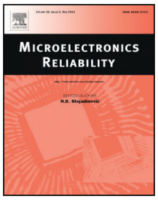
Microelectronics Reliability xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/mr



Novel heatsink for power semiconductor module using high thermal conductivity graphite

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ARTICLE INFO

Article history:
Received 23 June 2016
Accepted 6 July 2016
Available online xxxx

Keywords:
Power module
Heatsink
Graphite
Reliability
Laminate

ABSTRACT

The thermal properties and reliability of novel heatsinks that use high thermal conductivity graphite were investigated. Graphite plates with different high-thermal-conductivity directions were laminated together using an Ag-based brazing material, with thin Cu plates on their outer surfaces. The heatsinks were bonded to Si heater chips using Sn-3Ag-0.5Cu solder. Samples with conventional Cu or Cu-65Mo heatsinks were also fabricated as references. The samples were attached to an active cooling plate subjected to a constant water flow, and thermal and reliability measurements were conducted. The experimental results were also compared with the results of a finite element analysis. The novel laminated heatsinks exhibited a lower thermal resistance than the Cu or Cu-65Mo heatsinks, and the experimental results were in reasonable agreement with those of the finite element analysis. The graphite-based heatsinks had better power cycle reliability than Cu-based heatsinks. Therefore, these novel graphite heatsinks have potential for application to power semiconductor modules, it seems to be useful for applications with high heat flux of power semiconductor devices.

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1. Introduction

Next-generation power semiconductor devices such as wide bandgap SiC or GaN devices are being actively developed to achieve more efficient and smaller electrical invertors. Important advantages of such devices are their reduced size and their ability to operate at temperatures in excess of 200 °C; however, such features can lead to high heat flux or significant thermal stress [1–6].

Heatsinks for power semiconductor modules generally comprise materials such as Cu, Al, AlSiC, and CuMo. Cu and Al have excellent thermal conductivity but a large coefficient of thermal expansion (CTE) mismatch with semiconductor materials. AlSiC and CuMo have lower thermal conductivity but a small CTE mismatch with semiconductor materials. There is thus a general trade-off between the thermal conductivity and CTE for these heatsink materials for power semiconductor packaging.

Graphite has excellent thermal conductivity in excess of 1000 W/mK [7–10]; however, the thermal conductivity is anisotropic, being high in two directions and significantly lower in the third, as shown in Fig. 1. The CTE is also low for the first two directions and high for the third, as shown in Fig. 2.

Graphite has disadvantages in terms of higher cost, due to the prolonged high-temperature deposition process required for its fabrication, and it exhibits brittleness under mechanical impact.

In this present paper, laminated heatsinks using graphite plates with different in-plane directions were fabricated, and their thermal properties and power cycle reliability were investigated.

2. Experimental

2.1. Sample structure

Graphite plates were fabricated from hydrocarbon gas using thermal decomposition at temperatures greater than 2000 °C. For one of the plates (HT-x, Fig. 3(a)), the thermal conductivity was high and the CTE was low in the Y and Z directions, with the opposite being the case in the X direction. Another plate (HT-y, Fig. 3(b)), which was rotated by 90° with respect to HT-x, had a high thermal conductivity and a low CTE in the X and Z directions. A simple laminated heatsink with a single HT-x and HT-y plate would not exhibit symmetric thermal expansion and may deform with changing temperature. In contrast, a heatsink with a symmetrical laminated structure (HT3) comprising three layers of graphite, as shown in Fig. 4, would be expected to be stable with respect to temperature change. Therefore, this structure was used in the present study.

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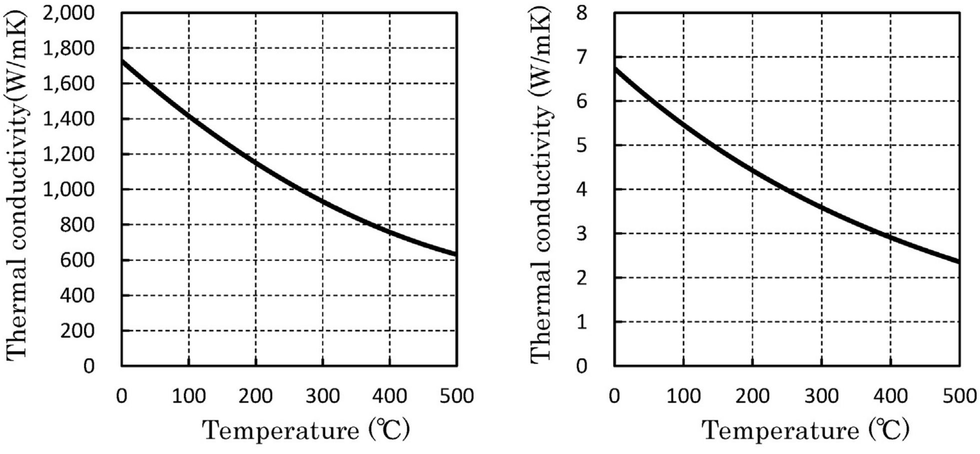
http://dx.doi.org/10.1016/j.microrel.2016.07.029
0026-2714/© 2016 Published by Elsevier Ltd.

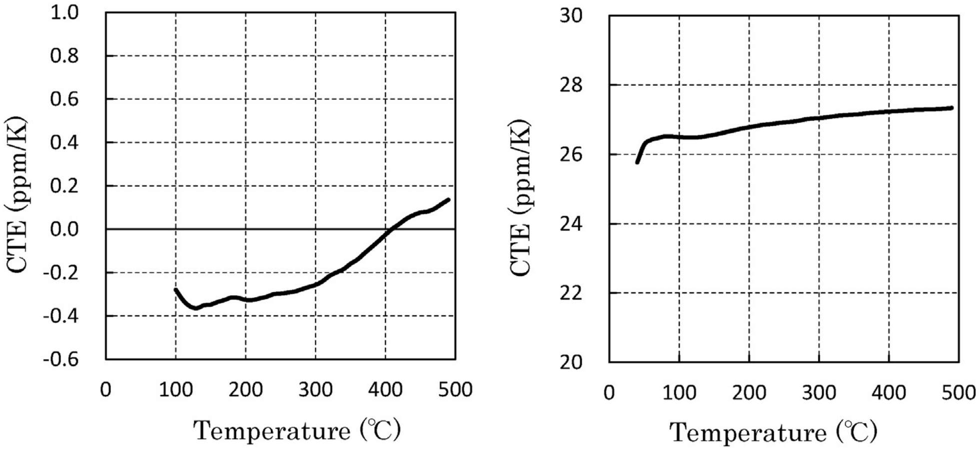
Please cite this article as: Y. Yamada, et al., Novel heatsink for power semiconductor module using high thermal conductivity graphite, Microelectronics Reliability (2016), http://dx.doi.org/10.1016/j.microrel.2016.07.029



(a) Y and Z axis

(b) X axis

Fig. 1. Thermal conductivity of graphite (HT-x).



(a) Y and Z axis

(b) X axis

Fig. 2. Coefficient of thermal expansion (CTE) of graphite (HT-x).

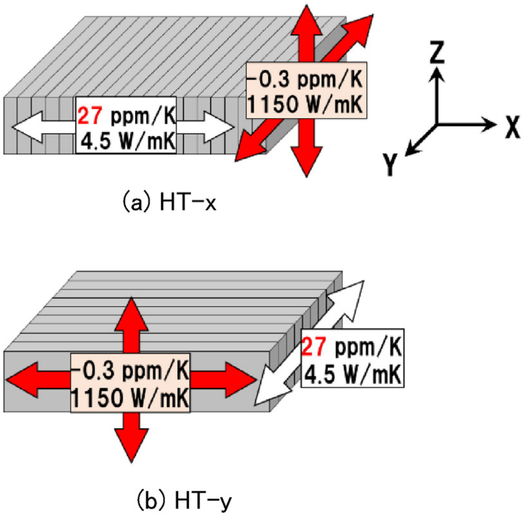
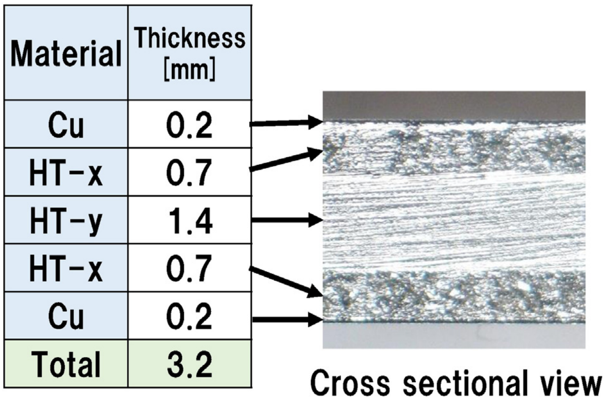


Fig. 3. CTE and thermal conductivity of graphite HT-x and HT-y (the values are at 200 °C).



Material	Thickness [mm]
Cu	0.2
HT-x	0.7
HT-y	1.4
HT-x	0.7
Cu	0.2
Total	3.2

Fig. 4. Laminated structure of fabricated heatsink.

Please cite this article as: Y. Yamada, et al., Novel heatsink for power semiconductor module using high thermal conductivity graphite, Microelectronics Reliability (2016), http://dx.doi.org/10.1016/j.microrel.2016.07.029

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