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Optimization of the thermal contact resistance within press pack IGBTs

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ABSTRACT

The research of thermal contact resistance between multi-layers within press pack IGBTs (PP IGBTs) is significant for optimizing the PP IGBTs' thermal resistance to improve reliability, as the thermal contact resistance accounts for approximately 50% of the total thermal resistance of PP IGBTs. In this paper, thermal contact resistance between multi-layers is analysed via a finite element model (FEM) of a single fast recovery diode (FRD) submodule. Most importantly, the influence of temperature and clamping force on the thermal contact resistance is also discussed, and findings are verified by submodule thermal resistance experiments. Based on the FEM and experimental results, nanosilver sintering technology is proposed to fill the gap between the contact interfaces to reduce thermal contact resistance. The fabrication of a sintered single FRD submodule is also investigated in this paper, and the results of the sintered sample indicate that the thermal resistance is reduced by approximately 18.8% compared to a direct contact sample.

1. Introduction

To meet the growing requirements of applications of IGBT devices, capacity and reliability have become great challenges for IGBT devices. Press pack IGBTs (PP IGBTs) have gradually been applied to high-voltage and high-power-density applications, such as electric locomotives and HVDC transmission, because of their high reliability, double-side cooling, high power density and ease of laying out in series [1] compared to typical wire-bonded IGBT modules. The simplified internal structure of the studied PP IGBT is shown in Fig. 1, as it may be observed that the PP IGBT has a multi-layered structure. Two copper electrodes (the collector and emitter pole) provide the electrical and thermal paths for the silicon chips, and the silicon IGBT chips are sandwiched by two molybdenum plates, which help with the uniform distribution of the clamping force. A silver shim plate, together with a silicon IGBT chip and two molybdenum plates, is used to form a chip assembly. An external clamping force is required to maintain the electrical and thermal contact of all components within PP IGBTs. Thermal contact resistance is a very important parameter for thermal resistance optimization and reliability improvement, as it accounts for approximately 50% of the total thermal resistance [2].

When two rough surfaces are bought into contact, actual contact only occurs at certain discrete spots or micro-contacts, while the non-contacting areas form vacuums or are filled with some medium (such as air, water or oil). The actual contact area accounts for approximately 0.01%–0.1% of the nominal contact area, and the proportion only increases to 1%–2% under a contact pressure of 10 MPa [3]. Because the actual contact surface area is relatively small, as is the thermal conductivity of the interfacial gases, heat flow across the interface experiences a relatively large thermal resistance, commonly referred to as thermal contact resistance [4,5]. Thermal contact resistance is a complex parameter affected by the material properties, surface morphology, contact pressure, temperature and so on [6,7], and thus the precision of the test bench will be a significant challenge for measurement. At present, steady-state and transient methods are used to predict the thermal contact resistance, and the steady-state method is most commonly used. The temperature difference between the interfaces can be obtained by a linear fitting after the temperature has been measured between two samples in the steady-state method [8]. Not only will the temperature distribution of the specimen be disturbed by the embedded thermocouple, but the accuracy of the adjacent measured temperature will also be influenced since this steady method requires a thermocouple to measure the temperature. Most importantly, many thermocouples should be located in the samples, and thus the steady-state method is not suitable for a specimen whose geometry is small (in the millimetre ranger). To cover some disadvantages of the thermocouple method, an infrared imaging system with an accuracy of 0.1 °C, instead of a thermocouple, is put forward by various scholars to record the temperature of the two-dimensional interface. Although the accuracy is greatly improved, an error of approximately 23% is still presented [9]. The optical-thermal method is the widely used method among transient thermal contact resistance measurement methods [10,11]. Thermal contact resistance is obtained by the phase difference of the heat wave and modulation wave after encountering the interface. However, the accuracy of the optical-thermal method is affected by the interface characteristic, as the heat wave is diffused at the contact interface, and it

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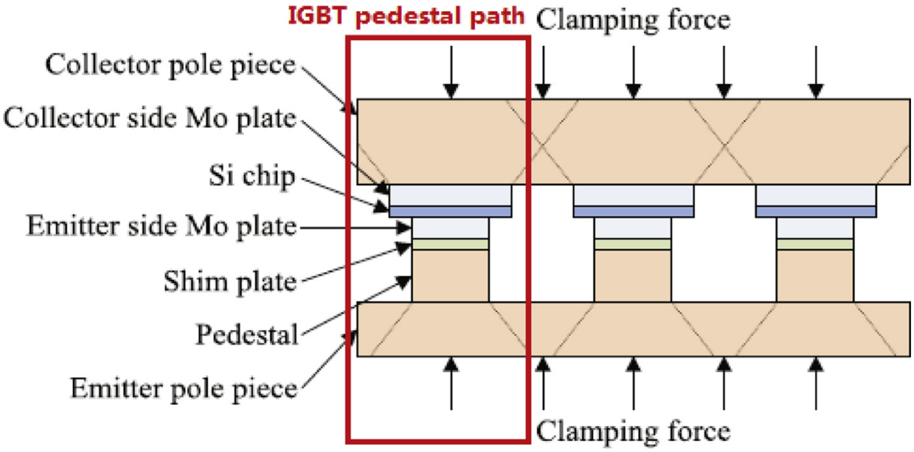

Fig. 1. A cross-section schematic diagram for press pack IGBTs.

destroys their phase relationship [12]. All the methods mentioned thus far are for the measurement of thermal contact resistance between power semiconductor devices and heatsinks or among copper bus bar junctions. Namely, all the methods are for the thermal contact resistance outside power semiconductors rather than within them. Although T. Poller et al. [13] measured the thermal contact resistance within PP IGBTs through a combination of experiments and a finite element method, the deviation of the thermocouple still exists, and the testing process is relatively complicated.

Thermal contact resistance within PP IGBTs has not been identified for its special packaging style and working conditions likewise thyristors. And the measurement of thermal contact resistance within PP IGBTs is still impossible with the limits that no probes can be placed between two test samples and the clamping force system. Furthermore, the optical-thermal or other non-contact methods are not suitable for PP IGBTs because the chips are clamped and encapsulated. Thus, the theoretical model with the measured data to make it more precise is proposed to predict the behaviour of thermal contact resistance in this paper. Meanwhile, an indirect measurement of junction to case thermal resistance is proposed to predict the thermal contact resistance within PP IGBTs and to identify the theoretical values. The point of this indirect measurement is to use the variation of junction to case thermal resistance to deduce the variation of thermal contact resistance. According to the theoretical and experimental results, nanosilver sintering technology is introduced to reduce the thermal contact resistance, and a nanosilver-sintered sample is manufactured to verify this. The structure of this paper is set as follows. Characteristics of PP IGBTs and the status of thermal contact resistance calculation and measurement are presented in the introduction. The finite element model based on theoretical model is used to calculate the thermal contact resistance within PP IGBTs, as well as the influence of temperature and clamping force in the second section. And some parameters needed in the calculation are measured through experiment to make the model more precise. A single fast recovery diode (FRD) chip submodule is fabricated to measure the thermal resistance change and compare it with the theoretical values in the experiment part. The optimization section presents a nanosilver sintering technology for optimizing the thermal contact resistance between the collector side of the chip and molybdenum, and a sintered sample is also manufactured to make a comparison with the direct contact submodule. Conclusions and outlook are provided in the last section.

2. Theoretical

2.1. Basic principle

A micro-structure diagram of the contact interface is shown in Fig. 2 [14]; the contact spot is always named micro-contact, and the non-contact area is filled with air. Because the thermal conductivity of the interfacial gases is relatively low (0.023 W/(m·K)), heat flow across the interface experiences a relatively large thermal resistance, commonly referred to as thermal contact resistance. Micro-contacts, which have a relatively long distance among them, are general distributed randomly when two rough surfaces came into contact. Only thermal conduction is considered between the micro-contact and the interfacial gaps, which are usually filled with air in this situation [15]. In most practical situations concerning thermal contact resistance, the gap thickness between two contacting bodies is quite small (<10 μm), and thus the Grashof number based on the gap thickness is <2000. Consequently, in most instances, the heat transfer of convection through the interstitial gas in the gap is neglected [16]. Thermal radiation across the interfacial gaps is generally considered as insignificant as the surface temperature is less than approximately 700 K [17]. In conclusion, the thermal contact conductance h_c of the contact interfaces, which can be calculated by

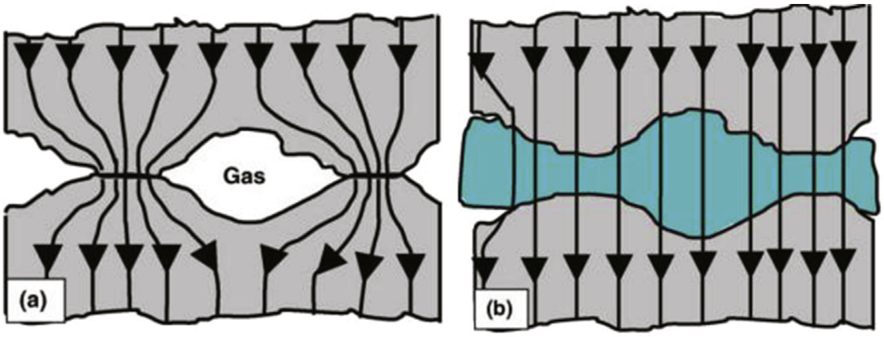

Fig. 2. Micro-contact interface schematic diagram.

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