Radiation Effects on Strain-Engineered p-MOSFETs


Abstract—Effects of heavy ion irradiation on process-induced strained-Si (PSS) p-MOSFETs are studied via simulation. It is shown that for the immediate (short term), irradiation can cause degradation in the transconductance and drain current.

Index Terms—radiation hardening, embedded SiGe S/D, traps, head-on collision.

I. INTRODUCTION

Many of the modern electronic systems are required to survive in considerably high radiation (such as alpha particle, heavy ion, gamma radiation etc.) environments, such as those naturally present in space or which are artificially created by machines or nuclear devices. Semiconductor devices are well known to be at risk in ionizing radiation. When heavy ions penetrate into a device structure, they usually loose the energy by generation of the electron–hole pairs. These charges perturb the normal operation of the device. Only a few reports have appeared in the literature on the effects of heavy ion damage in ultra thin gate oxide MOSFETs [1]. The impact of heavy ion damage on the electrical characteristics of deep submicron MOSFETs is still an open issue. The aim of this paper is to study the effect of ionizing radiation on process-induced strained-Si (PSS) p-MOSFETs characteristics.

II. DEVICE DESCRIPTION

In this work, towards calibration of our simulation results, we have chosen reported experimental strain-engineered p-MOSFET data for benchmarking from reference [2]. Fig. 1 shows the doping distribution in a PSS p-MOSFET and the location of the SiGe pockets. The final doping profiles for a cut line at the middle of the drain are shown in Fig. 2. The pockets show a depth of 58 nm. The MOSFETs have 46 nm effective gate length, 1.2 nm thick gate oxide and Si$_{0.83}$Ge$_{0.17}$ pockets.

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III. RESULT AND DISCUSSION

In this section, we present the main results obtained from simulation after the radiation hardening of the MOSFETs. The effect of a heavy ion, penetrating into the device in the middle of the gate, is modeled by generating electron-hole pairs in a cylindrical zone centered on the particle path. The incident particle, entering the device normally, is assumed to go through the target with a velocity of 2.7 nm/fs and the track diameter is 30 nm. The uniform radial density of generated pairs is adjusted according to the ion linear energy transfer. For the irradiation of the PSS p- and n-MOSFETs, the track has a constant LET value of 0.2 pC/µm across the track. The track length is 1µm ($l_{max}=1µm$) and the heavy ion crosses the device at the time 0.1 ps.

The MOSFETs show an appreciable change in the characteristics after irradiation, where a 7% change is observed. Comparison of $I_d$–$V_{gs}$ characteristics at $V_{ds} = -0.05$ V and $-1.25$ V simulated with SiGe and without SiGe pockets, before and after radiation are shown in Fig. 6.

The absolute value of threshold voltage required to turn on the p-channel MOS transistor increase due to total ionizing radiation damage. Oxide charge due to trapped holes and interface charge are both positive, contributing to a negative shift. At radiation doses, the contribution from oxide trap dominates and the threshold voltage increases. However, its effect on threshold voltage shift is lessened because the negative potential applied to turn ‘ON’ the transistor attracts the holes away from the SiO2/Si interface towards the gate. Transconductance or gain is defined as the ratio of $I_d$ to $V_{gs}$. Charges trapped near or at the SiO2/Si interface influences the mobility carriers beneath the channel. Radiation induced surface resistivity changes associated with lightly doped drain (LDD) regions in MOSFETS are also reported to degrade transconductance (Fig.7). Radiation-induced interface traps increase scattering of carriers in the channel of MOS transistors. This degrades the channel mobility of carriers. The following empirical relationship was reported to relate the degradation of normalized effective channel mobility with increase of interface trap density,

$$\mu = \frac{\mu_0}{1 + \alpha (\Delta N_i)}$$

where $\mu_0$ and $\mu$ are effective motilities before radiation and after radiation, respectively, $N_i$ is radiation induced interface trap increase and $\alpha$ is a fitting parameter.

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Fig. 8 show a decrease in drain current. E' centers are silicon “dangling bond” defects in SiO_2 in which an unpaired electron resides upon a silicon atom bonded to three oxygen atoms (Fig. 5). Recent experimental studies have shown that the oxygen vacancy E hole trap precursor has activation energy of about 1.5 eV [4]. The maximum energy transferred to silicon recoil for an elastic collision occurs when the heavy ion strikes the silicon atom in a “head-on” collision and is approximately 25 MeV [3], which is much greater than activation energy of E' trap. Therefore, this collision energy is sufficient to generate a physically damaged region (PDR) localized in the Si–SiO_2 interface. The decrease in transconductance and drain current for the transistors is due to the formation of this PDR localized in the Si–SiO_2 interface. Fig. 9 shows the threshold voltage shifts of bulk-Si p-MOSFETs and PSS p-MOSFETs before and after radiation. The shift is not the same for the both the devices and is higher in case of bulk-Si p-MOSFETs than strained-Si p-MOSFETs, indicating that the threshold voltage shift primarily depends on the strain incorporated in the PSS p-MOSFETs.

IV. CONCLUSION

Heavy ions in an energy range of ≤20MeV inflict significant damage to microelectronic devices. In this work, we have shown that heavy ion irradiation can severely affect the performance of process-induced strained p-MOSFETs. As for the immediate (short term) effects, irradiation causes a drop in the transconductance and drain current.

REFERENCES