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Analysis on the difference of the characteristic between high power IGBT modules and press pack IGBTs

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ABSTRACT

The insulated gate bipolar transistor (IGBT) has been widely employed in such applications as alternate current motors and inverters for its lower driving power and lower on-state voltage. IGBT modules and press pack IGBTs are the most commonly used packaging for high-voltage and high-power-density applications. The difference in the packaging style and working conditions between IGBT modules and press pack IGBTs creates distinctions in, for instance, the thermal characteristics and reliability. Those distinctions lead to different applications and working conditions. In this paper, the development of IGBT devices has been reviewed, including the distinction of IGBT modules and press pack IGBTs in packaging style. Most importantly, the thermal and reliability characteristics have been compared in detail and the applications that are most suitable for IGBT modules and press pack IGBTs were outlined. The comparison of the thermal characteristics, reliability and applications provides guidance for users to take full advantage of the devices according to their requirements.

1. Introduction

Insulated gate bipolar transistor (IGBT) is very suitable for application in conversion systems with DC voltage over 600 V, such as AC motors, inverters, switching power supplies, lighting circuits, traction drives and other fields with its advantages of low power for driving and low on-state voltage drop [1,2].

Currently, the typical wire-bonded IGBT module is the main packaging style, especially for high-voltage and high-power-density applications. Generally, IGBT modules contains several IGBT chips and anti-paralleled Fast Recovery Diode (FRD) chips to improve the current ratings, which can also be designed as half-bridge or full-bridge modules according to the requirements of specific applications. Bonding wire and soldering technology are used to realize the chip's electrical connections to external electrodes. However, the long life time reliability of this packaging style is mainly affected by the existed bonding wire and solder joint, for example the bonding wire lift-off and solder joint cracking [3]. Many new technologies are constantly being proposed to improve reliability by semiconductor manufacturers such as ABB, Infineon, Fuji, Semikron, IXYS and Dynex. For example, nanosilver sintering technology is proposed with its high electrical and thermal conductance to improve the solder reliability [4]. Currently, the available standard high-power and high-reliability IGBT module for high-voltage and high-current is 6500 V/750 A and 1700 V/3600 A, respectively, which can supplied by ABB, Infineon, etc. Although to a certain extent new technologies and structure layout optimization can improve the reliability of IGBT modules, there still exist the problem of vaporization of bonding wires at failure leading to possible severe explosion [5].

Meanwhile, in order to meet the growing requirements for high-power-density applications and overcome the disadvantages of early versions of IGBT modules caused by the bonding wire and solder joint, an alternative packaging style of a press pack for IGBTs, which is learned from thyristors and IGCTs, is proposed [6]. The original motivation in most cases was the poor power cycling capability of early versions of wire bonded modules and their explosion behaviour [5]. Press pack IGBTs (PP IGBTs) have gradually been applied to high-voltage and high-power-density applications, such as electric locomotives and High Voltage Direct Current (HVDC) transmission, because of their high thermal cycling capability [7], double-side cooling, high power density [8] and ease of laying out in series [9] compared to traditional or typical wire-bonded high power IGBT modules. Some semiconductor manufactories and research institutes, such as ABB, WESTCODE and TOSHIBA, focus on researching PP IGBTs and improving its voltage and current ratings. Currently, the available high-voltage and high-current PP IGBTs are as follows: StakPak for 4500 V/3000 A became available in 2015 (ABB) [10], ST3000GXH24A for 4500 V/3000 A became available in 2015 (TOSHIBA), T2400GB45E for 4500 V/2400 A became available in 2015 (WESTCODE) [11] and the 4500 V/2000 A PP IGBTs became available in 2001 (FUJI) [12]. All those PP IGBTs can be divided into square and circular layouts in terms of the external packaging structure and

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can also be divided into spring contact [13] and pedestal style direct contact from the point of internal layout. In this paper, the pedestal style direct contact PP IGBTs are studied and called PP IGBTs for short because all existing PP IGBTs are pedestal style except for ABBs.

The characteristics of PP IGBTs are much different from those of IGBT modules on account of their difference in packaging style, especially the thermal characteristics and reliability. In this paper, the internal structure of IGBT modules and PP IGBTs is presented along with their advantages. All distinctions between them, especially the thermal characteristics and reliability, are then analysed. Finally, the application of IGBT modules and PP IGBTs is put forward based on those distinctions, especially the failure modes.

2. Packaging styles

A typical high power IGBT module contains several semiconductor chips, DBC (usually consists of copper, ceramic and copper), baseplate, bonding wire, soldering joints and power electrodes as shown in Fig. 1. As the most important component of IGBT modules, the collector side of IGBT chips is connected to the DBC. The CTE of the DBC is well in between the CTE of Si and the CTE of Cu used as base plate. Taking into account the temperature gradient between Si, DBC and Cu the DBC is good adaptation layer. The emitter side of IGBT chips is connected to external electrodes through bonding wires. The structure integration can be easily realized through the layout of DBC and chips in IGBT modules—for example, the half-bridge module or full-bridge module. In addition, the driver circuit can be included to form an IPM (intelligent power module) [14].

The simplified internal structure of PP IGBTs is shown in Fig. 2. Two copper electrodes (the collector and emitter pole) provide the electrical and thermal paths for the silicon chips, and the silicon chips are sandwiched by two molybdenum plates, which help with the uniform distribution of the clamping force [7]. A silver shim plate, together with a silicon chip and two molybdenum plates, is used to form a silicon chip assembly. Several single chip assemblies are connected in parallel to improve the current ratings, and the single chip assembly can be used for pre-testing prior to encapsulation. Meanwhile, PP IGBTs are usually connected in series in application, and an external clamping force is required to maintain the electrical and thermal contact of all components within PP IGBTs [15].

Furthermore, the layout of the IGBT chip for the two packaging styles is also different due to their packaging distinction as shown in Fig. 3, where the gate location is marked in red. The gate of the IGBT chip for most IGBT modules is located in the centre, and the emitter pad is used to realize the connection to the external electrode. The gate for press pack packaging is in the corner of the IGBT chip with the limitation of the clamping system, and grooves are shaped into the pedestals on the emitter side for the gate pin of the housing. The electrical connection between IGBT chips and external electrodes of IGBT modules is realized by bonding wires. However, the emitter pad of IGBT chips of PP IGBTs is directly connected with external copper electrodes. In other words, the connection for silicon chips in IGBT modules is realized by some points contact and the connection for PP IGBTs is realized by the surface contact if the interface contacts well, such as the clamping force is enough. Thus, the current distribution on the surface of the single IGBT chip for PP IGBTs may be more uniform than IGBT modules.

3. Thermal characteristics

In this paper, a conceptual IGBT module and PP IGBT are proposed to compare their thermal characteristic, such as the temperature distribution. The conceptual IGBT contains 4 IGBT chips (2.5 kV/50 A) and 2 FRD chips (2.5 kV/100 A) as shown in Fig. 4, and the voltage and current rating is 2.5 kV/200 A. We can see that the only difference between the conceptual IGBT studied in this paper and the specified high power IGBT produces which is shown in Figs. 1 and 2 is the number of paralleled chips. Nowadays, the standard wire-bonded packaging style

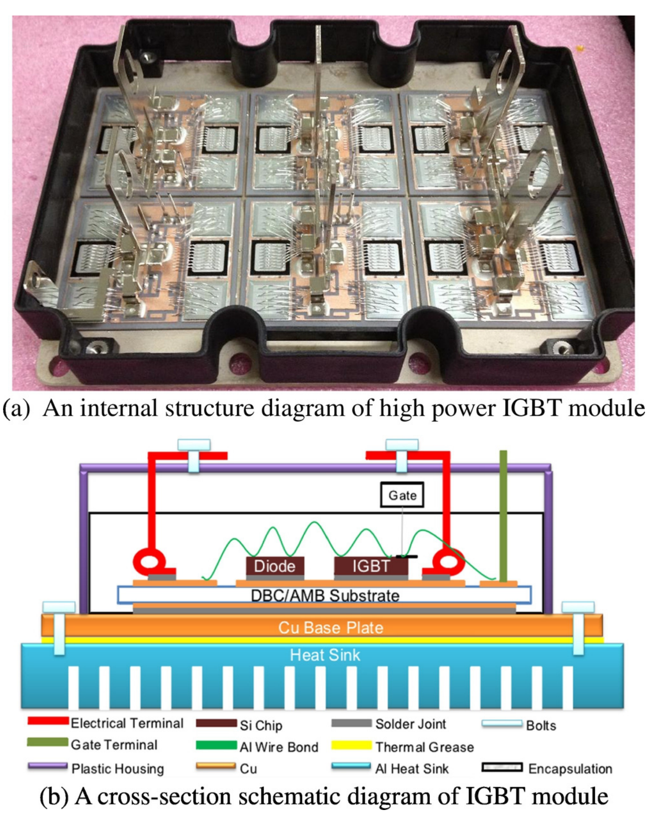

Fig. 1. A schematic diagram for high power IGBT modules.

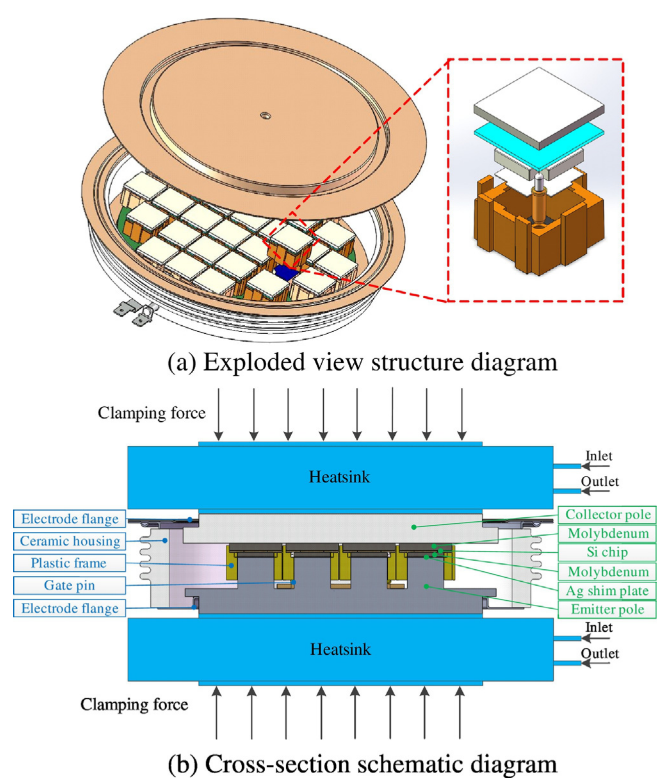

Fig. 2. PP IGBT schematic diagram.