can result in charge buildup in different types of oxides in the metal–oxide–semiconductor field-effect transistors (MOSFETs), resulting in gradual degradation and change in functionality.[2,3] The basic mechanism for the degradation is the trapping of holes in the oxide and the interface charge at the $Si–SiO_2$ interface. In addition to the TID effect, heavy ions induced single-event effects (SEEs) can also depress long-term reliability and lead to catastrophic device failure.[4] Hence, it is significant for us to research the radiation effects in MOSFETs.

Silicon-on-insulator (SOI) technologies have attracted more popularity for military and space radiation-hardened applications owing to there being some radiation hardness advantages in contrast with the bulk-silicon technology.[5] For instance, SOI devices have manifested their better resistance against dose rate effects and their very low SEEs sensitivity, owing to the limited charge collection volume for cosmic rays and full dielectric isolation between individual transistors.[6] However, SOI technologies are not inherently immune to the total dose irradiation. Actually, the existence of buried oxide (BOX) layer as well as shallow trench isolation (STI) can make SOI devices more vulnerable to TID irradiation.[7–11] With respect to the radiation-hardened applications, partially depleted SOI (PDSOI) devices are extensively used because of their better resistance to the coupling effect and their better controllability of the threshold voltage. To some extent, the floating body effects (FBEs) can weaken the PDSOI advantages, since these effects can make the device characteristic become abnormal.[12] The detrimental FBEs can be suppressed enough but not eliminated via device modifications, such as H-gate or T-gate structures with body ties.[13] The single transistor latchup (STL) effect, as an extreme case of the FBEs, can finally lead to an abnormally abrupt decrease of the subthreshold slope and the sustainability of high drain current state even at typical operating voltage.[14–17]

TID irradiation induced degradation of SOI devices has been reported by many previous published works. In Ref. [18], Ferlet-Cavrois *et al*. found that TID irradiation can induce the latchup effect for the SOI transistors fabricated with a 180 nm SOI technology, and it was demonstrated that the STL effect is strongly related to parameters such as the supply voltage, gate length, and TID induced positive trapped charge in the BOX. In a later work, Flament *et al.*[19] evaluated the total dose response of fully depleted SOI transistors, and figured out that the bias configuration during irradiation and the thickness of the buried oxide can have great influence on the coupling effect and STL effect. However, the total dose induced STL effects for PDSOI devices were not involved in that work. Re-

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cently, Peng *et al.*[20] studied the TID induced coupling effect observed in 130 nm PDSOI input/output (I/O) devices with the body floated. However, the authors only analyzed the influence of the coupling effect on the threshold voltage shift, subthreshold slope increase, and transconductance variation in the front channel device; the impact of the coupling effect on STL was not discussed. Fan *et al.*[21] investigated the bias dependence of TID induced STL effect for 130 nm PDSOI I/O devices, and figured out that TID irradiation can enhance the impact ionization (II) process and thereby make the device more sensitive to the STL effect. However, the basic mechanism of II is not sufficient to explain the STL effect observed at low drain voltage.

In this work, we comprehensively study the TID induced STL effect for 130 nm PDSOI devices. Different parameters like bias conditions, body doping concentration, and onset drain voltage are used to characterize the STL effect. It is found that the STL effect for partially depleted devices can behave like that for the fully depleted ones due to the coupling effect. What is more, the high body doping concentration can make the devices less sensitive to the STL effect, and the onset drain voltage at which latchup occurs can degrade as the total dose level rises. The two competitive mechanisms (impact ionization and band to band tunneling) are also discussed in detail, and band to band tunneling is considered to contribute a lot to the STL effect.

## 2. Experiment details

The I/O NMOSFETs devices employed in the following experiments, with H-gate layout pattern and external body contacts, were fabricated with a 130 nm SOI CMOS technology. Processing was performed on a 200 mm diameter UNIBOND® wafer from SOITEC. The thicknesses of the buried oxide, gate oxide, and top silicon film are 145 nm, 6.8 nm, and 100 nm, respectively. The gate width ($W$) to length ($L$) ratio of our device is chosen to be 10 μm/0.35 μm. The package type of our samples is 24-pin ceramic DIP. The nominal operating voltage for the I/O device is 3.3 V.

**Table 1.** Bias condition definition.

| Type | Gate/V | Source/V | Drain/V | Substrate/V |
|---|---|---|---|---|
| ON | 3.3 | 0 | 0 | 0 |
| OFF | 0 | 0 | 3.3 | 0 |

All experiments were conducted at the Xinjiang Technical Institute of Physics and Chemistry, the Chinese Academy of Sciences, by using $^{60}$Co $\gamma$-rays as the irradiation source. The dose rate is about 120 rad(Si)/s. As listed in Table 1, two different bias conditions were adopted during irradiation. Before irradiation and after each step irradiation, the experimental curves ($I_{DS}$–$V_{GS}$) were obtained by using a Keithley 4200 semiconductor parameter analyzer. It should be emphasized that all the devices were measured within 30 min after irradiation, and all the bodies of the devices should be floated.

### 2.1. Results and discussion

### 2.2. Bias dependence of single transistor latchup phenomenon

Figure 1 shows the $I_{DS}$–$V_{GS}$ curves of commercial H-gate devices under ON bias condition after different dose irradiation. The drain voltage $V_{DS}$ is kept at 3.3 V. Before irradiation, the $I_{DS}$–$V_{GS}$ curve behaves normally and there is no significant off-state leakage current ($I_{DS}@V_{GS} = 0$ V) during the forward front-gate voltage ($V_{FG}$) sweep. Note that a steep subthreshold slope is observed due to the conduction of the parasitic drain–body–source bipolar transistor in body-floated devices. Moreover, during the reverse $V_{FG}$ sweep, the $I_{DS}$–$V_{GS}$ curve cannot coincide with the curve obtained in the forward sweep. Therefore, a history-dependent hysteresis phenomenon appears in the subthreshold region before irradiation. After 100 krad(Si) irradiation, the characteristics of the $I_{DS}$–$V_{GS}$ curves, including forward and reverse sweeps, almost overlap with those measured before radiation.

As the total dose level has reached to 300 krad(Si), the window of hysteresis has become so wide that, even though the $V_{FG}$ is the reverse sweep to $-1$ V, $I_{DS}$ still remains at a high state. Therefore, the hysteresis degrades the STL effect, which is characterized by the high drain current state at negative front-gate voltage. After 500 krad(Si) irradiation, a significant leakage current, almost seven orders of magnitude higher than the value measured before irradiation, is observed. Meanwhile, negative shift of the steep subthreshold region has been observed from $V_{GS} = 0.3$ V before irradiation to $V_{GS} = -0.6$ V after 500 krad(Si) irradiation. This phenomenon indicates TID irradiation can make the STL effect triggered at lower gate voltage.

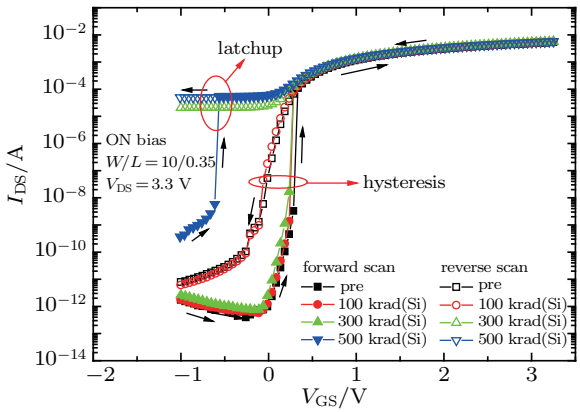



**Fig. 1.** (color online) $I_{DS}$–$V_{GS}$ curves of commercial H-gate SOI device before and after irradiation under ON bias condition. The device was measured at $V_{DS} = 3.3$ V with forward and reverse $V_{FG}$ sweep. Scan directions are indicated by the arrows in the figure.

Actually, both hysteresis and STL effects can be attributed to the generated excess holes in the floating body region. During the forward gate voltage scan, the generated holes will be accumulated in the floating body region, thus causing the elevation of the body potential. Finally, when the body potential is high enough to activate the conduction of the parasitic source–body–drain bipolar transistor, an abrupt increase of the drain current will be observed. Continuously, followed by a reverse gate voltage scan, the generated excess holes in the body region cannot be released because of the floating body. Hence, the parasitic source–body–drain bipolar transistor can still be in the conduction state to maintain the drain current at high value, even though the gate voltage has been decreased enough during the reverse scan. Eventually, the drain current curves with forward and reverse sweeps do not coincide with each other, leading to very different results.

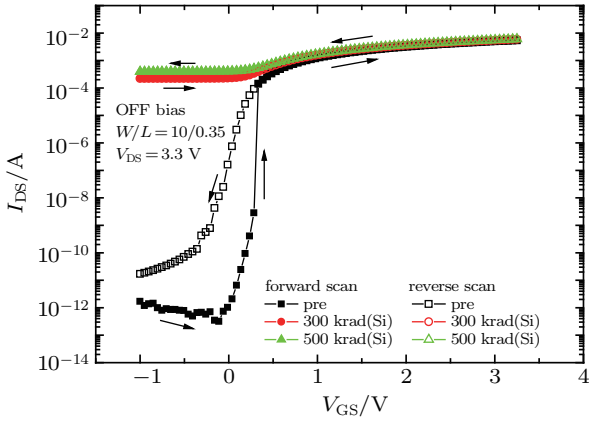



**Fig. 2.** (color online) $I_{DS}$–$V_{GS}$ curves of commercial H-gate SOI device before and after irradiation under OFF bias condition. The device was measured at $V_{DS}$ = 3.3 V with forward and reverse $V_{FG}$ sweep. Scan directions are indicated by the arrows in the figure.

We further investigated $I_{DS}$–$V_{GS}$ static characteristics verse dose of commercial H-gate devices under OFF bias configuration. As shown in Fig. 2, after 300 krad(Si) irradiation, a significant leakage current state occurs at the beginning of the $V_{FG}$ sweep. Moreover, the $I_{DS}$–$V_{GS}$ curves are nearly flat and coincide with each other during forward and reverse $V_{FG}$ sweep. It can be concluded that the device after OFF bias irradiation has been completely out of gate control and latched at the onset of forward $V_{FG}$ sweep. After 500 krad(Si) irradiation, latched drain current only has a slight increase as compared with 300 krad(Si). This is because the positive trapped charge in the BOX layer has nearly been saturated after 300 krad(Si) in the OFF bias case. It should be noted that latchup characteristics observed in OFF case for the PDSOI devices are similar to the results published in Ref. [19] for the fully depleted SOI (FDSOI) ones. This is because the trapped charge in the BOX layer resulting from TID irradiation can finally make the partially depleted body region to be fully depleted and lead to the coupling effect between front and back interfaces. Finally, according to the results shown in Figs. 1 and 2, we can conclude that devices under the OFF bias condition are more vulnerable to the TID induced STL effect than devices under the ON bias condition.

### 2.3. Impact of body doping concentration on single transistor latchup

Radiation-hardened H-gate devices are also investigated as compared with the commercial ones. With respect to the H-gate device, the leakage current is principally due to the positive trapped charge near the back-channel surface. Therefore, an important method to improve the H-gate device's resistance against TID induced degradation is improving the threshold voltage of the back-gate transistor by adjusting the body doping concentration. As for devices employed in our experiments, the hardened ones have a higher body doping concentration than the commercial ones.

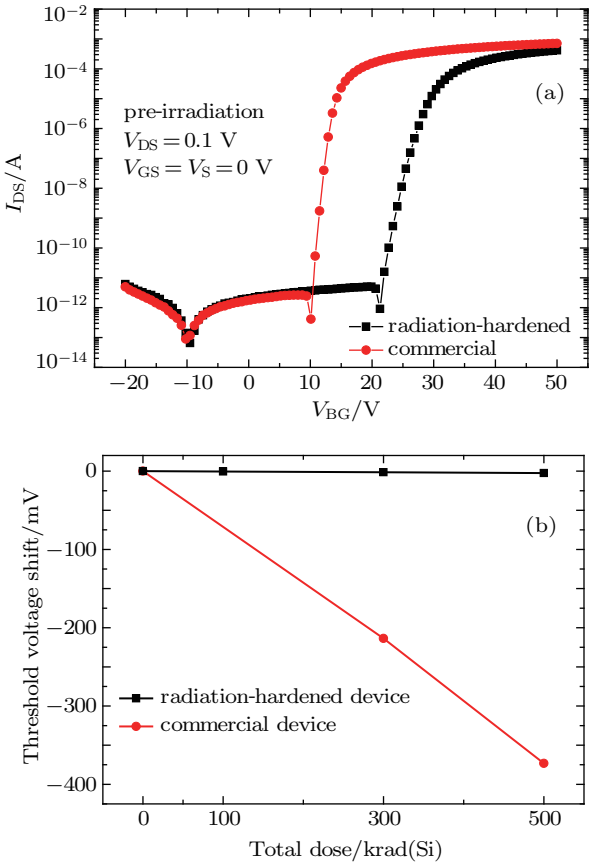



**Fig. 3.** (color online) (a) Back-gate transfer characteristics of commercial and radiation-hardened H-gate devices. Devices were measured before irradiation with drain voltage $V_{DS}$ = 0.1 V, the source and front gate were grounded. (b) Front-gate threshold voltage shift versus TID for commercial and radiation-hardened H-gate devices.

Figure 3(a) illustrates the back-gate transfer characteristics of radiation-hardened and commercial H-gate devices with different doping concentrations. It is clear that the radiation-hardened device with a higher doping concentration can result in a higher threshold voltage for the back-gate transis-

tor. Figure 3(b) shows the threshold voltage shift of the front-gate transistor versus TID irradiation for two different H-gate devices. Apparently, the threshold voltage shift of the commercial device increases to 373 mV after 500 krad(Si) irradiation, whereas the shift of the radiation-hardened device is almost zero, even though the dose level is accumulated to 500 krad(Si). Therefore, the high body doping concentration can make devices have greater resistance against the radiation-induced degradation, as well as the TID induced STL effect shown below.

Figure 4 shows the $I_{DS}$–$V_{GS}$ curves of the hardened H-gate devices under the OFF bias condition. Only hysteresis other than the latchup effect appears even though the dose level is up to 300 krad(Si). In contrast to the results shown in Fig. 2, the commercial H-gate device with a relatively low body doping concentration has already been latched after 300 krad(Si) irradiation under the same OFF bias condition. It should be noted that the latchup effect for the commercial H-gate device has occurred just at the onset of the forward voltage scan, even when there is no front channel current at negative gate voltage. However, the latchup phenomenon for the radiation hardened H-gate device has not been observed until after 500 krad(Si) irradiation during the reverse voltage scan. Therefore, it can be inferred that the high body doping concentration can effectively avoid the coupling effect observed in Fig. 2, and finally make the radiation hardened H-gate devices have a higher resistance against the STL effect as compared with the commercial H-gate devices.

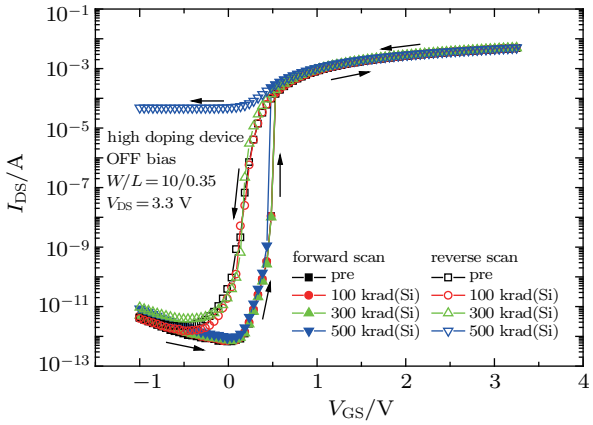



**Fig. 4.** (color online) $I_{DS}$–$V_{GS}$ curves of hardened H-gate SOI device before and after irradiation under the OFF bias condition. The device was measured at $V_{DS} = 3.3$ V with forward and reverse $V_{FG}$ sweep. Scan directions are indicated by the arrows in the figure.

### 2.4. Impact of drain voltage and its degradation

In the above discussion, TID induced single transistor latch effects are observed at high drain voltage $V_{DS} = 3.3$ V. The impact ionization induced by the high electric field at the drain body junction is usually suggested as a critical mechanism of the latchup effect. Hence, the latchup effect correlates strongly with the drain voltage, and it is necessary for us to study the onset drain voltage of the latchup.

In Fig. 5, front-gate $I_{DS}$–$V_{GS}$ curves measured with different drain voltages are presented after 500 krad(Si) irradiation under OFF bias. When $V_{DS} = 1.3$ V, only a slight increase for $I_{DS}$ has been observed between the forward and reverse $V_{GS}$ sweeps. However, when the $V_{DS}$ is up to 1.4 V, the $I_{DS}$ during the reverse sweep is almost 2.5 orders of magnitude higher than that during the forward sweep. Meanwhile, the reverse drain current can maintain this high value state even though $V_{GS}$ is down to $-2$ V. Therefore, we can regard $V_{DS} = 1.4$ V as the onset drain voltage for the TID induced latchup. It should be pointed out that the onset drain voltage can vary by the bias condition, the total dose level, and the device parameters like the body doping concentration.

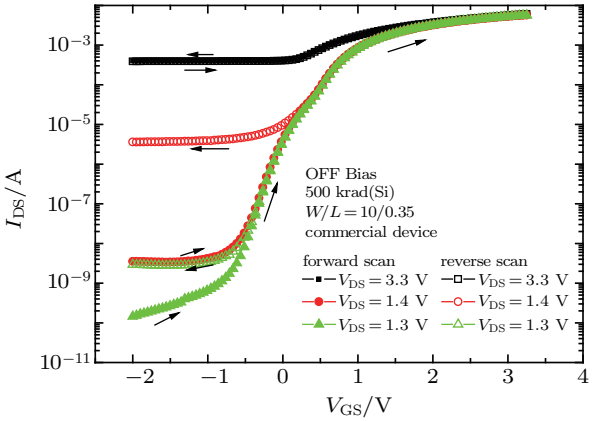



**Fig. 5.** (color online) $I_{DS}$–$V_{GS}$ curves of commercial H-gate SOI device irradiated under the OFF bias condition. Devices were measured at $V_{DS} = 3.3$ V, 1.4 V, and 1.3 V, after 500 krad(Si) irradiation under the OFF bias condition.

Three more experiments were conducted to further investigate the onset drain voltage for TID induced single transistor latchup. The details of experiment scenarios are as follows: 1) same bias conditions (ON bias), but different total dose levels (300 krad(Si) and 500 krad(Si)); 2) same total dose level (500 krad(Si)), but different bias conditions (ON bias and OFF bias); 3) same total dose level (500 krad(Si)) and same bias conditions (OFF bias), but different devices (commercial device with regular body doping concentration and radiation-hardened device with high body doping concentration).

The results are illustrated in Fig. 6. We can use the onset drain voltage as a criterion to measure the degradation of the STL effect. Smaller onset voltage means higher degradation of the STL effect. According to the results of the first scenario, the onset drain voltage degrades from 2.8 V to 2.5 V as the dose level increases from 300 krad(Si) to 500 krad(Si). This indicates that the onset drain voltage has a heightened sensitivity to TID irradiation, and the positive trapped charge in the BOX resulting from TID irradiation can degrade the onset voltage.

Moreover, the results of the second scenario can further demonstrate that the OFF bias condition is worse as to the TID induced STL effect. These results are consistent with the previously published data,[22] which mainly focused on the bias dependence for the shift of the subthreshold voltage or the off-state leakage current. Furthermore, as shown in the third scenario, the radiation-hardened device has a higher onset drain voltage compared with the commercial one, which can also prove that the high body doping concentration can mitigate the degradation induced by TID irradiation.

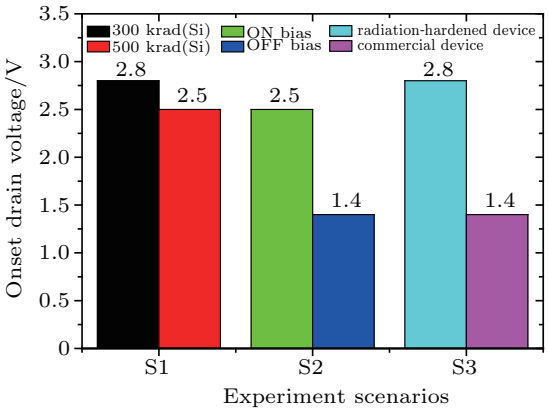



**Fig. 6.** (color online) Comparison of the onset drain voltages measured in three different scenarios.

### 2.5. Mechanism for single transistor latchup

STL as one of the floating body effects has been depicted by using an impact ionization (II) process in many previous studies. The II is very plausible in light of the fact that the current can be amplified significantly by the parasitic source–body–drain bipolar transistor. At high drain bias, electron–hole pairs are generated near the body–drain junction region owing to the II process, and the generated holes can finally accumulate in the floating body region to elevate the body potential. When the body potential is high enough to forward bias the parasitic body-to-source diode, more electrons can then drift to the body and be collected at the drain region to enhance the II process. Moreover, the increased body potential can also decrease the threshold voltage of the front gate, eventually resulting in an increase of $I_{DS}$ and much more II current. When H-gate devices are exposed to TID irradiation, the back-channel leakage current can also be collected by the drain and reinforce the II process, finally to form a positive feedback and lead to an abrupt rise of the subthreshold current.[14]

It should be pointed out that the II process strongly depends on the source current and the electric field being large enough to trigger the avalanche. This high field condition needed for the II process typically requires a high drain bias. However, the onset drain voltage of latchup can degrade to 1.4 V, according to our experiment results in the above discussion, which is not sufficient to form the strong electric field to trigger the II process, and electrons are also limited at the off-state ($V_{GS} < 0$ V). This implies that there exists another mechanism which can produce excess holes to accumulate in the floating body region, and eventually result in high drain current at negative gate bias.

Usually, several mechanisms are involved in the excess holes generation: 1) slow electron–hole recombination in the body region; 2) impact ionization process near the drain–body junction; 3) band to band tunneling due to the high electric field under the gate-drain overlap region; 4) thermal/optical generation carriers. In this work, the thermal and optical generation can be neglected for the operation at low temperature and dark conditions. It should be noted that the precise underlying mechanism of the latch effect is still a matter of debate. However, in the above discussion, we have found that the onset drain voltage at which latchup occurs can degrade as the total dose level rises, and the low drain voltage indicates that the probability of impact ionizing is very small. What is more, as the $I_{DS}$–$V_{GS}$ curves above show, while at $V_{GS} < 0$ V, the leakage current increases as the gate voltage becomes more negative whether pre or post irradiation. This phenomenon is attributable to gate induced drain leakage (GIDL) via band-to-band tunneling in the gate-to-drain overlap region.

Hence, it can be inferred that the gate induced drain leakage via band-to-band tunneling could be a critical mechanism that determines the drain current, including the apparent transition to the high current state. The most important difference between II and BBT is apparent that the II is initiated by the carrier supply and the electric field, whereas the BBT requires only the electric field. BBT is characterized by valence band electron tunneling across the silicon bandgap from the inverted drain surface across the Si bandgap into the quasi-neutral drain. The left valence band holes can then transport into the body region and raise its potential. The field dependent carrier generation rate of BBT can be expressed as

$$G_{\mathrm{BBT}} = A\varepsilon^{\sigma} \exp\left(-\frac{B}{\varepsilon}\right), \tag{1}$$

where $B$ is the tunneling probability constant ($\approx 30$ MV/cm), $\varepsilon$ is the magnitude of the local electric field, $\sigma$ is the transition constant ($\approx 2.5$ for Si), and $A$ is the effective mass of the electrons for Si ($4 \times 10^{14}$ V$^{-2}$·s$^{-1}$·cm$^{-1}$). The BBT-generated holes can directly affect the body potential and then enhance the parasitic bipolar conduction. Though, it is virtually impossible to evaluate the influence of BBT on the total dose latch experimentally, we can investigate how the electrostatic effects of the gate-voltage-induced BBT and trapped charge in the BOX combine to impact the negative gate bias leakage current response in irradiated PDSOI floating body devices through simulations in the following section.

### 2.6. Two-dimensional simulation

In order to investigate the TID induced single transistor latchup and the impact of BBT on it, we have chosen Sentaurus TCAD tools to conduct the two-dimensional (2D) simulations. Process simulation is chosen to produce the device structure and doping profile. Models employed in the device simulations contain high-field saturation mobility and doping dependent mobility degradation models. Band-to-band tunneling and Shockley–Read–Hall (SRH) recombination models are also required in the device simulations.[23] Note that the II model is turned off to exclude its effect on the results. Fixed charge is placed at the interface of the BOX layer and top silicon to perform the post irradiation simulations. The trapped charge density $N_{ot}$ is extracted according to the method introduced in Ref. [24]. Because oxide trapped charge density $N_{ot}$ is almost one order of magnitude higher than the interface trapped charge density $N_{it}$, as an approximate, we only choose $N_{ot}$ as $1.0\times10^{12}$ cm$^{-2}$, $1.7\times10^{12}$ cm$^{-2}$, $2.0\times10^{12}$ cm$^{-2}$ in our simulations. Figure 7 shows the simulated 2D structure of the floating body PDSOI NMOSFET.

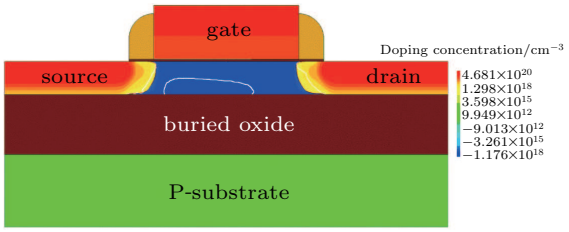



**Fig. 7.** (color online) 2D structure of a floating body PDSOI NMOSFET.

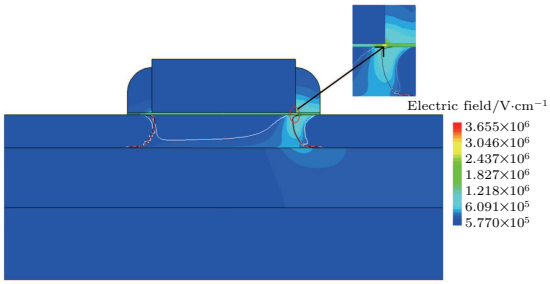



**Fig. 8.** (color online) Cross-section of simulated electric field in SOI NMOSFET with the BBT model. Trapped charge density $N_{ot}$ is $2.0\times10^{12}$ cm$^{-2}$, $V_{DS} = 3.3$ V, $V_{GS} = -1$ V, and the substrate and source are grounded.

BBT has been introduced to explain the high level leakage current in the above discussion. In order to examine the influence of BBT on a PDSOI device degraded by total dose, the tunneling model is turned on during the device simulation. Figure 8 shows the cross-section of the simulated electric field in SOI NMOSFET with the BBT model. Trapped charge density $N_{ot}$ is $2.0\times10^{12}$ cm$^{-2}$, $V_{DS} = 3.3$ V, $V_{GS} = -1$ V, and the substrate and source are grounded. It is clearly shown that a high electric field region appears in the drain region, underneath the gate–drain overlap, within the extended body–drain depletion region. Meanwhile, the back-channel depletion region can then interconnect the body–drain depletion region because of the existence of positive trapped charge in the BOX. This result further demonstrates that radiation induced positive trapped charge in the back-channel has a strong influence on the BBT process.

Figure 9 illustrates the simulated profile of the BBT induced generation rate within the high field region. The high generation of electron–hole pairs in the high electric field region without the II process can prove that BBT is one important mechanism for the high latch current. Furthermore, the BBT generated excess holes can accumulate in the body, and then forwardly bias the body–source junction to result in many electrons being back injected into the body. The following simulation of electron density in Fig. 10 can further support this point. Figure 10 shows the electron density across the p-type body at the front gate interface for simulations with and without the BBT model implemented. It is clear that the electron density with BBT is almost 7 orders of magnitude higher than that without the BBT model. It should be noted that the high density electrons can then drift to the drain as a supply of II, and reinforce this process to produce more carriers. In a word, the simulations in Figs. 8–10 can prove that the mechanism of the BBT process can also generate excess holes, which contribute a lot to the final STL effect.

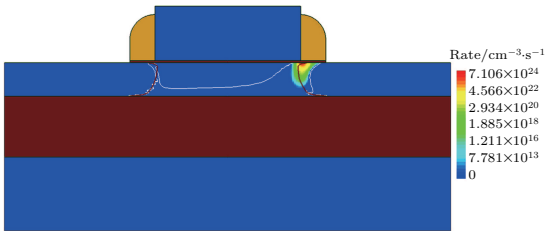



**Fig. 9.** (color online) Simulated profile of band to band tunneling induced generation rate within the high field region. Trapped charge density $N_{ot}$ is $2.0\times10^{12}$ cm$^{-2}$, $V_{GS} = -1$ V, $V_{DS} = 3.3$ V, and the substrate and source are grounded.

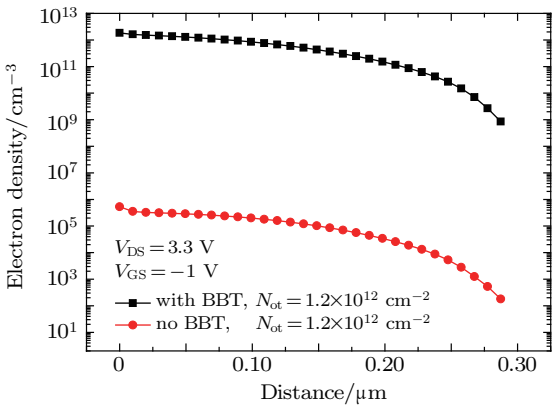



**Fig. 10.** (color online) Simulated electron density across the p-type body at the front gate interface with and without BBT. Trapped charge density $N_{ot}$ is fixed at $1.2\times10^{12}$ cm$^{-2}$, $V_{GS} = -1$ V, $V_{DS} = 3.3$ V, and the substrate and source are grounded.

Further investigation to examine the impact of the increased radiation exposure on a PDSOI device has been conducted as shown in Fig. 11. $V_{DS} = 3.3$ V, the substrate and source are grounded. Simulations are carried out by sweeping the $V_{GS}$ from $-1$ V to 3.3 V with the BBT model. It is obvious that the drain current increases as the gate voltage becomes more negative. This phenomenon is in agreement with the experimental results shown in Figs. 1 and 2. As the trapped charge density $N_{ot}$ at the back-surface increases, the BBT induced leakage current can increase exponentially. When $N_{ot}$ is up to $2.0\times10^{12}$ cm$^{-2}$, the leakage drain current at negative gate bias can reach to the magnitude of $10^{-5}$ A. This simulation indicates that BBT is a critical mechanism for the high latch current observed at negative gate voltage in our experiments.

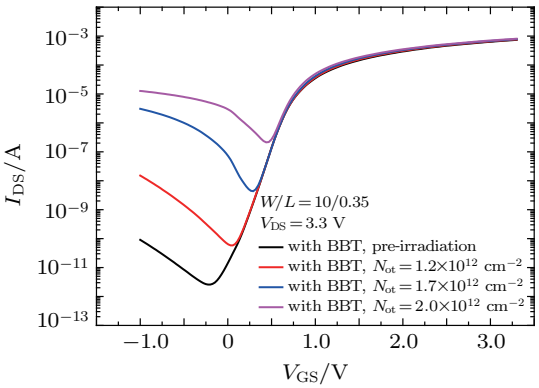



**Fig. 11.** (color online) Simulated PD SOI front gate $I_{DS}$–$V_{GS}$ curves as a function of trapped charge density $N_{ot}$ with the BBT model. $V_{DS} = 3.3$ V, the substrate and source are grounded.

Though the II model is turned off in the simulation, we cannot eliminate its effects on the final results. None of the BBT or the II can completely explain the total dose latch effect alone. In fact, carriers generated by the BBT can apply as a source for the II to further reinforce this process.

## 3. Conclusion

In this work, TID induced STL effects for the body-floated SOI devices have been studied in detail. Two different bias conditions (ON bias and OFF bias) are compared in experiments, and the results show that the OFF bias case is worse as to the total dose latchup effect. In addition, the high body doping concentration can make devices less sensitive to the TID induced single transistor latchup effect. It demonstrates that the onset drain voltage for single transistor latchup has a heightened sensitivity to TID irradiation, and positive trapped charge in the BOX resulting from TID irradiation can reinforce the degradation of the onset drain voltage. Band-to-band tunneling has been proposed as a critical mechanism to interpret the high latch current state at negative gate bias. 2D simulations have been conducted to evaluate the influence of BBT on the single transistor latch effect, and it demonstrates that the combination of BBT and charge buildup in the BOX contributes a lot to the high latch current. It should be noted that we are not claiming that the II cannot account for the latchup effect. Actually, carriers generated by the BBT can apply as a source for the II to further reinforce this process.

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