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IGBT junction and coolant temperature estimation by thermal model

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ABSTRACT

The capability of IGBT (Insulated Gate Bipolar Transistor) to handle heat is one of its main limitations of high power application. This paper aims to study an IGBT thermal model under flow cooling condition and estimate the IGBT module junction and coolant temperature. Firstly, this paper studies the IGBT module internal sandwich structure and calculates the thermal resistance and thermal capacitor for each layer using a 1D physical model. Then a Cauer electric model is built for the IGBT module to evaluate the thermal constant time of the model. The liquid cooling method is applied in this project for fast cooling and the thermal parameters are studied and measured since this cooling method involves both solid and liquid. In order to estimate the junction temperature, the sensing temperature from NTC (Negative temperature coefficient) resistor inside the module is used as reference temperature. The equivalent thermal models, also named Foster model, from both junction to NTC and NTC to coolant are built, respectively. With these thermal models, the junction and coolant temperature estimation methods are derived. For the purpose of making the estimation accurate, the thermal coupling effect is carefully studied. Finally, the thermal model is verified by inverter application with current steps sweeping; the estimated temperature is compared with thermal camera measurement result which demonstrates good accuracy of the thermal model. The estimated coolant temperature is also well matched with thermocouple measurement result.

1. Introduction

IGBTs are widely used in modern power electronics such as wind power generation, solar energy, rail transportation, new energy vehicles. As the main power switch in converter and inverter, IGBT suffers high current and high voltage pulses which could result in considerable power loss on IGBT. The power loss contains switching loss and conduction loss; the switching loss is determined by the terminal voltage, current and switching frequency while the conduction loss is determined by V_{ce} (the conduction voltage between collector and emitter) and the conduction current I_c. The heat generated by power loss causes high IGBT junction temperature referred to as T_j. For automotive applications T_j must be restricted to 150 °C at maximum. Many papers focused on IGBT thermal topic. The junction temperature measurement was discussed with power MOSFET by David L. and David W. [1]. This paper thoroughly studied the TSEP (temperature sensitive electrical parameter) of MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) such as $V_{gs(th)}$, R_{dson} and V_{fd}; and it could serve as a good reference for IGBT junction temperature estimation. However, the transient thermal impedance was not mentioned in that paper. The transient thermal impedance property was further studied by Jakopovic et al. [2–5]; both MOSFET and IGBT were investigated, and the accuracy of the modified ladder RC model network was verified by both experiment and simulation. The thermal characterization of modern IGBT power modules was covered by P. Cova; and the thermal test method and system are suggested in his paper [6]. Recently, new IGBT module TSEP such as dI_{ce}/dt [7] and short current were studied [8, 9]. These new TSEPs bring in new thoughts on IGBT temperature measurement; however, these new TSEPs are difficult to be measured in real time application. Considering the realization and accuracy, the classical TSEP V_{ce} is chosen in this paper for IGBT module thermal characteristic study.

Fig. 1(a) shows an uncovered view of the three phase full bridge IGBT module that is the study object of this paper. Usually there are several IGBT chips in parallel to increase the current capacity. Figs. 1(a) and 2(a) show one IGBT switch is formed by three IGBT chips; Green block in Fig. 2(a) represents IGBT cell. And blue blocks in Fig. 2(a) are anti-parallel diode chips which are for current freewheeling; so it is also called freewheeling diode, shorted as FWD.

The internal chips layout of the module is depicted in Fig. 2(a); three independent half bridges are mounted inside the IGBT module shown in Fig. 2(b). The IGBT module with FWD chip is a sandwich structure which contains silicon die, chip solder, DCB top layer, DCB AL_2O_3 layer, DCB bottom layer, system solder, base plate (thermal grease and thermal sink are for module cooling), shown in Fig. 3(a); the

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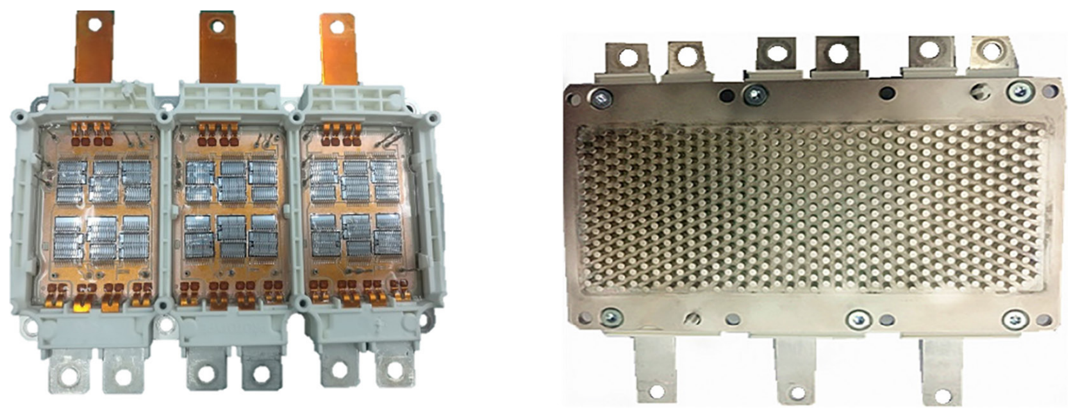
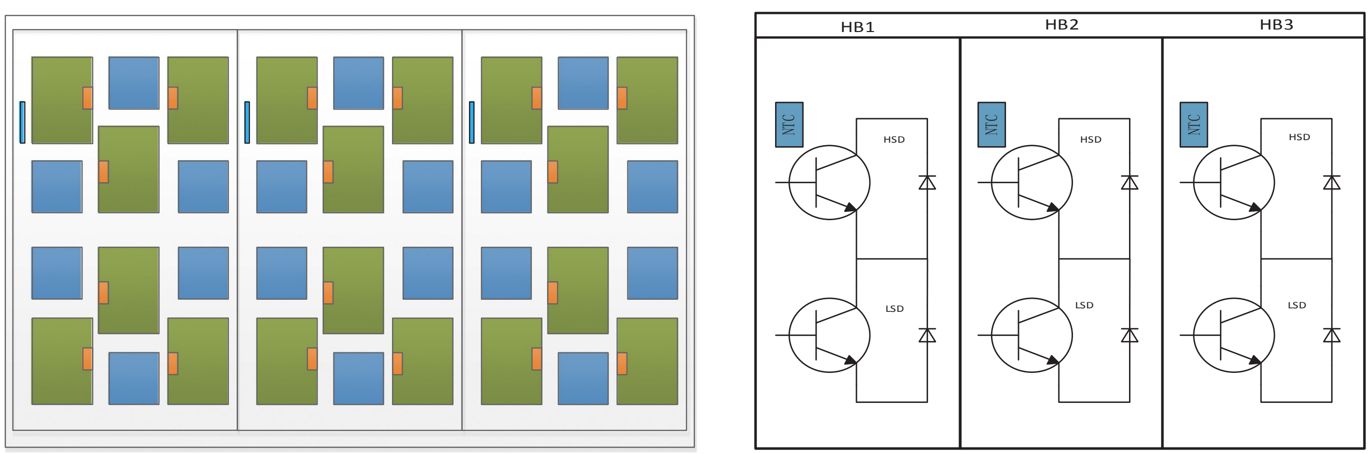


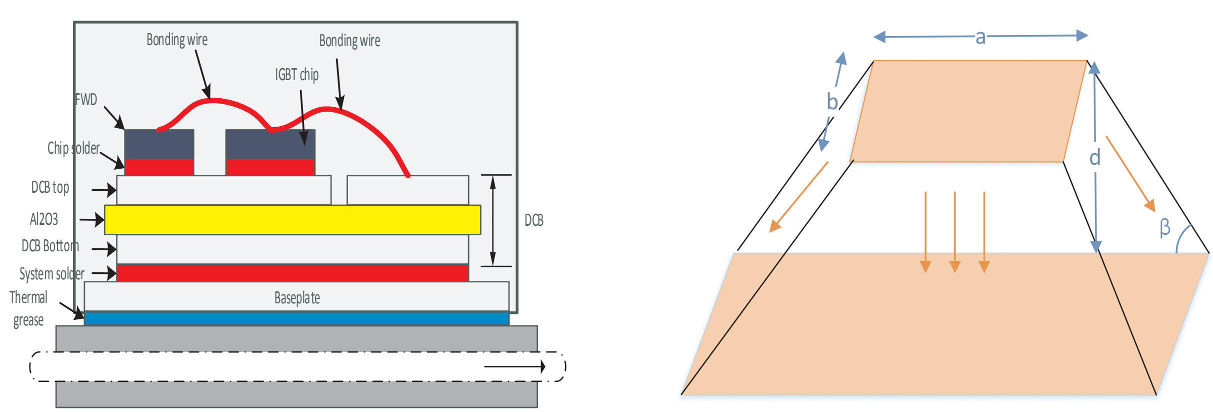
(a) 3ph full bridge module uncovered top view (b) IGBT module bottom view (pin-fin structure)

Fig. 1. (a) 3ph full bridge module uncovered top view.
(b) IGBT module bottom view (pin-fin structure).



(a) IGBT module internal layout (b) IGBT module electric diagram

Fig. 2. (a) IGBT module internal layout.
(b) IGBT module electric diagram. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



(a) IGBT module cross section view (b) Heat spreading effect

Fig. 3. (a) IGBT module cross section view.
(b) Heat spreading effect.