Abstract— Heterostructures have become essential constituents of most advanced electronic devices. These structures are well suitable for multiple applications like high frequency-fast switching, harsh condition electronics applications, etc. Heterostructures are of great interest because the motion of charge carriers possibly controlled by modifying energy band profiles of constituent materials. Past Many years, researchers were continuously working on the SiC material and heterostructures based on silicon carbide (SiC) polytypes to understand its Electrical-Physical properties and become eminence. Silicon carbide has many polytypes but it has seen that some of the polytypes like 3C-SiC, 4H-SiC and 6H-SiC have Suitable Electrical properties, more carrier mobility for semiconductor or electronic applications and also suitable for heterostructures fabrication. They extensively used as power electronic devices, sensors and light emitting diodes. Attractive properties and a wide range of applications of SiC heterostructures are appealing the researchers to work in this field. Furthermore, as silicon technology is approaching its geometrical limits so there is a need for an alternative that can replace it. Heterostructures have emerged as a potential candidate for future Micro and Nano electronics applications due to its optical, electrical and mechanical properties. In this paper, we are discussing an upright fabrication structure of Heterojunction device. We have used SILVACO TCAD to demonstrate 2D vertical structure design and simulation of Binary semiconducting material Silicon Carbide (SiC) Heterojunction diode. We have used Silicon Carbide (SiC) and Silicon to form n-n type heretojunction diode. IV characteristics simulation results were conducted over -10V to +10V range.

I. INTRODUCTION

The enormous growth in respective fields were possible due to the technological growth. It was possible due the continuous efforts of researchers, technologists, engineers, thinkers philosophers over the decades. As a result of this we have seen tremendous growth in use of Semiconductor in preexisted field as well as witnessed emergence of new fields like cloud computing, Internet of things, aerospace etc. [1]. Some of the important field mentioned below in figure 1. In digital side under study within the nano electronic research, initiative to carry the improvement in devices beyond Silicon Semiconductor working / Physical Boundaries [2]. Over the period, silicon is widely used as a building block in the electronic component and integrated circuit manufacturing or fabricating industry. Due to the small energy gap, silicon is not integrable beyond certain limits. Such restrictions of silicon attract researchers to find some alternative ways to solve the problem. In this pursuit, many researchers were trying to find out alternative material, which can overcome the silicon’s drawbacks.

Soon it has been discovered that silicon carbide which was developed in 1824 by Jons Jakob Berzelius, in early 90’s SiC has gained the popularity of wideband gap semiconductor [3] [4] [5] [6] [7] [8] [9] [10] [11]. Later on many applications had developed, because of many favorable possibilities of physical and electrical properties of wideband semiconducting material, SiC focused for various high power and harsh condition electronics applications [8]. Despite considerable advancement in SiC material and device technology, there are still vital issues to be resolved like; ohmic contacts require high concentration doping. Commonly used doping methods in SiC device processing include in-situ doping during epitaxial growth, thermal diffusion, and ion implantation. These methods require specialized equipment and elaborate processing protocols involving high temperature annealing in excess of 1900 K. High temperature processes are detrimental to the material and device performance. Therefore, a low temperature process needed. SiC is the only wide band gap semiconductor that can be oxidized to form native silicon dioxide (SiO2) [12]. Utilizing electronic devices in harsh radiation environment results in electrical damages to silicon based electronic and leading to degrading its working lifetime. On the contrary, silicon carbide shows sturdiness against such harsh working conditions. It shows the possibility to make use of these elements in satellite-based systems, detectors and high temperature electronics [13] [14] [15] [16] [17]. Even though SiC Diodes shows more reliable in harsh condition, it requires more research to improve their performance in terms of dark current, activation voltage etc. we has been witnessed that SiC
Diodes can be used for optical as well as particle detection, but less efficiency as it requires to improve contact resistivity [13][18]. Lateral diode fabrication have certain fabrication problems, which are mention in [19][20]. In this paper, we report simulation results of n-n heterojunction diode with uniform doping concentration across the device under simulation.

II. PRINCIPAL OF WORKING

We are working on the concept of heterojunction formation between wideband gap material and narrow band gap material as shown in the figure 2.

In general, we encounter four different kinds of heterojunctions based on the doping concentration on the both sides of heterojunction interface as

a) pn heterojunction diode
b) nn heterojunctions
c) pp heterojunctions
d) Quantum wells, quantum wires, and quantum dots

As we, care using SiC as a wide bandgap material who’s p type wafers are rarely available for fabrication, as it has low carrier mobility and difficult to produce. So we are more focused on the characterizing nn heterojunction device. In case of nn heterojunction small depletion region formed on wide bandgap side of junction and a small accumulation region formed on the narrow bandgap side of the junction. The built-in voltage of the junction is given as

\[ \text{Applied Voltage} (qV_{bh}) = E_{f1} - E_{c2} \] (1)

After applying external voltage across a heterojunction such that the potential on the wide bandgap side of junction is increased by \( V \), then The energy band diagram looks as shown in the Figure 3

Across the junction, interface electrons will move due to difference between conduction band energies either sides of junction. Thus, the current flow across this heterojunction is occur due to two phenomenon, one is thermionic emission, which cause conduction electron to jump across the heterojunction barrier another Quantum tunneling which pass through the heterojunction barrier. Both of these mechanisms can be depict from the energy band diagram of heterojunction.

III. DEVICE STRUCTURE AND SIMULATION ENVIRONMENT

In order to predict the performance of nn heterojunction diode we have performed simulation with two-dimensional Silvaco Atlas TCAD [21]. Before going to start with simulations we have finalize our device structure as shown in above figure 4, it can be formed by considering wide bandgap material at bottom and narrow bandgap material at top or a vice a versa. We have used metal contact on the both sides of structure, which will provide wide area for contact and heat dissipation. Top contact used for anode terminal and bottom contact used for cathode terminal. We have consider SiC as wideband semiconductor and silicon as Narrow band semiconductor in our Silvaco atlas simulation. Thickness of both region considered as 50um each. So the total thickness of 100um. Contact electrodes attached at top and bottom and named as anode and cathode. We have taken uniform doping concentration of \( 5*10^{18} \) cm\(^{-3} \).
IV. I-V CHARACTERISTICS SIMULATIONS

I-V characteristics is one of the best way to characterize behavior of any electronic device. I-V characteristics generally used to verify performance of electronic devices. Device IV performance is vulnerable due to material operating current, voltage and series resistance. Nn heterojunction device undergo forward and reverse bias Current–Voltage characteristic measurement to verify device behavior or character to respond particular voltage. In general, SIC diodes expected to witness tunneling, diffusion, and thermionic emission concepts in its Forward and reverse bias I-V characteristics[22] [23] [24]. Current-voltage characteristics measurement performed at room temperature i.e. 300K. At the beginning we have used -10V to +10V bias voltage to test the behavior of the device. In addition, gradually we can increase it up to 50V for further simulation. The I-V characteristics simulation performed on span of temperature provide quality analysis over the device behavior to determine effects of different current transports mechanisms.

Fig.6 Forward Bias I-V Characteristics at room Temp 300K

Above figure 6 shows the Forward bias I-V characteristics at room temperature 300 °K and figure 7 shows the reverse bias I-V characteristics at room temperature 300 °K. In forward bias heterostructure diode, we connect positive potential to the anode contact, which further extended to SiC region of the heterojunction diode. The other terminal attached with cathode contact, which further extended to silicon region of the heterostructure because of this connections electrons from SiC side moves away from junction interface whereas electrons from Silicon region accumulate near junction interface, as these electrons are at lower conduction energy band level so that they cannot jump to conduct at room temperature. If we keep increasing forward voltage across terminals then we can see small value leakage current, as it can seen by small current value in its forward characteristics. In reverse bias heterostructure diode, we connect negative potential to the anode contact, which further extended to SiC region of the heterojunction diode.

Fig.7 Reverse Bias I-V Characteristics at room Temp 300K

Fig.8 Energy band diagram of SiC/Si nn Heterojunction

The other terminal attached with cathode contact, which further extended to silicon region of the heterostructure because of this connections electrons from SiC side moves towards junction interface. As these electrons are at higher conduction energy band level so that they can jump to low energy conduction band and constitute a current flow room temperature. This transport of electrons across heterojunction can occurred due to thermionic emission and tunneling of them, Figure 8 shows the energy band diagram of SiC/Si nn Heterojunction.

V. RESULT AND CONCLUSION

A comprehensive study has been performed to verify the characteristic behavior of SiC/Si nn heterojunction Diode. It verifies that SiC/Si nn heterojunction diode can be work in reverse bias and the working voltage across the interface is less and comparatively more than the normal Silicon pn junction diode at the room temperature.
VI. SCOPE FOR FUTURE WORK

We have planned to verify this SiC/Si nn Heterojunction diode on different working temperature from -80 to +800 K. These simulations proved that the heterojunctions between Wide band material and narrow band material can used to forma diode, so next possibility to verify the working characteristics of nn heterojunction diodes with different material combinations with SiC. Second possibility to verify Quantum well structure diode with SiC Heterojunction.

REFERENCES


