Electrical Stress on Irradiated Thin Gate Oxide Partially Depleted SOI nMOSFETs

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Abstract

The effect of hot-carrier stress on 60 MeV proton irradiated thin gate oxide partially depleted SOI nMOSFETs has been studied. The results are compared with those from the electrical stress of non-irradiated devices. Whereas no significant differences are observed for the front channel degradation, hot-electron trapping in the buried oxide is found to be enhanced in the irradiated devices. This hot-electron trapping leads to a compensation or neutralization of the effects caused by the radiation-induced positive trapped charges. It is shown that a similar hot-electron trapping enhancement can be achieved in non-irradiated devices stressed under certain back gate bias conditions.

Keywords: Silicon on insulator; Partially-depleted SOI; Hot-carrier degradation; Radiation-induced damage; MOSFETs

1. Introduction

SOI technologies are promising candidates for the continued scaling of transistor size [1]. However, the presence of the thick buried oxide (BOX) may introduce some constraints. It is well-known that they can suffer from radiation-induced positive charge trapping in the BOX [2-4]. Moreover, in the case of

hot-carrier (HC) degradation, opposite channel injection phenomena may occur [5]. The consequences increase as the silicon film thickness is reduced and gate coupling arises.

In this contribution, the effect of hot-carrier stress on 60 MeV proton irradiated thin gate oxide partially depleted (PD) SOI nMOSFETs is studied. The results are compared with those from the electrical stress of non-irradiated devices. The interaction and similarities between the radiation damage and the one generated during electrical stress at different conditions are studied.

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2. Experimental

The PD SOI nMOSFETs used in this study were fabricated in a 0.1 μm -CMOS process using PELOX isolation and a 2.5 nm nitrided gate oxide. The BOX and film thickness were 400 nm and 100 nm, respectively. Isolated transistors with polysilicon gate lengths (L) ranging from 0.08 μm to 10 μm and fixed width ($W=10\text{ }\mu\text{m}$) were used for this work. The devices had no film contact. Some samples were subjected to unbiased 60 MeV proton irradiations at the Cyclone cyclotron facility (Louvain-la-Neuve, Belgium). A fluence of $2 \cdot 10^{11}$ protons/ cm^2 was used, which corresponds to a dose suitable for space applications assessment. For the hot-carrier degradation (HCD) analysis, both, irradiated and non-irradiated transistors, were stressed at constant-voltage stress under different drain voltages (V_D) and at the worst-case front gate voltage (V_{FG}) regime for the HCD of these devices ($V_{FG}=V_D$) [6]. Front and back channel characteristics were regularly measured between stress phases and their respective threshold voltages (V_{Tf} and V_{Tb}) were extracted. Unless otherwise is indicated, the back gate was grounded ($V_{BG}=0\text{ V}$) and V_D was kept at 25 mV.

3. Irradiation+HCD: front channel characteristics

Figure 1 shows typical I_D - V_{FG} characteristics for a non-irradiated nMOSFET, as well as its characteristics after $2 \cdot 10^{11}$ protons/ cm^2 irradiation. An increase in the subthreshold leakage current (hump) is observed after irradiation, which is originated by the presence of radiation-induced positive trapped charges in the thick BOX, giving rise to a back channel parasitic conduction [7]. This radiation-induced I_D subthreshold leakage can be suppressed by applying a sufficiently negative V_{BG} , which keeps the back channel into accumulation [7]. However, in this work, it is shown that the radiation-induced subthreshold leakage can be progressively eliminated by the HCD of such irradiated devices (Fig. 1). Regarding the portion of the characteristics above V_{Tf} , no significant HCD differences have been observed between irradiated and non-irradiated devices. The degradation is initially dominated by a positive shift of V_{Tf} , with a turn-around behavior for sufficiently longer/harder stress conditions (Fig. 2) [6,8].

Fig. 1: I_D vs. V_{FG} for an $L=0.13\text{ }\mu\text{m}$ non-irradiated (virgin) nMOSFET, after $2 \cdot 10^{11}$ protons/ cm^2 irradiation and after different subsequent HC stress times at $V_{FG}=V_D=2\text{ V}$.

Fig. 2: Front gate threshold voltage shift (ΔV_{Tf}), versus hot-carrier stress time for different non-irradiated and irradiated nMOSFETs stressed under $V_{FG}=V_D$ conditions.

Fig. 3: Degradation of I_D values measured during stress for Fig. 2 nMOSFETs. (Where $\Delta I_{Dstress} \equiv I_{Dstress} - I_{Dstress0}$ and $I_{Dstress0}$ is the $I_{Dstress}$ value at the beginning of the HC stress).

Occasionally the degradation of the front channel characteristics has been found to be a bit larger in the case of the irradiated devices, but this is similarly accelerated for reduced L and increased stress bias conditions (Figs. 2 and 3). Regarding the impact on the I_D hysteresis that can be observed in these floating body devices, apart from the observed V_{Tf} shift and I_D hysteresis peaks degradation associated with the HCD [9], the only difference between irradiated and non-irradiated devices is the existence of an initial subthreshold I_D hysteresis in the case of the irradiated devices, which gradually vanishes with the progress of the HC stress (Fig. 4).

Fig. 4: $|I_D \text{ hysteresis}|$ (I_D difference between accumulation to inversion and inversion to accumulation V_{FG} sweeps) for an irradiated nMOSFET before HCD and after different stress times.

4. Irradiation+HCD: back channel characteristics

Interestingly, the degradation of the back channel characteristics is characterized by a significant positive V_{Tb} shift (Fig. 5), which is found to be enhanced in the presence of the radiation damage (Fig. 6). In this way, the effect of the radiation-induced positive trapped charges is neutralized or compensated by the trapping of hot-electrons in the thick buried oxide (Fig. 7). In the past, a minimal interaction between hot-carrier and X-ray radiation effects was reported for pMOSFETs of a 0.3 μm fully depleted SOI technology [3]. On the other hand, a higher sensitivity of the BOX to hot-carrier aging was observed in nMOSFETs using SIMOX substrates when the transistors were subjected to back channel hot-carrier stress [2].

Fig. 5: I_D vs. V_{BG} for an $L = 0.13 \mu\text{m}$ non-irradiated (virgin) nMOSFET, after $2 \cdot 10^{11}$ protons/ cm^2 irradiation and after different subsequent HC stress times at $V_{FG} = V_D = 2.25 \text{ V}$.

Fig. 6: Back gate threshold voltage shift (ΔV_{Tb}) versus hot-carrier stress time for different irradiated and non-irradiated nMOSFETs stressed under $V_{FG} = V_D$ conditions.

Fig. 7: Sketch of a PD SOI nMOSFET showing radiation-induced trapped holes in the BOX and subsequent hot-electron trapping, leading to a neutralization or compensation of the radiation-induced damage effects.

5. HCD at different back gate bias conditions

HCD experiments carried out under worst-case $V_{FG}=V_D$ regime and different V_{BG} have also revealed an enhanced BOX hot-electron trapping under $V_{BG}>0$ conditions (Fig. 8). It is inferred that the application of a positive V_{BG} in non-irradiated devices, or, similarly, the presence of radiation-induced trapped holes in the BOX, can enhance the hot-electron trapping. However, as in the case of the irradiated devices (Figs. 2 and 3), no appreciable V_{BG} -induced changes are observed for the degradation of the front channel characteristics (Fig. 8). Finally, the results from additional HCD experiments carried out under $V_{FG}\approx V_{TF}$ regime have shown that a different sign for the BOX trapped charges can be achieved depending on the V_{BG} applied during the HC stress (Fig. 9).

Fig. 8: Degradation of V_{TF} and V_{TB} for different non-irradiated nMOSFETs stressed under a fixed $V_{FG}=V_D=2.25$ V condition and different V_{BG} biases.

Fig. 9: ΔV_{TB} for different non-irradiated nMOSFETs stressed under a fixed $V_D=2.25$ V and low V_{FG} regime ($V_{FG}=0.7$ V) condition and different V_{BG} biases.

6. Conclusions

The effect of HC stress on 60 MeV proton irradiated PD SOI nMOSFETs has been studied. Whereas no significant differences are observed for the front channel degradation, hot-electron trapping in the BOX is found to be enhanced in irradiated devices. This leads to a compensation of the effects caused by the radiation-induced trapped charges. It is shown that a similar hot-electron trapping enhancement can be achieved in non-irradiated devices stressed under certain V_{BG} conditions. The degradation of the thick BOX can introduce some constraints in emerging SOI technologies.

Acknowledgements

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