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Modeling of Floating-Body Effect in SOI-MOSFET with Complete Surface-Potential Description

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1. Introduction

Silicon-on-insulator (SOI) MOSFETs are considered to be suitable for high performance circuits due to its improved subthreshold slope and reduced junction capacitance [1]. However, compact models for SOI-MOSFETs are still under development for advanced applications. The main reason is a lack of the floating-body-effect model providing accurate at the same time stable circuit simulation. We have developed the circuit simulation model HiSIM-SOI based on the complete surface-potential description, solving not only the surface potential at the front-gate oxide (FOX) but also two surfaces at both sides of the buried oxide (BOX) isolation [2]. The model is extended to include the floating-body effect, which is done by considering stored charge at the source side in the Poisson equation after its origin.

2. Floating-Body Effect

If the impact ionization occurs, the drain current I_d of SOI-MOSFETs unusually increases much steeper as a function of the drain voltage V_d than that of bulk-MOSFETs. The enhanced I_d increase called the kink effect reaches easily up to 50% as shown in Fig. 1a. The problem caused by the impact ionization is demonstrated in Fig. 1b as an example for a ringoscillator, where the amplitude reduces down to about 1/3. Usually the kink effect is modeled by considering a parasitic bipolar junction transistor due to the impact ionization [3]. However, the real reason of the current increase is the potential increase at the source side by stored holes as schematically shown in Fig. 2. Thus accurate modeling of the phenomenon can be done only by the surface-potential-based approach considering the potential distribution along the channel.

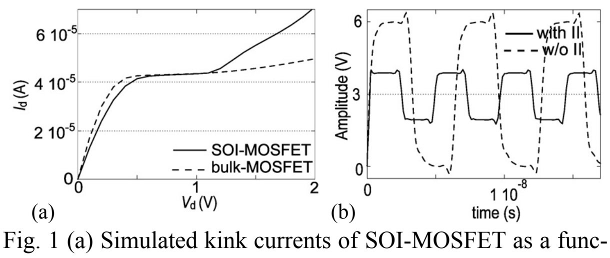

Fig. 1 (a) Simulated kink currents of SOI-MOSFET as a function of V_d in comparison to a bulk-MOSFET. (b) Transient analysis of a ringoscillator with the impact ionization (II) and without.

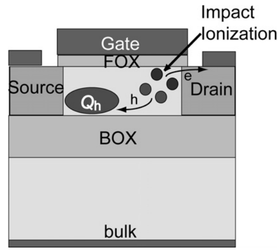

Fig. 2. Schematic of the stored hole Q_h generated by the impact ionization.

3. Modeling with Surface Potentials

As shown in Fig. 3, SOI-MOSFETs include three surface-potentials; $\phi_{s.SOI}$ at the front surface, $\phi_{b.SOI}$ at the back side of the SOI layer, and ϕ_{bulk} at the bulk surface. These surface potentials are strongly dependent on applied voltages. Therefore we solve the Poisson equation iteratively to calculate surface-potential values accurately. It has been investigated that the fully depleted (FD) SOI-MOSFET provides more stable *I-V* characteristics and more suitable for high performance applications than the partially depleted (PD) SOI-MOSFET [4]. Hence we focus on the FD SOI-MOSFET here.

Basic equations of the SOI-MOSFET for describing device features at given gate voltage (V_g) are

$$V_g - V_{fb} - \Delta V_{th} = \phi_{bulk} - \frac{Q_{bulk}}{C_{BOX}} + \phi_{SOI} - \frac{Q_{bulk} + Q_{SOI}}{C_{FOX}} \quad (1)$$

$$\phi_{SOI} = \phi_{s.SOI} - \phi_{b.SOI} \quad (2)$$

$$Q_{SOI} = Q_{dep} + Q_i \quad (3)$$

derived from the Poisson equation together with the Gauss law. V_{fb} and ΔV_{th} are the flat-band voltage and the threshold voltage (V_{th}) shift from a long-channel transistor, respectively. C_{BOX} and C_{FOX} are capacitances of BOX and FOX, respectively, and Q_{bulk} and Q_{SOI} are charges in the bulk layer and the SOI layer, respectively. Finally, Q_{dep} is the depletion charge and Q_i is the inversion

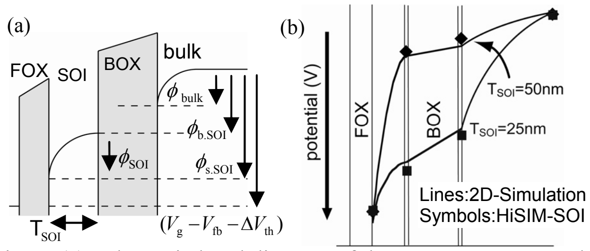

Fig. 3. (a) Schematic band diagram of the SOI-MOSFET, and its (b) calculated potential distributions along the depth direction.

charge. For FD SOI-MOSFET Q_{dep} is expected to be a constant value.

4. Modeling of Floating-Body Effect

The impact ionization generates electron-hole pairs, and these electrons flow to the drain and holes to the bottom of the SOI layer at the source side. The holes cannot flow into the source and are stored as depicted in Fig. 2. Simulation results of the potential distribution with a 2D-numerical device simulator are shown in Fig. 4a and its magnified scale in Fig. 4b. An important effect observed is that the potential value at the back side of the SOI layer $\phi_{b.SOI}$ increases drastically as the strength of the impact ionization increases, namely increase of the drain voltage V_d.

The stored hole Q_h is included in the Poisson equation as

$$V_g - V_{fb} - \Delta V_{th} = \phi_{s.bulk} - \frac{Q_{bulk}}{C_{BOX}} + \phi_{SOI}^{II} - \frac{Q_{bulk} + Q_{SOI}^{II}}{C_{FOX}} \quad (4)$$

$$Q_{SOI}^{II} = Q_{dep} - Q_h + Q_i \,. \quad (5)$$

For solving the Poisson equation Q_h has to be known. It is done with use of the hole current induced by the impact ionization. Thus Q_h is obtained by integrating the impact ionization current I_h with respect to the time as

$$Q_h(t) = \int_0^t \beta\, I_h\, dt \quad (6)$$

where β represents the decay of the charge storage as a function of time t. The reason is that the increase of the stored charge results in the hole flowing out to the source. Here I_h is equal to the substrate current I_{sub} of the SOI-MOSFET with the body contact or the bulk-MOSFETs. It has been reported that the time required until Q_h reaches its saturation condition (t_{sat} in Fig. 5a) is an order of nano second or less [4]. Therefore we ignore the time, and Q_h is modeled with the I_{sub} observed under the DC condition. Fig. 5b shows calculated Q_h as a function of I_{sub} with a 2D-device simulation. The calculation of Q_h is done by integrating stored holes in the SOI layer. From the calculated Q_h-I_{sub} characteristics, Q_h is approximated by a power function of I_{sub}. The Poisson equation including Q_h is solved by the Newton iteration.

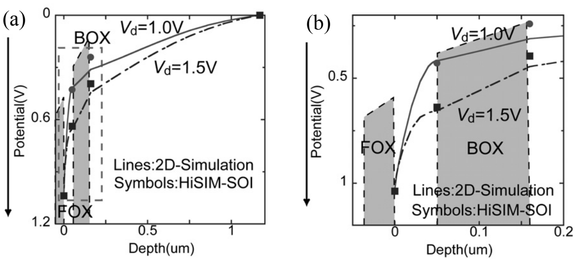

Fig. 4. Calculation results of the potential distribution, (a) the whole SOI-MOSFET vertical to the surface, and (b) with a magnified scale for the rectangular region marked by dash line in (a). Lines are 2D-device simulation results and symbols are HiSIM-SOI results.

5. Results and Discussion

Calculated surface potential values with the extended HiSIM-SOI are depicted gather in Fig. 4 by symbols. The result is shown for V_d=1.0V and 1.5V. The former voltage (V_d=1.0V) is a little bit smaller than the threshold voltage of the impact ionization, and V_d=1.5V is above the threshold. It is seen that HiSIM-SOI reproduces 2D-device simulation results very well. Calculated result shows drastic potential increase of the back side of the SOI layer for V_d=1.5V. Whereas V_d=1.0V induces no such effect. For the case of V_d=1.5V, the potential distribution along the depth direction is no more steep as the V_d=1.0V case. This shallow potential distribution induces the quasi PD condition. Under the condition, Q_{dep} is no more constant but is bias dependent. This effect is also included in HiSIM-SOI.

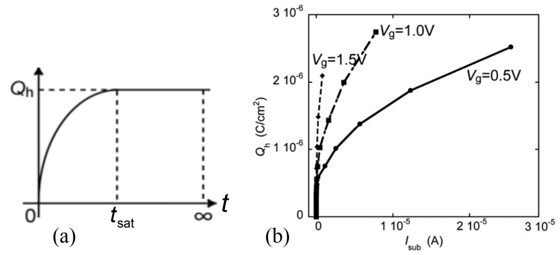

Fig. 5 (a) Schematic of the transient characteristic of Q_h. t_{sat} determines the saturation time which is an order of nsec or less. (b) Calculated saturated Q_h($t > t_{sat}$) as a function of the substrate current with a 2D-device simulator.

Fig. 6, shows a calculated I_d characteristics as a function of V_d in comparison to 2D-device simulation results. A good agreement is obtained. The reason for this high accuracy of HiSIM-SOI is the consistency of the floating-body effect modeling based only on the impact ionization.

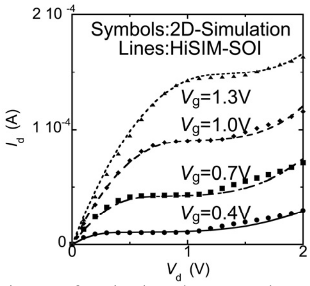

Fig. 6. Comparison of calculated I_d-V_d characteristics with HiSIM-SOI (lines) and a 2D-device simulator (symbols).

6. Conclusion

We have developed a compact model for the floating-body effect by introducing the stored charge in the Poisson equation. The model has been proved to calculate the potential increase at the back side of the SOI layer correctly. Calculated drain current reproduces observed steep increase as a function of V_d accurately.

References

[1] T. Ohno et al., *IEEE Trans. ED.*, **42** (1995) 1481.

[2] D. Kitamaru et al., *Jpn. J. Appl. Phys.* **43** (2004) 2166.

[3] M. -C. Hu et al., *Jpn. J. Appl. Phys.* **36** (1997) 2606.

[4] T. Tsuchiya, *Principles and Applications of SOI CMOS Devices,* REALIZE INC. (1999).