Advances in Intelligent Systems Research, volume 164
International Conference on Mathematics, Modeling, Simulation and Statistics Application (MMSSA 2018)

Simulation Study on High-Voltage IGBT Turn-Off with Polysilicon Distributed Gate Resistance Effect

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***Abstract*—This paper presents a device simulation study on a high-voltage 4-cell IGBT structure with a distributed gate resistance. It is shown that during turn-off, the emitter current of IGBT will demonstrate a "homogenous– non- homogeneous– re-homogeneous" evolution before the collector voltage rises. Therefore this effect will generate a small amount of local temperature rising, and will not affect the safe turn-off operation of the device on the whole.**

***Keywords*—IGBT; turn-off; distributed gate resistance**

I. INTRODUCTION

Nowadays, insulated gate bipolar transistors (IGBTs) are very popular in high-voltage power electronic applications, such as high-voltage power transmission, high-power processing, and high-speed transportations. The reliability and ruggedness of the devices are of great importance for their safe operations. As shown in Figure 1 [1, 2], on an IGBT die thousands of mini-cells are parallelly connected together and the polysilicon gate are distributed like a network on the surface within the active area. A metal gate pad for wire bonding with metal gate bus/runners starting from it will conduct the driving current first around and through the active area and then the current will go down to the polysilicon and flow along the polysilicon network locally to every cell. Since the resistivity of the polysilicon is much less than that of a metal, it is a big concern that if two gate bus fingers are separated too far from each other, or even there are no fingers at all [3], the cells in a larger area will face to a distributed resistance of the polysilicon and thus will not turn on or trun off at the same time. This could cause a crowding of the emitter current and thus a concentrated temperature profile. To examine the severity of this phenomenon, a device simulation study was carried out for high-voltage IGBT turn-off based a 4-cell 2D IGBT structure with the distributed gate resistance effect taken into account.

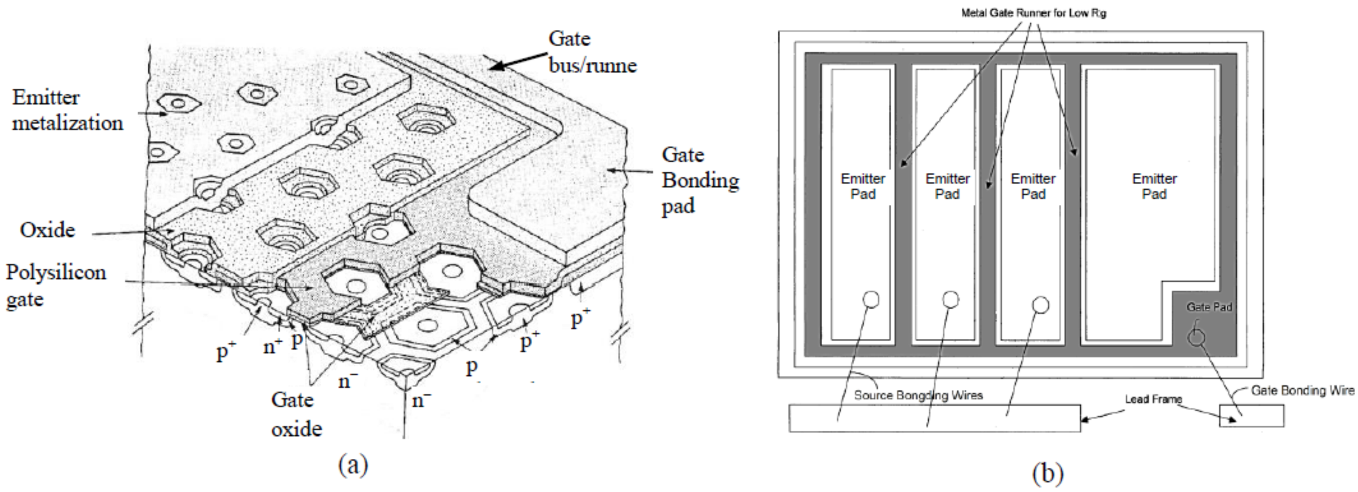

FIGURE I. SURFACE STRUCTURE OF AN IGBT (A) A TOP VIEW [1]; (B) A CUTAWAY VIEW [2]

II. DEVICE STRUCTURE AND SIMULATION

Switching a high-voltage IGBT often endures a higher voltage and a higher current occurring simultaneously.

Therefore, the concern of uneven current and temperature distribution for them is even larger. Hence, simulations were carried out, using Sentaurus TCAD tools, on a 3.3-kV rated, 4-cell (3 complete cells plus 2 half-cells) structure as shown in Figure 2. And its key structure parameters are listed in Table 1. As shown in Figure 2, a distributed polysilicon resistance effect is represented by three internal resistors of $R_g = 8\ \Omega$, and $R = 10\ \Omega$, is an external gate resistance. This virtual IGBT was then connected to a clamped inductive switching (CIS) circuit, with $I_C = 50$ A/cm^2, $V_{CC} = 1800$ V, and a mixed-mode simulation was performed. Then its turn-off waveforms and the interior physical profiles of the device were extracted and calculated to help analyze the detailed consequence of the distributed gate resistance.

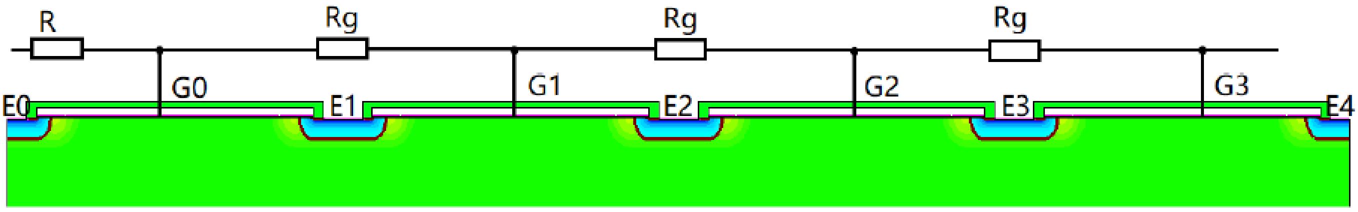

FIGURE II. SURFACE STRUCTURE OF THE SIMULATED 4-CELL, 3.3-KV IGBT

TABLE I. KEY STRUCTURE PARAMETERS OF THE SIMULATED 3.3-KV IGBT

p^+ collector		n^- drift layer		p^+ well		p-well	
Peak doping conc. (cm^{-3})	Junction depth (μm)	Doping conc. (cm^{-3})	Thickness (μm)	Peak doping conc. (cm^{-3})	Junction depth (μm)	Peak doping conc. (cm^{-3})	Junction depth (μm)
8×10^{17}	0.5	1.5×10^{13}	400	6×10^{18}	0.5	9×10^{16}	4

III. SIMULATION RESULTS AND ANALYSIS

The switching waveforms and the interior current line and hole density profiles for different instants during turn-off of the simulated IGBT are given in Figure 3 and Figure 4, respectively. It can be seen from these figures that, at the first stage of the turn-off, the current within the surface region is not homogeneous. As the distance becomes far from the external gate resistance, the channels of the cells to the right will disappear lately. So the rightmost channels of the cell with emitter E4 and of the right half of the cell with emitter E3 (see Figure 2) will switch off lastly. Therefore the electron current of emitters E3 and E4, which attracts hole current of all other cells to the right side, remains until $t \approx 50.40$ μs. After that, when it comes to the second stage of the turn-off, the whole current recovers to an homogeneous state because of the evenly distributed plasma remained in the drift region of the device. This constitutes a very distinct feature for the IGBT and is essentially different form that of a power MOSFET.

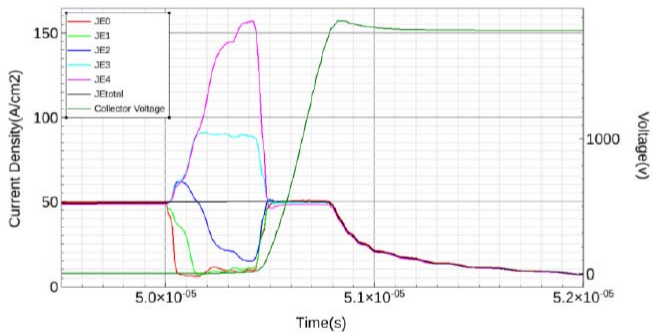

FIGURE III. WAVEFORMS OF THE SIMULATED IGBT. JE0~JE4: APPARENT CURRENT DENSITY OF EMITTERS E0~E4 (SEE FIGURE 2); JETOAL: THE TOAL APPRENT CURRENT DENSITY OF ALL EMITTERS

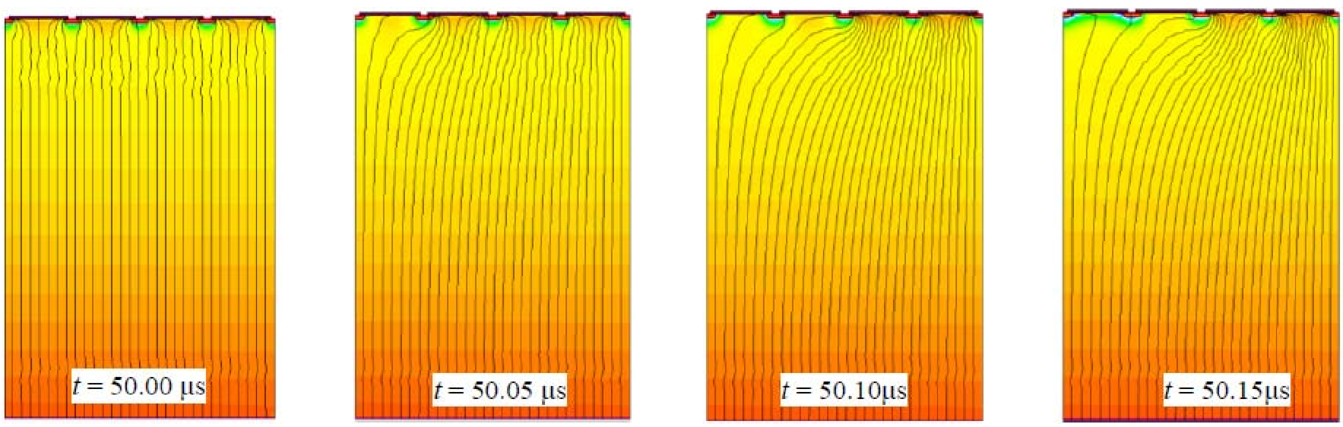

FIGURE IV.

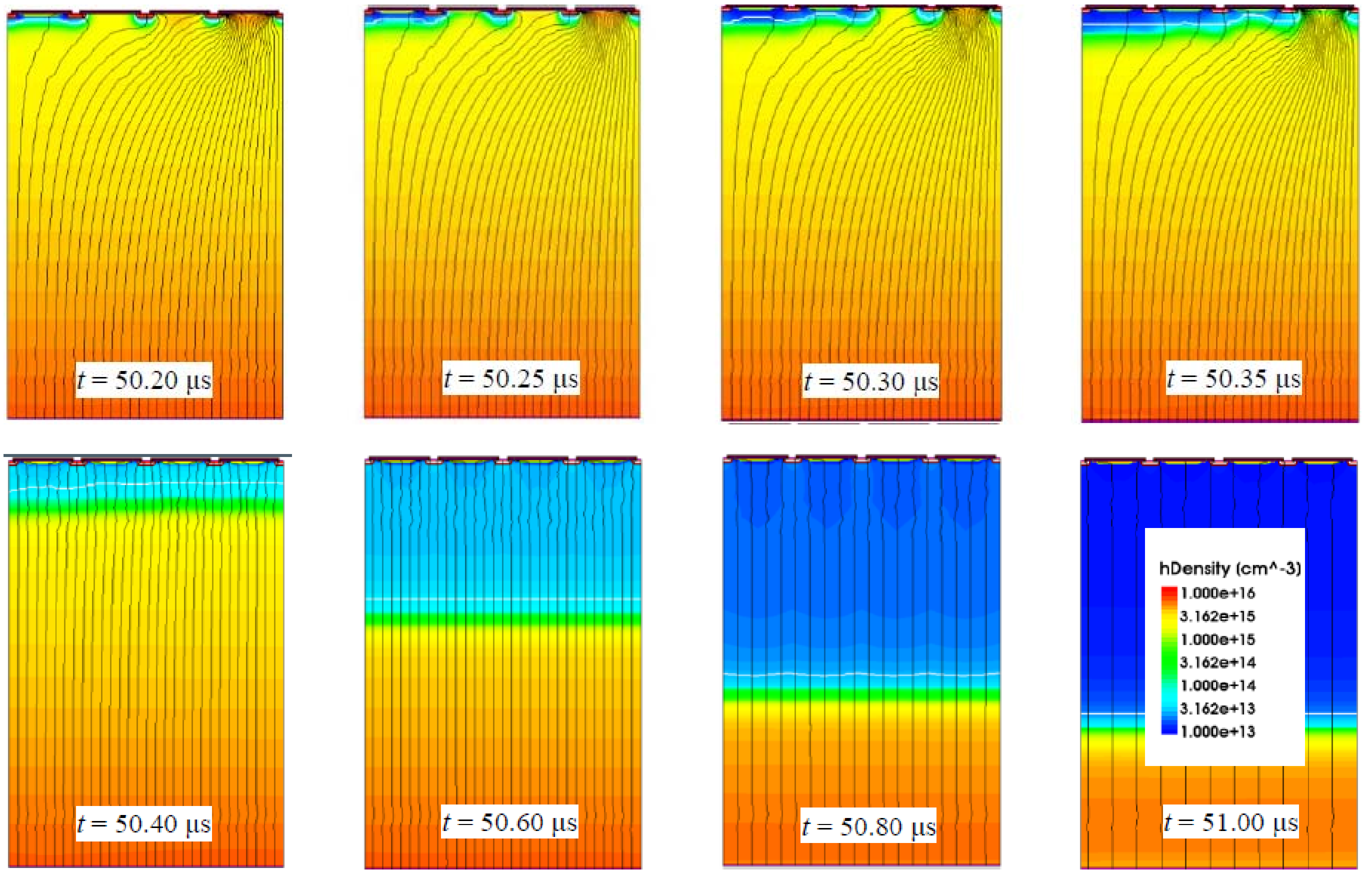

FIGURE IV. CURRENT LINES AND HOLE DENSITY PROFILES OF THE SIMULATED IGBT FOR DIFFERENT INTANTS DURING TURN-OFF

Another point must to be stated is that during the first stage, the collector voltage keeps low, and when it rises up, the current already becomes homogeneously distributed again. Then it can be expected that thermal effect associated with the first and current-uneven stage will not be noticeable. This can be verified by Fig. 5, which shows that the maximum temperature rise during the first stage of the turn-off, is only within 2 K. Therefore, it can be expected that in a high-voltage IGBT, the distributed polysilicon resistance effect, although generating current crowding in the early stage of the turn-off, will not remarkably affect the safe operation of the device on the whole when it is to be switched off.

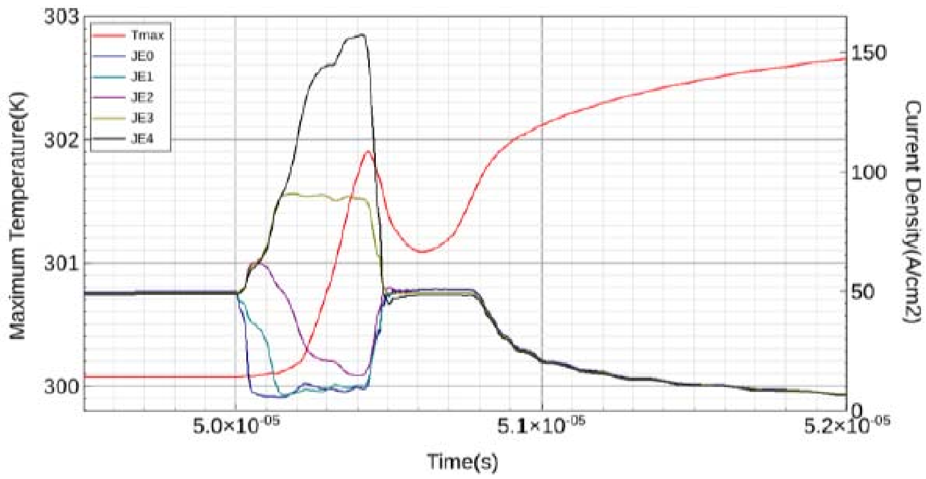

FIGURE V. SIMULATED CURRENT WAVEFORMS AND THE MAXMUM TEMPERATURE VARING WITH TIME. JE0~JE4: APPARENT CURRENT DENSITY OF EMITTERS E0~E4 (SEE FIGURE 2).

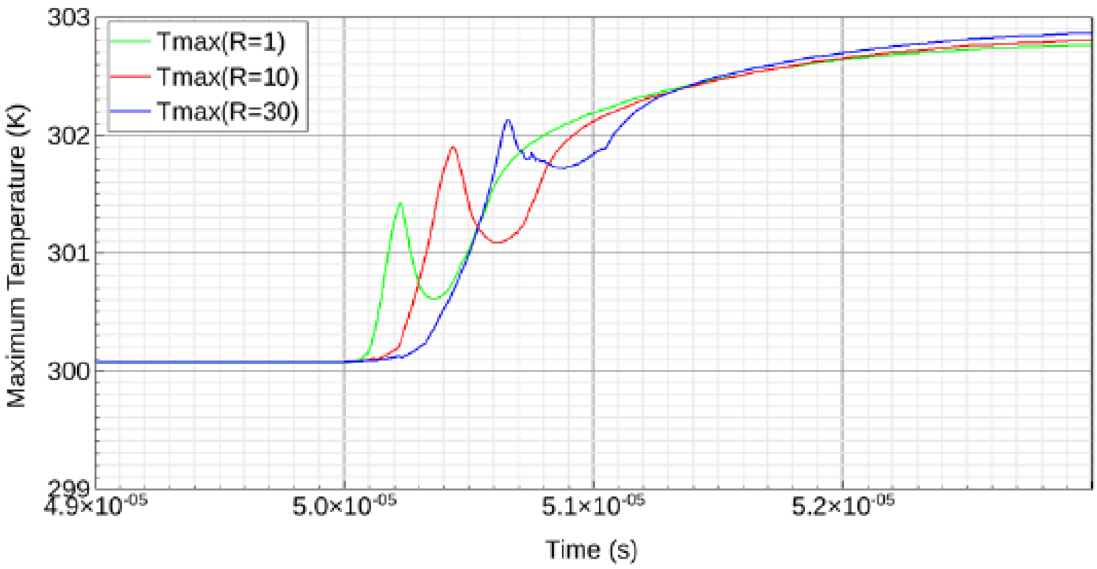

FIGURE VI. SIMULATED MAXMUM TEMPERATURE VARING WITH TIME FOR DIFFERENT VALUES OF THE EXTERNAL GATE RESISTANCE *R*.

If the external gate resistance *R* is changed, e.g. to 1 or 30 Ω, the delay time of the final channel extinction will be shortened or prolonged. Then the instant when the conversion of the non-homogeneous current profile to the homogeneous one occurs will see different degrees of collector voltage rising. The more the value of *R*, the more delay and thus the higher degree of collector voltage rising is encountered, causing the more prominent thermal effect for the same current crowding. Fig. 6 reveals this tendency explicitly. However, for a reasonable changing range of *R*, the maximum temperature rising will still be small enough and will not affect the safe turn-off.

IV. SUMMARY

The simulation results on a high-voltage multi-cell IGBT structure with a distributed gate resistance is presented. Under the conditions given in this paper, it is shown that that during turn-off, the emitter current of IGBT will demonstrate a "homogenous–non-homogeneous–re-homogeneous" evolution before the collector voltage noticeably rises. Therefore, this effect will generate a small amount of local temperature climbing, and will not affect the safe turn-off operation of the device on the whole.

ACKNOWLEDGEMENT

This research was financially supported by the China State Grid science and technology project GEIRI-GB-71-17-002 "Feasibility Research on the Principle and Application of Reverse-Blocking IGBTs."

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