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Design of Main Body and Edge Termination of 100 V Class Super-junction Trench MOSFET

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Abstract

For the conventional power MOSFET (metal-oxide semiconductor field-effect transistor) device structure, there exists a tradeoff relationship between specific on-state resistance (Ron,sp) and breakdown voltage (BV). In order to overcome this tradeoff, a super-junction (SJ) trench MOSFET (TMOSFET) structure with uniform or non-uniform doping concentration, which decreases linearly in the vertical direction from the N drift region at the bottom to the channel at the top, for an optimal design is suggested in this paper. The on-state resistance of 0.96 mΩ-cm2 at the SJ TMOSFET is much less than that at the conventional power MOSFET under the same breakdown voltage of 100V. A design methodology for the edge termination is proposed to achieve the same breakdown voltage and on-state resistance as the main body of the super-junction TMOSFET by using of the SILVACO TCAD 2D device simulator, Atlas.

Key words: TMOSFET, super-junction TMOSFET, trench MOSFET, power MOSFET, edge termination, breakdown voltage, on-state resistance

Ⅰ. Introduction

Super-junction (SJ) metal oxide semiconductor field effect transistor (MOSFET) power devices [1] are well known for lower on-state resistance and gate charge. However, it is some difficulty in fabricating the exact balanced doping profile, and the effect of imbalance results in varying breakdown voltage (BV). For the conventional MOSFET device structure, there exists a tradeoff relationship between specific on-state resistance and breakdown voltage. In this paper, the main body and the edge termination of a SJ trench MOSFET (TMOSFET) structure with the breakdown voltage at the class of 100 V is proposed to overcome the specific on-state resistance caused in the drift region. The widths of P pillar and N pillar in the edge termination structure are the same as those in the transition and main cell region.

Ⅱ. Main body for SJ TMOSFET

1. Design of Main body for SJ TMOSFET

In order to obtain the best performance in the SJ structure, the same doping concentrations for a SJ TMOSFET structure to have equal amount of positive and negative charges are applied for the precisely charge balanced P and N columns. It is assumed that the termination region is

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totally depleted, and the charge in the termination region and transition is balanced as shown in Eq. (1).

$$N_A W_P = N_D W_N \tag{1}$$

where *NA* and *ND* are the concentration of P pillar and N pillar, and *WP* and *WN* are the widths in Fig. 1, respectively. In the SJ TMOSFET, the breakdown voltage is proportional to the length of the drift region of *LD* as follows.

$$V_{BR} = E_C L_D \tag{2}$$

where *EC* is the critical electric field.

The design parameters for SJ TMOSFET are given by Table 1. The potential structures for 10 V and 120 V by using of the SILVACO TCAD 2D device simulator [2], respectively, are shown in Fig. 2. It is observed that the depletion region is created at N and P pillar direction for the 10 V case. As electric potential increases to 120 V, the complete depletion is formed at N pillar, and the constant electric field is made at the vertical direction.

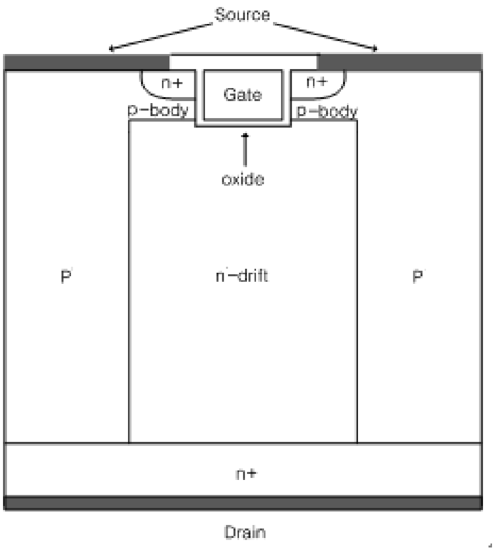
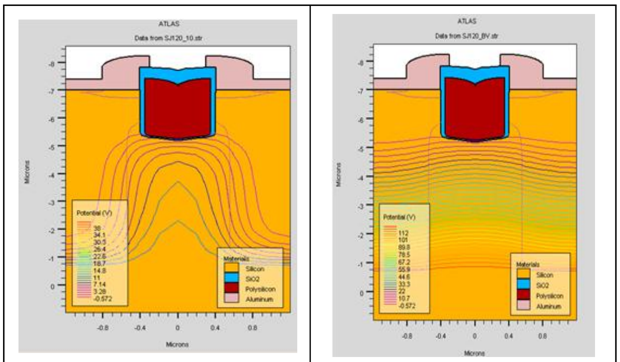


Fig. 1. Fundamental structure of SJ TMOSFET.

Table 1. Main characteristics of SJ TMOSFET.

Substrate	Dopant As Orientation (100), Flat Zone (001) Resistivity : 0.001-0.005 Ohm cm^2
Gate Oxide	500Å
Pwell Junction depth	Xjp=1.2 – 1.3um
Trench	Trench depth=1.8um Trench width=0.7um
N+ Source	0.5um
P+ Body Contact	1.5um



a) Vdrain = 10 V

b) Vdrain = 120 V

Fig. 2. Electric potentials for 10 V and 120 V.

2. Simulations and Discussion

The on-resistance can be computed by currents flowing from the channel between the source and the drain electrodes. The total on-resistance for the SJ TMOSFET structure is mainly composed of the channel on-resistance and the drift region on-resistance while neglecting the contact and source resistance [1] as follows.

$$R_{ON,SP} = R_{CH,SP} + R_{D,SP} \tag{3}$$

The pillar widths of P and N, the sheet resistance, and the on-resistance in the drift region are important factors in designing the vertical power SJ TMOSFET. Fig. 3 represents the breakdown voltage at 120 V, and Fig. 4 shows breakdown voltage and on-state resistance versus pillar doping concentration.

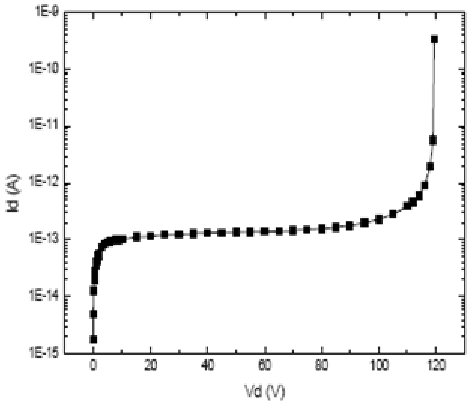


Fig. 3. I-V characteristic curve for SJ TMOSFET (VBR =120 V).

The difference of breakdown voltages between SJ TMOSFET and non-SJ TMOSFET [3] becomes larger, compared with the on-state resistance less than 1 mΩ-cm^2 as shown in Fig. 4. The I-V characteristics on on-state resistance of uniform and non-uniform SJ TMOSFET are shown in Fig. 5.

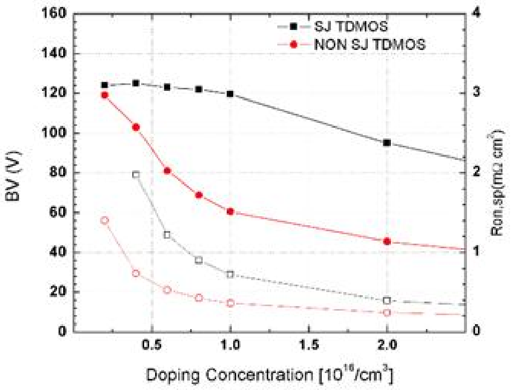


Fig. 4. Breakdown voltage and on-state resistance vs. pillar doping concentration (/cm^3) for SJ TMOSFET and non-SJ TMOSFET.

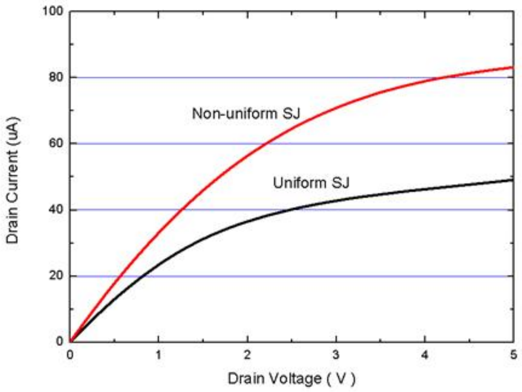


Fig. 5. I-V characteristic curves on on-state resistance of uniform and non-uniform SJ TMOSFET.

For the uniform SJ TMOSFET, the drain current is 8.03 x 10^{-6} A when the drain voltage is 0.3 V, and the on-state resistance of 0.8966 mΩ-cm^2 is obtained from the unit cell area for 2.4 x 10^{-8} cm^2. For the non-uniform SJ TMOSFET, the drain current of 10.97 x 10^{-5} A is flowing under the same drain voltage and the on-state resistance of 0.66 mΩ-cm^2 is designed. The simulation results meet the on-state resistance of Baliga's design parameters [1] when the breakdown voltage of 100 V is made.

III. Edge Termination for SJ TMOSFET

1. Design of Edge Termination for SJ TMOSFET

The edge termination structure in Fig. 6. is consisted of main, transition, and termination. The edge termination trench region has a depth of 10 μm and a width of 40 μm. The breakdown voltage is found to be 120 V which is same as that of the SJ TMOSFET [4]. This indicates that the breakdown voltage is producing in the cell region and is not limited by the edge termination. The widths of P column and N column in the termination region are identical with those in the transition region and main cell region.

The electric field at each P column and N column in the termination region [5] of non-uniform SJ TMOSFET can be described by

$$E(x) = \int_0^x \frac{qN(x)}{\varepsilon_{Si}} dx = -\frac{qN_o}{\varepsilon_{si} g}\left(e^{-gx} - 1\right) \qquad (4)$$

where q is the charge, $N(x)$ is a doping concentration with exponential function in vertical direction of N drift region, εsi is the dielectric coefficient of silicon, g is a slope, and ND is the doping concentration at the top. Then, the electric potential produced by the charge balance termination region can be obtained by

$$V_R = -\int_0^{L_D} E(x)dx = \frac{qN_o}{\varepsilon_{Si} g^2}\left(-e^{-gL_D} - gL_D + 1\right) \qquad (5)$$

where LD is the length of drift region.

The current through the channel does not flow at the surface at the gate since there does not exist the source of N^+ in Fig. 7. The scale of vertical and horizontal line is in μm.

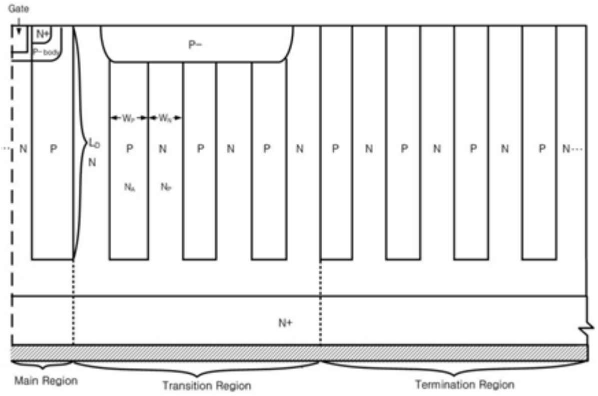


Fig. 6. Structure of SJ TMOSFET edge termination.

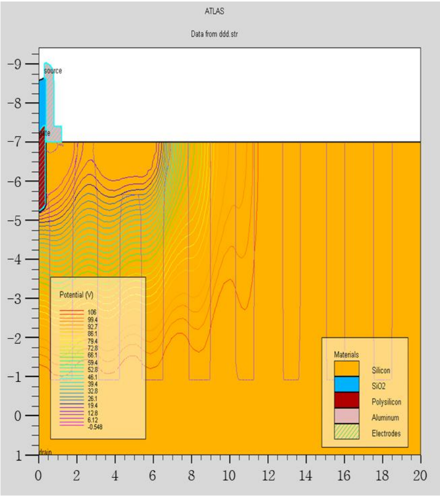


Fig. 7. Potential distribution of the edge termination at non-uniform SJ TMOSFET.

2. Simulations and Discussion

It is important to find the optimal values [6] of minimizing the on-state resistance, keeping the same breakdown voltage. The variation of breakdown voltage is relatively insensitive to the doping concentration for SJ TMOSFET. The potential distribution in the uniform SJ TMOSFET structure keeps constant [1], but the potential one in the non-uniform SJ TMOSFET structure [7] increases linearly with distance in the drift region between the drain and source regions.

The potential distributions obtained from the simulation at the edge termination for the breakdown voltage of 120 V are demonstrated in Fig. 6. The contour line starts at the top and ends at the bottom. The edge is composed of 30 contour lines. A line represents 4 V, and the total is equal to 120 V. The on-state resistance of edge termination for non-uniform SJ TMOSFET is obtained 0.66 mΩ-cm^2, which is consistent with that of main body and is much less than that of uniform SJ TMOSFET.

Ⅳ. Conclusion

The specific on-state resistance at the class of 100 V is successfully optimized by using SJ TMOSFET, showing better performance than that of the traditional trench double-diffused MOSFET. First, the specific on-state resistance and the breakdown voltage mainly depend on the doping concentration N drift region and ideal pillar width. Second, the fundamental structure of the edge termination for SJ TMOSFET is designed, and the profile is analyzed after simulation by SILVACO TCAD. It is estimated that the design of main body and edge termination can be applied to the implementation of the SJ TMOSFET for a chip, which requires the voltage of 100 V.

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