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Analysis of Punch-Through Breakdown Voltages in 3C-Sic Schottky Barrier Diode Using Gaussian Profile for 200µm Thick Wafer

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ABSTRACT: The punch through breakdown voltage of 3C-SiC Schottky Barrier Diode has been analysed in this paper using Gaussian profile. It is observed that 3C-SiC Schottky barrier diode yield high punch through breakdown voltage with higher values of peak doping concentration and lower values of constant m with increasing depletion region width. So, thinner wafers of 3C-SiC can be used to fabricate Schottky barrier diode to provide higher breakdown voltage using Gaussian profile.

KEYWORDS: 3C-SiC, Schottky Barrier diode, Punch-through breakdown voltage, Gaussian profile

I. INTRODUCTION

Silicon Carbide(SiC) is a wide band gap semiconductor that has energy gap wider than 2eV and has extremely high power, high voltage switching characteristics and high chemical, thermal and mechanical stability. The SiC devices have low mobility which is compensated by its ability to withstand high electric fields taking advantage of the higher carrier velocity. The parameters for the mobility models are collected from measurements for a temperature dependent mobility model [1]. SiC has large band gap, so the intrinsic carrier concentration (responsible for the thermal noise and also partly responsible for the leakage current) is negligible at temperatures up to 600°C. Silicon carbide occurs in many different crystal structures, called polytypes. Despite the fact that all SiC polytypes chemically consist of 50% carbon atoms covalently bonded with 50% silicon atoms, each SiC polytype has its own distinct set of electrical semiconductor properties due to the difference in staking order between the double layers of carbon and silicon atoms[2]. To date, SiC has more than 200 polytypes [3].

II. 3C-SiC SCHOTTKY BARRIER DIODE

Schottky barrier diodes have lower resistance, faster response, and negligible transient reverse current during switching in comparison to p-n rectifiers. Moreover, the reverse saturation current of Schottky diodes is larger than that of p–n junction diodes. Hence, a Schottky diode requires less forward bias voltage to obtain a given current than p–n junction diode. Schottky diodes based on silicon carbide (SiC) are of special importance because of their high voltages and high temperatures handling capacity.

SiC have exceptional chemical and physical properties such as high thermal conductivity, a wide band gap, high breakdown field, high saturation velocity, and chemical stability. So, metal-SiC Schottky contacts are suitable for electrical devices for harsh environments such as high voltage rectifiers, UV radiation detectors, signal mixers, and high temperature gas sensor. The cross section of SBD is shown in Figure 1.

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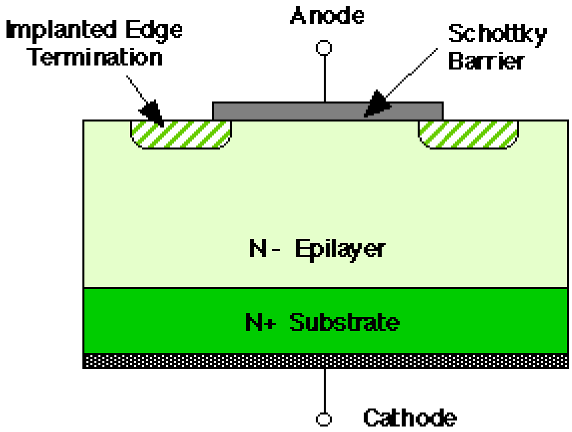

Figure 1 : Cross section of an implant-edge-terminated Schottky barrier diode in SiC [4]

A lightly doped n-type blocking layer is grown on a SiC substrate by chemical vapour deposition. The doping and thickness of the epilayer are selected so that the desired blocking voltage is achieved. On the top surface of the blocking layer an edge termination ring is implanted at the surface and then the Schottky metal is deposited to form Schottky junction. The edge termination ring is required to prevent field crowding at the edge of the metal in the blocking state; otherwise blocking voltage would be significantly reduced. Two types of edge termination rings used are resistive termination extension (RTE) and junction termination extension (JTE).

III. BACKGROUND

German physicist Walter H. Schottky created a theory in 1938 that illustrated the rectifying behaviour of a metal-semiconductor contact as dependent on a barrier layer at the surface of contact between the two materials. Schottky Barrier diodes were later fabricated on the basis of this theory. High voltage Schottky diodes were fabricated on 3C-SiC films grown on Si substrates in 1993. A Ni metallization process was developed to fabricate both rectifying and ohmic contacts to SiC by controlling the post annealing temperature [5]. The characteristics of vertical Schottky barrier diodes (SBD) fabricated on N /N$^+$ 3C-SiC grown on N$^+$Si substrate were reported in 1994[6]. The characteristics of 4H-SiC Schottky barrier diodes were reported in 1995 with breakdown voltages upto 1000 V for the first time [7]. Ni Schottky rectifiers was fabricated on 2.7×10^{16} cm^{-3} n-type 6H-SiC epilayer in 2001 using an effective edge termination based on an oxide ramp profile around the Schottky contact[8]. Silicon Carbide was discussed as energy efficient wide band gap device in 2006 which showed that SiC Schottky diodes allowed up to a 25% reduction in losses in power supplies for computers and servers when used in the power factor correction circuit [9]. The electrical characteristics of Au/3C-SiC Schottky diode was studied as a function of contact area in 2009 [10]. Isothermal and nonisothermal DC characteristics of SiC Schottky barrier diodes were measured in 2010 [11].

HOYA Corporation has succeeded in raising the SiC growth rate to more than 50 times the conventional rate, using a newly developed SiC fabrication process in 2012. With this new process, large monocrystal 3C-SiC substrates (at least 200 micro-meters thick after removing the Si base layer) can be manufactured [12]. An analysis of 4H-SiC power Schottky Barrier Diodes (SBDs) was done in 2013 which showed that these devices can be operated well below their true avalanche breakdown potential [13]. A cost-effective fabrication of Schottky-barrier (SB) diode was proposed in 2014 steering element for low power phase-change memory (PCM) application [14].

The paper is organized as follows: In Section IV, the theoretical analysis is done to study the behaviour of punch through breakdown voltage of 3C-SiC Schottky Barrier Diode using Gaussian profile. The calculations and results are presented in section V. The paper is concluded in section VI.

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IV. THEORETICAL ANALYSIS

The doping profile used here in Schottky Barrier diode is Gaussian profile. The carrier concentration is maximum at the base of the device decreasing upwards at the contact. The equation to this profile may be written as:

$$N(x) = N_0 e^{-\left(\frac{h-x}{m}\right)^2} \quad 1$$

where, N_0 is peak concentration, m is constant, h is the device height (200µm) and x is the distance from the contact. Here different Gaussian profiles have been generated with different values of peak concentration N_0 and constant m. N_0 has been varied from 10^{15} cm^{-3} to 10^{18} cm^{-3}.

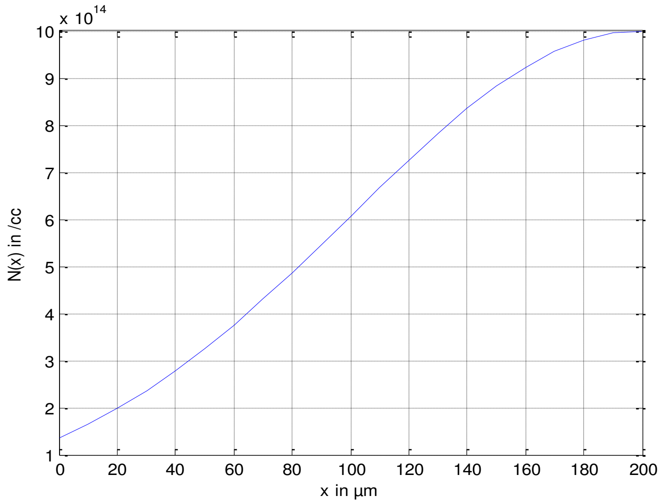

Figure 2. Profile1-Variation of carrier concentration N(x) with x with peak concentration N_0=10^{15} cm^{-3} and constant m=$100x10^{-4}$cm

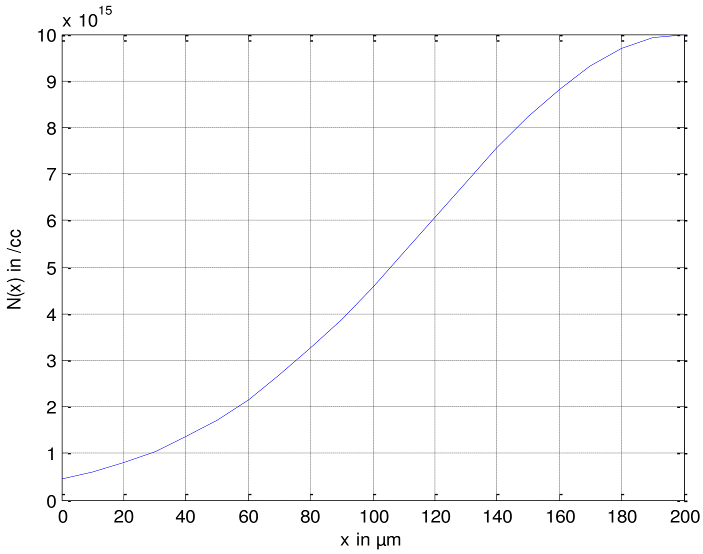

Figure 3. Profile2-Variation of carrier concentration N(x) with x with peak concentration N_0=10^{16} cm^{-3} and constant m=$80x10^{-4}$cm

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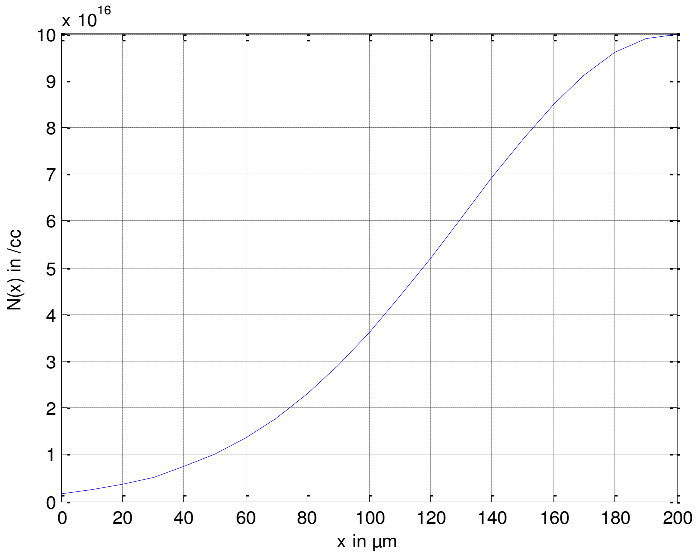

Figure 4. Profile3-Variation of carrier concentration N(x) with x with peak concentration $N_0=10^{17}$ cm^{-3} and constant $m=70x10^{-4}cm$

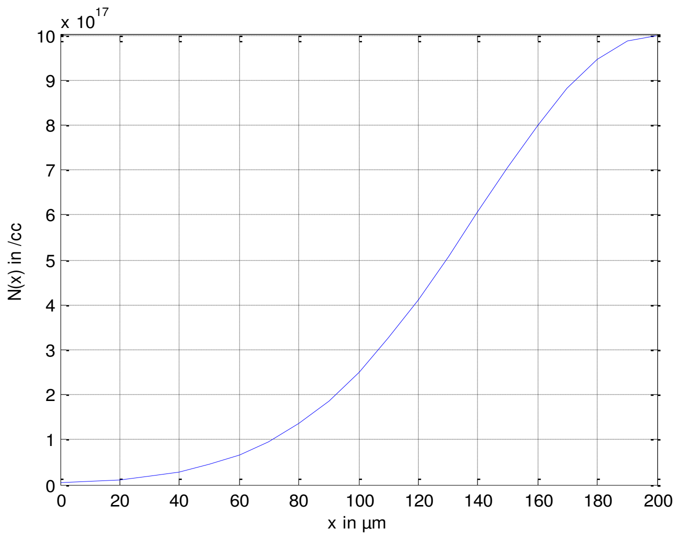

Figure 5. Profile4-Variation of carrier concentration N(x) with x with peak concentration $N_0=10^{18}$ cm^{-3} and constant $m=60x10^{-4}cm$

V. CALCULATIONS AND RESULTS

The equation for calculating depletion region width is given by [15]

$$\frac{W^4}{12m^2}-\frac{hW^3}{3m^2}-\frac{W^2}{2}\left(1-\frac{h^2}{m^2}\right)-\frac{\varepsilon_s V_R}{eN_0}=0 \qquad 2$$

The highest value of reverse voltage V_R in above equation at which maximum depletion region width is obtained for a given value of constant m gives the value of punch through breakdown voltage. The calculations have been done using MATLAB.

Permittivity of 3C-SiC semiconductor, $\varepsilon_s=9.7\ \varepsilon_o$

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Device height, h=200µm
Figure 6-9 shows the depletion region width calculated for different reverse voltages for the four profiles discussed above.

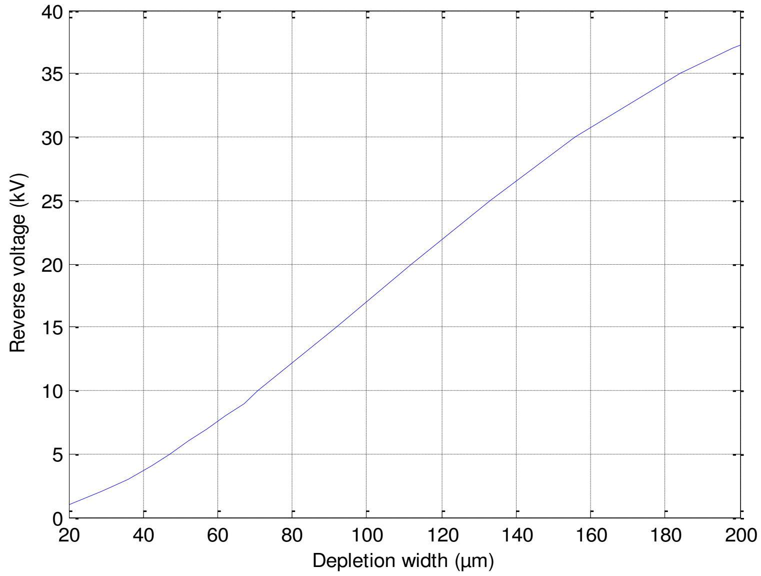

Figure 6. Variation of reverse voltage with depletion width for profile 1

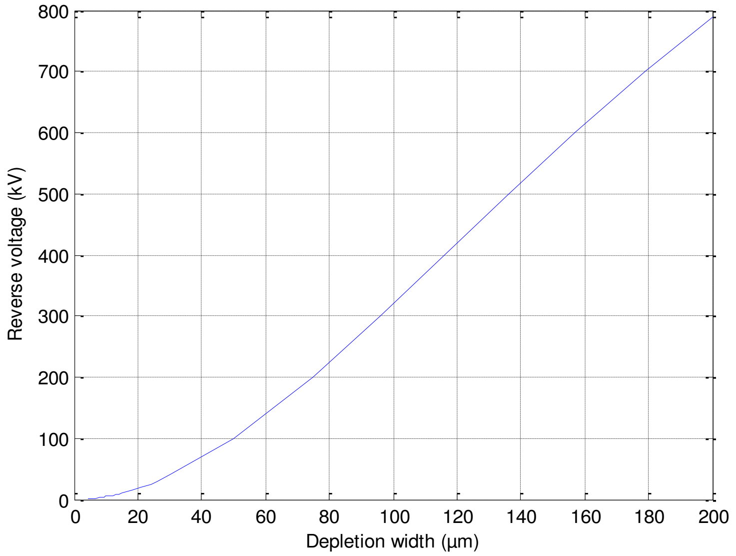

Figure 7. Variation of reverse voltage with depletion width for profile 2

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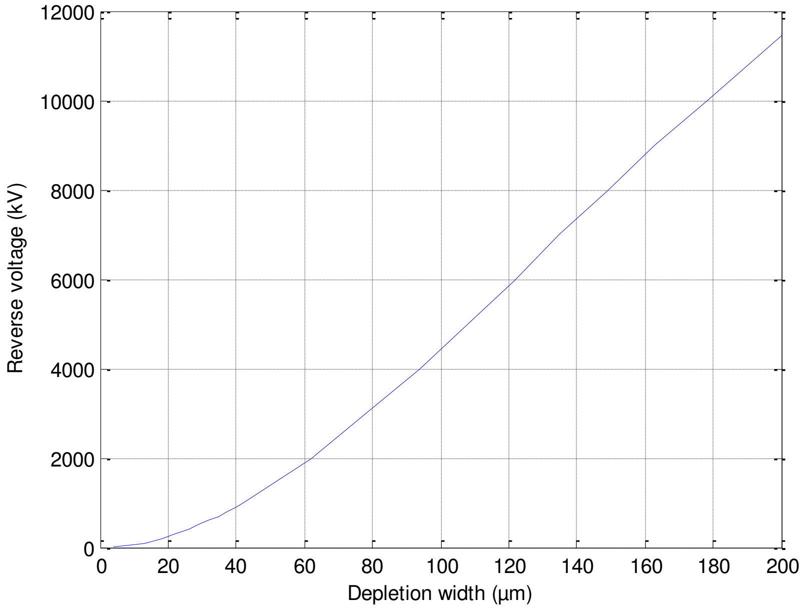

Figure 8. Variation of reverse voltage with depletion width for profile 3

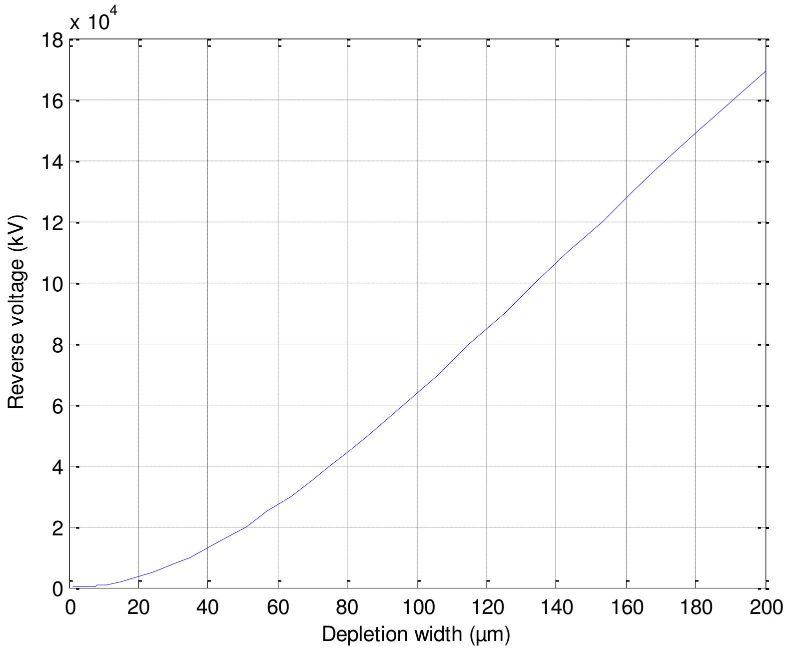

Figure 9. Variation of reverse voltage with depletion width for profile 4

For different values of constant m, breakdown voltage has been calculated for different values of the peak carrier concentration N_0 shown in Figures 10-14.

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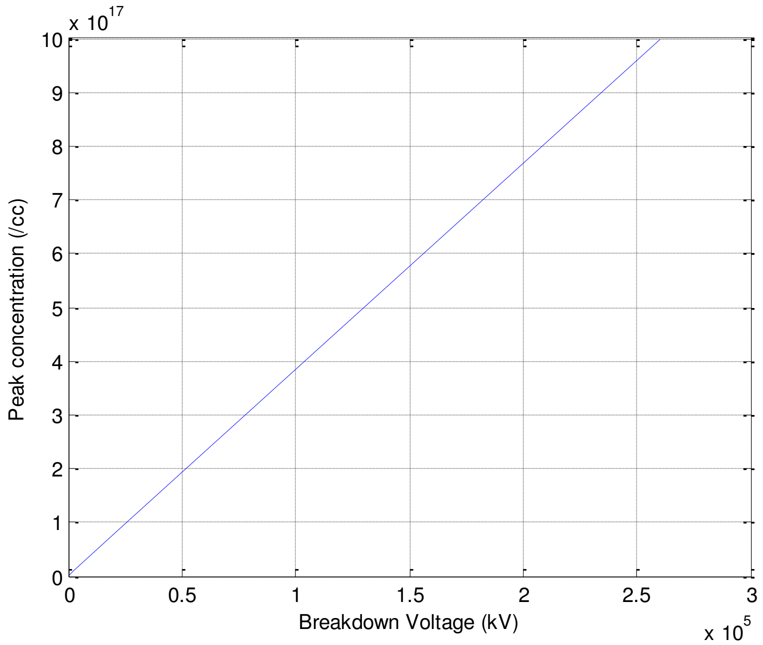

Figure 10. Variation of breakdown voltage with peak concentration for m=50x10^{-4} cm

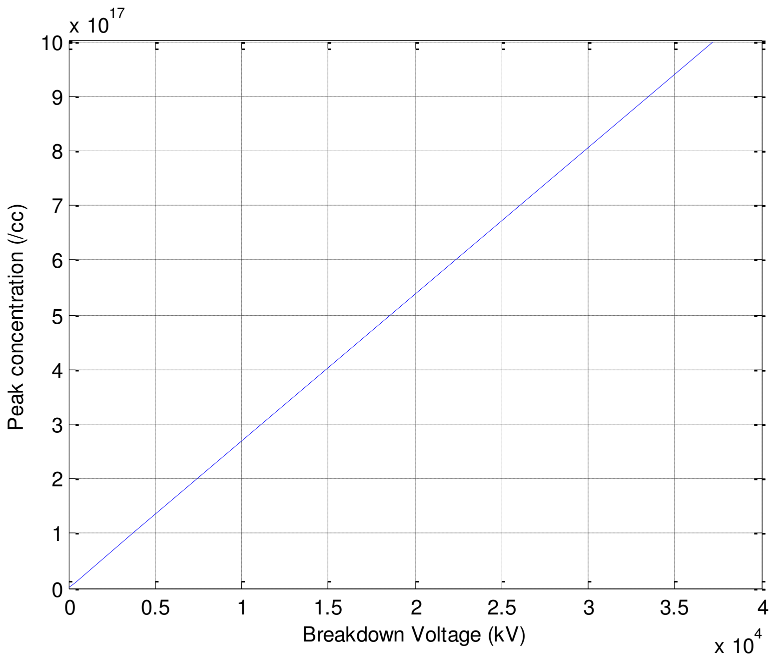

Figure 11. Variation of breakdown voltage with peak concentration for m=100x10^{-4} cm

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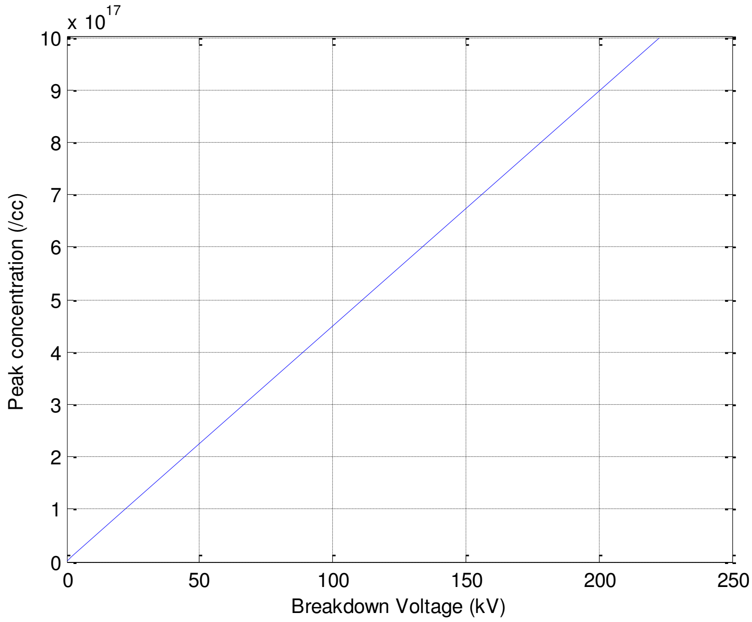

Figure 12. Variation of breakdown voltage with peak concentration for m=141x10^{-4} cm

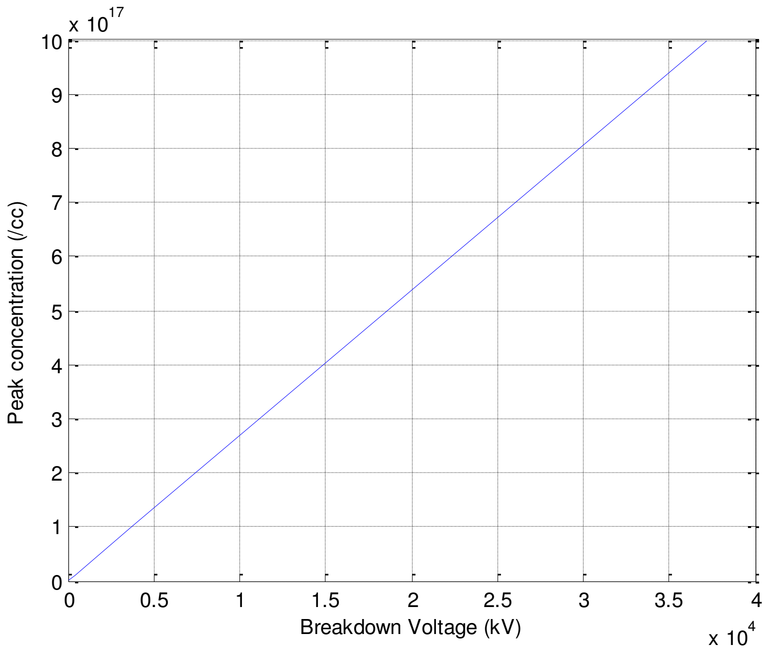

Figure 13. Variation of breakdown voltage with peak concentration for m=141.4x10^{-4} cm

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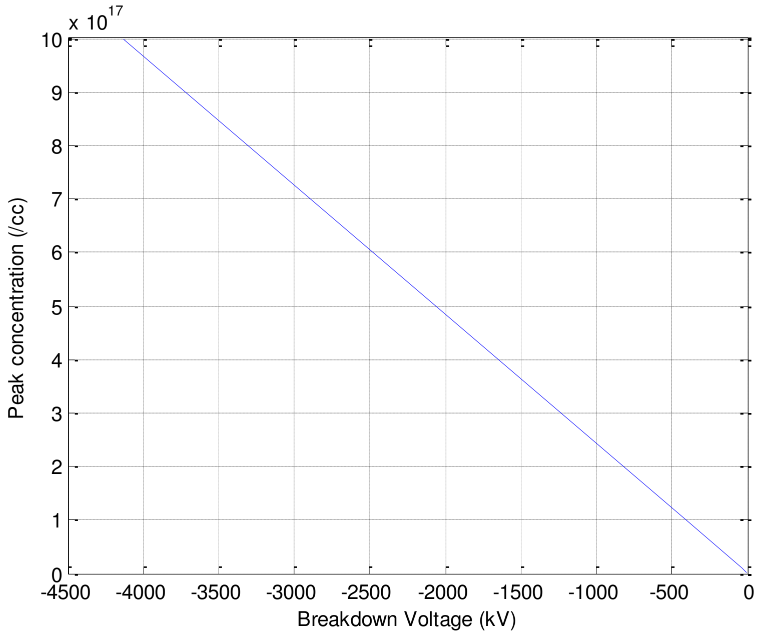

Figure 14. Variation of breakdown voltage with peak concentration for m=150x10^{-4} cm

Now, the variation of derivative of breakdown voltage w.r.t. peak concentration with the values of constant m and variation of derivative of depletion width w.r.t. breakdown voltage with peak concentration is studied shown in Figure 15-16.

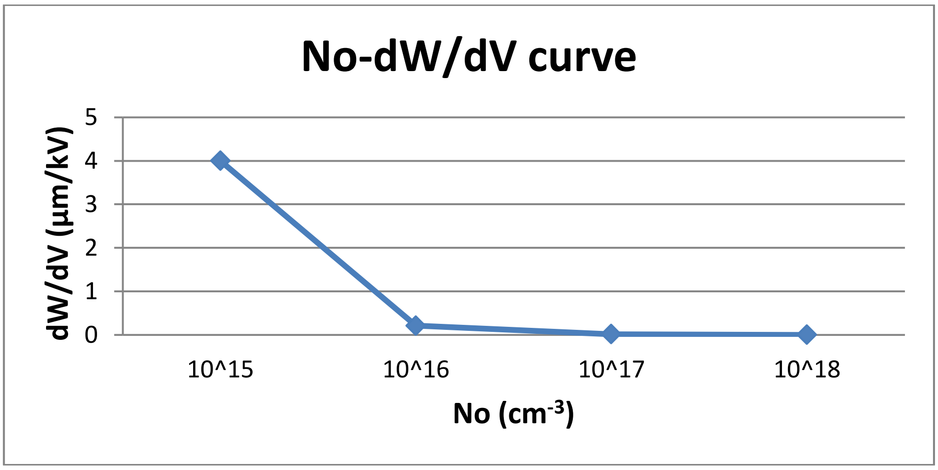

Figure 15. Variation of gradient of depletion width with breakdown voltage with respect to peak concentration

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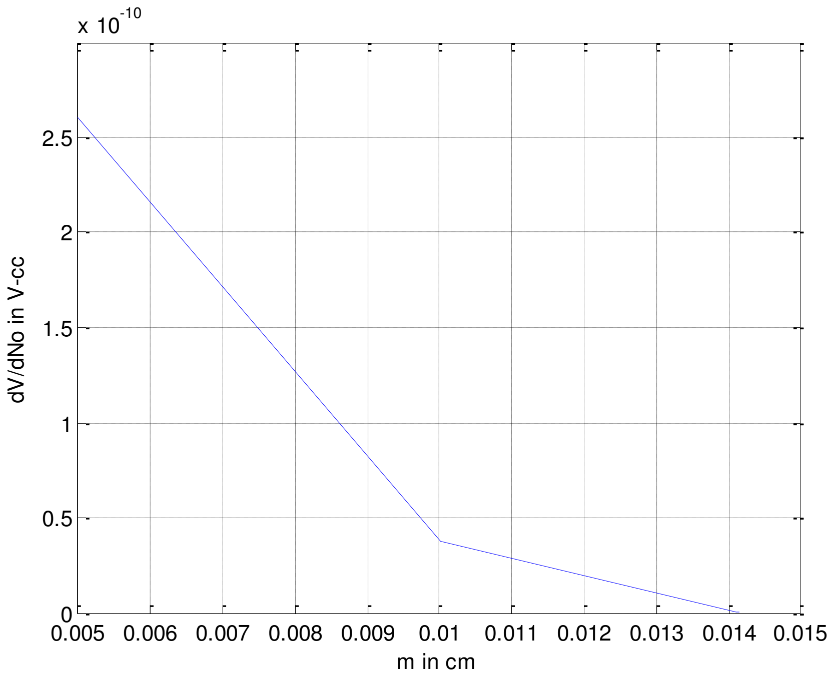

Figure 16. Variation of gradient of breakdown voltage with peak concentration with respect to constant m

An analysis of the Figures 6-9 shows that the magnitude of gradient of depletion region width with breakdown voltage is found to decrease for the Gaussian profiles considered in this study which is shown in Figure 15. So, it means that with an increase in N_0 associated with decrease in m gives rise to an increase in breakdown voltage with an increase in depletion region width.

The sequence of plots of N_0 against V_B for 200µm thick device of 3C-SiC Schottky Barrier Diode for increasing values of m ranging from m=50x10^{-4}cm to 150x10^{-4}cm are shown in figure 10-14. An analysis of these curves shown in Figure 16 shows that at over a range of values of N_0, if we consider the variation of breakdown voltage, it is seen that the variation of breakdown voltage with N_0 is found to increase with decreasing value of m.

VI. CONCLUSION

The present study which has been used to analyse punch through breakdown voltage of 3C-SiC Schottky Barrier Diode have been done based on using Gaussian profiles in semiconductor region of these devices. The analysis shows that an increase in N_0 with a decrease in m gives rise to an increase in breakdown voltage with increasing depletion region width.

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