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High-Voltage and High-Current IGBT Press-pack Module for Power Grid

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Abstract

On the basis of the development and application requirements of flexible DC transmission techniques, a 1 kA/10 kV half-bridge IGBT press-pack module is studied. The module is composed of three subunits in series, and each subunit consists of IGBT chips in parallel. In order to solve the problem of chips failure caused by non-uniform rigid-contacting pressure in the press-pack modules, the elastic-contacting structure is designed to ensure excellent electrical connection between chips and contact terminal. During the operating conditions, the heat generated by IGBT chips can induce the increasing of internal temperature of the module, affecting the reliability of the module. A cooling structure is introduced between the subunits to solve the heat dissipation problem of the module. In addition, the thermal analysis of subunit and the cooling structure is performed by using the finite element simulation, and the chip layout and water-cooling scheme are optimized. The testing of electrical parameters of the IGBT module is also conducted.

1. Introduction

With the rapid development of semiconductor technology, high-power electronic devices have played an irreplaceable role in the field of power grid. Owing to the maturity of IGBT in design, process, packaging, and outstanding electrical performance, it has become the mainstream device of power conversion and transmission. Meanwhile, because of the immature growth and epitaxy process of wide-bandgap semiconductor materials, silicon is still the mainstream material of IGBT. However, the limit of silicon itself restricts the application of traditional Si-based devices in the field of ultra-voltage, high current, and high temperature. Therefore, in order to meet the converter valve can withstand up to hundreds of thousands of volts of voltage and thousands of amperes of current, the circuit topologies are usually used to achieve high voltage or high current level of power conversion by series or parallel connection of power devices. Nevertheless, the series or parallel method causes difficulty in voltage or current balance between individual devices, complicated control, and increased cost. Meanwhile, multiple devices connected in series or parallel increase the size of converter valve, and have higher design requirements for operational reliability.

In power transmission applications, IGBT modules are mainly divided into welded modules and press-pack modules[1-4]. For welded IGBT module, the welding and wire bonding is adopted to realize the interconnection between chip and substrate. However, the difference in thermal expansion coefficient of distinct materials and the parasitic parameters of wire limit the performance and reliability of modules[5,6]. In contrast, press-pack IGBT modules realize the parallel connection of multiple chips and the electrical interconnection with external circuits through the rigid or elastic structure, possessing outstanding reliability[7,8]. In the packaging process, the welding and wire bonding are not used in press-pack IGBT modules. Thus, a large number of chips can be connected in parallel to realize IGBT modules with large capacity when the pressure or its variation on each chip does not affect the electrical and thermal performance of IGBT chips. At present, ABB, TOSHIBA, and WESTCODE have developed 3000A/ 4500V press-pack IGBT modules[9-11]. 3000V/4500V StakPak IGBT module designed by ABB, using the elastic press-pack structure, is composed of six subunits with 500A/ 4500V in parallel[9]. The disc spring press-pack structure is used to solve the issue of pressure balance on IGBT chips.

In this article, we propose a 1kA/10kV IGBT press-pack module. In order to enhance the insulation ability of IGBT chips, the insulated frame with silicone gel is applied. The optimized spring press-pack structure is introduced to enable the pressure balance on chips and excellent electrical interconnection. Meanwhile, the cooling structure is integrated into the IGBT module to ensure an internal temperature within the appropriate range, which improves the reliability of the IGBT module. The result of its electrical testing present an expected static electrical parameters.

2. Design and Simulation of IGBT Press-pack Module

The proposed IGBT press-pack module is shown in Figure 1(a), and its packaging dimension is 184 mm x 124 mm x 147.5 mm. The circuit topology of the IGBT module is a half-bridge structure, as displayed in Figure 1(b), in which 1~8 are the numbers of electrode pins. The specifications of IGBT and FRD chips used in the module are 63A/3300V and 126A/3300V, respectively. The IGBT module is composed of three subunits in series, in which each subunit includes 16 IGBT chips and 8 FRD chips. The module mainly contains insulating housing, upper and lower pressing plates, IGBT and FRD chips, cooling unit, and controlling circuit of gate. The copper terminal and IGBT/FRD chips are electrically interconnection by elastic press-pack structure. The cooling structure acts as the role of heat dissipation and conductivity. To ensure

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the tightness of the proposed IGBT module, a sealing ring is introduced between the pressing plate and the insulating housing.

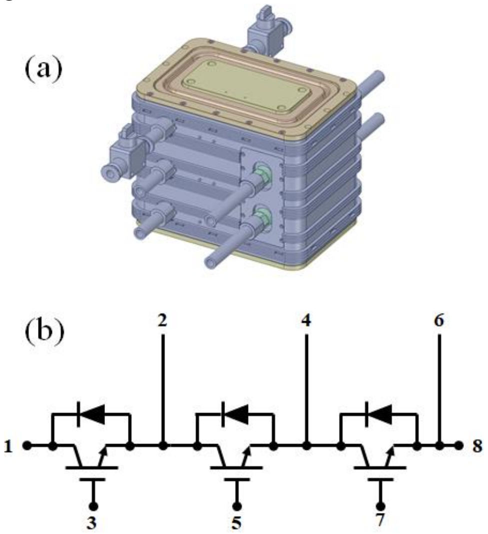

Figure 1. (a) Packaging scheme and (b) circuit topology of 1kA/10 kV IGBT press-pack module.

In the design of high voltage module, the internal chips are welded on the same substrate, and the modules adopts external heat dissipation. When the packaging dimension is limited, the number of IGBT/FRD chips can be arranged on the internal substrate of modules is restricted. This greatly limits the voltage level and current capacity of modules. At the same time, the efficiency of heat dissipation of the external cooling system is relatively low, which can not effectively dissipate the internal heat of modules. To solve these technical issues, our IGBT press-pack module uses the stacked scheme of subunits in series to achieve the purpose of higher voltage and higher current. As exhibited in Figure 2, the cooling channels are designed in the copper baseplates to lower the internal temperature of the proposed IGBT module.

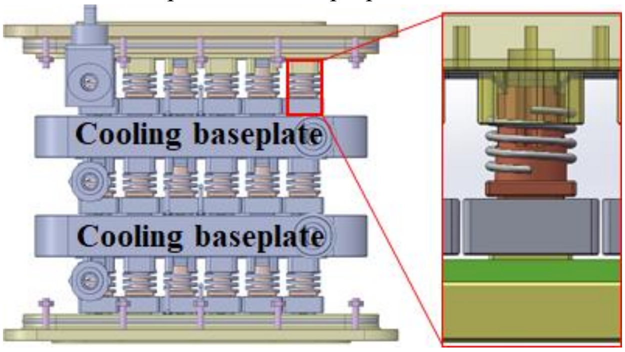

Figure 2. Cooling basplate and press-pack structure.

The press-pack types of press-pack power modules are mainly divided into rigid and elastic press-pack. For the rigid press-pack, the height error of each copper terminal determines the electrical and thermal performance of IGBT/FRD chips. On the contrary, elastic press-pack can overcome the issue of pressure imbalance caused by manufacturing accuracy. Therefore, to avoid the unbalanced pressure on IGBT/FRD chips, we propose a new elastic press-pack structure. A spring structure is introduced between copper terminal and pressing baseplate, as plotted in Figure 2.

To confirm that the cooling structure meets the heat dissipation of our IGBT press-pack module, a thermal analysis is conducted by using finite element simulation. Figure 3 exhibits the internal design of the cooling baseplate and the thermal distribution. In this simulation, the inlet temperatures of the cooling baseplate are set as 30 ℃ and 54 ℃, respectively. Moreover, flow rate at intake is ~20 L/min and the power dissipation of the cooling baseplate is 3750 W. The results displays that the peak temperature of the cooling baseplate is 77.9 ℃ when the inlet temperature is 30 ℃. In the case of 54 ℃ of the inlet temperature, the peak temperature is 98.6 ℃. As a result, the peak temperature of the cooling baseplate is lower than 125 ℃ that is the highest operating temperature for Si power devices.

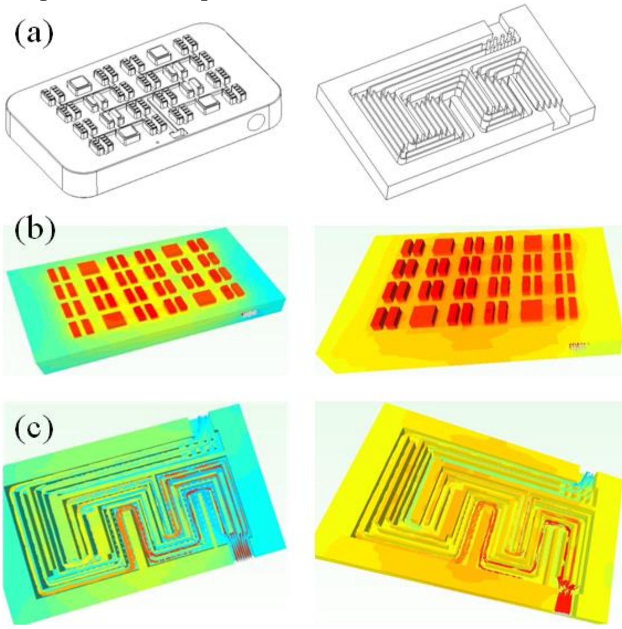

Figure 3. (a) The cooling baseplate and its internal channel. The thermal distribution with the inlet temperature of (b) 30 ℃ and (c) 54 ℃.

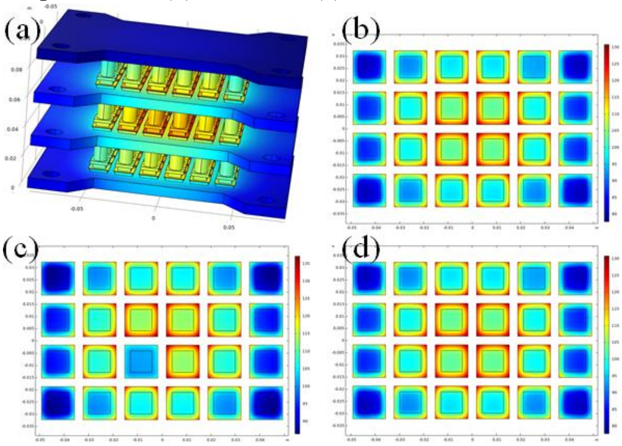

Figure 4. The thermal distribution of (a) the proposed IGBT module, (b) first sbunit, (c) second subunit, and (d) third subunit.

The 1kA/10 kV IGBT press-pack module is composed of three subunits, and each subunit includes 16 IGBT and 8 FRD. Therefore, the internal thermal distribution of the IGBT module must be studied. The cooling structure is not considered to decrease the time consumption and improve computational efficiency. Besides, the elastic press-pack is also simplified. The internal thermal distribution of the proposed IGBT module is presented in Figure 4. It is clearly show that the temperature in the central region of each subunit is higher than that in the edge. Meanwhile, the peak temperature in the first and third subunit up to 130 ℃, whereas that in the second subunit is higher than 130 ℃. Consequently, there is a reasonable layout for IGBT/FRD chips. When the cooling baseplate is taken into account, the internal temperature of the proposed IGBT module can decrease to an acceptable range.

Ultimately, in order to prove the feasibility of the design and the functionality of the proposed IGBT module, the components of the IGBT module are manufactured and the corresponding assembly process is determined. The main process of the IGBT module packaging as following: I) IGBT/FRD chips are placed in an insulating frame and the gaps are filled with silicone gel. II) the gate controlling circuits are mounted to the cooling baseplates. III) the IGBT/FRD units are placed on the copper terminals of the cooling baseplates. IV) three subunits are stacked vertically. V) installing the insulating housing and upper pressing copper-plate. Figure 5 shows the IGBT press-pack module after packaging and its internal structures.

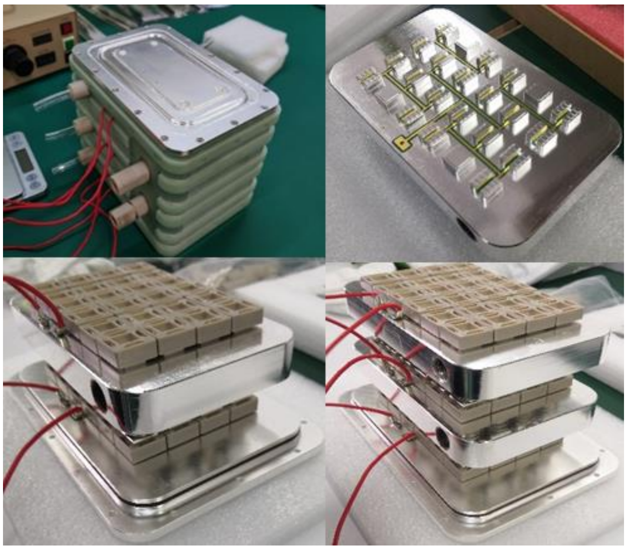

Figure 5. The IGBT press-pack module after packaging and its internal structures.

3. Testing of IGBT Press-pack Module

In order to obtain the static electrical parameters of 1kA/10kV IGBT press-pack module, the static testing system and high-voltage testing platform are applied. Table 1 lists the tested electrical parameters. Due to the limitation of driver and testing tools, the testing experiment of dynamic parameters is not carried out. As listed in Table 1, the voltage and current level of the proposed IGBT press-pack module achieve the designed capacity of 10kV and 1kA. Meanwhile, the saturation voltage of the collector-emitter is 7.8V, which is less than designed upper limit of 10V. Figure 6 is the electrical parameters testing of the IGBT press-pack module.

Table 1. The breakdown voltage of collector-emitter ($V_{(BR)CES}$), cut-off current of collector (I_{CES}), the saturation voltage of collector-emitter (V_{CEsat}), leakage current of gate (I_{GES}), and forward peak voltage (V_F) of the proposed IGBT press-pack module.

Para.	Test conditions	Value	Unit
$V_{(BR)CES}$	V_{GE}=0 V, I_C=0.1 mA	10.8	kV
I_{CES}	V_{CE}=10 kV, V_{GE}=0 V	18	μA
V_{CEsat}	V_{GE}=15 V, I_C=1 kA	7.8	V
I_{GES}	V_{CE}=0 V, V_{GE}=+20 V	15	nA
	V_{CE}=0 V, V_{GE}=-20 V	11	nA
V_F	I_F=1 kA	8.8	V

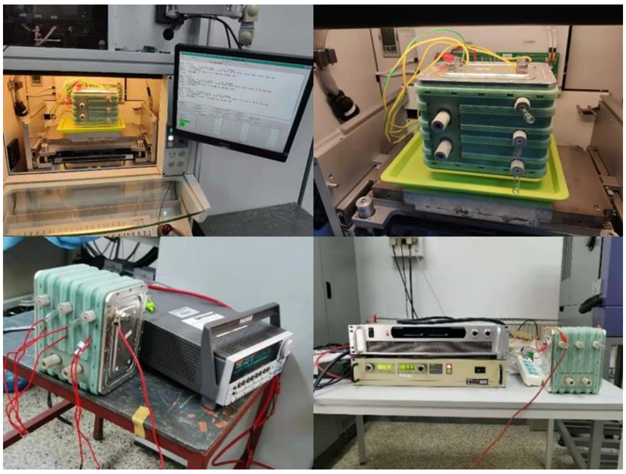

Figure 6. Electrical parameters testing of the proposed IGBT press-pack module.

4. Conclusions

In summary, we design a 1kA/10kV IGBT press-pack module based on subunit stacked scheme, focusing on cooling scheme, insulation of chip unit, elastic press-pack structure, and chip layout. The IGBT module consists of three subunits that are stacked vertically in series. Each subunit is composed of 16 IGBT chips in parallel and 8 FRD chips reverse parallel to achieve the capacity of 1kA. To overcome the problem of unbalance pressure on IGBT and FRD, a new press-pack structure with a spring structure is designed. Meanwhile, the scheme of built-in cooling baseplate is introduced to ensure the proper internal temperature of the IGBT module, which can enhance the operating reliability. In addition, by mean of finite element method, the thermal distribution in the IGBT module and the cooling baseplate is analysed, which proves the feasibility of chip layout and reasonability of the cooling channel. The testing results clearly show that the voltage and current level of the IGBT press-pack module are 10kV and 1kA, which meets the design expectation. The saturation voltage of collector-emitter is 7.8V, being less than 10V. Our work on 1kA/10kV IGBT press-pack module paves the path to the design and development of higher-voltage and higher-current power module for power grid.

Acknowledgments

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