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A NUMERICAL POWER IGBT MODEL AND ANALYSIS OF IMPROVING SUPPRESSION OF ITS LATCHING

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Abstract

During the last few years, great progress in the development of a new power semiconductor devices has been make the new generation of the power semiconductor is capable of conducting more current and blocking higher voltage that is the insulated gate bipolar transistor (IGBT). The aim of this paper, is to present a new approach which consists in defining our computer program (numerical model) of the IGBT based on the finite element technique (FEM), to offer an easy to use IGBT and other devices for our program, showing short computing time and reasonable accuracy, to predict and understand the behavior of various topologies of devices, to perform automated layout of the device to overcome some of the difficulties associated with analytical methods and to identify the failure mechanisms e.g. latch up, current redistribution limiting SOA, are know as the undesirable characteristics of IGBTs devices, then we propose some remedies. The validity of our computer program (this approach) is confirmed by comparison between simulation and theory results as well as the manufacture's data, and a good agreement is recorded for IGBT devices.

Keywords: Modeling, Numerical Simulation, IGBT, FEM, latch up.

1. Introduction

With the increasing acceptance of the insulated gate bipolar transistor (IGBT) as a new power-switching device in both discrete and integrated power circuit for various power electronics application. An investigation and analytical modeling have been made done by Hefner and al [1,2], but the IGBT library models are not easily attainable yet, so, we have decided to develop our own numerical model as it has already been reported in [4], to simulate various mechanisms governing the behavior of IGBT device and it takes into account several failure e.g. : latch up, current redistribution during the turn off, limiting its SOA , are know as the undesirable characteristics of IGBTs. The numerical model developed below is the first numerical IGBT based on FEM method, to describe its electrical characteristics.

A schematic of the structure of two of the several thousand cells of an IGBT is shown in fig1, and it equivalent circuit is shown in fig.2. This circuit consists of an n-channel mosfet driving the base current of p-n-p transistor.

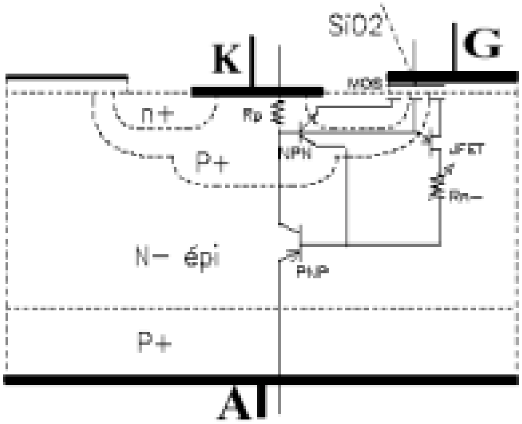


Fig. 1. Cross-section of basic IGBT structure [1,2]

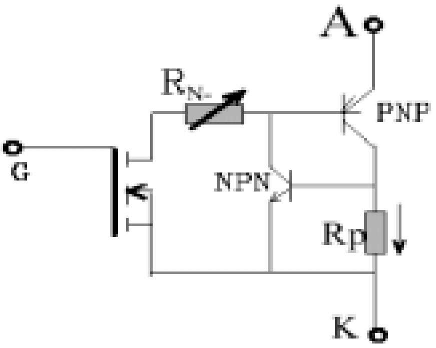


Fig.2. Basic equivalent circuit for IGBT [1,2].

2. Physical model

Modeling semiconductor devices can be done using different concepts for implementation. The first way is in our approach consist to describe the physical behavior of the IGBT by solving the drift and diffusion equations. The system of the five (5) essential equations:

$$div\left(grad(V)\right) = \frac{-\rho}{\varepsilon} \quad \textbf{(1)}$$

$$J_n = q\mu_n n\vec{E} + qD_n\vec{\nabla}n \quad \textbf{(2)}$$

$$J_P = q\mu_p p\vec{E} - qD_p\vec{\nabla}p \quad \textbf{(3)}$$

$$div\vec{J}_n - q\frac{\partial n}{\partial t} = +qg_n \quad \textbf{(4)}$$

$$div\vec{J}p + q\frac{\partial p}{\partial t} = -qg_P \quad \textbf{(5)}$$

3. Numerical Model

Exact numerical modeling can be a valuable tool when analyzing new device types such as the IGBT. It can also be used to anticipate problems, which are, might encounter during development as well as providing an accurate quantitative prediction of the device characteristics. The model is simple, fast and easy to use for basic applications. Its main applications is to quickly provide initial solutions for IGBT device.

In the node k, the Poisson equations discretized is then obtained:

$$F_k^{\varphi}(\varphi, \varphi_n, \varphi_p) = 0, \quad \textbf{(3.1)}$$

which is written :

$$L_k^{\varphi}(\varphi) - \varphi_n^{k}.e^{\varphi_k} + \varphi_p^{k}.e^{-\varphi_k} + DOP_k = 0 \quad \textbf{(3.2)}$$

With

$$L_k^{\varphi}(\varphi) = G_k.\varphi_{k-1} + B_k.\varphi_{k-n} + D_k.\varphi_{k+1} + H_k.\varphi_{k+n} - C_k.\varphi_k$$

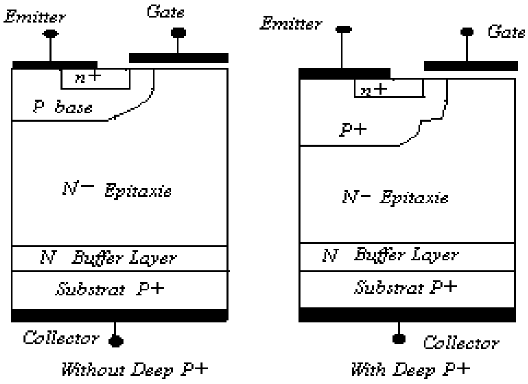


Fig.3. Cross section of IGBT structure contain a deep p+ in the p-base region [1,2].

4. Numerical results and discussion

The description of the structure of IGBT realized by a computer program speared (module) type question/answers in order to generate rapidly a data file type text, which serve to enter to the main program. An option used for previous simulation for the same structure, of course, is simulation of initial solution. A better automatic is then written in order to give an appreciable help. The results are stored in a file and called back when needed in the main program. Thought this study, the internal distribution of carrier concentration (electron and holes respectively (fig4,5), profile doping and electric field (where is a useful parameter for determination of how the device(IGBT) approaching avalanche breakdowns), (fig.6,7), current flow before (fig.8.a) and after (fig.8.b) beginning of latch up phenomena, at key points on the I-V characteristics of the representative IGBT at middle of caisson P/P^+ of IGBT device.

In order to verify the proposed numerical model, the results from the simulation of IGBT device will be discussed in detail to elucidate the physical mechanisms responsible for latch up the IGBT, in final paper. Moreover, our computer program has to be user-friendly.

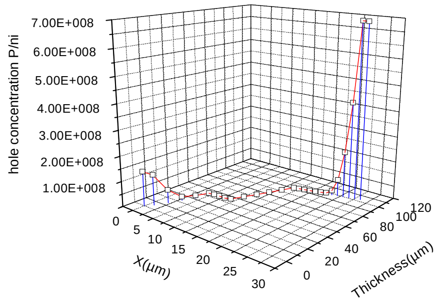


Fig.4. Plots of hole concentration at five points on the I-V characteristics of the simulated IGBT [5].

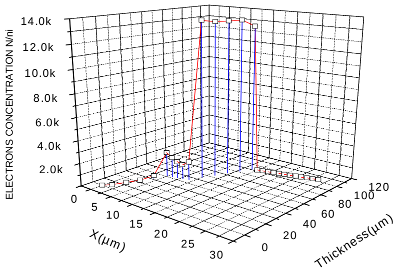


Fig.5. Plots of electron concentration at five points on the I-V characteristics of the simulated IGBT [5].

Latching current.

One of the limitations to operating the IGBT at high current level has been found to be latch up pf the parasitic P.N.P.N thyristor structure inherent in the device structure shown in fig.3. So we have decided to simulate this failure phenomena with our own computer program in order to identify the failure mechanisms, then we propose some remedies about the conception of the device. With increasing the anode voltage for 1V to 1.25V, we can see dramatic differences in the in the modulation level in the region n- between the two, and the current density, Ic is $9.2^{E}01$ A/cm² at 1V compared to $2.17^{E}03$ A/cm² at 1.25V. This indicates that with the increased forward applied voltage, the device has been latched into a thyristor like conducting state. This mode of operation is highly undesirable because it leads to loss of the control collector current by the applied gate voltage. The solution of this problem to increase the conductivity of this region, with the goal of both techniques being to reduce the lateral voltage drop below 0.5V. One solution to increase the p-base conductivity without increasing the gate turn on threshold voltage is by the addition of the deep p+ region shown in fig.3[1]. So, our results shows that the presence of the deep P+ region allows device operation at collector current densities in excess of 200A/cm² without latch up**.**

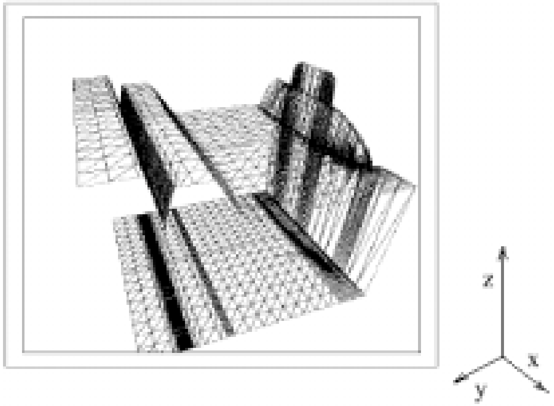


Fig.6.a.Doping Profile distribution in (3D) for IGBT[3,5]

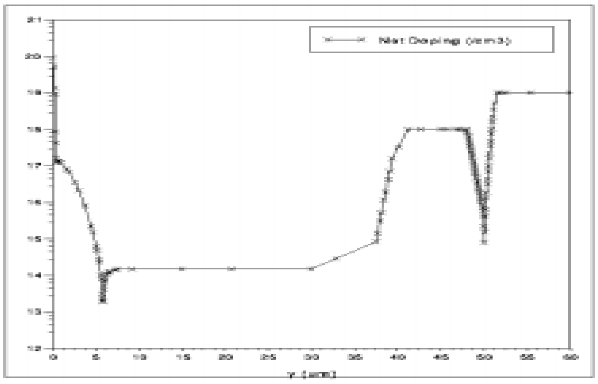
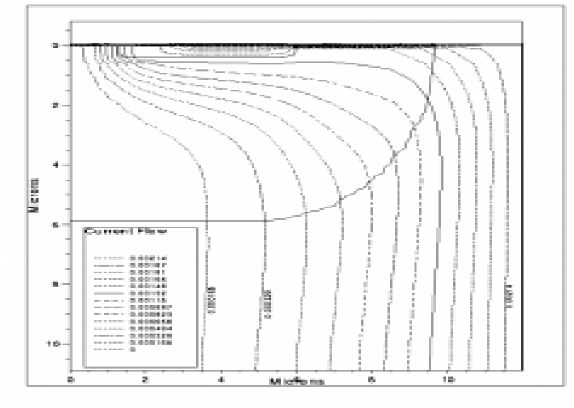
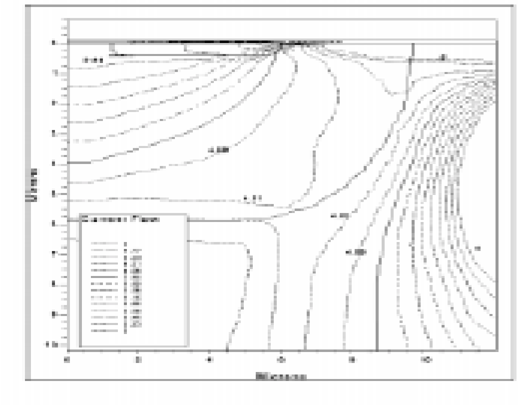


Fig.6.b. Doping Profile Distribution for IGBT [3,5].



a) without latch up



b) after latch up release

Fig.8. Current flow of the simulated IGBT[5].

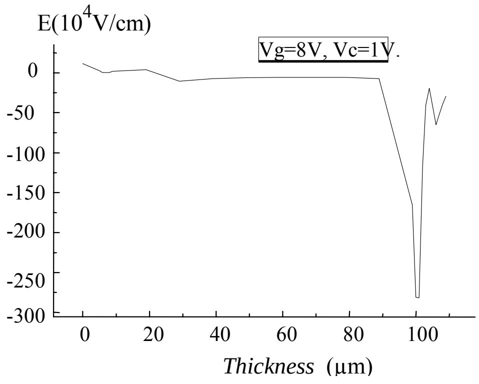


Fig.7. Plots of electrical field at five points on the I-V characteristic of the simulated IGBT[3,5].

5. Conclusion

In this paper, a new numerical IGBT model has been presented. The key improvement in our numerical model is to simulate any power electronics device with adequate accuracy and reasonable computing time and is provided to simulate various mechanisms governing the behavior of the IGBT based on the numerical resolution method that is Finite Element Method. The computer program labored is used in order to identify the failure mechanisms, and then we propose some remedies about the conception of the IGBT. The validity of the resulting solutions is tested by visual inspections of the plots as well as the data sheets, and a good agreement is recorded for IGBT device.

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