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High Breakdown Voltage Analysis of DIMOSFET with Linear Doping Profile in the Drift Region for 3C-SiC Wafer

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ABSTRACT

The aim of the present work is to analyze 3C-SiC Double Implanted Metal Oxide Semiconductor Field Effect Transistor (DIMOSFET) with linearly graded doping profile in the drift region for high breakdown voltages. By varying the device height 'h' and concentration gradient 'a' various calculations have been made for optimum profiles with high breakdown voltages. When the device height is set at 300 μm, a maximum breakdown voltage of 280 kV has been estimated with concentration gradient 'a' as $66.6\times 10^{16}\,\mathrm{cm}^{-4}$ and drain end doping concentration N_D as 2×10^{16}/cc. Wolfram Mathematica and Matlab have been used for various equation solving and plotting purposes.

Keywords: Avalanche breakdown voltage, concentration gradient, DIMOSFET, Punch through breakdown voltage, Silicon carbide (SiC)

Introduction

Silicon carbide (SiC) is a wide band gap compound semiconductor that can be used for high-voltage switching applications, high temperature electronics, and high power microwave applications in the 1-10 GHz range. Due to its extreme thermal stability, wide band gap, high saturated drift velocity, high breakdown electric field and high thermal conductivity SiC is a probable material for various applications. SiC exists in a number of poly-types. Stacking order of double layers between carbon and silicon atoms determines a type[1]. The most important poly-types of SiC are cubic (3C) and hexagonal (4H and 6H) forms. These poly-types differ in both band gap energies and electronic properties[2]. Thus band gap varies with the polytype from 2.2eV for 3C-SiC over 2.86eV for 6H-SiC to 3.2eV for 4H-SiC. 3C- SiC poly-type is superior as compared to other poly-types due to isotropic electron Hall mobility[3], smaller band gap (that permits "inversion" at lower electric field strengths). Due to presence of interface states in conduction band there is no effect on the transport properties of the channel[4]. However, lack of techniques to grow semiconductor crystalline substrate and epilayers has been a factor for the under development of 3C-SiC power devices and their practical applications. However, recently a lot of work has been done in the area of crystal growth in order to get defect free 3C-SiC wafers[5]. HOYA (Japan) has developed a low temperature process (1000^0 C) for the growth of 3C-SiC films on 150 mm Si wafers and by increasing the deposition rate managed to grow a 300 μm thick, freestanding 3C-SiC film after removing the Si substrate[3]. So in this paper, device height 'h' has not been used in excess of 300 μm.

Analysis of DIMOSFET for high breakdown voltage

Fabrication of DIMOSFET structure is normally done by planar diffusion technology. A gate such as poly silicon is used in this process. The edge of the poly silicon gate serves as a common window for the diffusion of p-base and n+-source regions. Figure 1 shows a cross section of a power DIMOSFET. Surface channel is formed due to the lateral difference in diffusion between the p-base and n+ source region[1]. The p-base region and the n- drift region junction determine the forward blocking capability of the device.

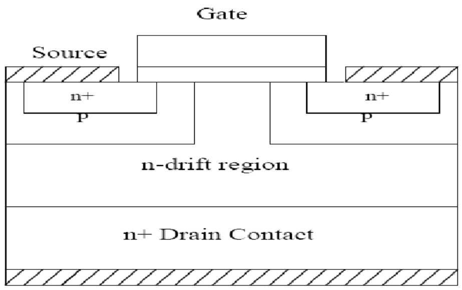

Figure 1. Structure of basic DIMOSFET[1]

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The p-base and n-drift region junction is reverse-biased by applying a positive bias to the drain and short-circuiting the gate to the source. Thus, the drain voltage is supported by the extension of a depletion layer on both sides of the junction[1]. However, due to lower doping level of n-drift region as compared to p-base region, the depletion layer extends primarily into the n-drift region. By applying a positive bias to the gate electrode, a conductive path between the n+-source region and the n-drift region is formed[1]. Current flows between drain and source through the n-drift region and through conductive channel by the application of a positive drain voltage. In this paper linearly graded doping profile has been assumed in the drift region of DIMOSFET and analysis has been done in order to get high breakdown voltage.

Punch through breakdown voltage V_{BPT} and Avalanche breakdown voltage V_{BAV}

The depletion region width at breakdown can be estimated by first calculating the depletion width for punch through breakdown voltage V_{BPT} and the same can be obtained by[6]

$$W=(12\,\varepsilon_s V_R\,/\,e\,a)^{1/3} \qquad (1)$$

where ε_s is the relative permittivity of the medium, ‘a’ is the concentration gradient (calculated by taking the difference in concentrations at drain end and source end and then dividing it by the device height), e is the charge on an electron and W is depletion region width at punch through breakdown. Analysis of equation (1) has been done in order to increase the reverse voltage to a value for which maximum depletion width does not go beyond the device height. That maximum value of reverse voltage is taken as punch through breakdown voltage V_{BPT}. Avalanche breakdown voltage V_{BAV} for linearly doped profile is obtained by using the equation[6]

$$V_{BAV} = 2/3\, E_c W' \qquad (2)$$

where E_c is the critical field and W' is depletion width at breakdown. For linearly graded profile critical electric field is given as[6]

$$E_c = (eaW'^2/8\varepsilon_s) \qquad (3)$$

Depletion region widths at two breakdown voltages have been made equal to each other.

Results and Calculations

Calculations of the 3C-SiC DIMOSFET with a linearly graded drift region have been made by using a doping profile with a fixed doping level of 5×10^{12} /cc near the source end and by taking different doping concentrations at the drain end. Three analysis have been made for the calculations of punch through breakdown voltages (V_{BPT}) and avalanche breakdown voltages (V_{BAV}) for linearly doped profiles depending upon the different values of device height ‘h’. The lower of these two breakdown voltages has been considered as the breakdown voltage of the device for that profile. Table 1 represents the first analysis, where device height has been set as 300 µm.

Table 1. Results of breakdown voltages (V_{BPT} and V_{BAV}) for various doping profiles for h= 300µm

Profiles	**N_D (cm^{-3})**	**a (cm^{-4}) $\times 10^{16}$**	**E_C (V/cm) $\times 10^5$**	**V_{BPT} (kV)**	**V_{BAV} (kV)**
1.	3×10^{13}	.0834	.1756	.35	.3512
2.	5×10^{14}	1.65	3.474	6.9	6.948
3.	1×10^{15}	3.3	7.457	14	14.91
4.	4×10^{15}	13.3	28	56	56
5.	2×10^{16}	66.6	140.2	280	280.4

It can be seen that there is a constant increase in the values of two breakdown voltages as the concentration gradient ‘a’ increases. Values of two breakdown voltages are almost same for a given profile. For this analysis, a maximum breakdown voltage of 280 kV has been estimated with concentration gradient ‘a’ as $66.6\times 10^{16} cm^{-4}$ and N_D as 2×10^{16}/cc.

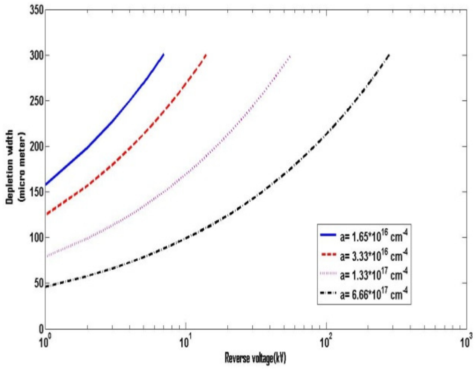

Figure 2. Variation of depletion width vs. reverse voltage for the four profiles

The analysis of depletion region width and reverse voltage for all the four profiles is shown in Figure 2. Reverse voltage has been shown in semi-log scale. It can be seen that as reverse voltage increases, depletion region width variation follow the same pattern for all the four profiles.

In the second analysis, device height ‘h’ has been set as 200 µm. Again as the concentration gradient ‘a’ increases, breakdown down voltage of the device also increases almost linearly as shown in table 2.

Table 2. Results for breakdown voltages (V_{BPT} and V_{BAV}) for various doping profiles for h= 200µm

Profiles	**N_D (cm^{-3})**	**A (cm^{-4}) $\times 10^{16}$**	**E_C (V/cm) $\times 10^5$**	**V_{BPT} (kV)**	**V_{BAV} (kV)**
1.	3×10^{13}	0.125	0.1169	.155	.1488
2.	5×10^{14}	2.475	2.316	3.1	3.088
3.	1×10^{15}	4.975	4.655	6.3	6.266
4.	4×10^{15}	19.975	18.692	25	24.92
5.	2×10^{16}	99.975	93.55	125	124.73

A maximum breakdown voltage of 124.73 kV has been calculated for this analysis with concentration gradient ‘a’ as $99.975\times 10^{16}\text{cm}^{-4}$ and N_D as 2×10^{16}/cc.

Breakdown voltage analysis with device height as 100 µm has been done in table 3. For ‘a’ as 199.95×10^{16} cm^{-4} and N_D as 2×10^{16}/cc, a maximum breakdown voltage of 31.184 kV has been estimated for the device.

Table 3. Results for breakdown voltages (V_BPT andV_BAV) for various doping profiles for h=100µm

Profiles	N_D (cm^{-3})	A (cm^{-4}) $\times 10^{16}$	E_C (V/cm) $\times 10^5$	V_BPT (kV)	V_BAV (kV)
1.	3×10^{13}	0.25	.05848	0.039	0.0389
2.	5×10^{14}	4.95	1.158	0.78	0.772
3.	1×10^{15}	9.95	2.327	1.56	1.551
4.	4×10^{15}	39.95	9.346	6.25	6.230
5.	2×10^{16}	199.95	46.776	31.5	31.184

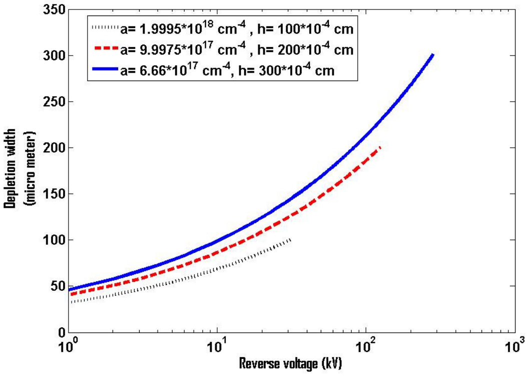

Figure 3. Variation of depletion width vs. reverse voltage for the three optimum profiles

Figure 3 shows the variation of depletion width with respect to reverse voltage for three profiles that yielded maximum breakdown voltage for their corresponding analysis.

It can be seen as device height ‘h’ decreases, breakdown voltage also decreases. And a maximum breakdown voltage of 280 kV has been estimated for the device height of 300µm.

Conclusion

Analysis for high breakdown voltage has been done for different device height ‘h’ as shown in table 1, 2 and 3. It can be seen that as the concentration gradient ‘a’ increases, breakdown voltage also increases for a fixed device height. When device height is set at 300 µm in the first analysis, a maximum breakdown voltage of 280 kV has been estimated with concentration gradient ‘a’ as $66.6\times 10^{16}\text{cm}^{-4}$ and drain end doping concentration N_D as 2×10^{16}/cc. A maximum breakdown voltage of 124.73 kV has been found when device height is taken as 200µm with concentration gradient ‘a’ as $99.975\times 10^{16} cm^{-4}$ and N_D as 2×10^{16}/cc. For third analysis, when device height has been set as 100µm, a maximum breakdown voltage of 31.184 kV has been found for ‘a’ as 199.95×10^{16} cm^{-4} and N_D as 2×10^{16}/cc.

In conclusion it can be said that with linear graded doping profile in drift region of 3C-SiC DIMOSFET breakdown voltage has a direct relationship with device height. As device height ‘h’ increases, breakdown voltage also increases.

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References and notes

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