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Comparative Study Of Power Dissipation Of 6H –SIC DIMOSFET using Gaussian and Uniform Doping Profile in the Drift Region

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Abstract

This paper analyzes the device on power dissipation of 6H SIC using Gaussian and uniform doping in drift region. The aim of the paper is to find minimum power dissipation among the two. Due to excellent physical and electrical properties such as high break down voltage, wide band gap it is best suited for power electronics device.

Keywords: Silicon carbide, Power electronics, High temperature Drift Region Uniform Doping.

1.Introduction

While SiC's smaller on-resistance and faster switching helps minimize energy loss and heat generation, SiC's higher thermal conductivity enables more efficient removal of waste heat energy from the active device. Because heat energy radiation efficiency increases greatly with increasing temperature difference between the device and the cooling ambient, SiC's ability to operate at high junction temperatures permits much more efficient cooling to take place, so that heat sinks and other device-cooling hardware (i.e., fan cooling, liquid cooling, air conditioning, heat radiators, etc.) typically needed to keep high-power devices from overheating can be made much smaller or even eliminated. While the preceding discussion focused on high-power switching for power conversion, many of the same arguments can be applied to devices used to generate and amplify RF signals used in radar and communications applications. In particular, the high breakdown voltage and high thermal conductivity coupled with high carrier saturation velocity allow SiC microwave devices to handle much higher power densities than their silicon or GaAs RF counterparts, despite SiC's disadvantage in low-field carrier Uncooled operation of high-temperature and high-power SiC electronics would enable revolutionary improvements to aerospace systems. Replacement of hydraulic controls and auxiliary power units with distributed "smart" electromechanical controls capable of harsh ambient operation will enable substantial jet-aircraft weight savings, reduced maintenance, reduced pollution, higher fuel efficiency, and increased operational reliability. Performance gains from SiC electronics could enable the public power grid to provide increased consumer electricity demand without building additional generation plants, and improve power quality and operational reliability through "smart" power management.

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More efficient electric motor drives enabled by SiC will also benefit industrial production systems as well as transportation systems such as diesel-electric railroad locomotives, electric mass-transit systems, nuclear-powered ships, and electric automobiles and buses.

Applications of high-temperature power devices include aircraft, space, oil and gas exploration [3], where power systems are expected to operate in an elevated ambient temperature. These devices are also interesting in milder environments, because they should require less cooling. This latter approach is described in [4]: using a power module designed for 250°Cin a 150°C environment allows for the use of a much smaller heatsink. Si-based devices indeed offer less headroom between the ambient and maximum junction temperatures, requiring very efficient cooling. This is of great importance, as the thermal management system is one of the bulkiest and heaviest parts of a converter.

1.1 BASIC EQUATION USED IN TO EVALUATE SPECIFIC ON RESISTANCE & POWER DISSIPATION OF UNIFORM DOPING OF DRIFT LAYER

The width of depletion region is given by

- $R_{on\text{-}sp} = 1/ [\mu_{eff} q N_B (Wt\text{-}Wj\text{-}Wd\text{-}L_p \tan\alpha)$ (1)
- where
- Wt=40x10-4cm
- Wj=10x10-4cm
- Lp=25x10-4cm
- $\alpha = 25°$
- N_B is drift region doping
- μ_{eff} is effective mobility

The total resistance is given sum of resistances

- $R_{onsp} = R_{n+} + R_c + R_A + R_J + R_D + R_{S\ (2)}$ (2)

R_{n+} is the contribution from the N+ source region,

R_c is the channel resistance,

R_A is the accumulation layer resistance,

R_J is the resistance of the JFET pinchoff region,

R_A is the accumulation layer resistance,

R_J is the resistance of the JFET pinchoff region,

R_D is the drift region resistance and,

R_S is the substrate resistance

Power dissipation is given by

- $P_D=1/2(j_{on}^2 R_{on\text{-}sp}+J_L V_B)$ (3)

Where j_{on} is on state current density

J_L is reverse saturation current

$V_{B\ is}$ breakdown voltage

Theoretical Analysis

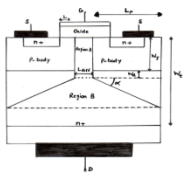

Figure 1 BASIC STRUCTURE OF DIMOSFET

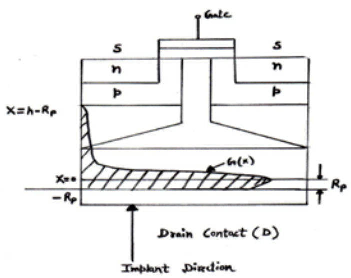

Figure 2 The Effective Carrier Concentration (Neff) of a Gaussian profile in the drift region

1.2 BASIC EQUATION USED IN TO EVALUATE SPECIFIC ON RESISTANCE & POWER DISSIPATION OF GaussianPROFILE OF DRIFT LAYER

- $G(x) =(S/ (2\Pi)1/2\sigma p)\exp[-(x-Rp)2/2\sigma p2]$….(4)

where S is the ion dose per unit area and σp is the longitudinal or projected straggle

- $N_{eff} = N_d/ A_o h = S/h\ [erf(y)]^{y2}$ (5)
- Calculations for evaluation of channel current ,Ich and power dissipation ,PD can be carried out using the same set of equations given in sec. A. above, the only change being that NB will have to be replaced by Neff given by eq.(1). The magnitude of Neff will of course depend upon the ion doze and ion energy and will be effected in the magnitude of Rp and σp.
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1.3 *EFFECTIVE DOPING N(EFF)FOR PHOSPHOROUS IN GAUSSIAN DISTRIBUTION*

After implantation, the SIMS measurements were conducted on the as-implanted samples to obtain the implant depth profiles. These profiles were then analyzed, using formulas:

Rp(average range)=$\int x f(x) dx$ ---------- (6)

ζ_p(range strangle)=$\{\int (x- Rp)^2 f(x)dx\}^{-1/2}$ (7)

table 1.

Effective Doping N(eff)for Phosphorous in Gaussian Distribution					
Energy	Dose	Projected Range	Longitudnal Straggle	Integral	N(eff)/cc
K eV	cm-2	Rp(µm)	σp(µm)	I	
50	$3.4x\ 10^{14}$	0.059	0.027	$8.54x\ 10^{14}$	$5.2\ x10^{16}$
100	$6.0x10^{14}$	0.097	0.039	$1.50\ x10^{15}$	$9.3\ x10^{16}$
250	$1.2\ x\ 10^{15}$	0.249	0.073	$3.01\ x10^{15}$	$1.9\ x10^{17}$
500	$1.8\ x\ 10^{15}$	0.47	0.109	$6.28\ x\ 10^{15}$	$3.9\ x10^{17}$
750	$2.2\ x\ 10^{15}$	0.616	0.119	$5.53\ x\ 10^{15}$	$3.4\ x10^{17}$
1.0Mev	$2.4\ x\ 10^{15}$	0.764	0.131	$6.03\ x\ 10^{15}$	$3.7\ x10^{17}$
2Mev	$2.8\ x\ 10^{15}$	1.28	0.157	$7.03\ x\ 10^{15}$	$4.3x10^{17}$
3Mev	$3.0\ x\ 10^{15}$	1.67	0.163	$7.54\ x\ 10^{15}$	$4.6\ x10^{17}$
4Mev	$3.2\ x\ 10^{15}$	2.00	0.168	$8.04\ x\ 10^{15}$	$4.9x10^{17}$

D Plot of power dissipation (w) at different values of Breakdown voltages(volts) for different Doping levels of Uniform distribution & Gaussian Profile in Drift Region

Table & related Graph

Values of specific On-Resistance at different values of Breakdown voltages(volts) for different Doping levels(NB) of uniform Distribution					
$N_B=10^{15}/CC$	$N_B=10^{15}/CC$	$N_B=10^{16}/CC$	$N_B=10^{16}/CC$	$N_B=10^{17}/CC$	$N_B=10^{17}/CC$
$V_{B(VOLTS)}$	$R_{ON-SPX}X10^{-1}$	$V_{B(VOLTS)}$	$R_{ON-SPX}X10^{-1}$	$V_{B(VOLTS)}$	$R_{ON-SPX}X10^{-1}$
208.5	0.26	89.09	0.03	38.11	0.0048
294.92	0.31	125.99	0.037	53.9	0.0056
361.21	0.36	154.29	0.044	66.01	0.0064
417.09	0.41	178.17	0.052	76.23	0.0072
466.32	0.45	199.21	0.059	85.23	0.008
510.82	0.49	218.21	0.066	93.36	0.0088
551.76	0.53	235	0.073	100.84	0.0096
589.86	0.57	251.97	0.079	107.8	0.0103

Values of Power Dissipation at different values of Breakdown Voltages(volts) for different Doping levels(N_B) level at Uniform Distribution					
$N_B=10^{15}$	$N_B=10^{15}$	$N_B=10^{16}$	$N_B=10^{16}$	$N_B=10^{17}$	$N_B=10^{17}$
$V_{B(VOLTS)}$	P_D(w)	$V_{B(VOLTS)}$	P_D(w)	$V_{B(VOLTS)}$	P_D(w)
208.5	0.92	89.09	0.097	38.11	0.0064
294.92	2.62	125.99	0.29	53.9	0.021
361.21	4.45	154.29	0.51	66.01	0.04
417.09	6.29	178.17	0.76	76.23	0.061
466.32	7.98	199.21	0.99	85.23	0.083
510.82	9.57	218.22	1.22	93.36	0.1

Plot of specific on- resistance at different at different values of breakdown voltages (volts) for different Doping levels (N_B) of uniform Distribution Figure 3.

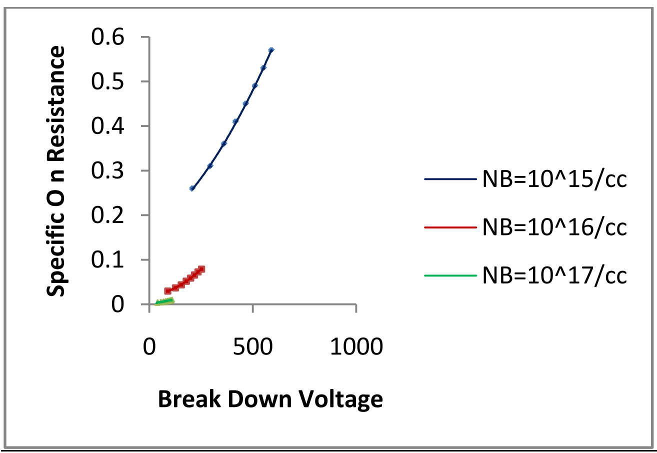

Figure: 3

Values of specific On-Resistance at different values of Breakdown voltages(volts) for different Neffective levels for Gaussian Distribution

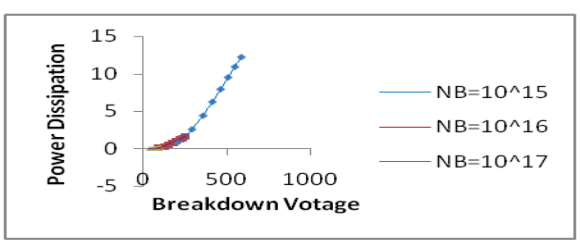

Fig4

Plot of Power Dissipation at different at different values of breakdown voltages (volts) for different Doping levels (N_B) of uniform Distribution Fig4.

Table 4

N_{eff}=5.2x10^16/CC	N_{eff}=5.2x 10^{16}/CC	N_{eff}=9.2x10^16/CC	N_{eff}=9.2x 10^{16}/CC	N_{eff}=18.5x10^17/CC	N_{eff}=18.5x 10^{17}/CC	N_{eff}=33.9x.5 x10^{17}/CC	N_{eff}=33.9x.5x 10^17/CC
$V_{B(VOLTS)}$	R_{ON-SPX}X10^{-4}(cm^2)	$V_{B(VOLTS)}$	R_{ON-SPX}X10^{-4}(cm^2)	$V_{B(VOLTS)}$	R_{ON-SPX}X10^{-4}(cm^2)	$V_{B(VOLTS)}$	R_{ON-SPX}X10^{-4}(cm^2)
48.48	5.91	39.63	3.33	30.32	2.64	24.3	1.44
68.57	7.43	56.05	4.21	42.88	3.7	34.4	1.68
83.98	9.01	68.64	5.08	52.52	3.51	42.1	1.92
96.97	10.48	79.26	5.95	60.64	3.94	48.6	2.16
108.4	11.95	88.62	6.78	67.8	4.37	54.4	2.4
118.8	13.43	97.06	7.64	74.27	4.81	59.6	2.64
128.9	14.91	104.9	8.49	80.22	5.23	64.3	2.87
137.1	16.41	112.1	9.34	85.77	5.66	68.8	3.11

Table 5

Values of Power Dissipation at different values of Breakdown Voltages(volts) for different N_{eff} levels at Gaussian Distribution							
N_{eff}=5.2^10^{16}/CC		N_{eff}=9.2^10^{16}/CC		N_{eff}=18.5^10^{17}/CC		N_{eff}=33.9x10^^{17}/CC	
$V_{B(Volts)}$	$P_{D(mw)}$	$V_{B(Volts)}$	$P_{D(mw)}$	$V_{B(Volts)}$	$P_{D(mw)}$	$V_{B(Volts)}$	$P_{D(mw)}$
48.48	19.13	39.63	3.19	30.32	3.48	24.31	1.9
68.57	57.99	56.05	10.55	42.88	11.47	34.38	6.28
83.98	104.81	68.64	20.16	52.52	21.85	42.09	11.98
96.97	152.89	79.26	30.98	60.64	33.48	48.62	18.21
108.42	201.44	88.62	42.42	67.8	45.75	54.36	25.11
118.77	249.56	97.06	54.13	74.27	58.27	59.55	32.01
128.28	296.66	104.85	65.87	80.22	70.76	64.33	38.87
141.28	342.71	112.1	77.51	85.77	83.11	68.76	45.72

Figure 5:**Plot of specific On-Resistance at different values of Breakdown voltages(volts) for different Neffective levels for Gaussian Distribution**

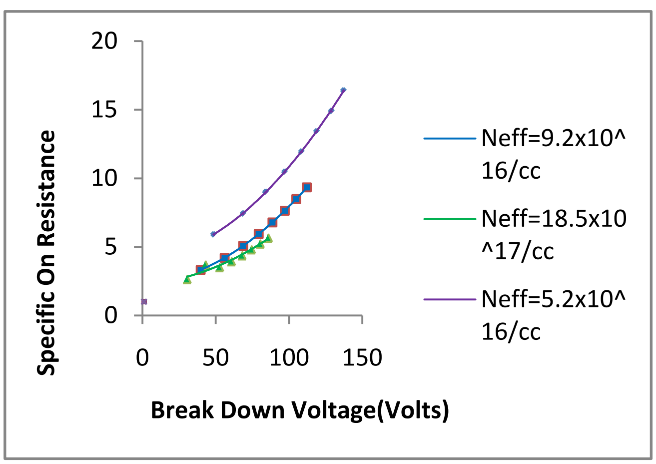

Figure 5:

Figure 6: **Plot of Power Dissipation at different values of Breakdown Voltages(volts) for different N_{eff} levels at Gaussian Distribution**

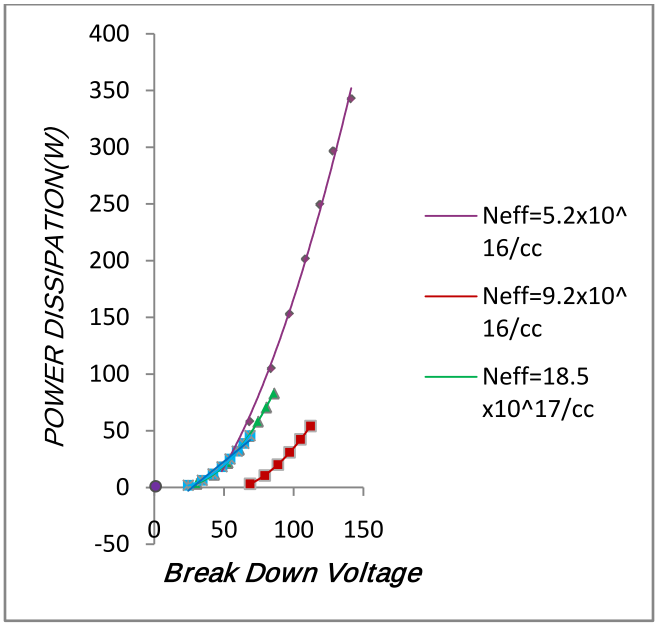

Figure 6:

2. Result & Conclusion

The decrease in doping level will lead to increase in breakdown voltage, which is desirable for any power electronics device. As we increase doping Specific on resistance and power dissipation of the device decreases. This is because effective mobility decreases with increase in doping, It is seen an increase in P_D results for a decrease in N_B and an increase in V_{DS}. However, Gaussian profiles show a decline in P_D at the same value of N_{eff} compared to N_B for uniform doping at the same VDS. This can be verified

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