ARTICLE IN PRESS
MR-12243; No of Pages 9
Microelectronics Reliability xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Microelectronics Reliability
journal homepage: www.elsevier.com/locate/microrel

Failure and stress analysis of through-aluminum-nitride-via substrates during thermal reliability tests for high power LED applications

M.Y. Tsai [a,*], C.H. Lin [a], K.F. Chuang [a], Y.H. Chang [a], C.T. Wu [b], S.C. Hu [b]

[a] *Department of Mechanical Engineering, Chang Gung University, Taiwan*
[b] *Chemical Systems Research Division, Chung-Shan Inst. of Science and Technology, Taiwan*

ARTICLE INFO

Article history:
Received 18 August 2016
Received in revised form 24 October 2016
Accepted 10 November 2016
Available online xxxx

Keywords:
Through-aluminum-nitride-via
Aluminum nitride
Thermal reliability
Strength
Shadow moiré
Failure mode
Stress analysis

ABSTRACT

The objective of this study is to evaluate the reliability of through-aluminum-nitride-via (TAV) substrate by comparing those experimental results with the finite element simulation associated with measurements of aluminum nitride (AlN) strength and the thermal deformation of Cu/AlN bi-material plate. Two reliability tests for high-power LED (Light emitting diode) applications are used in this study: one is a thermal shock test from −40 °C to 125 °C, the other is a pressure cook test. Also, the strength of AlN material is measured by using three-point bending test and point load test. The reliability results show that TAV substrates with thicker Cu films have delamination and cracks after the thermal shock test, but there are no failure being found after the pressure cook test. The determined strengths of AlN material are 350 MPa and 650 MPa from three-point bending test and point load test, respectively. The measurement of thermal deformation shows that the bi-material plate has residual-stress change after the solder reflow process, also indicating that a linear finite element model with the stress-free temperature at 80 °C can reasonably represent the stress state of the thermal shock test from −40 °C to 125 °C without considering Cu nonlinear effect. The further results of the finite element simulation associated with strength data of AlN material have successfully described those of the reliability test.

1. Introduction

With relatively high thermal conductivity, low coefficients of thermal expansion (CTE), excellent heat-resistance and chemical-resistance, direct-plated-copper (DPC) and direct-bonded-copper (DBC) ceramics have been used for the high-power module applications such as LED lighting and IGBT packaging [1–7] to replace conventional plastics-based printed circuit board. The DPC aluminum nitride (AlN) substrate with a high thermal conductivity (k = 170 W/mK) provide a good alternative to conventional aluminum oxide (Al_2O_3) substrate (with k = 24 W/mK) for better heat dissipation. However, besides its higher cost, AlN substrate ($\alpha = 4.3$ ppm/°C) still suffers the higher CTE mismatch with copper material ($\alpha = 16.3$ ppm/°C), compared with Al_2O_3 substrate ($\alpha = 6.9$ ppm/°C). The high stresses in DPC AlN substrate induced by such CTE mismatch would lead to the delamination failure between Cu film and AlN substrate or crack at AlN substrate during thermal shock and thus result in a reliability problem of the modules [4,6]. In the literature, the adhesion strength between resistor thick films and AlN substrate has been investigated [8]. The morphology and composition of the metalized copper film on AlN substrate have been studied [9]. The effect of edge-tail length of Cu films on thermal reliability of DBC AlN substrates has been proposed [10]. Recently, geometric parameters and Cu nonlinear behavior in DPC AlN substrate have been analyzed for enhancing its thermal reliability [11]. For the high-power LED applications, through-aluminum-nitride-via (TAV) substrates with a high thermal conductivity can provide better heat dissipation than Al_2O_3 substrates. However, the high mismatch of CTE between the AlN and copper film may cause the failure, and thus affect the reliability of TAV substrate. Therefore, this study focuses on experimental and numerical evaluations of the reliability of TAV substrates used in high-power LED application.

2. Methodologies

2.1. Specimens and reliability tests

The test specimens of TAV substrate are shown in Fig. 1 with a detailed configurations and dimensions. There are four types of TAV substrates with different thicknesses of Cu films and symmetric and non-symmetric pads, shown in Fig. 2. Two reliability tests: thermal shock (TS) test and pressure cook test (PCT), which are typically applied to LED packages and modules, are used in this study. The TS test is in accordance with MIL-STD-202G Method 107G, which states test conditions at temperature ranging from −40 °C to 125 °C with dwell time of 15 min and transfer time of less than 20 s. For the other one, PCT is based on

* Corresponding author.
E-mail address: mytsai@mail.cgu.edu.tw (M.Y. Tsai).

http://dx.doi.org/10.1016/j.microrel.2016.11.005

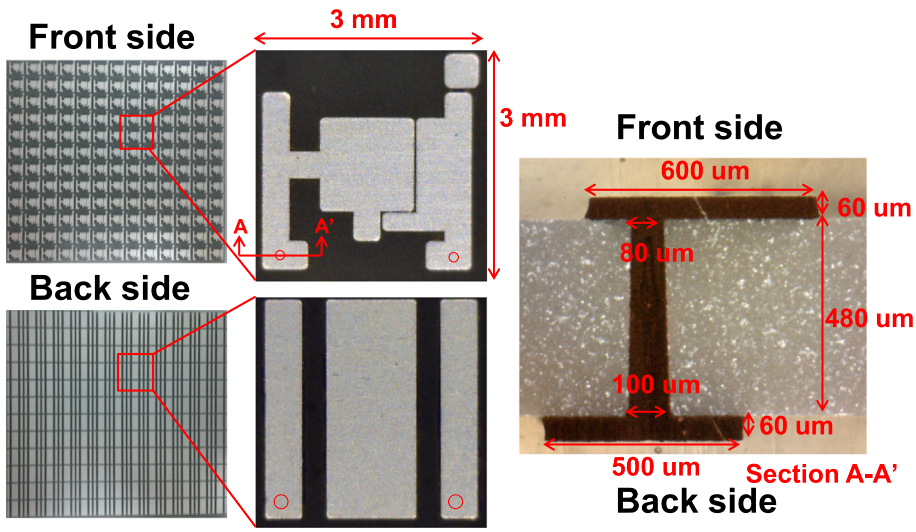

Fig. 1. Configurations and dimensions of TAV substrate with Cu via and films.

Standard JEDEC-22-A102, which specifies test time of 96 h in the test environment with a temperature at 121 °C and relatively humidity of 100%, and at pressure of 2 atm.

2.2. Bending strength tests

There are two bending tests being used in AlN strength evaluation: One is a conventional three-point bending test, and the other is a newly-developed point-load bending, so-called point-load on elastic foundation (PoEF). The PoEF [12–14] having been developed over last ten years features locally spherical (or bi-axial) bending and thus avoids the specimen edge chipping effect, in contrast to the three-point (or uni-axial) bending. Test specimens of AlN material with a size of 25 × 10 × 0.36 mm are used in conventional three-point bending with an inner spacing of 20 mm, while the size of those in the PoEF test is 10 × 10 × 0.36 mm loaded by a pin with a 2 mm-in-radius ball tip. Ten specimens in each group are tested.

2.3. Thermal deformation measurements

The specimens of Cu/AlN bi-material plates were fabricated by electrically plating Cu on the AlN substrate after sputtering a 0.1 μm-thick adhesion film of Ti material on the substrate using commercial equipments. Then, a full-field shadow moiré method [15,16] was used for measuring the out-of-plane displacements of the deformed specimens under thermal loads. The fringes of the pattern represent the out-of-plane displacement (w) contours of the specimen surface. The curvature (K) of the specimen deformation is calculated, on the basis of the assumption of small deformation, by using.

$$K = \frac{1}{\rho} = \frac{2w}{x^2}, \tag{1}$$

where ρ is a radius of the curvature, and x is a pre-defined distance. The thermally-induced out-of-plane displacements of the Cu/AlN bi-material plate were measured by the shadow moiré system with the

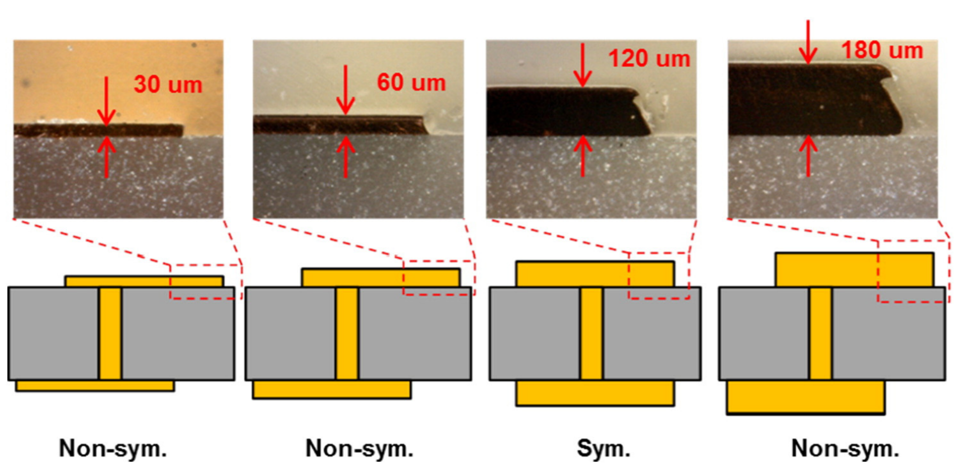

Fig. 2. TAV substrates with four different thicknesses of Cu films.

Please cite this article as: M.Y. Tsai, et al., Failure and stress analysis of through-aluminum-nitride-via substrates during thermal reliability tests for high power LED applica..., Microelectronics Reliability (2016), http://dx.doi.org/10.1016/j.microrel.2016.11.005