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Modeling of RESURF LDMOS for Accurate Prediction of Junction Condition on Device Characteristics

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1. Introduction

It is known that the laterally diffused MOS (LDMOS) is becoming increasingly important in high-power and high-voltage applications [1], where HiSIM-HV was selected as the standard model for circuit simulation by Compact Model Council. Fig. 1 shows a cross-section of a typical n-type structure called the Reduced Surface Field (RESURF) LDMOS [2]. As can be seen, a specific feature of the RESURF LDMOS is the lightly doped n-type drift region fabricated on the p-type Si substrate. Since the impurity concentration of the drift region N_{over} is low, the breakdown voltage is affected by the junction condition at the drift/substrate region. Because the drift resistance and impact-ionization current are strongly influenced by the depletion width extended from the junction into the drift region.

It is our purpose to extend HiSIM-HV to reproduce measured *I-V* characteristics of the RESURF LDMOS for any junction conditions. For the purpose we have investigated the substrate voltage dependence of the *I-V* characteristics instead of investigating different junction profiles. The high accuracy of the developed model has been proved, which enables the device optimization.

2. Model Development of RESURF LDMOS

Fig. 2 shows an enlarged cross-section of the drift region denoted by a square in Fig. 1. The depletion width W_{dep} at the drift/substrate junction is dependent on N_{over} and the impurity concentration in the substrate N_{subsub} as

$$W_{dep} = \alpha\sqrt{VBISUB - V_{sub}} \quad (1)$$

$$\alpha = \sqrt{\frac{2\varepsilon_s}{q}\cdot\frac{N_{subsub}}{N_{over}\left(N_{subsub}+N_{over}\right)}} \quad (2)$$

where, *VBISUB* is the built in potential at the junction, and V_{sub} is the substrate voltage. Since N_{over} is low, W_{dep} extends deeply into the drift region. This extension increases the resistance in the drift region, which is modeled as [3]

$$R_{drift} = R_{drift0}\cdot\left(\frac{L_{drift}}{DDRIFT - W_{dep}}\right) \quad (3)$$

where, R_{drift0} is the resistance without the RESURF junction. Simulation results with HiSIM-HV are compared with 2D-device simulation results in Fig. 3a. Deviation of HiSIM-HV results increases as V_{sub} and V_{d} increase. With increased V_{d}, W_{dep} increases as depicted in Fig. 2b. Thus the drain bias dependence of the depletion width must be considered to improve the deviation. W_{dep} at position y in the drift region is written as

$$W_{dep}(y) = \alpha\sqrt{VBISUB + V(y) - V_{sub}} \quad (4)$$

where, $V(y)$ is the potential value in the drift region at position y. The integration of Eq. (4) along the drift region results in

$$\mathrm{int}\left[W_{dep}(y)\right]dy = \frac{2}{3}\alpha\left(\left(VBISUB + V_d - V_{sub}\right)^{3/2} - \left(VBISUB + V_{ddp} - V_{sub}\right)^{3/2}\right) \quad (5)$$

where V_{ddp} is the inner potential node determined in HiSIM-HV. To integrate the equation into HiSIM-HV, averaging of W_{dep} is required. For the purpose the Taylor expansion is applied to simplify the power function, and up to the second term is considered. The equation within the large brackets is reduced to

$$\sqrt{VBISUB + V_d - V_{sub}}\left(V_d - V_{ddp}\right) \quad (6)$$

If a linearly increasing potential $V(y)$ is assumed, the averaged depletion with is written as

$$W_{dep} = \sqrt{VBISUB + V_d - V_{sub}} \quad (7)$$

This simplified equation includes two major approximations, namely a steep and linear potential distribution. To compensate the approximations we introduce model parameters and also the average potential value along the drift region as

$$W_{dep} = \alpha\sqrt{VBISUB + RDVDSUB\cdot V_x - RDVSUB\cdot V_{sub}} \quad (8)$$

$$V_x = \frac{V_d + V_{ddp}}{2} \quad (9)$$

where, *RDVDSUB* and *RDVSUB* are model parameters. The simulation result including the V_{d} effect is compared in Fig. 3b, resulting in good agreement with 2D-device simulation results for wide range of V_{sub} variation.

3. Inclusion of Impact Ionization Effect

Till now no impact ionization effect is considered in the modeling. However, the impact ionization is unavoidable for HV-MOSFETs, which occurs mostly in the drift region for high V_{g} values. The feature of the impact ionization current occurs in the drift region is an exponentially increasing function of V_{d}. However, the exponential current increase is strongly suppressed due to the storage of generated charges under the overlap region (see Fig. 4) [4]. This effect is called the expansion effect [5]. As shown in Fig. 5, the effect is sensitive to the RESURF condition. The reason is that the expansion effect is caused by the

high resistance effect in the drift region, which is enhanced in the RESURF LDMOS by extension of the depletion width. To model the enhancement, the depletion width increase is included in addition to the charge storage under the overlap region. The calculation results are depicted in Fig. 6 in comparison to measurements.

4. Conclusion

The compact model for high-voltage MOSFETs HiSIM_HV was extended to provide the optimization capability for the RESURF LDMOS. The model considers the influence of the dynamically varying depletion width at the drift/substrate junction, causing the resistance modification of the high resistive drift region. The model was proved to reproduce the wide range of the *I-V* characteristic variations including the enhanced expansion effect.

5. References

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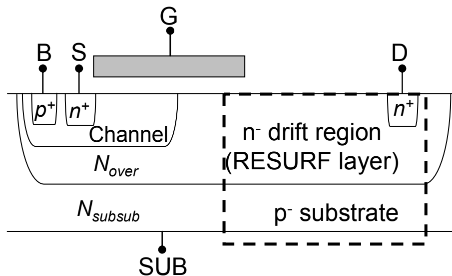

Fig.1. Cross section of a typically n-LDMOS called RESURF LDMOS.

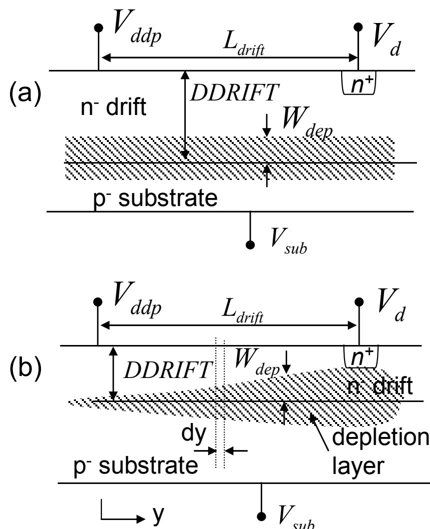

Fig.2. Enlarged cross-section of Fig. 1 showing the depletion width Wdep, (a) without and (b) with the V_d effect.

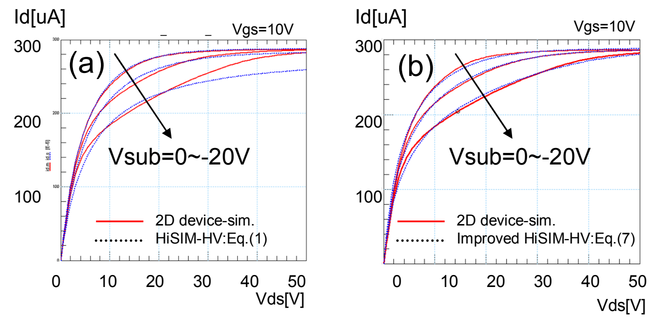

Fig.3. Calculated I_d-V_d characteristics of the V_{sub} dependence in comparison to 2D-device simulation results. (a) Calculation results with Eq.(1), and (b) with Eq.(8). Device parameters used for the comparison are N_{over}=1e16/cm^3, DDRIFT=2.0µm, N_{subsub}=1e15/cm^3, where the impact ionization is neglected.

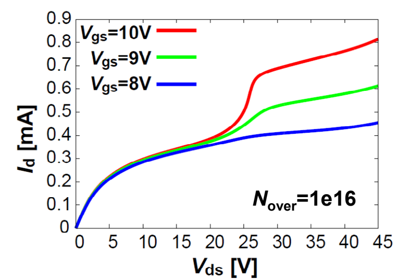

Fig. 4. Simulated I_d-V_d characteristics for various V_g values. The current increase is due to the impact ionization. Suppression of the current increase observed for large V_g is called the expansion effect.

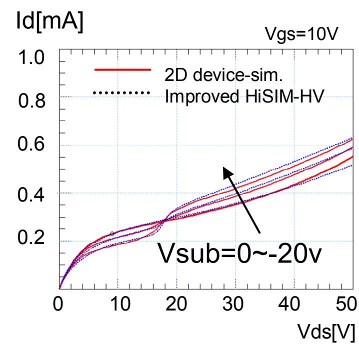

Fig.5. Vsub dependence of the expansion effect, lines are 2D device simulation results including the impact ionization and lines are HiSIM-HV results with the developed model. The same device parameters given in Fig. 3 are applied.

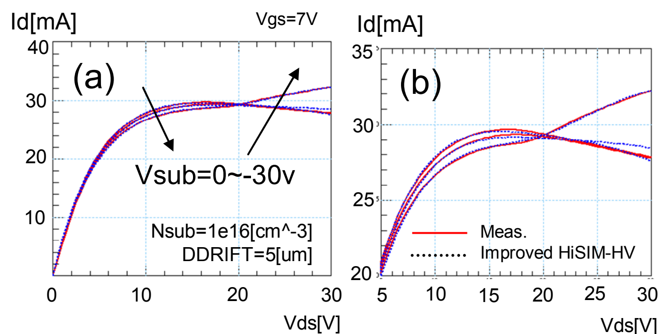

Fig.6. (a) Verification of the developed model with measurements, (b) zoomed result of (a).