Numerical Analysis on the Electrical Characteristics of FS TIGBT

Jong-Seok Lee, Ey-Goo Kang[*], Man Young Sung
Korea Univ. [*]Far East Univ.

Abstract : Here we present detailed simulation results of trench field stop IGBTs. Besides the reduced on-state voltage drop there is also an increase of forward blocking voltage. A trench gate IGBT has low on-state voltage drop mainly due to the removal of the JFET region and a field stop IGBT has high forward blocking voltages due to the trapezoidal field distribution under blocking condition. We have simulated the static characteristics of TIGBT with field stop technology by 2D simulator(MEDICI). The simulated result of forward blocking voltage and on-state voltage drop is about 1,408V and 1.3V respectively at 110㎛ N-drift thickness.

Key Words : Trench gate IGBT, Field Stop, Forward Blocking voltage, on-state voltage drop

1. Introduction

Obvious is an improvement of the NPT structure to a device with a trapezoidal field distribution under blocking conditions as it is typical for the PT IGBT. But the inherent advantages of the NPT concept of the low efficient emitter and the high carrier lifetime should not be given up. This is possible by implementing a field stop layer with a very low dose not influencing the low dose p emitter of the NPT IGBT but high enough for stopping the electrical field under blocking conditions[1-3]. So, in this paper the advantage of trench and Field stop structures are investigated by 2D simulator MEDICI on static characteristics and optimum condition of device design were obtained.

2. IGBT with trench and field stop technology

The improvement of the IGBT technology is mainly reached in two fields: the optimization of the vertical carrier concentration by improving the trench cell and by the reduction of the thickness of the n-base in combination with a vertical concept named "Field Stop". The field stop concept is an evolution of the NPT concept and consists of an additional n doped layer which is implanted into the backside of the wafer. With the reduced wafer thickness a further reduction of the on-state loss was found.

3. Device simulation and results

The simulation flow chart is shown in Fig. 1 for optimizing the device parameters. For the FS IGBTs, the FSL should be designed to completely vanish the electric field within it, and not to degrade the injection efficiency of the collector[3,4].

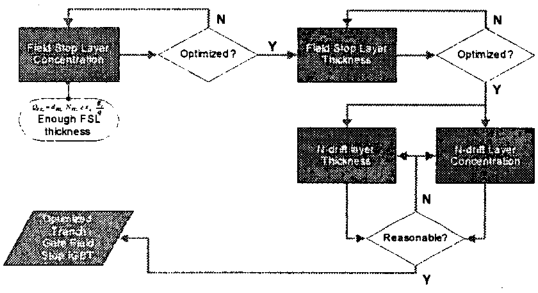

Fig. 1 Simulation flow chart for optimizing parameters.

The number of total charges required in the FSL Q_{FSL}[cm^{-2}] can be simply given by[5]

$$Q_{FSL} = d_{FSL} \cdot N_{FSL} \geq \epsilon_{si} \cdot \frac{E_c}{q} \quad (1)$$

Where d_{FSL} is the thickness of the FSL, N_{FSL} is the doping concentration of the FSL, and E_c is the critical electric field of silicon. Unlike the buffer concentration of the PT structure, N_{FSL} ranges from 10^{15} to 10^{16}cm^{-3}. Assuming E_c as 2×10^5 V/cm , 2~3㎛ d_{FSL} ensures eqn. (1) for N_{FSL} of 10^{16}cm^{-3} and 14~15㎛ d_{FSL} ensures eqn. (1) for N_{FSL} of 10^{15}cm^{-3}.

Figure 2 represents the breakdown voltage and $V_{ce(sat)}$. When the doping concentration exceeds 5×10^{15} cm^{-3}, $V_{ce(sat)}$ continues to increase but the breakdown voltage increment decreases. This is due to the decrease of hole injection which in effect lowers the conductivity modulation, even through the increase of doping concentration of FSL. Due to the trade-off relationship of the two variables, simulation was carried out with the doping concentration of FSL set to 5×10^{15} cm^{-3}.

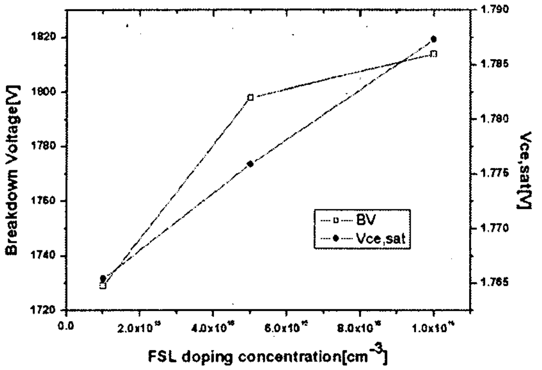

Fig. 2 Breakdown voltage and $V_{ce(sat)}$ according to FSL doping concentrations.

As seen from Figure 3, increasing thickness of the FSL results in a linear increase of V_{ce}, however the breakdown voltage increment decreased. Therefore we conclude that when the doping concentration of FSL is 5×10^{15}cm^{-3}, the effective FSL thickness is 4㎛.

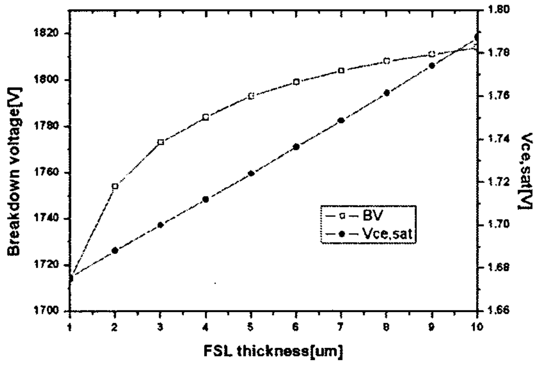

Fig. 3 Breakdown voltage and $V_{ce(sat)}$ according to FSL thickness.

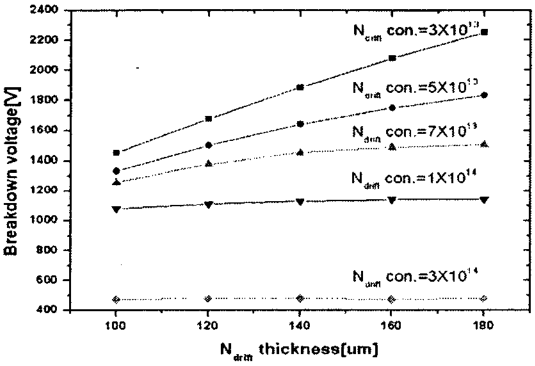

Fig. 4 Breakdown voltage according to N_{drift} thickness and N_{drift} concentration.

Figure 4 represents the breakdown voltage with respect to the thickness and the doping concentration of N-drift layer. It can be seen that the breakdown voltage decreases considerably when the doping concentration exceeds 1×10^{14} cm^{-3}. When the doping concentration of the N-drift exceeds 1×10^{14} cm^{-3}, FSL could not stop the electric field even if the FSL doping concentration was 1×10^{16} cm^{-3}.

Figure 5 represents the on-state voltage drop results with respect to the thickness and the doping concentration of N-drift layer. Simulation results show the breakdown voltage of 1408V, $V_{ce(sat)}$ of 1.3V at 110㎛ N-drift layer. The results show excellent trench gate field stop IGBT characteristics with low on-state voltage drop and high breakdown voltage.

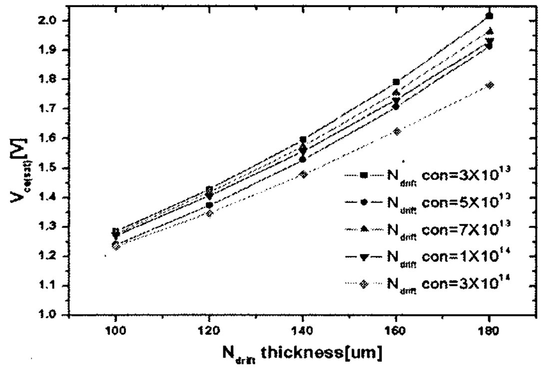

Fig. 5 On-state voltage drop according to N_{drift} thickness and N_{drift} concentration.

4. Conclusions

We carried out the simulation process as in Figure 1, and achieved optimized FSL doping concentration and thickness. Then with the decided N-drift layer concentration and thickness we utilized the optimized structure in the simulation to gain breakdown voltage of 1408V and on-state voltage drop of 1.3V at 110㎛ N-drift thickness.

Acknowledgement

The authors would like to thank the Ministry of Commerce, Industry and Energy in the process of Power IT "Development on Power Semiconductor for Electric Power Generation and industrial inverter Applications."

References

[1] Y. Onishi et. al, Proc. ISPSD, 85(1998).

[2] T. Laska et. al Proc. ISPSD, 355(2000).

[3] E. G. Kang et. al, Microelectronics J. Vol. 32, 9, 749(2001)

[4] E. G. Kang, M. Y. Sung, S. S. Electronics, Vol. 46, 2, 295(2002)

[5] K. H. Oh et. al, IEEE Trans. Electron Devices, Vol. 53, No. 4, 884(2006)