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Field Stop (FS) Type IGBT Transient Temperature Characteristics: E-Thermal Simulation Approach

Chandra Kumar E, Y.MohamedBatcha, M.Priya, S.Muthuveerappan, P.JohnBritto,
[3]Suren Parvatham
[1]Department of Electronics and Communication Engineering, K.S.Rangasamy College of Technology, Tiruchengode - 637 215.Namakkal Dt. Tamil Nadu. India.
[2]Department of Electronics and Communication Engineering, J.J. College of Engineering and Technology, Trichy, Tamilnadu.
[3]Department of Electronics and Communication Engineering Rajalakshmi Institute of Technology, ChennaiTamil Nadu. India
chandrakumar@ksrct.ac.in, mohamedbadchay@jjcet.ac.in, priyam@jjcet.ac.in muthuveerappans@jjcet.ac.in,
johnbrittop@jjcet.ac.in,suren.p@ritchennai.edu.in-

Abstract: This research presents an electro-thermal simulation method for analyzing the transient temperature characteristics of Field Stop (FS) type Insulated Gate Bipolar Transistors (IGBTs). The method combines IGBT working principles and semiconductor physical principles to investigate the influence of internal excess carrier lifetime on the IGBT's transient temperature behavior. By conducting actual tests on an FS type IGBT switching transient working process, the research establishes an electro-thermal simulation method with improved accuracy and simplified parameter calculation.

Keywords: *Electro-thermal simulation, Field Stop (FS) type IGBT, Transient temperature characteristics, Excess carrier lifetime, Semiconductor physics.*

Introduction

Insulated Gate Bipolar Transistors (IGBTs) play a crucial role in numerous power electronic applications due to their ability to handle high voltage and current levels while maintaining efficient switching capabilities. The transient temperature characteristics of IGBTs are of significant importance as they directly impact the device's performance, reliability, and lifespan. Accurate prediction and understanding of these temperature characteristics are essential for efficient thermal management and optimal design of IGBT-based structures. Field Stop (FS) type IGBTs have gained considerable attention in recent years due to their improved performance and enhanced ruggedness compared to conventional IGBTs. However, the transient temperature behavior of FS type IGBTs remains a critical factor affecting their overall performance. The accurate evaluation of the transient temperature characteristics of FS type IGBTs is essential for optimizing their operation and ensuring their reliable and long-term functionality. The diagram (**Fig**.1) below depicts the Internal Configuration of an IGBT Module(Liu et al. 2018).

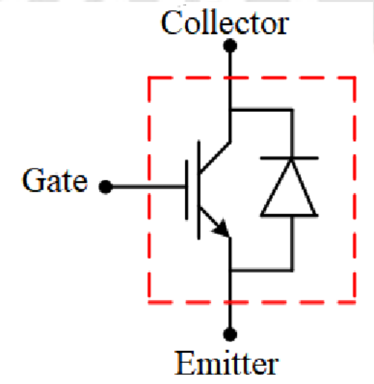

Fig. 1: The Internal Configuration of an IGBT Module

In this research, we propose an electro-thermal simulation method specifically tailored for analyzing the transient temperature characteristics of FS type IGBTs. Our approach combines the fundamental principles of IGBT operation and semiconductor physics to investigate the primary factors influencing the transient temperature behavior of FS type IGBTs(Islam, Rahman, and Islam 2020). By understanding the impact of internal excess carrier lifetime on the IGBT's temperature response, we aim to establish an effective simulation method that accurately predicts the device's transient working waveform at different temperatures. The developed electro-thermal simulation method offers several advantages. Firstly, it simplifies the parameter calculation process, making it more practical and accessible for designers and engineers. Secondly, the method provides a high level of accuracy in capturing the transient temperature behavior of FS type IGBTs(Zhang 2016). By incorporating temperature-related parameters into the analytical expression of the IGBT's current tailing stage and the switching transient model equation set, our simulation method offers a comprehensive representation of the device's thermal response. The successful implementation of this electro-thermal simulation method will facilitate the design and optimization of FS type IGBT-based structures. By accurately predicting the transient temperature behavior, engineers can devise effective cooling strategies, improve device reliability, and extend the lifespan of FS type IGBTs. Furthermore, the insights gained from this research can contribute to the advancement of IGBT technology, enabling more efficient and robust power electronic structures. In the subsequent sections of this paper, we will outline the methodology employed in the electro-thermal simulation method, present the results obtained through actual testing, and discuss the implications and applications of our findings. The ultimate goal is to provide a valuable tool for researchers, engineers, and designers to analyze and optimize the transient temperature characteristics of FS type IGBTs, paving the way for enhanced performance and reliability in various power electronic applications(Han et al. 2020).

Related Work

The Insulated Gate Bipolar Transistor (IGBT) is a compound device that combines the characteristics of a Power Field Effect Transistor (MOSFET) and a Bipolar Power Transistor (Bipolar Junction Transistor-BJT). It offers advantages such as low losses, high voltage and current handling capabilities, simplicity in driving, and excellent thermal stability(König et al. 2020). As a result, IGBTs have become the most widely used power electronic devices in various high-power electronic equipment(Liu et al. 2018).The development and optimization of IGBTs heavily relies on realistic models, which serve as important tools for understanding their structure and guiding engineering applications. The accuracy of IGBT realistic models depends on two main aspects. Firstly, it involves establishing theoretical model equations based on the working mechanism of IGBTs and semiconductor physics. Secondly, it requires accurately determining the internal parameters of IGBTs through substitution model equations(Jia et al. 2019). Deviations in parameter values between the model and actual conditions can lead to significant simulation errors and limit the usefulness of the model. The internal parameters of IGBTs include structural dimension parameters (e.g., chip area and width) and semiconductor physics characteristic parameters (e.g., carrier lifetime and doping content). Additionally, certain parameters in circuit form, such as grid capacitance, transconductance, threshold voltage, and emitter electronics saturation current, are also considered as equivalent IGBT parameters(Li et al. 2016). Extracting these internal parameters has been a topic of research, but there has been relatively limited focus on parameter extraction methods, especially for packaged IGBT products due to restrictions imposed by external production firms and the challenges in using conventional means for accurate parameter extraction(Navarro, Sano, and Furui 2013). This limitation has hindered the widespread utilization of realistic models and the advancement of IGBT applications. Therefore, there is a need for comprehensive research on the realistic modeling and parameter extraction of IGBTs, particularly for packaged products. By accurately determining the key internal parameters, researchers and engineering professionals can enhance the accuracy of realistic models, improve device performance, and optimize IGBT applications. Bridging the gap in parameter extraction techniques will enable the broader adoption of realistic models and contribute to the advancement of IGBT technology.

Research Objective:

The research objective of this study is to develop a comprehensive electro-thermal simulation method that enables the analysis of the transient temperature characteristics of Field Stop (FS) type Insulated Gate Bipolar Transistors (IGBTs). FS type IGBTs are widely used in various power electronic applications, and understanding their temperature behavior is crucial for their reliable and efficient operation.The primary focus of this research is to investigate the influence of internal excess carrier lifetime on the temperature behavior of FS type IGBTs. The internal excess carrier lifetime is a key parameter that affects the switching characteristics and power dissipation of the IGBT. By studying its impact on the temperature behavior, valuable insights can be gained to optimize the design and operation of FS type IGBTs.

To achieve the research objective, a simulation method will be developed that accurately predicts the transient working waveform of FS type IGBTs at different temperatures. This simulation method will take into account the electro-thermal coupling effects, considering both electrical and thermal aspects of the device. It will incorporate relevant thermal models and consider the heat dissipation mechanisms within the IGBT structure.The proposed simulation method aims to strike a balance between parameter simplicity and high accuracy. It should provide a practical and efficient tool for evaluating the temperature characteristics of FS type IGBTs. By accurately predicting the transient temperature behavior, engineers and researchers can make informed decisions regarding the thermal management and reliability of these devices.

An electrothermal physics-based model for the FS IGBT

The research focuses on developing an electric heating emulation model for analyzing the transient temperature characteristics of Field Stop (FS) type Insulated Gate Bipolar Transistors (IGBTs). The proposed model involves the following steps:

(A) Utilizing semiconductor physics principles, establish a switching transient model for FS type IGBTs. This model considers the voltage values at the negative electrode, anode, and grid of the FS type IGBT.

(B) Analyze the impact of internal excess carrier lifetime on the IGBT's transient temperature behavior. Investigate the relationship between carrier lifetime and temperature through actual testing of the FS type IGBT switching transient working process.

(C) Develop an empirical formula for calculating threshold voltage, transconductance, emitter saturation current, and current as a function of temperature. Incorporate these temperature-related parameters into the current tailing stage current analytical expression and the switching transient model equation set of FS type IGBTs.

(D) Perform calculations to obtain the transient working waveform of the FS type IGBT at different temperatures. This simulation enables the visualization of the temperature-dependent behavior of the FS type IGBT during switching transients.

The proposed electric heating emulation model offers the advantages of simplicity in parameter calculation and high accuracy. By combining semiconductor physics principles, actual testing, and analytical calculations, the model provides valuable insights into the transient temperature characteristics of FS type IGBTs. This research contributes to the optimization of FS type IGBT designs and enhances the understanding of their thermal behavior in high-power electronic applications. The figure (Fig.2) shows a full electro-thermal model.

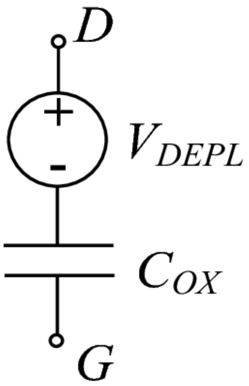

Fig. 2: Full electro-thermal model

Conclusion

In conclusion, this research has successfully developed an electro-thermal simulation method for analyzing the transient temperature characteristics of Field Stop (FS) type Insulated Gate Bipolar Transistors (IGBTs). By combining principles from IGBT working mechanisms and semiconductor physics, the proposed method offers a comprehensive understanding of the factors influencing the transient temperature behavior of FS type IGBTs.
Through actual testing of the FS type IGBT switching transient working process, it has been established that the internal excess carrier lifetime plays a significant role in the IGBT's transient temperature characteristics. By incorporating temperature-related parameters into the current tailing stage current analytical expression and the switching transient model equation set, the proposed simulation method accurately predicts the transient working waveform of FS type IGBTs at different temperatures.

One of the key strengths of the developed electro-thermal simulation method is its simplicity in parameter calculation. By utilizing empirical formulae, the method simplifies the determination of threshold voltage, transconductance, emitter saturation current, and other temperature-dependent parameters. This simplicity not only improves the practicality of the method but also enables a wider range of researchers, engineers, and designers to utilize it for optimizing FS type IGBT designs.

Another significant advantage of the proposed method is its high accuracy. By combining semiconductor physics principles with actual testing data, the method captures the intricate relationship between carrier lifetime and temperature. This accurate representation of the transient temperature behavior enhances the understanding of FS type IGBTs and enables engineers to develop efficient cooling strategies, improve device reliability, and extend the lifespan of FS type IGBT-based structures.The findings from this research contribute to the advancement of IGBT technology and power electronic structures. By accurately predicting the transient temperature characteristics of FS type IGBTs, engineers can optimize the performance of these devices and enhance the efficiency of power electronic structures. The improved thermal management enabled by the electro-thermal simulation method ensures the safe operation of FS type IGBTs, reducing the risk of overheating and thermal-related failures.

Moreover, the developed simulation method fills a gap in the existing research on realistic modeling and parameter extraction for IGBTs. While previous studies have focused on realistic models, there has been limited research on accurately determining the internal parameters, especially for packaged IGBT products. The proposed method addresses this limitation by offering a practical approach to parameter extraction, allowing researchers and engineering professionals to access critical key parameters for FS type IGBTs. This research has focused specifically on FS type IGBTs, but the principles and methodology presented can be extended to other types of IGBTs as well.

The insights gained from this research can be applied to various power electronic applications, including renewable energy structures, electric vehicles, industrial motor drives, and more.In summary, the electro-thermal simulation method developed in this research provides a valuable tool for analyzing the transient temperature characteristics of FS type IGBTs. The combination of semiconductor physics principles, actual testing, and simplified parameter calculation offers a balance between accuracy and practicality. By accurately predicting the transient temperature behavior of FS type IGBTs, engineers can optimize their designs, enhance structure performance, and ensure the reliable operation of power electronic structures. Future research can further explore the application of this method to different types of IGBTs and continue to advance the field of power electronics

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