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Time Dependent Dielectric Breakdown and Time to Failure Analysis of 4H-SiC Power MOSFET

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Abstract

In this paper, a simulation study is conducted to study the time dependent dielectric breakdown mechanism and time to failure for a 4H-SiC power MOSFET device in the room temperature operation. It is observed that the acceleration factor for more than 25000 hrs of operation is almost two which implies that in moving from a normal operating condition to highly accelerated test environment of long hours of operation will reduce time to failure of the device by almost a factor of two than the normal operating condition.

1. Introduction

The core of power switching is DC/DC or DC/AC converter. The power MOSFET devices play the key roles in these converter topologies. The failure of this device would result in unconventional switching power supply. So the research of reliability and failure analysis of the power MOSFET is the dire need to guarantee the products to work in a real- time working environment and to maintain its performance under different loads or stress conditions. In this work, time to failure of the 4H-SiC power MOSFET device and acceleration factor using Time Dependent Dielectric Breakdown mechanism (TDDB) [1,2] is analyzed.

2. Simulation Results and Analysis

The structure of the 4H-SiC power MOSFET device simulated with the help of ATLAS [3] device simulation software package is shown in Fig.1 and is inspired from the structure given in ref. [4]. The results of the simulation is provided in Table 1.

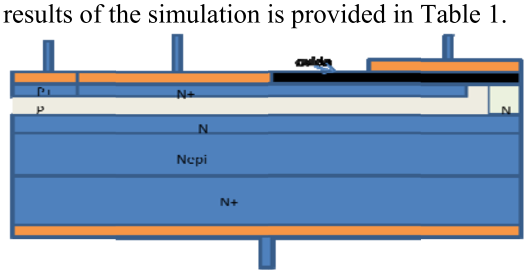

Fig. 1 Simulated 4H-SiC power MOSFET Device structure.

Table 1 Simulated results for Threshold voltage and Breakdown voltage at T = 300K for half-cell of 4H-SiC power MOSFET considering TDDB failure mechanism.

Parameters	Time of operation 0 sec. – 10000 sec.	Time of operation 10000 sec. – 1000000 sec.	Time of operation > 10000000 sec.
Breakdown voltage (V)	1000	867	865
Threshold voltage (V)	4	9.0	9.3

As the device operation goes on for long time, the electric field across the oxide increases leading to dielectric breakdown and thus, creates a path for the carriers to penetrate through the oxide layer leading to shift in threshold voltage. This mechanism is shown in Fig. 2. We can see that with the increase in time of operation, the electric field across the oxide is getting increased causing wear and tear of the Silicon dioxide layer. In this process, the chemical bonds across Silicon dioxide layer get broken and therefore increasing the local tunneling current and shifting the threshold voltage of the device as tabulated in Table 1. Also, from Table 1, the breakdown voltage of the device is decreasing with the increase in time of operation with TDDB mechanism. The reason can be explained from the following expression [5]:

$$BV \ \alpha \ (1/\varepsilon \, \varepsilon_0 Eox) \quad (1)$$

1

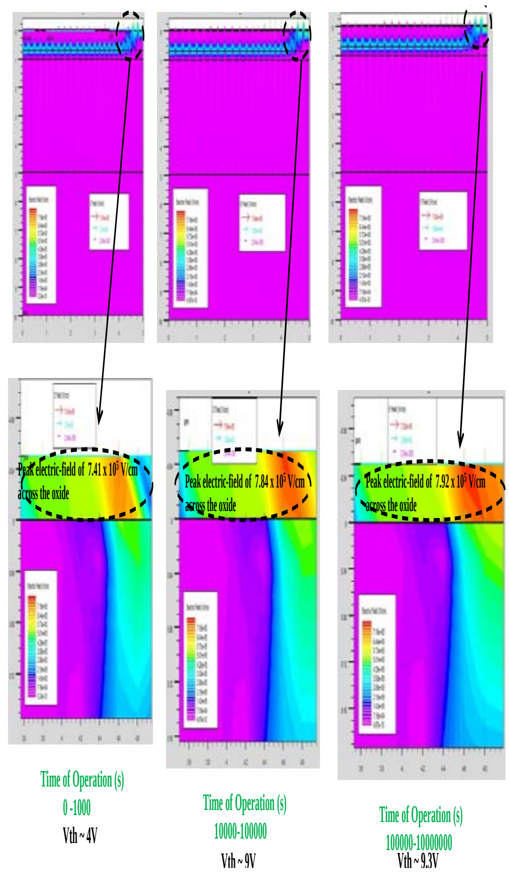

Fig. 2 Simulated TDDB mechanism for 4H-SiC power MOSFET for different time intervals.

Where ε = material dielectric constant, ε_0 = permittivity of empty space and *Eox* = electric field across the oxide.

From the above expression, we can see with the increase in electric field across the oxide, breakdown voltage decreases, which is evident from Table 1.

Acceleration Factor (AF):

Using TDDB failure mechanism, the time to failure of the simulated 4H-SiC power MOSFET, is given by

$$TF = A0 \exp[-\gamma\, Eox] \exp[Ea/kT] \qquad (2)$$

Where,

TF = time to failure, *AF* = Acceleration Factor = *TFcond2*/ *TFcond1*, *A0* = process/material-dependent constant or scaling factors, *Ea* = activation energy ~0.75 eV, k = Boltzmann's constant = 8.62 x 10^{-5} eV/ K, T = absolute temperature in Kelvin, *Eox* = electric field across the dielectric in MV/cm., γ = field acceleration parameter (=~3 Naperians per MV/cm).

In our simulation, Eox = 0.741 MV/cm from 0 sec. – 10000 sec. and corresponding T is 8000K and 0.792 MV/cm for more than 10000000 sec. of operation and corresponding T is 12000K.

So, the *AF* = *TF*(0 sec. to 10000 sec.)/ *TF*(more than 10000000 sec.)

= 1.67

i.e., in moving from a normal condition to highly accelerated test environment of long hours of operation, will reduce TF of the device by almost a factor of two than the normal operating condition.

3. Conclusions

In this simulation study, it is observed that the acceleration factor for more than 25000 hrs of operation for a 4H-SiC power MOSFET device is almost two which implies that in moving from a normal operating condition to highly accelerated test environment of long hours of operation will reduce the time to failure of the device by almost a factor of two than the normal operating condition.

References

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