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2-D simulation Study of a SOI-MESFET with Two Steps in the Channel to Improve Breakdown Voltage

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Keywords

Simulation,
Breakdown,
Transistor,
Current,
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Abstract

The presented structure improves the breakdown voltage in silicon on insulator metal semiconductor field effect transistors (SOI-MESFETs). Two steps have been symmetrically used in the bottom of the channel. To simulate the device behavior, SILVACO software is employed together with Newton-Raphson method in order to numerically solve the equations. These two additional steps increase the breakdown voltage of the proposed device in comparison with its conventional counterpart. This increase is due to the redistribution of the potenial lines inside the device and modification in electric field in the presence of two additional steps. So, the proposed structure is a proper device for high voltage applications.

1. Introduction

Nowadays, SOI technology has attracted a lot of attention due to its great efficiencies. Reduction in capacitances, removing the latch up and improving the isolation due to the using oxide under the channel region, i. e. buried oxide (BOX) [1, 2]. Metal semiconductor field effect transistors are one of the efficient devices which can be considered in designing the high power applications because of major characteristics such as high breakdown voltage, high current density, and operating at high temperatures [3-8].

SOI-MESFET is a high voltage and frequency and low power technology capable of emerging RF and high voltage abilities [2, 9-11]. In recent years, some of the novel structures have been proposed to improve the device characteristics. But due to the trade off between current density and breakdown voltage, the application of these structures encountered some limitations [8, 12-16].

Increase in channel impurity increases the current density while reduces the breakdown voltage and vice versa [8, 17]. Breakdown voltage occurs at gate corner near the drain region where the electric field reaches its highest value [8]-[18-23]. If the expansion of depletion region toward the drain and source is controlled, the breakdown voltage would be increased. In this paper we propose a device with two additional oxide regions in channel which controls the electric field distribution. It modifies the capacitances and also improves the radio frequency (RF) charcteristics. The main idea is to redistribute the potential lines and consequently improving the tolerable voltage. In next sections we illustrate and describe the proposed structure and simulate the current and breakdown characteristics by SILVACO software and compare the electrical charcteristics of the proposed and conventional structures.

2. Proposed Structure and Simulation Method

In this paper SILVACO software and Newton-Raphson method are used to simulate the device behavior and solving the transport equations numerically. Basic equations are drift-diffusion, Poisson, and continuity equations. In this section, we briefly describe the Newton method.

Suppose that x_0 is a good approximation of r, and h is equal to r-x_0. So, h is the distance of x_0 from real root. Because h is small, we can use linear approximation as [24]

$$0 = f(r) = f(x_0 + h) \approx f(x_0) + h f'(x_0) \quad (1)$$

and

$$h \approx -\frac{f(x_0)}{f'(x_0)} \quad (2)$$

which results into

$$r = x_0 + h \approx x_0 - \frac{f(x_0)}{f'(x_0)} \quad (3)$$

x_1 as a new approximation of r is as follows

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)} \quad (4)$$

In a similar way, x_2 which is a newer approximation can be obtained from x_1

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$$x_2 = x_1 - \frac{f(x_1)}{f'(x_1)} \quad (5)$$

and in nth step

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \quad (6)$$

In this paper, the equations have been evaluated in mesh oriented structure as Figure 1. Some models have been activated in SILVACO software including FLDMOB, AUGERSRH, ANALYTIC, INCOMPLETE, BBT.STD, CVT to simulate the device with high accuracy. Figures 2 and 3 depict the schematic views of the conventional and proposed structures, respectively.

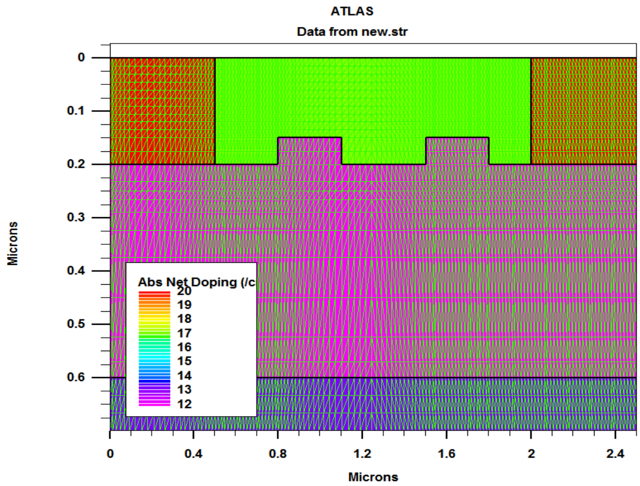

Figure 1. Proposed structure with related meshes

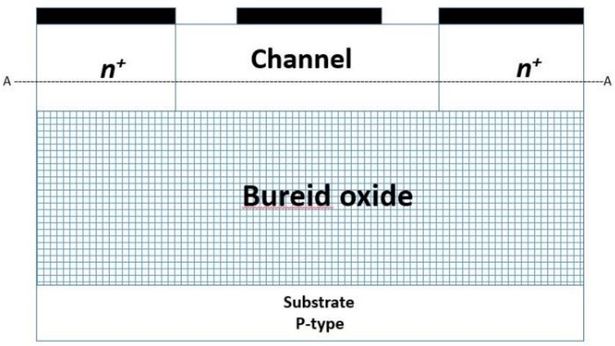

Figure 2. Schematic view of the conventional structure

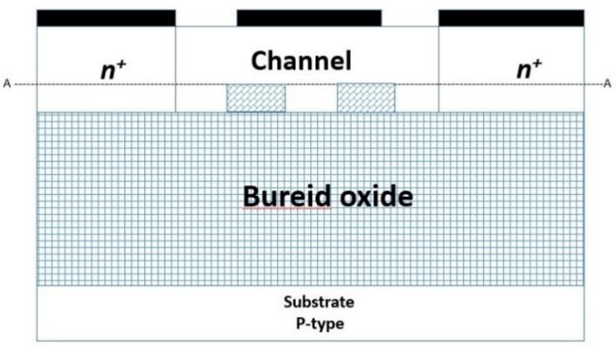

Figure 3. Schematic view of the proposed structure

3. Simulation Results and Discussion

Figure 4 illustrates the drain current and leakage gate current versus drain voltage at specific gate voltage of -2 V. This plot has been illustrated for conventional structure at Figure 5. These figures show the breakdown characteristics of the devices.

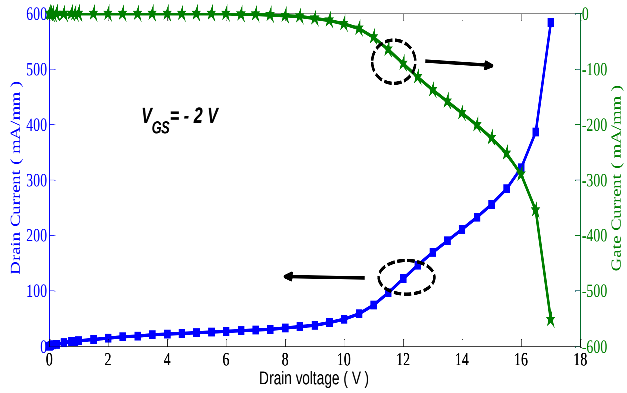

Figure 4. Breakdown characteristics of the proposed structure

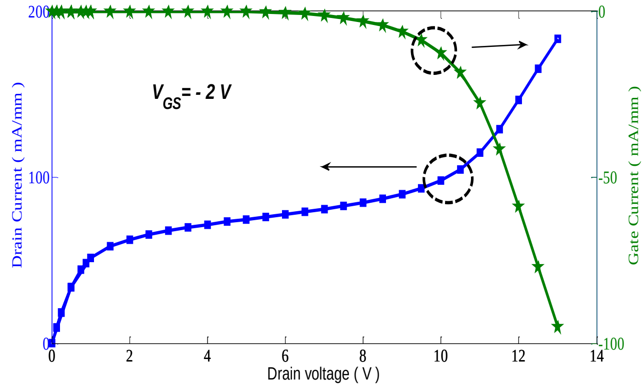

Figure 5. Breakdown characteristics of the conventional structure

It can be observed that the breakdown voltage of the proposed structure is higher than its conventional counterpart. This parameter is 17 V in proposed structure while for conventional structure is 13 V which shows 4 V increase in this important parameter in DC applications at high voltages. This improvement has been achieve due to the presence of two steps of oxide in the channel region. These two regions redistribute the equi-potential lines.

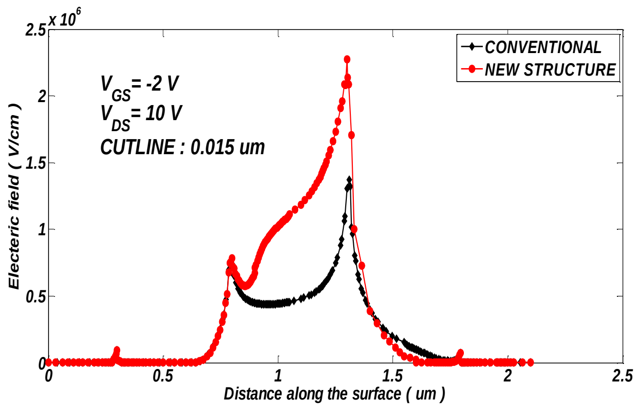

Figure 6. Electric field along the surface (cutline AA') for both structures at V_{DS}= 10 V and V_{GS}= -2 V.

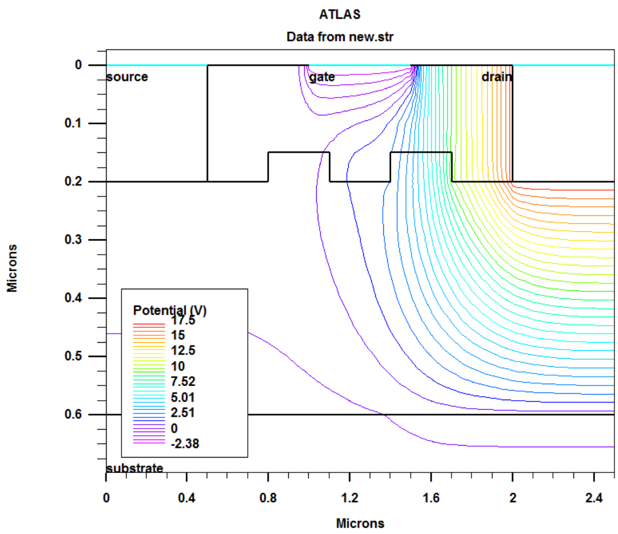

Figure 7. Equi-potential lines at breakdown voltage of the proposed structure.

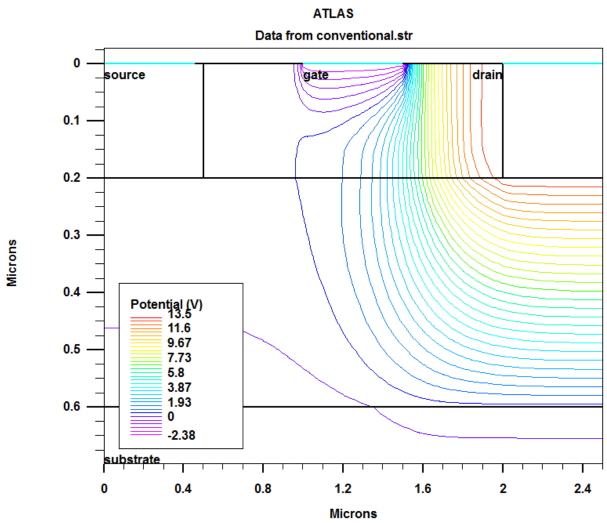

Figure 8. Equi-potential lines at breakdown voltage of the conventional structure.

Electric field of both structures along cutline of AA' have been illustrated in Figure 6. It can be seen that the proposed structure has modified the electric field distribution. Electric field is derivative of potential lines. Figures 7 and 8 illustrate the equi-potential lines at breakdown point of proposed and conventional structures, repectively. Change in equi-potential pattern of proposed structure in comparison with conventional structure is apparent which shows the improvement in breakdown voltage.

Output characteristics of both structures at gate voltage of -1 V has been illustrated in Figure 9. It can be seen that the proposed structure results in a reduction in current capability. It is due to the presence of oxide steps in the drift region where prevent the current to pass through the lower part of channel and consequently the current is reduced by applying the proposed structure. Beside an improvement in breakdown voltage this is a drawback for proposed structure. It should be mentioned that this feature can not destroy the performance of device at high voltages. The device can operate in high voltage even with lower currents. Another drawback for the new structure is its more fabrication process steps in comparison with conventional structure due to two additional steps in the channel.

Adding some materials to the basic structure of Si creates some difficulties in fabrication process. It is worth mentioning that the proposed structure uses additional steps made from SiO_2 , the material which is compatible with Si where the desighner doesn't have problems with additional materials.

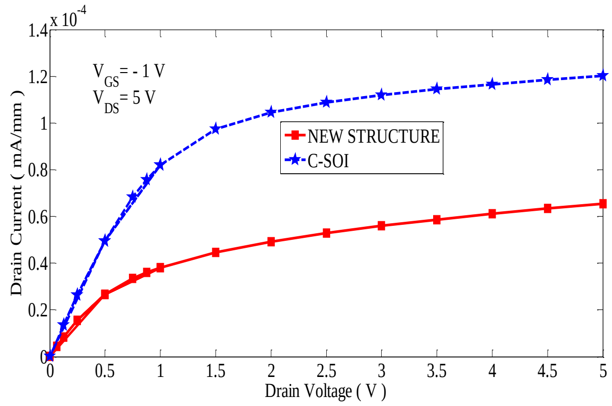

Figure 9. Drain current versus drain voltage at fixed gate voltage for proposed structure and its conventional counterpart

4. Conclusion

In this paper we discussed about a novel structure for SOI-MESFETs. These devices due to their low noise operation, low cost, operation at high voltages and high temperatures can be used in most of electronic circuits. We propose a modified structure to enhance the breakdown voltage. Using SILVACO software and by solving the equations by Newton-Raphson method we simulate the device behavior and compare our proposed structure with its conventional counterpart. It can be stated that our proposed structure is a device with higher breakdown voltage due to the presence of two additional steps in the drift region. Breakdown voltage in conventional structure is 13 V while for proposed structure increased to 17 V.

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