

Effect of Carrier Motion Variations Inside the Press-pack IGBT Chip on External Electromagnetic Parameters

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The reliability of Press-pack insulated gate bipolar transistors (PP IGBTs) is closely related to their internal multi-physical field interaction mechanism. The uneven pressure between parallel chips affects the current distribution and temperature distribution, which in turn makes the local aging of the module aggravated. Therefore, this paper builds a multi-physical field coupling model of PP IGBT considering piezoresistive effect based on COMSOL. And based on this model, we simulate and analyze the micro-motion characteristics of the carriers inside the PP IGBT chip under different pressures and temperatures, as well as the changes of external macroscopic electromagnetic parameters, so as to reveal the mechanism and law of the influence of the carriers inside the PP IGBT chip on the external electromagnetic parameters under the effect of temperature and pressure.

Index Terms—finite element method (FEM), insulated gate bipolar transistors (IGBTs), piezoresistive, semiconductor charge carriers.

I. INTRODUCTION

The current flexible DC transmission project has a large demand for IGBT modules that can withstand higher voltages. High-voltage high-power IGBT devices are divided into two types: wire-bonded IGBT modules and press-pack IGBTs (PP IGBTs). Compared with the wire-bonded IGBT devices, the PP IGBT devices have the advantages of double-sided heat dissipation, short-circuit failure and easy to connect in series, which are more suitable for all kinds of high-voltage and large-capacity power converter and control equipment [1].

In order to make the developed PP IGBT chips and devices can meet the operating conditions and reliability requirements of high-voltage and large-capacity power converter in the smart grid, it is necessary to study the multi-physical field interaction mechanism within the PP IGBT. Existing research has found that there is uneven pressure distribution inside the PP IGBT device, which affects the current distribution and temperature distribution when multiple chips are connected in parallel, and increases the local aging of the module [2], so it is necessary to carry out the study of equalization of current from the perspective of pressure.

Existing research results mainly analyze the influencing factors of uneven current in IGBT parallel connection from the circuit level [3], which is less related to the motion and distribution of carriers inside the chip. Ref. [4] shows that the piezoresistive effect of semiconductors needs to be taken into account when considering the factors affecting the electrical parameters of the chip.

Based on the current research status, this paper combines the piezoresistive effect to study the micro-motion characteristics of the carriers inside the PP IGBT under different pressures and temperatures, and analyze the external macromagnetic parameters such as the on-state current, and obtain the change curves of the difference of the on-state currents with the pressures and temperatures to reveal the effect of the change of the carriers' motions on external electromagnetic parameters of PP IGBTs in the different pressures and temperatures distribution states. In order to reveal the mechanism and law of the influence of different pressure and temperature distribution

states on the internal carriers of the PP IGBT on the external electromagnetic parameters.

II. THE BACKGROUND THEORY

A. Multiple Physical Field Coupling

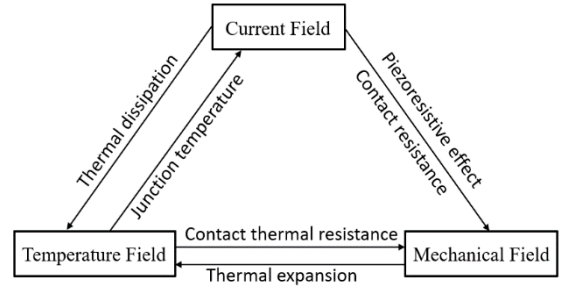


Fig. 1. Multiphysics field of Press-Pack IGBTs.

IGBT power module in normal operation electric field, temperature field and stress field three physical fields are coupled and interact with each other. The passing current causes an increase in temperature, which generates thermal stresses; at the same time, the increase in temperature affects the magnitude of the material conductivity, and the damage to the module caused by thermal stresses also causes the temperature to increase further, and even the initial failure of the module causes a change in the current of the electrical part. Therefore, IGBT power modules involve the coupling of electric, thermal as well as stress fields [5].

In this paper, the basis for realizing the coupling of electric-thermal-force multiphysical fields is to abide by the principle of electromagnetic loss and the theory of thermal expansion.

B. IGBT metastructure

The basic structure of an IGBT is shown in Fig. 2. And it can be seen that each IGBT metamerism can be regarded as a composite structure of a PNP transistor and an N-channel-type MOSFET.

The on-state current of an IGBT can be divided into two parts, the electron current I_n that flows through the MOS channel, and the hole current I_p that flows through the PNP transistor [6].

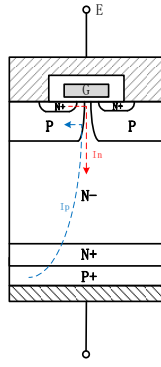


Fig. 2. IGBT metastructure.

The electron current is dominated at the MOS side, and therefore the I_n this paper, n-type silicon has been chosen for the doping setup of the IGBT chip.

III. INTRODUCTION TO SIMULATION

COMSOL is a multi-physics field simulation software, which provides an integrated modeling environment through the finite element method (FEM) to simulate and couple different physical phenomena simultaneously. The IGBT power module involves the coupling of electric, thermal and stress fields, so COMSOL is used for the multi-physics field coupling simulation in this study.

The simulation conditions are set as follows: the PP IGBT is considered to be convective heat dissipation, double-sided water cooling is simulated, other surfaces of the device are set to be thermally insulated, and the total power of the heat source is taken as the pass-state loss of the device. On the basis of the above model, 80A total current is injected into the parallel chip.

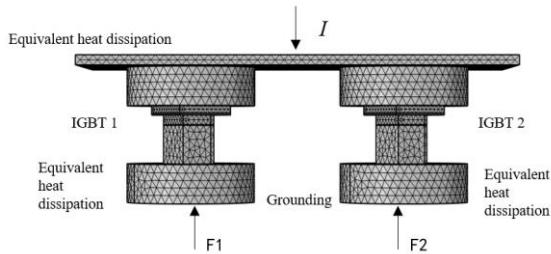


Fig. 3. Boundary conditions of the FEM model for paralleled modules.

The physical fields involved in the simulation are electric field, temperature field, and pressure field. In addition, this paper focuses on adding the coupling between pressure and conductivity. The number of model degrees of freedom in this paper is 737440.

IV. ANALYSIS OF SIMULATION RESULTS

A. Clamping Pressure

Apply different pressures to the parallel dual chips respectively, where the fixed pressure on IGBT 2 is 1000N, adjust the pressure applied on IGBT 1, and record the current density of the parallel dual chips under different pressure differences.

From the Fig. 4., it can be seen intuitively that the current density between parallel chips with large forces is greater, and

the current density difference between chips increases with the increase of pressure difference.

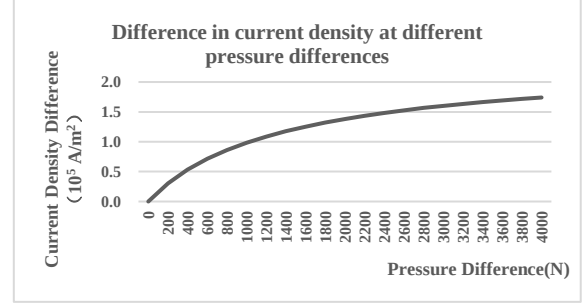


Fig. 4. Variation curve of current density difference with pressure difference.

B. Temperature

Different water-cooled heat transfer coefficients were set for parallel dual chips and the current density on the chips was recorded. And the clamping force on both IGBTs is 1000N.

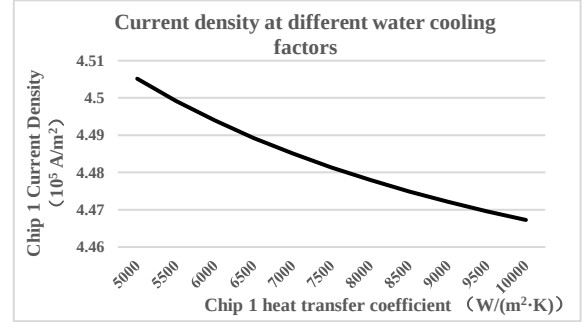


Fig. 5. Current density at different convective heat transfer coefficients.

As can be seen from the Fig.5., the greater the water-cooled heat transfer coefficient of the PP IGBT, the lower the temperature of the device and the lower the current density of the chip.

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