SOI DEVICE SIMULATION OF AN AREA EFFICIENT BODY CONTACT

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ABSTRACTS

We have used three-dimensional simulation to investigate application of a new body contact to SOI devices. Performance characteristics of the new body contact on high-voltage SOI devices were studied. Our comparative investigation showed increased current drive, improved cutoff frequency, reduced on-resistance while attaining satisfactory breakdown voltage. The new body contact is applicable to both high and low voltage SOI MOSFETs.

KEYWORDS

Three-Dimensional Simulation - Floating Body Effects - On-resistance - Breakdown Voltage - Isothermal Drift-Diffusion Model – Cutoff Frequency.

1- INTRODUCTION

Power MOSFETs posses many attractive properties including high power density and co-fabrication with mixed signal circuitry while using as RF power amplifier for wireless applications. However, the lossy substrate prevents integration of the high-quality factor passives, particularly inductors, which are needed for VCOs, tuning and matching. The buried dielectric of silicon-on-insulator (SOI) power MOSFET permits monolithic integration of high-Q inductors and has the advantage of low inter-device noise coupling and substrate interference with the RF, high-speed analog and digital signals [1]. However, SOI power MOSFET suffers from floating body effects due to the activation of the lateral BJT at high drain voltages, which causes significant reduction of the breakdown voltage. In order to suppress "kink effect" and obtain a high breakdown voltage, body-tied-source (BTS) structures can be used to fix the body potential. There are several methods to make a body contact [1,3]. An under-source body contact has been implemented in [3]. This type of body contact has the advantage of uniform body potential along the width of the device which essentially suppresses floating body effects and attains a high breakdown voltage. However, using shallow source junction in thin film SOI processes increases the source parasitic resistance (R_s), which affects R_{ON} and increases power dissipation. This is especially true for power devices which are co-fabricated with short channel signal level transistors where silicon film thickness scales as channel length scales down [1]. In addition, maximum oscillation frequency of the device (f_{max}) reduces as source parasitic resistance increases [4]. "Stripped" body contact, which is introducing P^+ diffusion regions in the source, is another method of contacting body of the device to the source [1,2]. By proper spacing between P^+ stripes, high breakdown voltage can be achieved while source parasitic resistance is not affected. However, this type of body contact reduces effective device width and increases on-resistance for the same drawn width devices or increases parasitic capacitances for the equal effective width devices.

In this paper, we investigate application of a novel area efficient body contact to SOI LDMOSFETs [5]. Simulation results showed that this novel body contact increases device effective width and decreases on-resistance in SOI CMOS devices [6]. This investigation presents comparative study of this body contact with conventional body contact structure on SOI LDMOSFET using three-dimensional simulation. In the following, three-dimensional simulation model and

the device structures, simulation results and discussion are presented.

2- THREE-DIMENSIONAL SIMULATION APPROACH

Fig.1 shows side view of a SOI LDMOSFET. We considered an nMOSFET with the following parameters: Buried oxide layer thickness t_{BOX}=0.4µm; Silicon film thickness t_{BODY}=0.15µm; Drift region length L_D=1 µm; Body doping N_A=5×1017 cm^{-3}. The source and drain lateral diffusions were modeled by Gaussian profiles along the X-axis. The gate of the device was an n+ polysilicon with dimensions L=1µm and W=8µm.

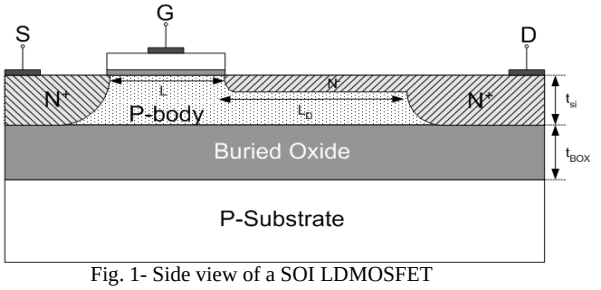

Fig. 1- Side view of a SOI LDMOSFET

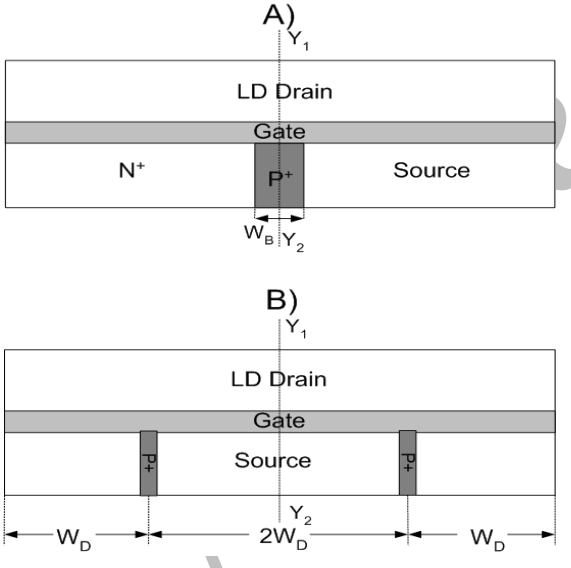

Fig. 2- A) Conventional body contact,
B) Novel area efficient

All the electrode contacts were considered to be an ohmic contact. The bulk contact was an electrical contact at 0V. The minimum feature size for this process was considered to be 1µm which is the minimum drawn width in the layout. In the "stripped" body contact or novel area efficient body-tie-source structure, the P^+ diffusions are along the device width and three-dimensional simulation is required to capture the physical characteristic of the device. The drift-diffusion model was used in our three-dimensional simulation using ISE TCAD's device simulator (DESSIS) [7]. A floating body LDMOSFET device was simulated using non-isothermal drift-diffusion model to take into account the impact of self-heating in the device. At gate voltage of 1.5V and drain voltage of 10V, very small temperature rise was observed. As a result, isothermal drift diffusion was used for the biasing point of interest. We considered V_{GS}=1.5V since the highest impact ionization rate occurs at low gate voltages where the body effect is the largest [8]. Obviously, at higher gate voltages, the impact of lattice temperature rise on the characteristic of the device cannot be ignored.

Three device structures were simulated: (1) a floating body (FB) device, (2) a conventional body-contacted device with one contact in the middle and W_B=1µm as shown in Fig. 2-A, (3) a device with two of the novel contacts as shown in Fig. 2-B with W_D=2µm. Since the devices are symmetric with respect to the line Y_1Y_2 and to reduce the simulation complexity, parts of the devices at one side of the line Y_1Y_2 were considered for three-dimensional simulation. Note that after determining different parameters of the devices, they appropriately scaled.

Fig. 3 shows part of the device including one of the novel area efficient body contacts with the corresponding mesh structure. Very fine refinements are required to cover the body contacts especially at the edges. Total number of grid points was 20,000 to 30,000 depending on the structure. Due to the complexity of three-dimensional simulations and big size of the power devices, total simulation time for a simple ramp was almost 120 hours.

3- SIMULATION RESULTS AND DISCUSSION

As mentioned in the last section, symmetric parts of the devices were considered for isothermal drift-diffusion simulation. Current drive, body voltage, on-resistance and off-state breakdown voltage were simulated and scaled properly to show the parameters of the actual devices. Fig. 4 presents I_{DS} variation as V_{DS} changes.

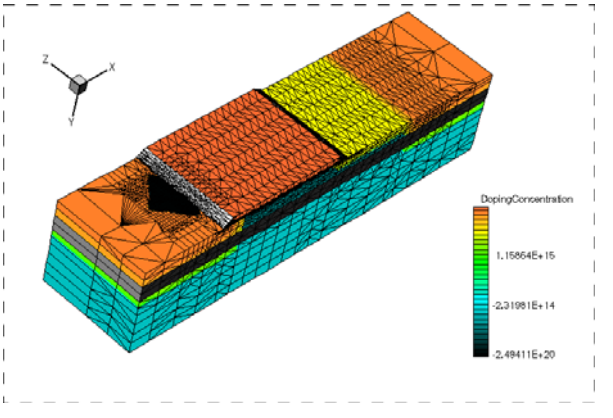

Fig. 3- Part of the device including one of the area efficient contacts

Using body contacts, the kink apparent in the floating body device has been eliminated in the body-contacted structures.

At V_{DS}=5V, the novel body contacted device shows 14% increase in current due to increased effective device width in comparison with the conventional body contact structure. However, the difference in the current between the two body contacted structures become smaller as drain voltage increases. This is due to the increase in body voltage in the conventional body contact structure where, part of the body farthest away from the body contact has highest voltage and lowest threshold voltage. This causes increase in the current drive.

Body voltage variation along the device width close to the back-oxide where the impact ionization generated holes accumulates, is an indication of effectiveness of the body contact in controlling body voltage. Fig. 5 shows the body

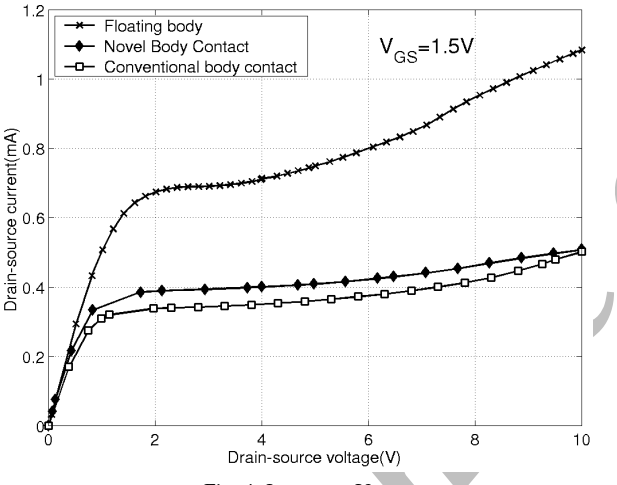

Fig. 4- I_{DS} versus V_{DS}

potential along the device width at V_{GS}=1.5V and V_{DS}=10V. As can be seen, maximum body potential in the conventional body contacted structure is greater than the novel structure.

Breakdown voltage and on-resistance were also simulated. As can be seen from Table 1, break down voltage of the floating body device is significantly lower than the body contacted devices due to the activation of lateral BJT. Novel body contacted and the conventional body contact structures have almost equal off-state breakdown voltage. In order to simulate on-resistance of the devices, gate voltage was ramped to 5V and drain voltage to 50mV where we evaluated R_{ON}. In order to see the effect of lattice temperature on R_{ON}, a floating body device was simulated. Since the drain current at the above biasing point is very small, the effect of lattice temperature variation on the on-resistance can be ignored and non-isothermal drift-diffusion model for the three-dimensional simulation was used. The novel body contacted device shows 9% decrease in on-resistance in comparison with the conventional body contacted structure. Floating body device has the lowest on-resistance due to the lowered threshold voltage at this bias point.

One major application of power MOSFETs is switching high load currents. Application of area efficient body

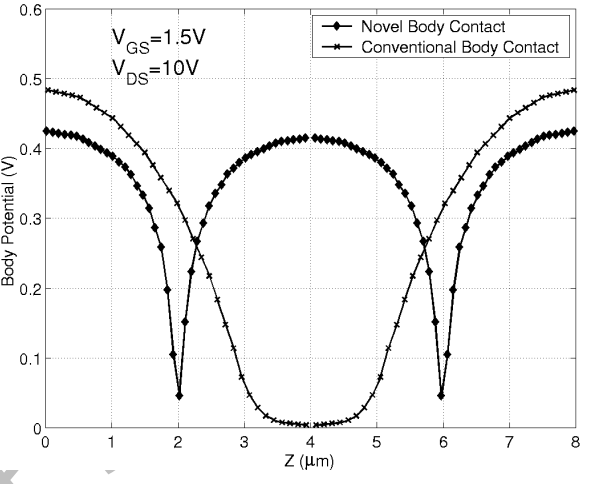

Fig. 5- Body potential along the device width

Table 1- Breakdown voltage and on-resistance

	Floating Body	Conventional Body Contact	Novel Body Contact	Comment
V_{BR}(V)	5.5	65.3	65.2	Off-state Breakdown voltage
R_{ON}(Ω)	910	1150	1050	V_{GS}=5V

contact to these devices will result to lower power dissipation. If we consider devices in Fig. 2 and the situation where they are designed to deliver the same current to a load, the one with the novel contact has smaller device area due to the area efficiency of the body contact. This results to the smaller parasitic capacitances. Power dissipation in power MOSFETs is mainly addition of the resistive and switching losses [9]:

$$P_{Total} = P_{Resistive} + P_{Switching} \quad \text{where} \qquad (1)$$

$$P_{Resistive} \propto I_{DS}^2 \cdot R_{ON} \quad \text{and} \qquad (2)$$

$$P_{Switching} \propto C_{RSS} \cdot f_{SW} \cdot I_{DS} \qquad (3)$$

C_{RSS} is the device reverse transfer capacitance (C_{gd}) and f_{SW} is the switching frequency. From equation (3),

it's obvious that smaller parasitic capacitance leads to smaller switching power dissipation.

In order to evaluate the impact of parasitic capacitances on the frequency behavior of devices, small-signal analysis was performed. For this reason, the information required to restart the simulation, the solution variables on the mesh and the bias conditions on the

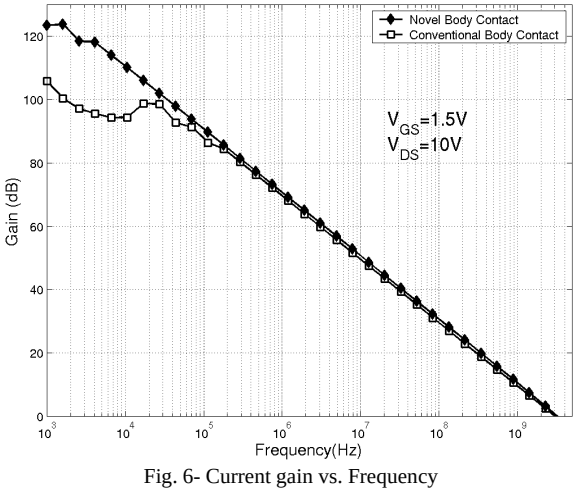

Fig. 6- Current gain vs. Frequency

electrodes were saved in separate files during the DC ramp of the drain electrode voltage. These files were loaded in AC mixed mode simulation where DESSIS computes the complex admittance Y matrix. Then current gain curves as frequency increases was computed using the equation:

$$h_{21} = \left| \frac{y_{21}}{y_{11}} \right| \quad (4)$$

Fig. 6 shows the current gain in dB versus frequency at V_{DS}=5V and V_{GS}=1.5V. As can be seen, the novel body contact curve is slightly higher than the conventional body contact one. Cutoff frequency is the frequency at which the curve crosses 0dB axes. The cutoff frequency of the novel body contacted device is f_T=3.3GHz while the conventional one is 3GHz. This leads to 10% increase in the cutoff frequency of the novel body contacted structure.

The smaller parasitic capacitance (C_{gd}) leads to smaller switching power dissipation and higher efficiency in power MOSFETs.

4- CONCLUSION

Application of the area efficient body contact to LDMOSFETs using three-dimensional simulation showed performance functionality of the body contact. Current drive and on-resistance were improved while high breakdown voltage was attained. The new body contact requires a novel layout design without adding any complexity to the manufacturing process.

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