ISDRS 2013, December 11-13. 2013

Heavy-ion and laser-induced transients in SiGe channel *p*MOSFETs

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SiGe-channel pFETs are leading candidates for high-mobility channel applications due to their (a) excellent V_{TH} controllability at thin equivalent oxide thickness (EOT) [1], (b) excellent reliability when combined with a Si capping layer and high-K dielectric stack [2-5] and (c) CMOS compatibility [4-5]. It is therefore important to study single-event radiation effects on SiGe-channel devices, in advance of their anticipated wide-scale commercial implementation, and their eventual use in space systems.

In this work, 14.3 MeV O^{6+} and backside two-photon absorption (TPA) laser irradiation are used to investigate single-event charge collection in SiGe channel *p*MOSFETs. Heavy-ion and TPA laser data show that the single-event transient (SET) pulse polarity can depend on the location of the strike along the device channel, which differs from SETs in Si-based CMOS devices. The drain bias can significantly affect the total amount of collected charge and peak current values of the SETs in the tested devices.

The $SiGe_{0.45}$ *p*MOSFETs were fabricated on an *n*-type 300-mm Si wafer with a 4.0 nm $SiGe_{0.45}$ layer deposited onto a 2.0 nm Si buffer. A 1.4 nm Si cap was partially oxidized, yielding an unconsumed 1.0 nm thick Si cap layer to passivate the $SiGe_{0.45}$ surface and improve the interface quality [2-5]. On top of the SiO_2 interfacial layer (IL), a ~1.5 nm HfO_2 layer and TiN metal gate were deposited [3,4]. The EOT of the gate dielectric stack is 1.5 nm. A sketch of the device is shown in Fig. 1, and the schematic band diagram in inversion is shown in Fig. 2. The dimensions of the tested devices are $W \times L$ = 10 μm ×10 μm, 1 μm × 1 μm, 1 μm × 0.12 μm, and 1 μm × 0.04 μm.

TPA occurs when two photons are simultaneously absorbed to create a single electron-hole pair [6,7]. SETs were measured using the experimental setup shown in Fig. 3. The DUTs were mounted in high-speed packages that were fixed on an *xyz* stage with 0.1-μm resolution. Details concerning the TPA laser setup and spot size measurement are in [8]. The 14.3 MeV O^{6+} experiments were performed using a Pelletron accelerator. During the experiment, the high speed packaged DUT was mounted in the vacuum chamber under the ion beam. The same electronics setup as for the TPA experiment was used to visualize and record the transients. The trigger channel was set on the drain with a threshold voltage of 2 mV. A semiconductor parameter analyzer, HP4156A, was used for DC bias during the experiment, as well as the I-V characterization before and after transient testing.

Fig. 4 shows typical laser induced transients at a struck drain in a SiGe channel *p*MOSFET with a dimension of $W \times L$ = 1 μm×0.12 μm under a bias condition of V_D = -1 V and $V_G = V_S = V_{Body}$ = 0 V. Fig. 5 shows the peak currents at the drain and source terminals as a function of the laser pulse location in the devices during TPA irradiation. The polarities of the transients are reversed for drain and source strikes, which does not typically occur for SETs in CMOS devices with Si channels. Similar SET pulse polarity inversion was seen for all channel lengths tested, from 10 μm to 40 nm. SET peak current magnitudes are ~ 3× greater for drain strikes than source strikes. We attribute the polarity inversion of the SET pulses in these SiGe *p*MOSFETs to a reduction in potential of the struck node due to the IR drop in the resistive Si layer that underlies the blanket well implant of these test devices, as we will discuss at ISDRS.

Figs. 6 and 7 show 14.3 MeV O^{6+}-induced transient peak current values from the gate, drain, source, and body terminals during negative and positive triggering, respectively. During ion irradiation, individual strike locations are randomized. Consistent with laser TPA results, large negative drain transients occur for negative triggering and positive drain transients for positive triggering. Fig. 8 shows the average peak SET values as a function of drain bias for the transients captured during heavy ion exposure with all other terminals grounded. The peak currents have a strong drain bias dependence for both the negative and positive triggering. Fig. 9 shows the collected charge as a function of drain bias during the heavy-ion exposure for a SiGe *p*MOSFET with dimensions of $W \times L$ = 1 μm×0.12 μm with all the other terminals grounded. A much weaker dependence on drain bias is observed for the collected charge.

In conclusion, we have measured SETs in SiGe channel *p*MOSFETs. We find a pulse polarity inversion for strikes near the source, which we attribute to voltage drops in the Si body that underlies the blanket *n*-well implant. The transient peak current increases with increasing drain bias magnitude, but the total collected charge is nearly independent of drain bias for the devices and experimental conditions of this work. We will compare these results to SETs in Si-based CMOS devices at the ISDRS.

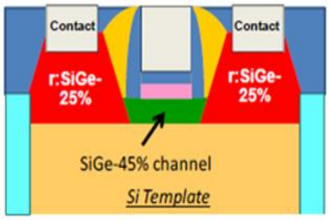

Fig. 1.Schematic diagram of the SiGe channel MOSFET with raised SiGe source/drain region in this work. The material for the channel is $SiGe_{0.45}$, with $SiGe_{0.25}$ for the source/drain. After [3].

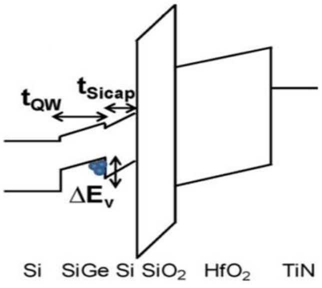

Fig. 2. Band diagram in inversion for SiGe *P*FETs in this paper. After [4].

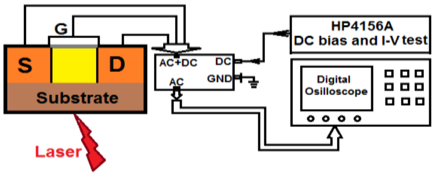

Fig. 3. Schematic diagram of the experimental setup used to record transients in SiGe MOSFETs during TPA experiments. A 12 GHz TDS6124C oscilloscope with 50 Ω input impedance was used to visualize and record the transients. The laser beam was focused using a 100× microscope objective to a charge generation spot size of approximately 1.2 µm. Laser pulses with a wavelength of 1260 nm and a normal pulse width of 150 fs at a repetition rate of 1 kHz were used; the oscilloscope trigger was synchronized with the laser signal.

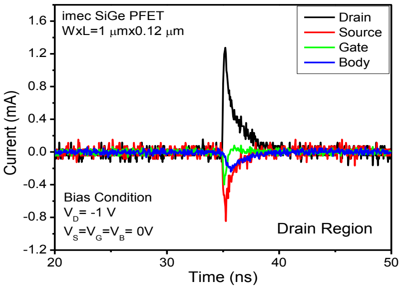

Fig. 4. SET captured during TPA experiment for a SiGe *p*MOSFET with a dimension of $W \times L = 1$ µm x 0.12 µm with the bias condition of $V_D = -1$ V and $V_G = V_S = V_B = 0$ V.

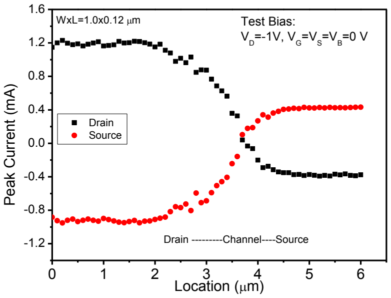

Fig. 5. Peak current on drain and source *vs.* the laser location during TPA irradiation for the device of Fig. 4 with the same bias condition.

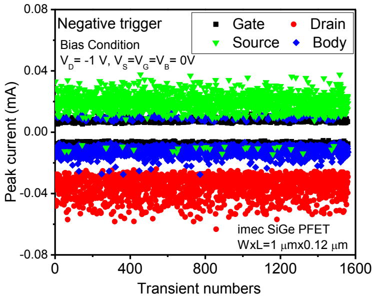

Fig. 6. Negative triggering peak current for the devices of Figs. 4 and 5, exposed to 14.3 MeV O^{6+} irradiation; the biases are $V_D = -1$ V and $V_G = V_S = V_B = 0$ V.

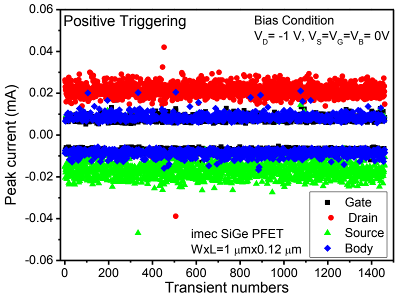

Fig. 7. Positive triggering peak current for gate, drain, source, and body for 14.3 MeV O^{6+} irradiation, for the same device with the same bias condition as in Fig. 6.

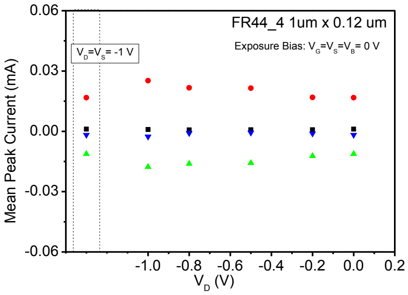

Fig. 8. Average peak current as a function of drain bias during heavy ion exposure for a SiGe *p*MOSFET with a dimension of $W \times L = 1$ µm×0.12 µm with all the other terminals grounded ($V_G = V_S = V_B = 0$ V).

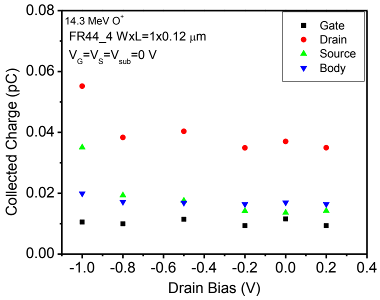

Fig. 9. Collected charge as a function of drain bias during the heavy ion exposure for a SiGe *p*MOSFET with a dimension of $W \times L = 1$ µm×0.12 µm with all the other terminals grounded ($V_G = V_S = V_B = 0$ V).

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