Breakdown Analysis of Normally-Off 4H-SiC Trenched and Implanted VJFET

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The optimum channel width and temperature is necessary for high and stable breakdown voltage of normally-off 4H-SiC based VJFET. The dependence of breakdown voltage on variation of channel width (0.8-0.9 µm) and temperature (300K to 773K) was studied using sentaurus TCAD. The highest breakdown voltage was 2048 V reported at channel width of 0.8 µm at 300K. As channel width and temperature increases breakdown voltage decreases due to depletion region width decreases. The strong electric field and impact ionization decreases from gates towards drain with increase in channel width and tempearture which reduces breakdown voltage.

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1. Introduction

4H-SiC based devices shows attractive performance for high power, temperature and frequency devices due to superior intrinsic material properties such as transport property, excellent thermal conductivity, high saturation velocity, high breakdown electric field [1,2].

The normally-off 4H-SiC VJFET is prefered power device structure due to uniform electric field distribution, low on resistance, high current density and device conduct after applying positive gate voltage and fail safe structure [3]. A large number of device edge termination techniques have been discovered to control breakdown voltage in device technology such as abrupt parallel plane junction, planer junction, planer field ring terminations, Junction termination extensions. Among theses techniques, Trenched and implanted (TI) techniques is prefered in VJFET because of its many structural advantages. it does not require epitaxial regrowth in the middle of the device, accurate adjustment of channel width, low value of specific on-resistance due to elimination of internal lateral JFET gates [4,5]

The factors which are responsible for controlling breakdown voltage are channel width, temperature, drift doping concentration and layer thickness. These factors are critical in order to control the breakdown voltage. Basically they directly effect the development of electric field and impact ionization within the device which in turn are related to breakdown phenomena.

A suitable value of channel width and temperature is critically important for high breakdown voltage [6], until now lot of research articles published to optimize breakdown voltage at different channel width and temperature range [7,8]. In this paper, the breakdown analysis of normally-off 4H-SiC TI-VJFET was studied at various channel width (0.8-0.9µm) and temperature (300K-773K) using Sentaurus TCAD. The simulated results are in agreement with experimental work [5] and highest breakdown voltage 2048 V at 300K was reported todate on any normally-off 4H-SiC TI-VJFET.

2. Proposed structure and models

Fig.1 shows cross sectional view of TI-VJFET structure, the n-type vertical channel and drift layer having a doping concentration of $7\times10^{15}cm^{-3}$ and $5\times10^{15}cm^{-3}$ respectively.The vertical channel width varies from 0.8-0.9µm while temperature varies 300K to 773K. Gate is p-type doped upto $3.5\times10^{17}cm^{-3}$ above this gate there is a layer of highly doped P^{++} layer for reliable ohmic contact. Both drain and source regions have n+type doping of $1\times10^{18}cm^{-3}$. The following models have been used for breakdown analysis of TI-VJFET, Shockley-Read-Hall (SRH) and Auger recombination model, avalanche generation, bandgap narrowing, Impact ionization, incomplete ionization model [9].

3. Results and disscusion

3.1 Electrical characteristics

Fig.2 shows variation of breakdown voltage with channal width, as expected [7] it was found that breakdown voltage decreases with increase in channel widths due to increased path for current flow which decreases depletion region width. As a result the effect of electric field is reduced lateral and vertical penetration of electric field decreases discussed in next section. The optimum breakdown voltage was 2048 V achieved at channel width of 0.8 µm which is in close agreement with experimental work [5] while least breakdown voltage of 201 V was obtained at channel width of 0.9 µm.

Fig. 3 shows breakdown voltage with temperature variation (300K-623K) at different channal width (0.8 µm & 0.9µm). As expected [8] it was found that breakdown voltage decreases with increase in temperature for all channel width. At high temperature, most of the impurities have been ionized and effect of phonon scattering becomes significant which degrades electron mobility and consequently decreases breakdown voltage with temperature [10]. Due to strong elctric field at small channel width 0.8 µm device can operate successfully from 300- 623 K while at 0.9 µm channel width the operational range became 300- 423 K due to weak electric field discused in next section.

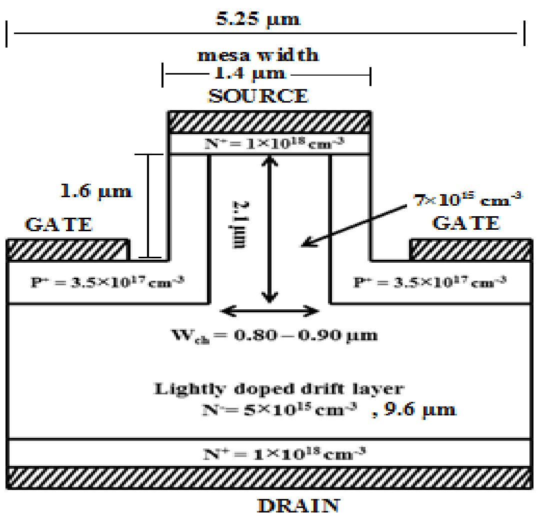

Fig. 1. A cross-sectional view of TI-VJFET.

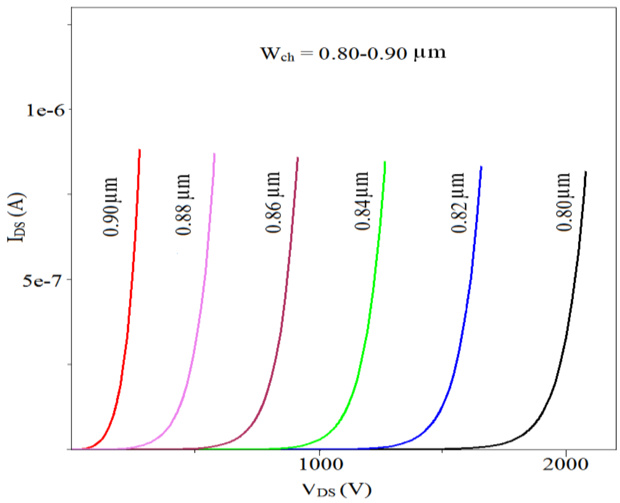

Fig.2. Effect of channel width on breakdown voltage.

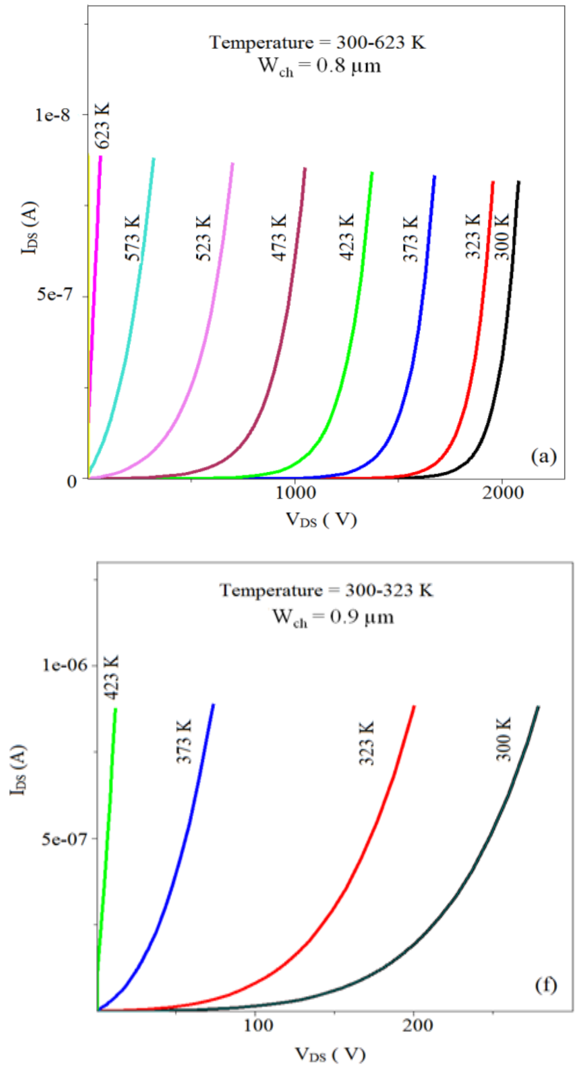

Fig. 3. Effect of temperature (300-623K) on breakdown voltage (a) W_{ch} = 0.8µm (f) W_{ch} =0.9µm.

3.2 Electric field and impact ionization

Electric field variation due to channel width is very critical in controlling breakdown voltage. Fig.4(a,b) shows variation of electric field with channel width. It is clear from results that electric field decreases from gates towards drain with incraese in channel width. At small channel width electric field is very strong near the gate and decreases with the increase in channel widths. The electric field penetrates to a much larger depths at small channel width, this effect of electric field is critical for breakdown analysis. The strong electric field increase the electron drift velocity with in depletion width consequently increases breakdown voltage.

Fig. 4(c,d) shows variation of impact ionization with channel width. A prominent decrease in impact ionization with increase in channel width is clear from the results. The regions which are in close vicinity of gate having higher electric field and impact ionization because electrons gain high energy and are accelerated more in these areas and create more electron hole pairs causing a multiplicative process to start. So, impact ionization is high near the gate region for small channel width where electric field is strong and decreases away from the gate with increase in channel width due to weak electric field.

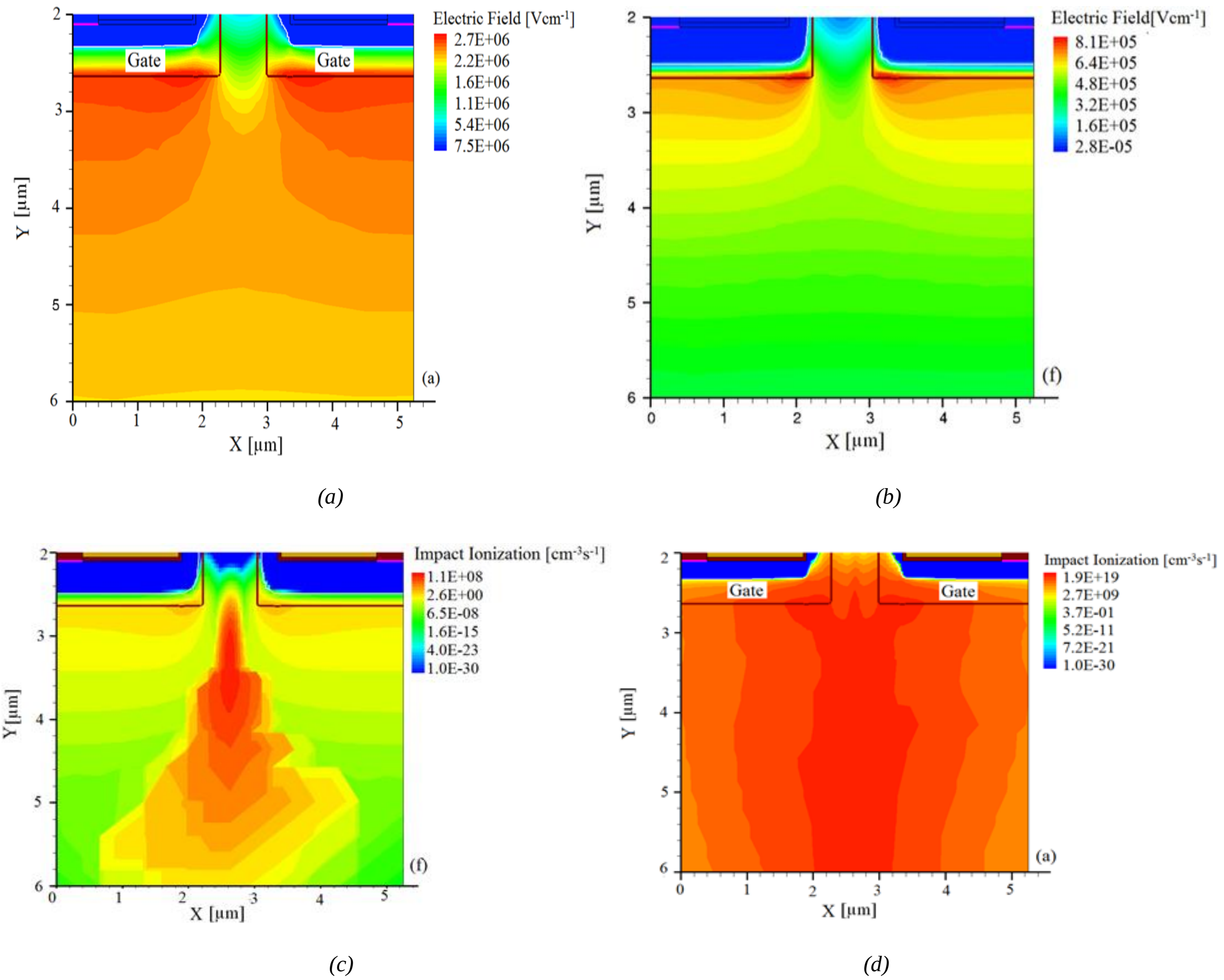

Fig. 4. Variation of electric field (a,b) and impact ionization (c,d) at 0.8&0.9 µm channel width.

Fig.5 (a,b) shows the variation of electric field in the whole vertical structure of the device at various channel widths (0.8µm & 0.9µm) and wide temperature range (330K to 773K). Results clarified that electric field decrease with increase in channel width and temperature. The electric field increase sharply with in the gate region where it is very high. With an increase in vertical dimension of the device, going away from gate towards drain side electric field decrease sharply to zero on approaching drain terminal. At large channel widths and temperature electric field falls to zero before the drain terminal, thus providing small thickness for impact ionization consequently breakdown voltage decreases.

Fig. 5 (c,d) shows impact ionization with increase in channel width and temperature. It was found that impact ionization decreases with increase in channel width and temperature. The impact ionization increase sharply in the gate region where electric field is high then it becomes uniform in the vertical depth of device and decrease suddenly on approaching drain terminal. At high channel widths and temperature impact ionization decreased to zero before approaching drain,therefore depletion region width decreases consequently breakdown voltage decreases.

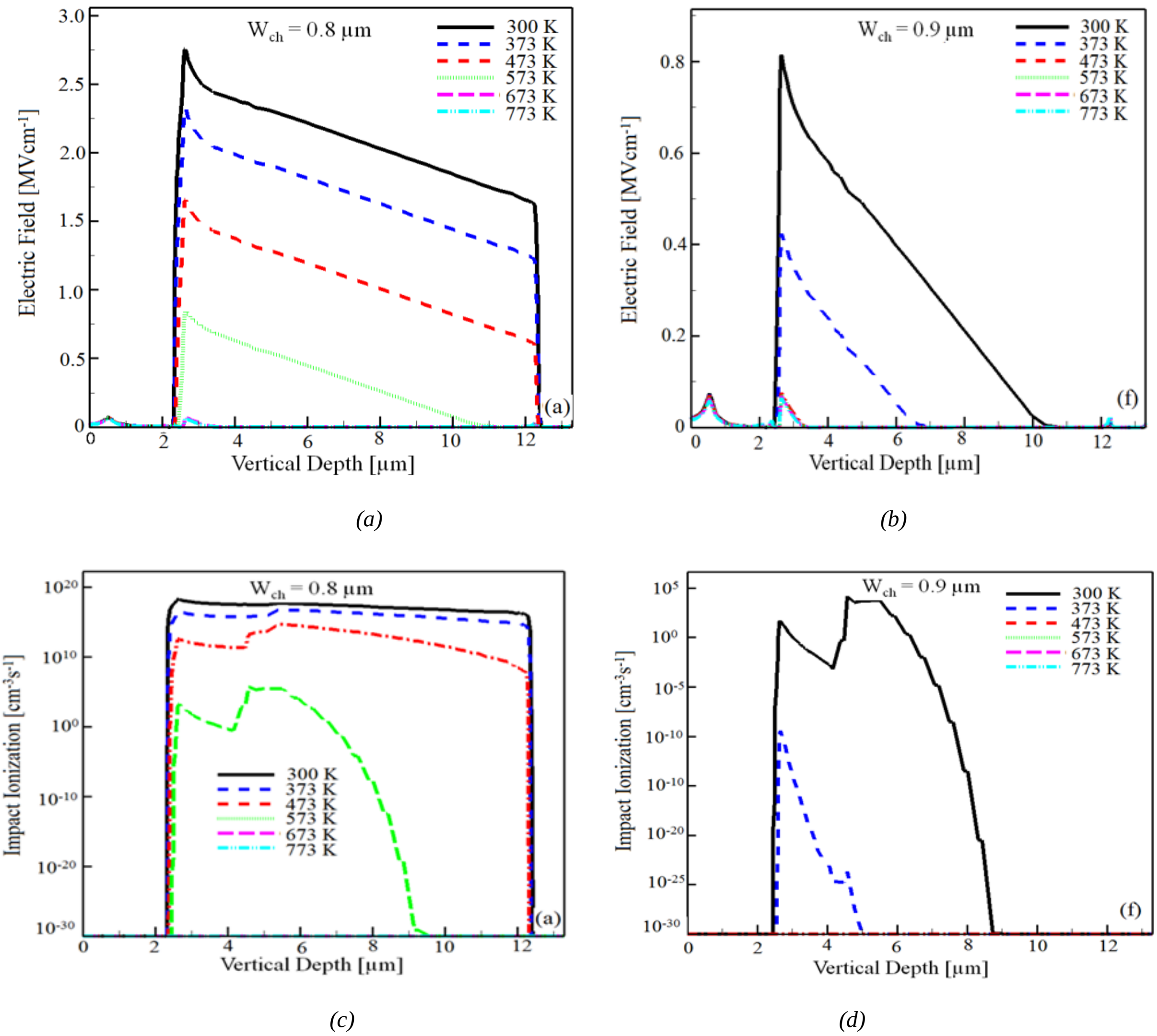

Fig. 5.Variation of electric field (a,b) and impact ionization (c,d) with temparature from 300K to 773K at W_{ch} = 0.8μm and W_{ch} = 0.9μm.

4. Conclusion

The dependence of breakdown voltage on variation of channel width (0.8-0.9 µm) and temperature (300K-773K) was studied using sentaurus TCAD. The highest breakdown voltage 2048 V was achieved at channel width 0.9 µm and 300K. The increase in channel width and temperarture decrease breakdown voltage due to decrease in depletion region width.The electric field and impact ionization showed a high values near the gate region and decreased on approaching drain terminal with increase in channel width and temperature consequently decreases breakdown voltage.

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