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Estimation of Power Dissipation and Breakdown Voltages of a 4H-SiC Schottky Barrier Diode for a Linearly Graded and Uniformly Doped Drift Region.

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ABSTRACT

The present paper focuses on the relative decrease in the values of power dissipation and the increase in breakdown voltages of 4H-SiC Schottky barrier devices compared to those with uniformly doped drift regions. The paper also highlights the possibility to design and develop 4H-SiC Schottky Barrier Diode (SBD) which can yield higher breakdown voltages at a lower device thickness by using linearly graded drift region.

Keywords: 4H-SiC, Schottky Barrier Diode, Linear Graded Doping, Breakdown Voltage

1 INTRODUCTION

The role of efficient power electronics and power devices become more important in the modern society since we consume more and more electricity. Silicon carbide is considered as the semiconductor material that will enable the transition of traditional silicon power electronics into efficient power electronics. Silicon carbide has material properties that allow devices with higher voltage rating and higher operating temperatures compared to traditional silicon, which translates into smaller and less expensive components. Reduced energy loss, more efficient use of the power grid, increased controllability and better switching properties are all attributes to devices made of silicon carbide.

The calculation of power dissipation using uniformly doped drift regions is presented in the paper, followed by the estimated breakdown voltages. These results are compared with those obtained for linearly graded profiles in the drift region of these devices. A comparison of the results of power dissipation and breakdown voltages for these two types of devices is presented. The final results show the superiority of linearly graded drift region devices over uniformly doped ones.

2 POWER DISSIPATION OF UNIFORMLY DOPED DRIFT REGION DEVICES.

2.1 The Specific on Resistance (R_{on-sp})

The specific on resistance, R_{on-sp} of the device can be expressed as:[1-2]

$$R_{on-sp} = \rho_D \frac{d}{\tan\alpha'} \ln[1 + \frac{2h}{a}\tan\alpha'] \quad (1.1)$$

where
d is the metallic contact width
α' is the angle at which current spreads with respect to vertical at the edge of the metallic contact with SiC
h is the device height
a is the contact length of device

The specific resistance, ρ_D is given by

$$\rho_D = \frac{1}{\mu e N_D} \quad (1.2)$$

where d = a for minimum overlap of the contact metal has been used.

The drift region resistance is represented by R_D, which is the sum of the resistance R_d of the trapezoidal current flow region and the parasitic series resistance R_s having uniform current flow.

The structure along with regions of the 4H-SiC SBD with the uniformly doped drift region and its equivalent circuit[3] is shown alongside in Fig. 1.

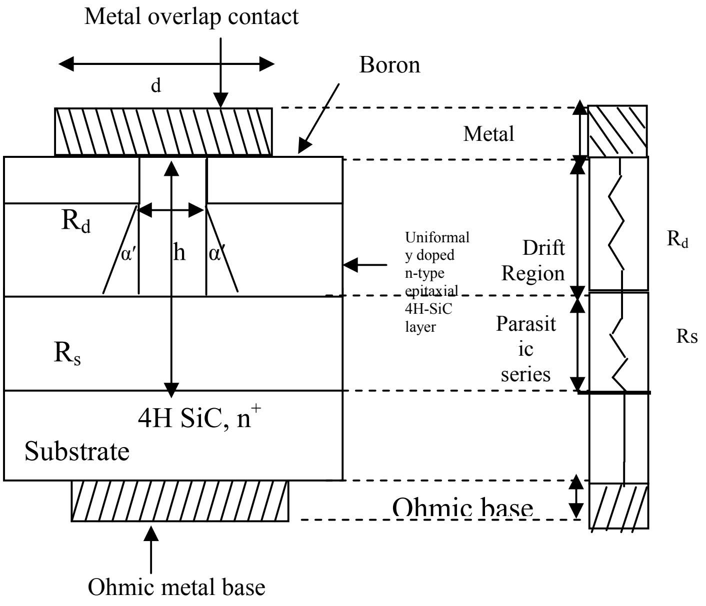

Fig.1 The structure along with regions of the 4H-SiC SBD with the uniformly doped drift region and its equivalent circuit

2.2 Device Height (h) and breakdown voltages (V_{PBV} & V_{AvBV})

The device height 'h' has been set using a specific value of reverse bias voltage and the lowest doping level of 10^{14} per cc which gave a depletion region width W of 227μm. Thus the condition W=h has been used to determine the device height 'h'. This value of the reverse bias voltage is the value of the punch through breakdown voltage, V_{PBV}. The condition $\alpha_p W = 1$ gave the value of α_p, the hole ionization coefficient. The corresponding field which generated this value of W was obtained from [4]. This gave the critical field Ec and the magnitude of the avalanche breakdown voltage V_{AvBV} for the uniformly doped drift region devices given by

$$V_{AvBV} = \frac{1}{2} E_C W \qquad (1.3)$$

The depletion region width W for a given reverse voltage V_R is given by

$$W = \sqrt{\frac{2\varepsilon_s (V_{bi} + V_R)}{eN_D}} \approx \sqrt{\frac{2\varepsilon_s V_R}{eN_D}} \qquad (1.4)$$

where V_{bi} is the built in potential and $V_{bi} << V_R$. At the breakdown $V_R = V_{AvBV}$.

2.3 Power Dissipation(P_D)

For a given on-state current density J_{on} and specific on resistance R_{on-sp}, the value of power dissipation, P_D can be calculated using equation

$$P_D = \frac{1}{2}(J_{on}^2 A R_{on-sp}) \qquad (1.5)$$

where A is the device cross-sectional area

3 CALCULATION OF POWER DISSIPATION (P_D)

The device height ‘h’ was set equal to the depletion region width ‘W’ using equation (1.4) corresponding to a reverse bias of 5kV for the uniformly doped epitaxial layer with a doping level of 10^{14} per cc. The value of W obtained was 227μm with ϵ_s=9.7 for

4H-SiC. The doping dependent mobility values were obtained from Roschke and Schwierz [5]. The magnitude of R_{on-sp} was calculated using equation (1.1) with α=26 and Schottky contact of length ‘a’ of 100μm.The contact width was taken to be 78.5x10^{-6} cm^2.

The on state current density(J_{on}) values were then selected, ranging from 100 to 1000 amps/cm^2. The corresponding values of power dissipation (P_D) were then calculated using equation (1.5). This was repeated for drift region doping levels of 10^{15}, 10^{16} and 10^{17} per cc. The results are shown in Table 1.1

(Table 1.1)

Results of Power dissipation (P_D) of 4H-SiC SBD with uniformly doped drift region

Current density (amps per cm^2)	N_d = 1x 10^{14} atoms per cc	N_d = 1x 10^{15} atoms per cc	N_d = 1x 10^{16} atoms per cc	N_d = 1x 10^{17} atoms per cc
	μ_n= 960 cm^2 per Vs	μ_n = 950 cm^2 per Vs	μ_n = 900 cm^2 per Vs	μ_n = 600 cm^2 per Vs
	Ronsp=1.577 Ω-cm^2	Ronsp=159.38 x10^{-3} Ω-cm^2	Ronsp=16.82 x10^{-3} Ω-cm^2	Ron-sp=2.52 x 10^{-3} Ω-cm^2
J_{on}	P_D(1) Watts	P_D(2) Watts	P_D(3) Watts	P_D(4) Watts
100	0.6195	62.55x10^{-3}	6.601 x 10^{-3}	989.1 x 10^{-6}
200	2.478	0.2502	26.40 x 10^{-3}	3.956 x 10^{-3}
400	9.912	1.0008	0.1056	15.82 x 10^{-3}
600	22.302	2.2518	0.2376	35.607 x 10^{-3}
800	39.649	4.0032	0.4225	63.30 x 10^{-3}
1000	61.95	6.255	0.660	98.91 x 10^{-3}

The plots of power dissipation, P_D versus current density for uniformly doped and linearly graded drift region devices for a 4H-SiC SBD has been obtained. These are shown in Fig. 2.

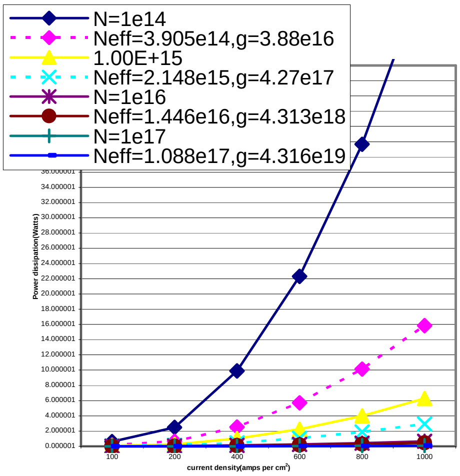

Figure 2 Plot of power dissipation verses on-state current density for uniform and linearly graded drift region in 4H-SiC SBD

It can be seen from an analysis of the plots of Fig 2. that for nearly same values of doping levels N_D for uniformly doped and Neff for linearly graded drift region devices, the fall in power dissipation is significant at high current density levels. Thus for $N_D=10^{14}$ per cc and $N_{eff}= 3.905x10^{14}$ per cc at a gradient of $3.88x\ 10^{16}$ cm^{-4} ,the percentage drop in power dissipation is as high as 74.4 at a value of Jon of 1000amps/cm^2. This percentage drop decreases with increasing magnitude of doping levels and concentration gradient, falling to values as low as 7.74% at a gradient of $4.32x10^{19}$ cm^{-4} at a the same value of J_{on}. This has been shown in Fig. 3

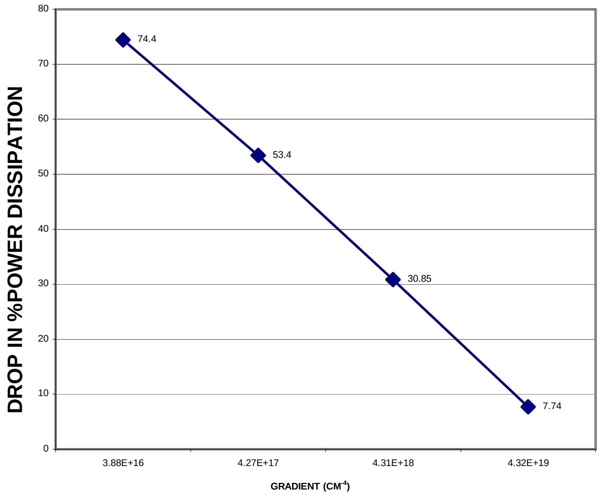

Figure 3. Percentage drop in power dissipation versus concentration gradient in a 4H-SiC SBD compared to SBD's with uniformaly doped drift regions.

4 CALCULATION OF BREAKDOWN VOLTAGES (V_{PBV} and V_{AvBV})

The punch through breakdown voltage, V_{PBV} was set for a breakdown voltage of 5kV for a 4H-SiC SBD with a uniformly doped drift region having a doping level of 10^{14} per cc. The corresponding device height was equal to the depletion region width 'W' at this voltage which was found to be equal to 231µm. The condition of avalanche breakdown $\alpha_p W=1$ was then used which gave the value of α_p for W = 227 µm. The magnitude of

Ec, the critical field for avalanche breakdown was obtained from Ayalew [4] from this value of α_p. The avalanche breakdown voltage V_{AvBV} was then calculated using equation (5.3) and knowing Ec and W, the depletion region width at breakdown. This was repeated for values of doping levels of 10^{15},10^{16}, 10^{17}. The results are shown in Table 1.2.

Table 1.2

Breakdown voltages of 4H-SiC SBD for Uniformly doped epitaxial layer

Device height=h=W=231μm

S.No	Doping Level(N per cc)	W(μm)	α_p	Ec(V per cm) x 10^6	V_{AvBV}(kV)	V_{PBV}(kV)
1	10^{14}	231	44.05	1.33	14.94	5
2	10^{15}	71.78	139.31	1.66	5.95	5
3	10^{16}	22.7	440.05	1.82	2.06	5
4	10^{17}	7.17	1394.7	2.12	0.7575	5

5 CONCLUSION

The analysis of power dissipation, P_D for 4H-SiC Schottky Barrier Diodes for uniformly doped drift regions and those for linearly graded drift regions shows that for a given value of the drift region doping level N_D approximately equal to N_{eff} for linearly graded regions, the later always yield a lower value of P_D. This decline in power dissipation on a percentage basis becomes significant at higher values of on-state current density levels, Jon. However, as the doping level is increased with increase in power dissipation also decreases falling from 74.4% at doping levels of 10^{14} per cc to 7.74% at doping levels of 10^{17} per cc. The corresponding concentration gradients range from 3.88×10^{16} cm^{-4} to 4.32×10^{19} cm^{-4}.

The avalanche breakdown voltages, V_{AvBV} for uniformly doped drift region devices can be made to vary from maximum of 5kV at a drift region doping level N_D of 10^{14} per cc to a minimum of 757.5 at a value of N_D of 10^{17} per cc. The corresponding device thickness may range from 231μm to 7.17μm respectively. However, linearly graded drift region devices have avalanche breakdown voltage of about 5kV for gradients ranging from 3.88×10^{16} cm^{-4} to 7.96kV at a gradient of 4.4×10^{19} cm^{-4}.The corresponding device thickness may change from 201.07µm to 231µm. Hence it is possible to design and develop 4H-SiC SBD's which can yield higher breakdown voltages at a lower device thickness by using linearly graded drift region. Deplition Width W for linearly graded profiles is shown in Table 1.2. Hence thinner device with higher breakdown voltages and lower power dissipation can be developed by using linearly graded profiles in the epitaxially grown drift regions of 4H-SiC Schottky barrier diodes. Finally, if the device height is reduced from the standard 231µm to the punch through the magnitude of $R_{on\text{-}sp}$ and P_D would decline further. The parasitic series resistance and hence $R_{on\text{-}sp}$ would be still smaller than what it would be with if the device height was kept at 231µm.

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