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Simulated Transient Behavior of Partially Depleted 0.18 μm SOI n-MOSFET

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silicon on insulator (SOI), floating body, transient behavior

2-D simulations are used to study the behavior of partially depleted SOI devices under transient conditions. The parameter of interest is the potential of the floating body (V_{body}) which determines important device parameters such as threshold voltage and breakdown. Two phenomena govern V_{body}: capacitive coupling of the body to the other nodes of the device and impact ionization currents generated near the drain. Capacitive coupling, particularly to the drain, affects V_{body} during transients of arbitrarily short duration. On the other hand, impact ionization requires a finite body charging time to affect V_{body}. This charging time due to impact ionization has been simulated and depends critically on the bias condition.

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INTRODUCTION

In partially depleted SOI devices, a neutral substrate region exists at all bias conditions of interest. The potential of this floating region is important since it influences the threshold voltage of the MOSFET. The floating body also forms the base of a parasitic open-base bipolar which controls the breakdown behavior of the device. In steady state, the body potential (V_{body}) is determined by the currents injected into the neutral substrate region which may originate from thermal generation or impact ionization. In the transient state, the body potential is also governed by the coupling of the substrate region to the other device nodes via junction, depletion and oxide capacitances. In this study we focus on the effect of the drain-to-body capacitance and the body charging time due to impact ionization currents.

SIMULATIONS

The SOI structure used in this simulation study has a silicon film thickness of 0.1 μm with a constant $10^{18} cm^{-3}$ p-type doping. The 0.18 μm gate electrode is n+ polysilicon with 4 nm gate oxide. The source/drain structure uses shallow moderately-doped extensions. The threshold voltage is 0.5V at $V_{body}=0$ decreasing to 0.25V at $V_{body}=+0.6$V. The 2-D device simulator MEDICI^{TM}(1) was used for all simulations. Poisson's equation, electron and hole continuity equations, and the electron energy balance equation were solved simultaneously. Carrier-temperature dependent impact ionization was included self-consistently in all simulations. Lattice temperature was not included. Band-gap-narrowing and auger recombination were included to get realistic estimates for the emitter efficiency of the parasitic bipolar. The Shockley-Read-Hall minority carrier lifetime was varied. This has the effect of changing the ideality of the base current.

RESULTS AND DISCUSSION

Fig. 1 shows a simple example of transient behavior. Here the drain node is pulled up to 1.5V in 100 ps. The V_{body} increases due to capacitive coupling between the drain and floating body. This behavior is independent of impact ionization for short enough periods of time. Figs. 2 and 3 show the transient V_{body} (at $t=300ps$) resulting from various drain sweeps (all 100 ps in duration). Also shown, for comparison, are the steady-state values of V_{body}. These results indicate that the SOI device may exist in transient states that are substantially different than the corresponding steady-state conditions. In Fig. 3, for V_{drain} greater than 2.0V, the transient value of V_{body} becomes critically dependent on impact ionization, indicating that the ionization current is large enough to partially charge the body within 300 ps.

Figs. 4 and 5 show the time evolution of V_{body} after the 100 ps V_{drain} (1.5V) ramp. In Fig. 4 the device is in the off-state and the steady-state currents are very small, thus V_{body} changes slowly. This long-lived (at least 1μs) transient value of V_{body} is independent of impact ionization and carrier lifetime. In Fig. 5, the device is in the on-state and the impact ionization current is much larger, resulting in faster charging of the body. For $V_{drain}=1.5$V, the body charging time is roughly 30 ns decreasing to about 300 ps at V_{drain} = 2.5V. In circuit applications, these long lived transients cause device characteristics to become a function of the history of the device operation.

Fig. 6 shows the IV characteristics resulting from a set of transient simulations. Here V_{drain} is ramped from zero to 2.5V over various times (0.1, 1, 10, 100, 1000 ns) for several gate biases. Two distinct features are apparent in this figure: the high output conductance and the kink effect. The high output conductance is due to capacitive coupling between drain and body which occurs even at low V_{drain} and is independent of impact ionization. For the fastest ramp time (100 ps) this effect dominates and I_{drain} is almost independent of impact ionization even at high V_{drain} (2.5V). For V_{drain} = 1.5V, I_{drain} is independent of impact ionization for ramp times of 10 ns or less. The kink in I_{drain} results when the impact ionization current has sufficient time to charge the body. Fig. 6 demonstrates the time and voltage dependence of this phenomenon.

CONCLUSIONS

Transient 2-D simulations have been used to study the behavior of partially depleted SOI devices. The capacitive coupling of the drain to the body has a significant effect on V_{body}. The body charging time due to impact ionization has been simulated and depends critically on the bias condition.

(1) Technology Modeling Associates, Palo Alto, CA. Medici User's Manual, Version 2.0 (1994)

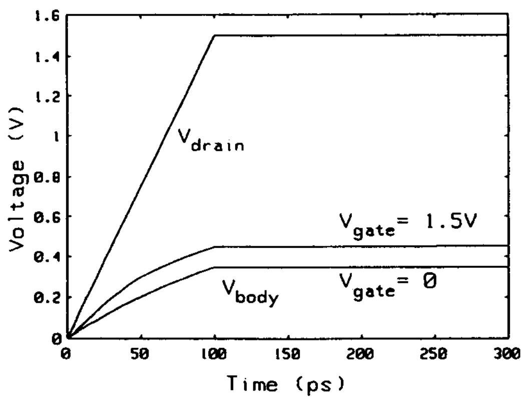

Fig. 1 Transient Simulation: The drain voltage is ramped from zero to 1.5V in 100 *ps* and then held constant. V_{body} follows due to capacitive coupling to the drain. In this example impact ionization has no effect.

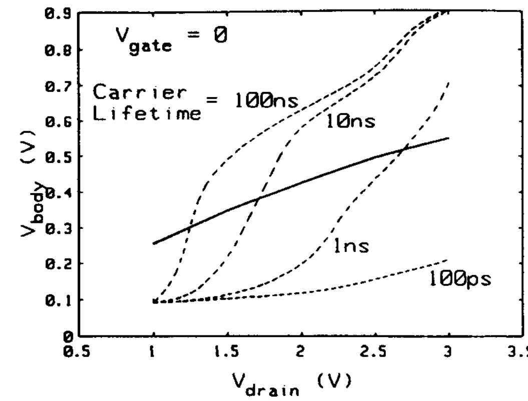

Fig. 2 Comparison of transient and DC: Transient = solid line; DC = dashed line. For the transient case, the V_{drain} ramp time is 100 *ps* in all cases and the V_{body} is measured at t = 300 *ps*. V_{body} (transient) does not depend on impact ionization or carrier lifetime.

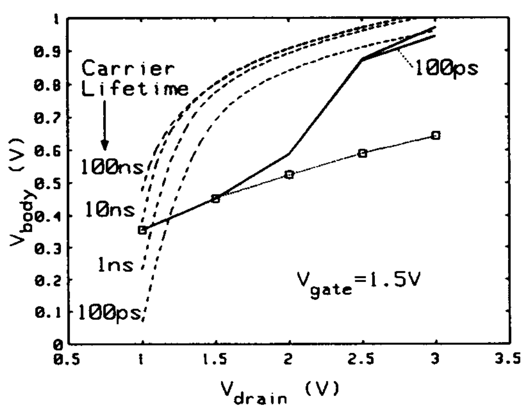

Fig. 3 Comparison of transient and DC. Transient = solid line; Transient without impact ionization = symbols; DC = dashed lines. For the transient cases, the V_{drain} ramp time is 100 *ps* in all cases and the V_{body} is measured at t = 300 *ps*.

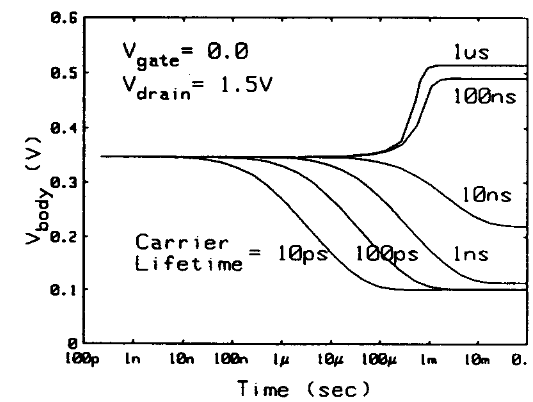

Fig. 4 Time Evolution of V_{body}. This figure continues the time axis of the simulation in Fig. 1.

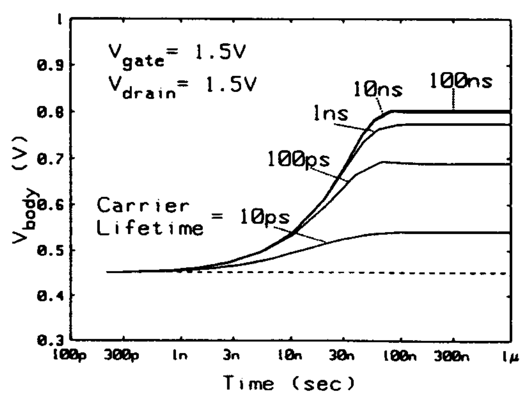

Fig. 5 Time Evolution of V_{body}. This figure continues the time axis of the simulation in Fig. 1. Dashed line is for no impact ionization.

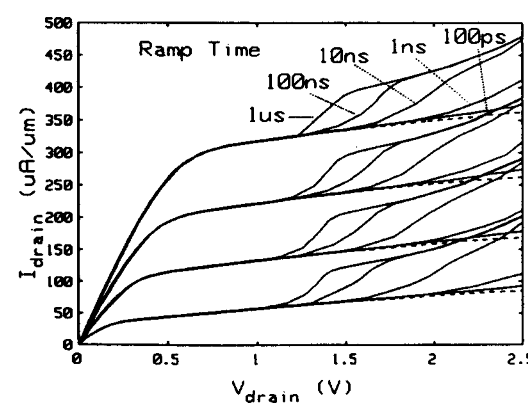

Fig. 6 Transient IV Characteristics. V_{drain} is ramped from zero to 2.5V in varying times for V_{gate} = 0.75, 1.0, 1.25 and 1.5 V. Dashed lines are for no impact ionization.