Thermochimica Acta 589 (2014) 278–283

Contents lists available at ScienceDirect

Thermochimica Acta

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

Heat dissipation performance of metal-core printed circuit board prepared by anodic oxidation and electroless deposition

Junghoon Lee [a], Junho Kim [b], Donghyun Kim [a], Wonsub Chung [a,*]

[a] Department of Materials Science and Engineering, Pusan National University, 30 Jangjeun-dong, Geumjeung-gu, Busan 609-735, Republic of Korea
[b] Korea Institute of Industrial Technology, Busan 618-230, Republic of Korea

ARTICLE INFO

Article history:
Received 3 March 2014
Received in revised form 8 May 2014
Accepted 2 June 2014
Available online 4 June 2014

Keywords:
Aluminum alloys
Anodic oxidation
Electrochemical processes
Metal–insulator structure
Metal-core PCB
Thermal resistance

ABSTRACT

An aluminum anodic oxide layer was applied as the insulation layer of metal-core printed circuit board (MCPCB). Copper electroless- and electro-deposition were conducted on the insulation layer to form a copper circuit layer. In the present work, thin epoxy layer was coated on the aluminum anodic oxide to secure the electrical insulation between aluminum alloy substrate and copper layer. The MCPCB with the aluminum anodic oxide layer showed a good break down voltage and dielectric strength. The thermal resistance with respect to the thickness of oxide layer was measured using a thermal transient method. The thermal resistance of the MCPCB was increased by increasing the thickness of aluminum anodic oxide layer, and a lower thickness of aluminum anodic oxide was effective to reduce the LED junction temperature.

1. Introduction

Heat dissipation has been a challenging issue in improving the reliability and life-time of electric devices. In particular, as high-power light emitting diodes (LEDs) generate substantial heat, heat dissipation must be considered when designing a LED module to secure the optical performance, photoelectric efficiency and reliability [1–3]. Unlike in other electrical components, such as central procession unit and memory, a heat sink cannot be arranged on top face of the LED packages, because of the light emitting direction. Therefore, to reduce the rising temperature of the LED chip, the heat must be transmitted to the other side of the PCB, and thus to reduce the thermal resistance of LED module various studies have been conducted [4–8]. Among the studies to improve the heat dissipation, the metal-core printed circuit boards (MCPCBs), of which the substrate is made of metallic materials, is considered one of the most effective methods for reducing the junction temperature of LEDs [9,10]. Aluminum alloys are the most ideal substrate material because they have not only a high thermal conductivity but also a low density.

If aluminum alloys are applied as the substrate material, most of the thermal resistance is taken by the insulation layer between the aluminum alloy substrate and copper circuit, because of the high thermal conductivity of the copper circuit and aluminum alloy substrate. Basically, a high breakdown voltage is required for the insulation layer. Accordingly, enhancing the thermal conductivity of the insulation layer, while maintaining the breakdown voltage, is a desirable research objective. In an attempt to reduce the thermal resistance of the insulation layer, an Al_2O_3 and AlN aerosol deposition technique was adopted, and improved heat dissipation was reported [11,12]. However, the aerosol deposition is not suitable for the mass production and large size aluminum alloy substrate.

If the aluminum alloys are used as a substrate of MCPCBs, the aluminum anodic oxide (AAO) layer, which is formed by electrochemical methods, can be applied to build up the insulation layer. Unlike the aerosol deposition, the anodic oxidation is advantageous for the mass production, manufacture cost and large size substrate. In addition, AAO is known to have a high insulating ability and have been reported to be suitable for the fabrication of hybrid integrated circuits [13–15]. For these reasons, some application methods of AAO for electric devices have been proposed [16,17].

In the present work, anodic oxidation known to a peculiar surface treatment of aluminum alloys was applied to form an insulation layer of a MCPCB. Electroless- and electro-deposition were used to form a copper circuit layer on the insulation layer. The heat dissipation performance of MCPCB with AAO layer was evaluated after mounting the LED package on the copper circuit layer. In addition, breakdown voltages of MCPCB with respect to the thickness of the AAO layer were measured.

* Corresponding author. Tel.: +82 51 510 2386/1446; fax: +82 51 510 4457.
E-mail address: wschung1@pusan.ac.kr (W. Chung).

http://dx.doi.org/10.1016/j.tca.2014.06.001

2. Experimental

Al 1050 alloy (Al – 0.24Fe – 0.15Si, in wt.%) plate was used as the substrate for metal-core PCB. The specimen was cut into 30 mm × 30 mm × 2 mm sized pieces. Before anodic oxidation, the specimens were polished mechanically with 1500 grit SiC paper. Subsequently, etching in NaOH solution and activation in nitric acid were conducted. Before anodic oxidation, electro-polishing was conducted in perchloric acid/ethanol (1:4 vol.) electrolyte under a constant voltage of 20 V at 15 °C for 2 min.

Anodic oxidation was carried out in a 0.3 M oxalic acid electrolyte under a constant current density of 50 mA/cm^2, and the electrolyte temperature was maintained at 10 °C. The electrolyte and temperature condition were adopted from our previous research on the thermal conductivity of the AAO layer [18]. The thickness of the anodic oxide was controlled by the anodizing time. After anodic oxidation, the porous AAO was sealed in distilled water at 95 °C for 30 min.

AAO was etched in a 1.5 M NaOH solution for 30 s at room temperature to improve the adhesion of the epoxy layer. A thin polymer layer was build up on the AAO layer using a spray gun with a phenol-novolac type epoxy resin. This coated layer was cured in an oven at 130 °C for 6 h. To improve the adhesion of the copper layer, a swelling treatment was conducted in a 25% 2-(2-butoxyetoxy)ethanol aqueous solution for 1 min at 80 °C, followed by an oxidizing treatment by immersing the specimen in a 0.35 M $KMnO_4$ + 1.2 M NaOH solution for 1 min at 80 °C.

Separated $SnCl_2$ and $PdCl_2$ electrolytes as catalyzing procedures were used. Surface sensitization was achieved by immersing the oxidized specimen in a 0.08 M $SnCl_2$ + 0.29 M HCl solution at 25 °C for 10 min. Catalyzation was then conducted in a 1.4 mM $PdCl_2$ + 29 mM HCl solution at 25 °C for 10 min. A thin copper layer was deposited in an electrolyte containing $CuSO_4$ 0.07 M, $C_4O_6H_4KNa$ 0.2 M, NaOH 0.3 M and HCHO 0.2 M at 25 °C for 10 min. A thick copper layer was then grown by electro-deposition in a pyrophosphate copper electrolyte.

Surface morphologies and cross section of the prepared MCPCB were observed using field emission electron scanning microscopy (FE-SEM). The thermal resistance and breakdown voltage of MCPCB were measured using a thermal transient tester (T3Ster) and a withstanding voltage tester (TOS5101), respectively. The breakdown voltages were determined by sweeping the applied voltage to copper circuit layer and aluminum alloy substrate until the current reaches 0.1 mA. In order to improve the accuracy of obtained breakdown voltage, five samples with a same AAO thickness were measured and averaged. To measure the thermal resistance using T3Ster, a LED chip (CREE XP-G LED Cool White R4) was mounted on the prepared MCPCB using a silver paste solder. Three samples with a same AAO thickness were prepared for the measurements using T3ster, and the measurement was repeated three times for each sample.

3. Results and discussion

3.1. Fabrication of MCPCB on aluminum alloy

Surfaces and pore morphology of AAO were observed after sealing and etching, and images are shown in Fig. 1. AAO is composed of a hexagonal columnar cell with a high aspect ratio cylindrical pore at the center. Therefore, exposed circular pores could be observed on the AAO surface (Fig. 1(a)). The thermal conductivity of AAO grown under the abovementioned conditions was reported to be 1.62 W m^{-1} K^{-1} [18]. A dense oxide layer without pores is desirable for the thermal conductivity of AAO, but cylindrical pores are inevitable during the growth. Therefore, to improve the thermal conductivity of the AAO, hydrothermal sealing was used to plug the nano-sized pores. To achieve a completely sealed AAO, the residual water in pores, which was reported to be helpful to seal the inner pores, was allowed to remain before sealing [19]. The morphology of inner pores is shown in Fig. 1(b) and all of the pores were filled with boehmite (AlO·OH), which is known as a sealant of hydrothermal sealing [20,21].

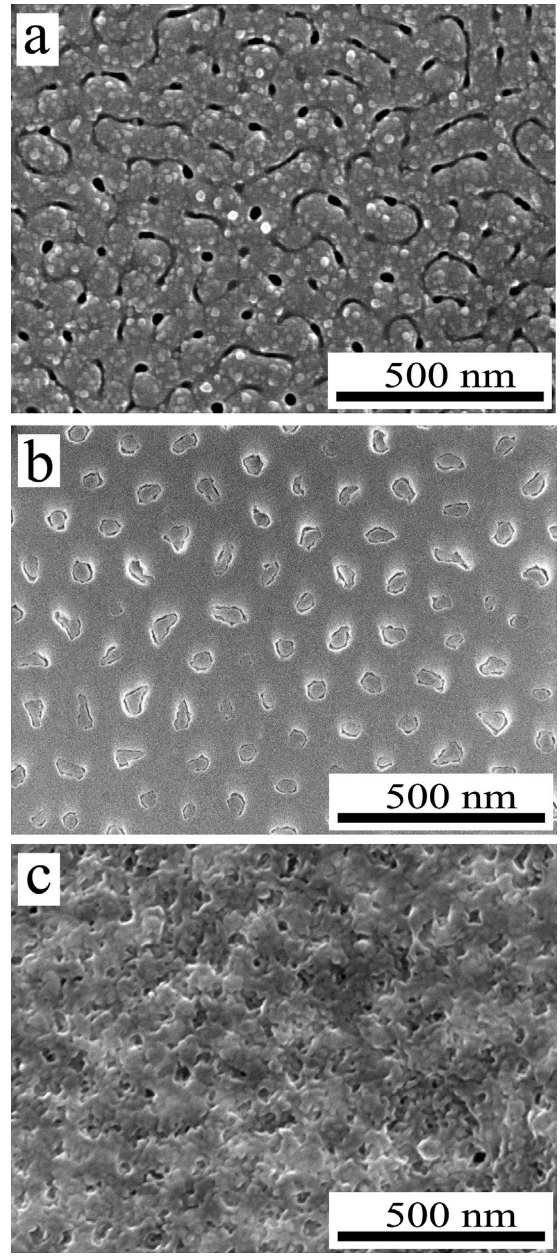

Fig. 1. Pore morphologies of aluminum anodic oxide; (a) as anodized, (b) after hydrothermal sealing, and (c) after etching in a 1.5 M NaOH solution.

It was reported that stress between the AAO and aluminum alloy substrate were generated during the hydrothermal sealing and sometimes that results in surface cracks [22,23]. In addition, precipitates, intermetallic compound, and inclusions, involved in the aluminum alloy substrate are known to cause some irregular surface of the AAO [24–26]. During the electroless copper deposition processes, Sn^{2+}, Pd^{2+} and Cu^{2+} ions can be absorbed in cracks and irregular surface, and then they migrated toward the aluminum alloy substrate. Absorbed elements have higher reduction potential than aluminum, thus tin, palladium and