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Direct Measurement of Transient Drain Current in PD-SOI MOSFETs Using Nuclear Microprobe for Highly Reliable Device Design

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1. Introduction

Soft error in memory and logic devices for the next generation will become more severe. Thin-film SOI MOSFETs can realize highly reliable devices due to the buried oxide. However, characteristics with floating channel SOI MOSFETs suffer from parasitic bipolar effects[1]-[3]. Therefore, body-tied structures are necessary to suppress excess carrier accumulation in the channel regions[4][5]. Significantly low soft error rate of body-tied SOI SRAM was also reported[6]. However, detailed analysis of effects the body-tied for partially-depleted(PD) SOI MOSFET by proton incidence has not been reported.

In this report, transient drain currents on the PD-SOI MOSFETs are observed directly by proton microprobe irradiations. Analysis by using device simulation is performed for measurement SOI MOSFETs with and without body-tie. It is found that drain currents increase of the body-tied SOI MOSFETs are suppressed even in high incident conditions, and the body-tied structure is considered to be necessary for sub-quarter micron generations and below. Moreover, a highly reliable structure of the body-tied SOI MOSFET is proposed.

2. Experiment

Parallel connection for 10000Trs of PD-SOI MOSFETs were used to measure the drain currents during and after proton irradiation. Proton irradiation energy was 1.3MeV, and currents were 5～250pA. The condition of the 5pA almost corresponds to that of the 5MeV alpha particles incidence. Transient drain current characteristics of the PD-SOI MOSFETs with and without body-tied conditions were compared. Gate length and channel width were $0.6\,\mu$ m and $10.0\,\mu$ m. The thickness of the gate oxide and buried oxide were 7nm and 380nm, respectively. 3-dimensional device simulation was also performed to analyze the transient characteristics after proton irradiations. The number of proton particles was changed from 1 to 1000 in order to compare for the measured results.

3. Results and discussion

Fig. 1 shows schematic diagram of a simulated SOI MOSFET. Structures with and without body-tie were compared, and body-electrode was fabricated on the side of the channel region in case of the body-tied MOSFET. Proton was struck at the center of the channel region. Mechanism of the transient drain current flows is shown in Fig. 2. Incident proton induced electron-hole pairs in SOI body region. Body potential increased by created holes accumulation, and electron currents flow due to the increased potential. Transient drain current characteristics and drain collected charge(Qd) with and without body-tied MOSFETs are compared in Fig. 3. Drain current of the body-tied MOSFET was recovered at 10^{-8} sec after proton strike. However, drain current without body-tied(floating) MOSFET was kept at high level due to the floating body effects. Qd increasing of floating MOSFET was not saturated until to 10^{-6}sec.

Fig. 4 shows the measured drain current characteristics of the proton irradiated SOI MOSFETs. Just after the proton incidence, drain current of the floating MOSFET increased rapidly. This phenomenon is caused by the parasitic bipolar effect as explained in Fig. 2.

Fig. 5 shows the simulated and measured Qd of SOI MOSFETs with and without body-tied structures. The number of protons was changed from 1 to 1000 particles, and generated electron-hole pairs in the SOI layer were about from 2×10^3/cm^3 to 2×10^6/cm^3. For many-particles case, both of the simulated and measured Qd of floating SOI MOSFETs were larger than those of the body-tied MOSFETs. These results indicate that the generated excess carriers by the proton irradiation were collected through the body-electrode near by the channel. For few-particles case, however, generated charge(Qi) and Qd were almost the same for the SOI MOSFETs between with and without body-tied structures. These results show the parasitic bipolar action was not occurred remarkably even in the floating SOI MOSFETs, because channel profile was optimized for the $0.35\,\mu$ m rule device, and channel width was set wide condition. Measured Qd of MOSFETs with and without body-tie were also almost the same in low beam current conditions. From these results, Qd increased for the floating SOI MOSFETs even in the optimized conditions; for instance, increased channel impurity, longer and wider channel.

Stability of the body-tied structure was investigated for narrower MOSFETs. Figs. 6 and 7 show the comparison for Id and Qd between with and without body-tied MOSFETs. Qd of the narrow channel body-tied MOSFET is lower than that of wide channel MOSFET. However, dependence of Qd on channel width was smaller than that on the body-tied MOSFET because of increased large channel potential due to the low parasitic capacitance(Fig. 8). Fig. 9 shows the body currents of the MOSFETs. Holes in W=$1\,\mu$ m MOSFET were extracted rapidly due to the lower body resistance(R).

We propose the highly reliable body-tied structure as shown in Fig. 9. Body impurity concentration near the bottom surface region is increased for reducing body resistance. Simple analytical model is shown in Fig. 10. Estimated Qd of the proposed MOSFETs by using the equations is lowered with reducing the body resistance. These results indicate the superiority of body-tied MOSFET with proposed structure. It is suggested that SOI devices of narrow channel body-tied structures are realized for reliable operation under radiation exposed environment.

4. Conclusions

Transient Drain current in PD-SOI MOSFETs by using proton microprobe irradiation were analyzed. It was found that body-tied SOI MOSFET can suppress for increasing Qd even in the high irradiation conditions. Mechanism of suppression for Qd increase of narrow channel MOSFET is indicated. Moreover, lowered body resistance of body-tied SOI device structure is proposed for high soft error immunity. It is suggested that the concept will be usable for the next generation.

Reference

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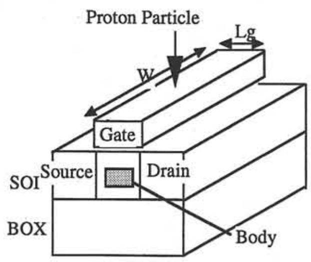


Fig.1 Schematic diagram of the simulated SOI MOSFET by proton micro probe irradiations.

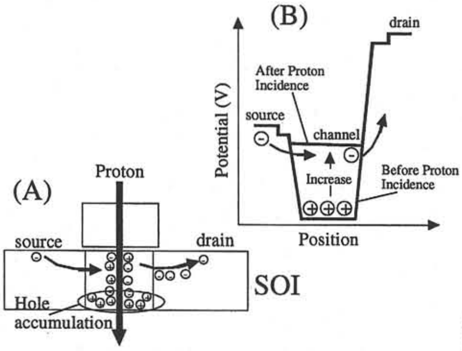


Fig.2 Cross sectional views of the SOI MOSFET (A) , and Potential profiles before and after proton incidence(B). Mechanism of transient drain currents flow by proton incidence is shown.

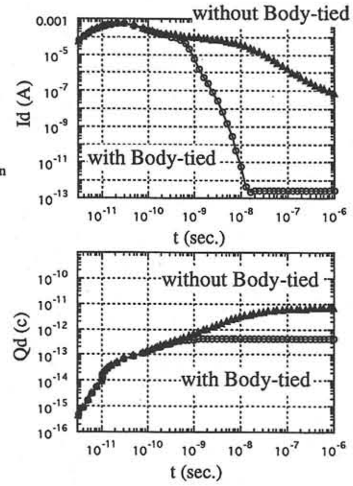


Fig.3 Simulated drain currents and drain collected charge(Qd) as the function of the time for the SOI MOSFETs with and without body-tied structures. 1000 ions was struck.

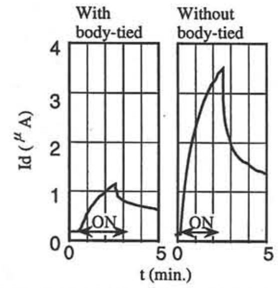


Fig.4 Measured Id-t characteristics with and without body-tied SOI MOSFETs by proton micro probe irradiations. Beam current was 250 pA.

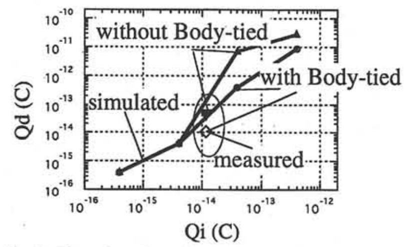


Fig.5 Simulated and measured Qd vs. generated charge(Qi) in the SOI MOSFTEs with and without body-tied structures. L/W=0.6 μ m/10.0 μ m Charge was calculated to 1 μ sec.

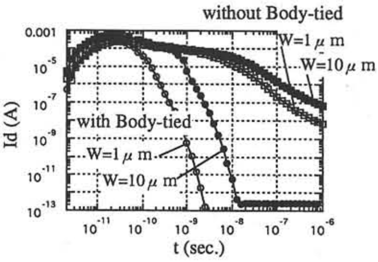


Fig.6 Simulated Id vs t of SOI MOSFETs with and without body-tied structures. Channel width of those MOSFETs were 10 μ m and 1 μ m, respectively.

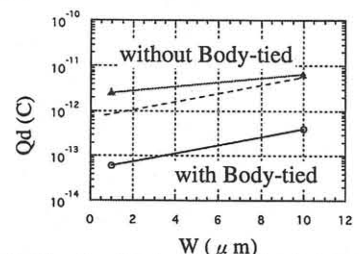


Fig.7 Simulated Qd vs channel width(W) of the with and without body-tied SOI MOSFETs.

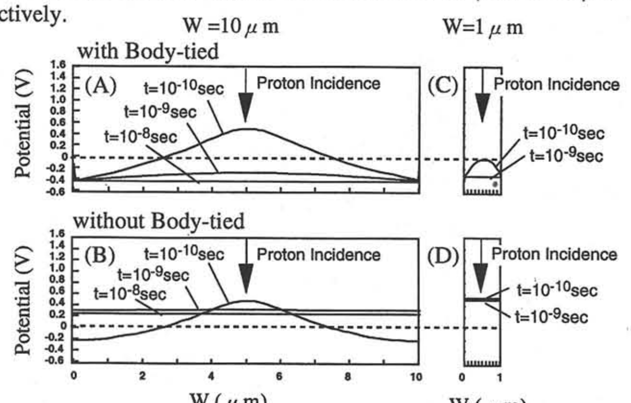


Fig.8 Simulated potential profiles for channel width directions. (A)body-tied structures(W=10 μ m), (B)without body-tied structures(W=10 μ m), (C)body-tied structures(W=1 μ m), (D)without body-tied structures (W=1 μ m),

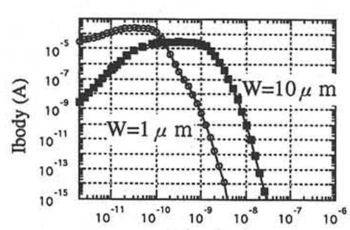


Fig.9 Simulated body currents as the function of the time for the SOI MOSFETs.

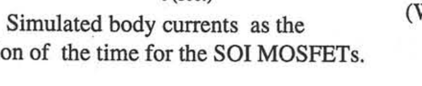
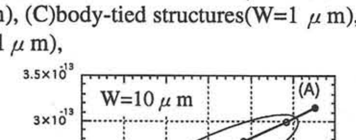


Fig.10 Schematic crosssectional views of the normal SOI MOSFET(A) and proposed SOI MOSFET(B) . Channel impurity concentration was increased in the bottom SOI channel region for the MOSFET(B) to suppress for increassing Qd by proton irradiation.



$Qd = \int Id(t)\,dt$ (1)

$Id(t) \propto \exp(q/kT \times V(t))$ (2)

$V(t) = Vm \times \exp((tm-t)/RC) - Vinit.$ (3)

$R = \rho \times W/(L \times tSOI)$ (4)

$C = Cox$: Gate Capacitance (5)

V(t): channel potential at t.

Vm: maxinum channel potential.

Vinit: channel potential before proton incidence.

tm: time at channel potential reached to maxinum.

Fig.11 Estimated Qd by using analytical equations(1)-(5) for normal MOSFET(A) and proposed MOSFET(B) with body-tied structures. Qd of the (B) structure will be reduced.