Mechanism of Super Steep Subthreshold Slope Characteristics with Body-Tied SOI MOSFET

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***Abstract*— Super steep subthreshold slope characteristics in the FB and the BT are investigated with TCAD. The mechanism of the enhanced DIBL and the addition of the positive feedback PBT action by the forward biased emitter-base voltage are proposed to explain the difference between the FB and the BT.**

Keywords—steep subthreshold slope; SOI MOSFET; Floating-Body; Body-Tied; Parasitic Bipolar Transistor

I. Introduction

Extremely low power LSI's require the steep subthreshold slope (SS) MOSFET. However, the fundamental SS limit of the conventional MOSFET is 60mV/dec at the room temperature. Recently, devices which have the less than 60mV/dec SS, such as the Tunnel FET (TFET) [1] and the Impact ionization MOS (I-MOS) [2] have been studied. In addition to those, the steep SS MOSFETs using the Floating-Body (FB) SOI have been proposed [3][4]. In this work, we have found out that the super steep SS (<1mV/dec) appears in the Body-Tied (BT) SOI MOSFET, which is occurred at the lower drain voltage (V_d = 2.0-3.0V), compared with the bulk I-MOS and its mechanism have investigated with TCAD.

II. Device Structure & Simulation Condition

The measurements and the simulations were done with the available 0.15μm SOI technology [5]. Device parameters are T_{OX} (gate oxide) = 2.5nm, T_{Si} (SOI thickness) = 40nm, T_{BOX} (buried oxide) = 145nm and L_g (gate length) = 150nm. Device structures are shown in Fig. 1. 3D device simulations were done with HyENEXSS [6].

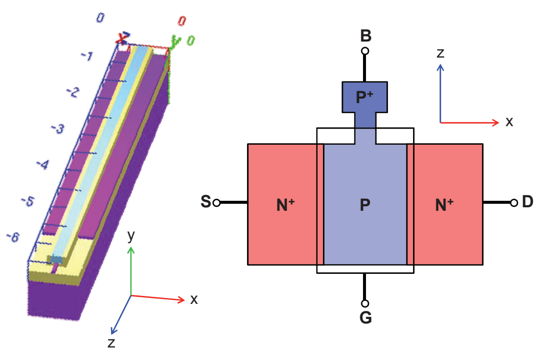

Fig. 1. Illustrations of bird's-eye view and top view of the BT. The FB doesn't use body contact. Device parameters are; T_{OX} (gate oxide) = 2.5nm, T_{Si} (SOI thickness) = 40nm, T_{BOX} (buried oxide) = 145nm and L_g (gate length) = 150nm.

SRH recombination included Trap Assisted Tunneling (TAT), Surface recombination, Auger recombination, Band to band tunneling, and Rang model were used. We fitted the impact ionization parameters in Rang model to the measured results and found out that the effective electric field should be reduced to 1/3 of the default value. It seems to be reasonable, because the impact ionization rate in Rang model (local field model) is overestimated in the highly inhomogeneous electric field [7].

III. Result & Discussion

Fig. 2 shows the measured and the simulated I_d-V_g characteristics with the FB and the BT. When the drain voltage V_d is increased, the off current of the FB increases. In contrast, the super steep SS characteristics (less than 1mV/dec at V_d = 2.0-3.0V) were appeared in the BT.

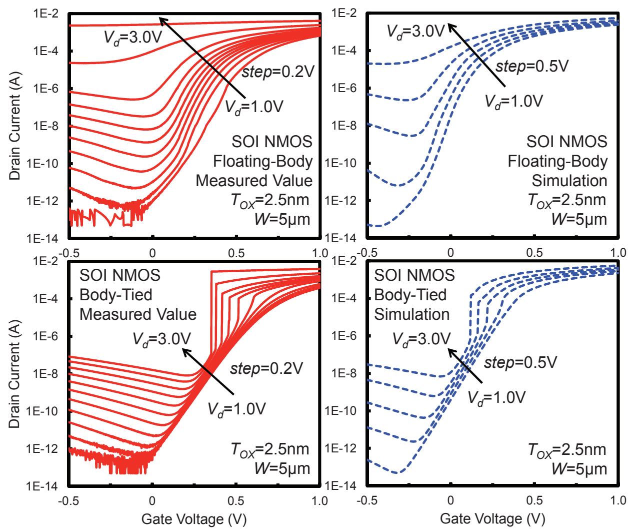

Fig. 2. Measured (line) and the simulated (dotted line) I_d-V_g characteristics with the FB and the BT. V_d of the measured results is changed with 0.2V step. V_d of the simulation results is changed with 0.5V step. We fitted impact ionization parameters to the measured result.

Fig. 3 shows the body potential in the FB and the BT in the SOI region at V_g = 0V. The body potential of the FB is increased by the increase of V_d, which results in that the source-body potential barrier becomes very low at V_d = 3.0V. However, the source-body potential barrier in the BT doesn't decrease at V_d = 3.0V. These findings suggest that the Drain Induced

Barrier Lowering (DIBL) is enhanced by the Floating Body Effect (FBE) in the FB, because the hole are accumulated in the FB and it flows to the body contact in the BT.

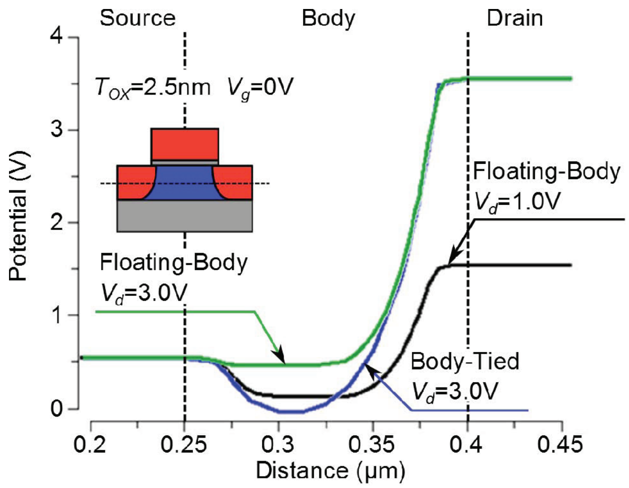

Fig. 3. Body potential in the FB and the BT (W=5μm) at V_g = 0V. Cut along x-axis at a depth of 20nm from the gate oxide and z = 0.

The body potential and the electron current in the BT are shown in Fig. 4. When the super steep SS of the BT is appeared, the body potential increases rapidly and the electron current flows in all of the body regions. This means that the Parasitic Bipolar Transistor (PBT) is on.

Therefore, the super steep SS don't appear in the FB because the enhanced DIBL results in enlarging the short channel effect (increase of the off current), which diminishes the appearance of the super steep SS. However, non-occurrence of the enhanced DIBL results in the appearance of the positive feedback of PBT action in the BT.

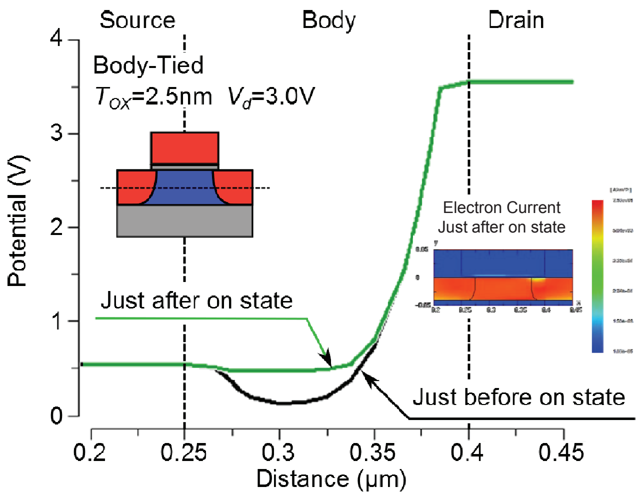

Fig. 4. Body potential and the electron current in the BT (W=5μm) at V_d = 3.0V. This figure represents change from the off state to the on state.

Fig. 5 shows the measured I_d-V_g characteristics dependent on W's in the BT. The super steep SS regions of the W = 1μm's is smaller than that of the W = 5μm's. In addition, Fig. 6 shows the body potential on the direction of the gate width (W). The body potential increases as the distance from the body contact. Fig. 7 shows the hole concentration on the direction of the W. The hole diffuses to the source when it is away from the body contact. Fig. 8 shows the electron and hole concentration with the different W in the BT. The electron flows in all of the body regions at the far side of the body contact. However, at the near side of the body contact, the electron flows only on the surface. These mean that the PBT action depends on the distance from the body contact.

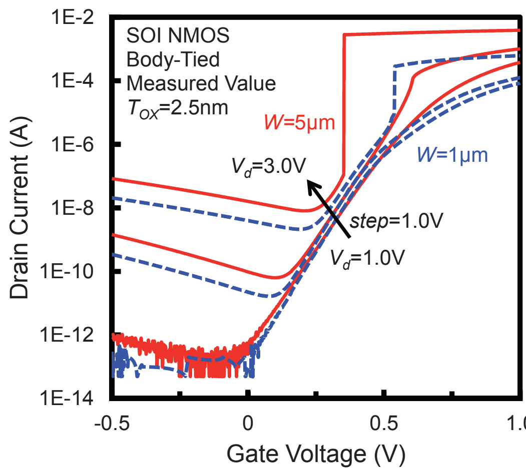

Fig. 5. Measured I_d-V_g characteristics dependence on a W in the BT. Line is W = 5μm and dotted line is W = 1μm.

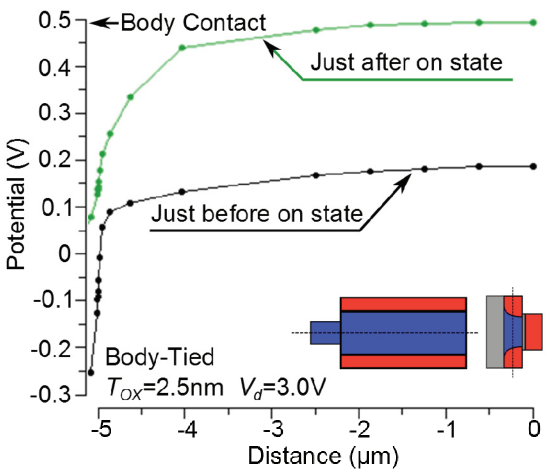

Fig. 6. Body potential in the direction of the W. Cut along z-axis at a center of body.

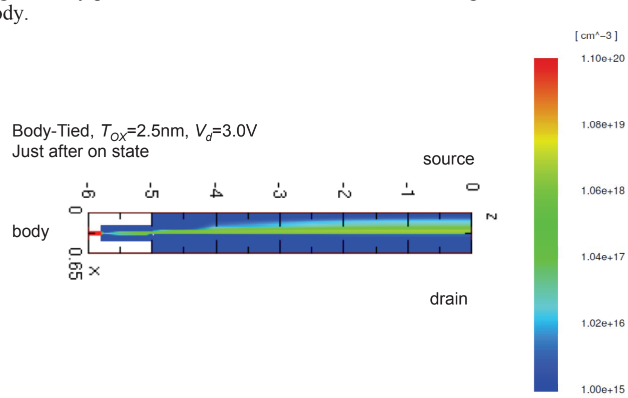

Fig. 7. Hole concentration in the direction of the W. on state at V_d = 3.0V.

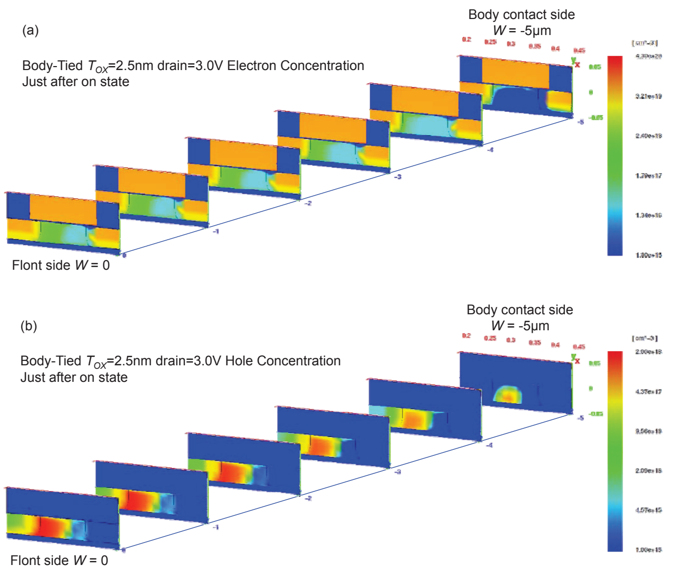

Fig. 8. (a) Electron and (b) hole concentration in the BT at W=0, -1μm, -2μm, -3μm, -4μm, and -5μm.

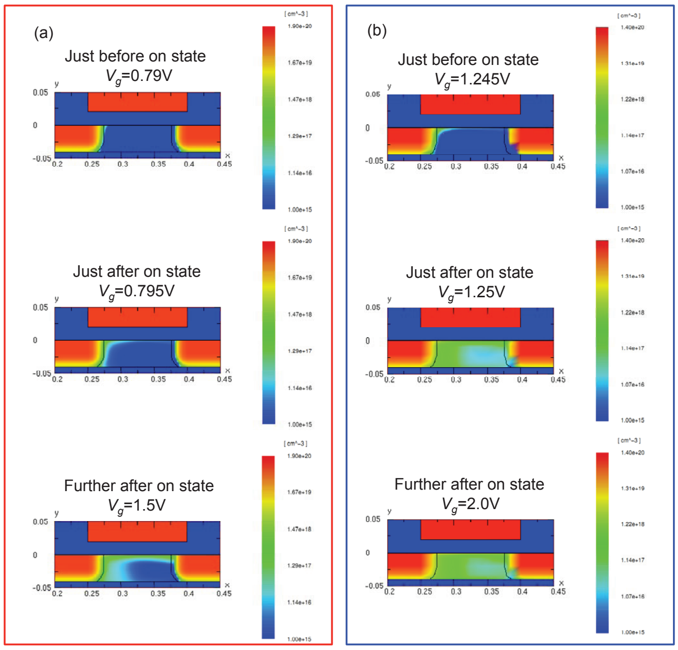

Fig. 10. Electron concentration in the FB and the BT at T_{OX} = 20nm.
(a) Just before on state, just after on state, and further after on state in the FB.
(b) Just before on state, just after on state, and further after on state in the BT.

Results of Fig.5-8 suggest that the hole current causes the voltage drop, which results in reducing the source-body junction voltage which corresponds to the forward biased emitter-base voltage of PBT. It is supposed that the addition of it to the positive feedback of PBT action is the important mechanism in the BT.

Large T_{OX} (i.e. large body effect factor r) enhances the positive feedback loop gain in the FB [3]. So, in order to clarify the difference of the mechanism between the FB and the BT, we simulated the dependence on T_{OX}. Fig. 9 shows the simulated I_d-V_g with the different T_{OX} in the FB and the BT. When T_{OX} is increased, the super steep SS's are appeared, even if with the FB. On the other hand, the SS's of the BT always have the steep SS. Fig. 10 shows the electron concentration in the FB and the BT with T_{OX} = 20nm. The new findings are that the electron in the FB flows on the surface, whereas it flows in all of the body regions in the BT, when the steep SS just appears. Fig. 11 shows the proposed mechanism, which are different between the FB and the BT. The mechanism of the BT is noted as the contribution of enhancing the positive feedback loop of the PBT action by adding the forward biased emitter-base voltage by the hole flow to the body contact. The steep SS of the FB comes from the hole accumulation and the r effect, already known [3].

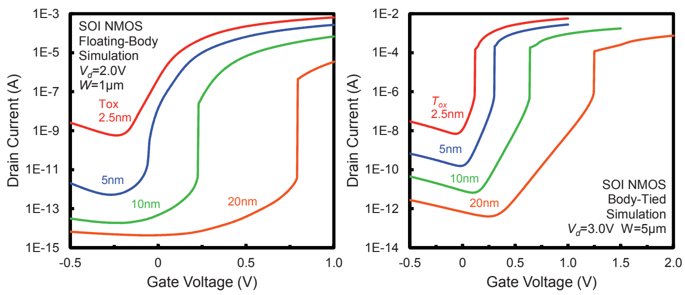

Fig. 9. Simulated I_d-V_g with the different T_{OX} in the FB and the BT. T_{OX} are changed with 2.5nm, 5nm, 10nm, and 20nm.

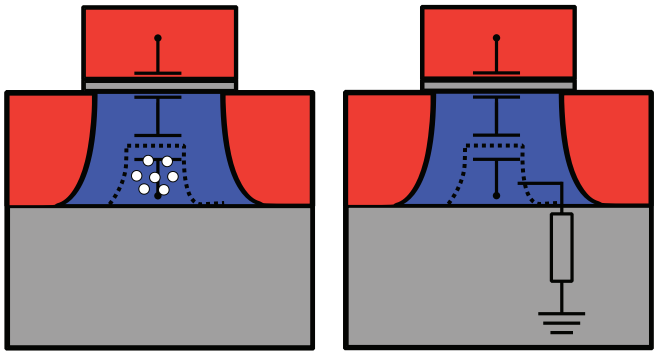

Fig. 11. Proposed mechanism of steep SS in the FB and the BT. The hole accumulates in the FB. The hole current causes the voltage drop in the BT.

IV. Conclusion

We found the steep SS characteristics in the BT and analyzed the phenomenon. The mechanism of the enhanced DIBL and the addition of the positive feedback PBT action by the forward biased emitter-base voltage are proposed to explain the difference between the FB and the BT. The BT will have the possibility as the next steep SS device, to reduce the voltage and also is promising by the body control.

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