Power device, EV/HEV car, Drone, Aerospace, 5G/6G communication

Development of power module thermal evaluation and structural reliability evaluation system using SiC heater chip

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Abstract

Despite the rapid progression of silicon carbide (SiC)power devices, the thermal characteristic evaluation during power cycling at high temperature (>200 °C) is an issue. In this study, a fast and miniaturized evaluation system with online thermal characteristic measurement function was introduced by an n-doped 4H SiC thermal engineering group (TEG) chip. Online thermal resistance measurement of a power module structure by Ag sinter joining with micron/submicron Ag particles paste in low temperature, low pressure, and cooling system by a thermal interface material bonding was performed. High-temperature reliability was systemically investigated by power cycling tests by switching ON/OFF the power source which is connected to the SiC-TEG chip by Au wires. The total thermal resistance of the power module from the SiC-TEG chip to the cooling system increased from 0.5 to 0.53 K/W with the enhanced power source, and remained almost same after 20 000 power cycling at a swing temperature ΔTj of 150 °C. Furthermore, the SiC-TEG power module structure with the die attached with Pb and Pb-free solders, alongwith the same power source as sinter Ag paste was also measured. The Ag sinter joint possesses the lowest thermal resistance and highest high temperature reliability during power cycling compared with Pb and Pb-free die-attach materials.

Background & Results

In power electronics, the greatest aspect of power loss during the power conversion process depends on the performance of the semiconductor devices. To improve this limitation of conventional silicon (Si)-based power devices, wide-bandgap (WBG) semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) have been introduced and have revolutionized the power electronics components. Until now, the measurement of thermal resistance characteristics and power cycling reliability for power module structures such as SiC MOSFETs require two equipment systems. One is the power cycling system and the other is the transient thermal resistance measurement mechanism (T3Ster). The T3Ster is applied to understanding package thermal metrics and structure, calibration of thermal simulation models, reliability, and quality assessment, which can detect failure phenomenon nondestructively. For example, failures have been reported in structures around semiconductor chips, joint structures of chip-substrate-metal base plate and in joint structures. However, both systems are expensive and need large space, due to which it has been difficult to apply in a wide range of applications in the power electronics domain. Most importantly, to measure the thermal resistance by T3Ster, the power cycling test must be stopped, which means that online thermal characteristic measurement of the power module structure during power cycling is impossible. Usually it is needed to stop the power cycling test many times to obtain the change of the thermal resistance and failure conditions, which influences the measurement accuracy itself. Hence, a fast and miniaturized evaluation system with online thermal resistance record functioning is needed.

In this study, we present a significant advance in the measurement of thermal resistance through the junction temperature during the operation of an assembled SiC power module structure, where the thermal resistance can be measured online by using a thermal test engineering group (TEG) chip at the first instance. The junction temperature and temperature distribution of the SiC-TEG chip with input power was analyzed by experiment and simulation. The results show that SiC-TEG can accurately evaluate the thermal characteristics with different die attach materials. Additionally, the sinter Ag joint possesses the lowest thermal resistance and highest high-temperature reliability during power cycling compared with Pb and Pb-free die attach materials.

Significance of the research and Future perspective

This study proves the possibility of a precise measurement method of the junction temperature and thermal resistance at high power density, which is no longer limited by the actual SiC direct bonded power module structure. This technology can be extended to perform reliability test standardization for all WBG semiconductors by providing a method that can record the information of the thermal and electrical properties online, but with a fast and miniaturized evaluation system. The SiC-TEG technology can benefit the controlled and site-specific power conversion industries and may lead to new avenues for power electronics design with the capability to perform well at increased junction temperature.

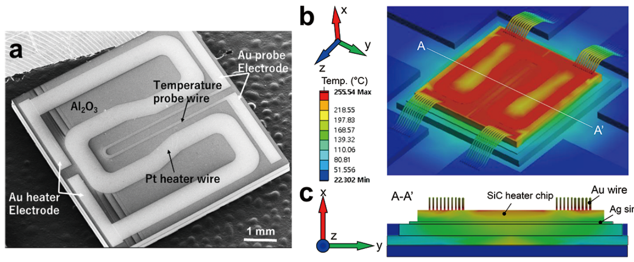

Figure 1 (a) the SEM image of SiC heater chip, (b) Temperature distribution of SiC heater chip attached on DBC substrate by Ag sinter paste joining in the case of the power source being ON by finite element simulation. (c) Temperature distribution in the vertical direction.

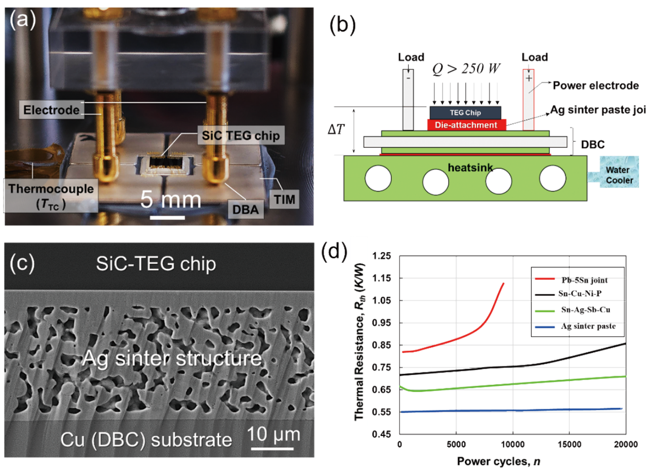

Figure 2 (a) Measurement system of thermal property characterization and Power source electrode applied on the DBC substrate. (b) Schematic diagram of the thermal characterization evaluation system of the SiC heater chip die-attached structure, (c) SEM image of the cross section of SiC heater chip connected to the DBC by Ag sinter paste joining. (d) Change of thermal resistance of the die-attached structures by various solders and Ag sinter paste joining during power cycling.

Patent

Treatise: Kim, Dongjin; Nagao, Shijo; Chen, Chuantong et al. Online thermal resistance and reliability characteristic monitoring of power modules with Ag sinter joining and Pb, Pb-free solders during power cycling test by SiC TEG chip. IEEE Transactions on Power Electronics. 2021, 36(5) pp. 4977-4990, doi: 10.1109/TPEL.2020.3031670

URL

Keyword: power electronics, SiC heater chip, thermal resistance measurement, Ag sinter joining