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Temperature monitoring inside IGBT modules at forward bias from the cross section and its finite element analysis

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ABSTRACT

Temperature distribution inside IGBT modules is considered as the key factor for their reliability and applications. In the present work, the IGBT module with cross section was prepared by metallographic technologies. Microstructure of the IGBT module was characterized from the cross section by scanning electron microscope (SEM). Electrical characteristics of the IGBT modules after cross section operation were tested at conduction and switching status. It indicates that the IGBTs remained well electrical functions. Temperature distribution inside the IGBT was measured by high resolution IR camera from the cross section at forward biased status, based on which the transient and steady thermal impedance were calculated. Finally, a 2D finite element model concerning on the heat conduction process inside IGBT was realized, which exhibited that the simulated results were quite consistent with the experiment. Although the mechanical cross-section method is impossible to employ in practical applications of IGBT, this work may provide a new insight on the study of the package fatigue and thermal behavior inside IGBTs at forward bias.

1. Introduction

Semiconductor power devices (IGBT, MOSFET, IGCT etc.) are the core components for power electronic systems, laying foundation for power and energy efficiency conversion technologies, and widely used in new energy, transportation and defense industry [1]. Because of high switch speed, high input impedance and low control dissipation, IGBTs become the most popular semiconductor power devices for motor control, inverter and intelligent electrical grid [2–5]. However, any sudden failures in the low tolerance systems, such as aircraft, high speed train and hybrid car, would be fatal [6–8].

Heat dissipation inside IGBT modules is considered as one of the most important factors for reliability and application of IGBT [9–12]. Due to great expansion mismatch between inner layers of IGBTs, some interfaces of the layers suffer from great cyclical thermal stress in the working conditions. It would result in mechanical fatigue failure of IGBT. Amounts of studies showed that the fatigue failure of IGBTs was mainly resulted from lifting-off of Al wires and die-attach solder cracking. It was directly related to the temperature distribution inside IGBT modules [13–18]. Although some analytical fatigue lifetime models for IGBT had been build using real-time monitoring of some electrical characteristics [12,15,17,19,20], the temperature distribution inside IGBT modules was rarely directly measured by experimental methods.

K.B. Pedersen [4] et al. used a micro-sectioning approach based on mechanical and chemical polishing to characterize quality and reliability assessment of wire bonding interfaces in IGBT modules. It gave a possibility to obtain resolution on the micro scale and to investigate metal grain structure and interface. However, because the IGBT module after cross section operation lost its basic electrical functions, few studies had been carried out concerning on evolution of electrical/thermal characteristics and microstructure inside IGBTs at the forward bias state. T. Kociniewski [21–23] et al. presented for the first time an original way to characterize vertical thermal distributions of IGBT-chips under forward bias by using a cross sectioned IGBT module embedding in epoxy resin. However, thermal behavior and temperature distribution inside the whole IGBT modules at the switching-on or steady conduction state had not been discussed.

In this paper, the cross sectioned IGBTs were prepared by the metallographic technologies. Microstructure inside the IGBT module was characterized by electron scanning microscope (SEM) to obtain its internal geometric parameters. Then the switching and conduction electrical characteristics of the IGBTs after cross section operation were tested. After that, the temperature distribution and transient thermal behavior inside IGBT modules at forward bias was studied by a high resolution IR camera, based on which the transient and steady thermal impedance were calculated. Finally, a two-dimension finite element model for heat conduction was realized to simulate the temperature

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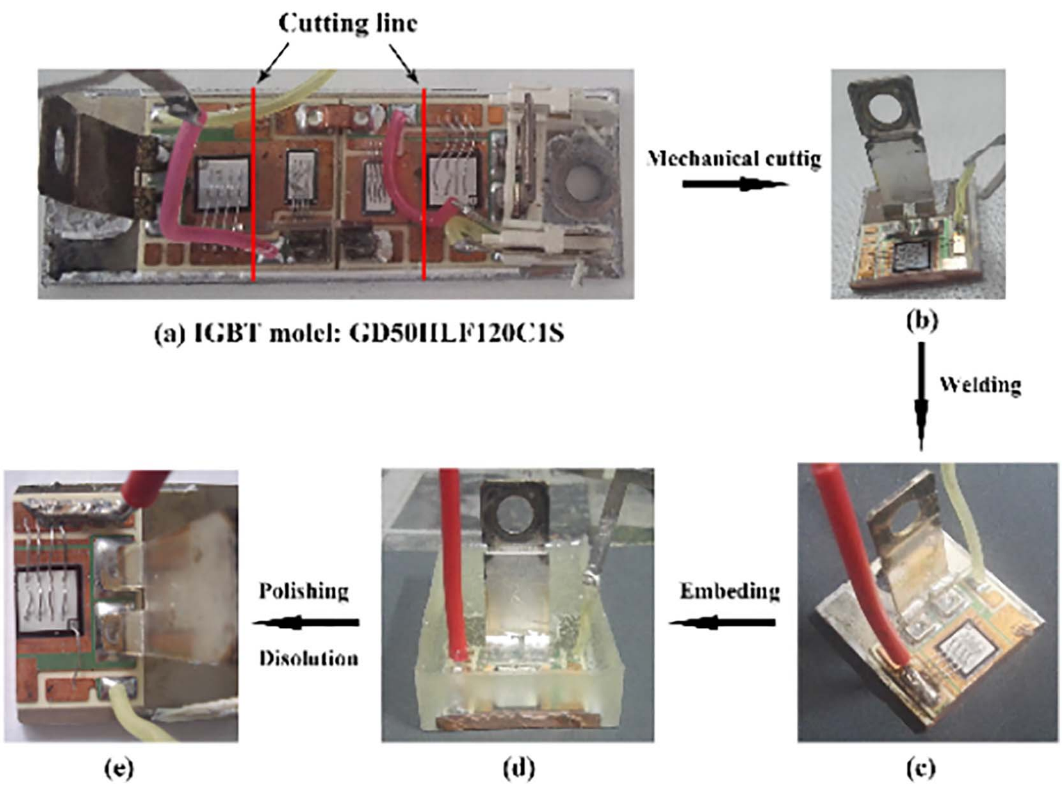

Fig. 1. Preparation of the cross section IGBTs.

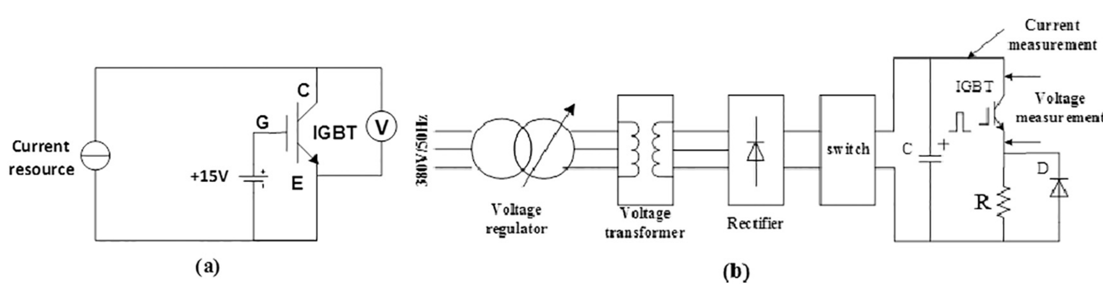

Fig. 2. Measurement circuits for steady and transient electrical test: (a) steady conduction circuit, (b) transient switching circuit.

distribution inside IGBTs. Although the mechanical cross section method is impossible to employ in practical applications of IGBT, this work may provide a new insight into the study on the package fatigue and thermal behavior inside IGBTs.

2. Experimental

2.1. Samples preparation

In Fig. 1a, the plastic package and silicone gel of IGBTs (1200 V/50A, STARPOWER Semiconductor Ltd. Co.) was removed by mechanical cutting and chemical dissolution approach. IGBT modules were mechanically cut along the edge of Si-chip (Fig. 1b: cutting line) with a feed rate of about 2 mm/min. After the mechanical cutting operation, a copper wires (Φ2.5 mm) was welded on the DBC copper layer as the emitter terminal (Fig. 1c). The as-received IGBT modules were hypersonically cleaned in deionized water and alcohol successively, dried at 80 °C in a vacuum oven for 5 h. Then the mechanical cutting IGBTs were embedded in resin for convenience of mechanical polishing (Fig. 1d). The specimen was grinded by SiC abrasive papers from 400 to 4000 mesh and polished using man-made diamond grinding paste (W0.1) until meeting the requirements for microstructure analysis. After that, the resin outside of IGBT models was dissolved in organic solvents assisted by hypersonic cleaner (Fig. 1e). Finally, these IGBT modules were hypersonically cleaned in deionized water and alcohol, dried at 80 °C in a vacuum oven for 5 h.

2.2. Characterization

2.2.1. Microstructure analysis

Microstructure of IGBT modules was characterized on the cross section by scanning electron microscope (SEM). Thickness of internal layers was accurately measured by SEM image tools to obtain accurate geometric parameters of each layer. Width of each layer was measured by a Vernier caliper.

2.2.2. Electrical tests

Both the conduction and switching characteristic of the cross sectioned IGBT modules were tested using the measurement circuits (Fig. 2). During tests, the IGBT modules were assembled on the Cu heat sink. In order to provide good thermal contact between the Cu baseplate and heat sink, a thin layer of thermal grease was pasted at the interface between them. Temperature of the heat sink were controlled by the flow rate of cooling water with an accuracy of ± 1 °C. Before each measurement, a dwell lasting for 10 min was carried out to reach the thermal equilibrium between the Si-chip and Cu baseplate.