Fabrication of Al-based Metal PCB having Excellent Heat Dissipation Characteristics using Polyimide/AlN powder and Evaluation of Thermal Resistance of LED module

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A light-emitting diode (LED) module consists of a chip, a Package(PKG) substrate, a Printed Circuit Board(PCB), and a heat sink. The heat generated from the LED chip is dissipated via the PKG substrate, PCB, and heat sink. If the heat generated from the LED chip is not controlled, serious problems occur such as shortening of life, reduction in the optical characteristics, and reduced reliability of the surrounding parts. In this study, a metal PCB was fabricated to improve the heat dissipation characteristics of the PCB of which the heat dissipation efficiency was the lowest in the LED module. For a metal PCB with an Al substrate, whose heat conductivity was excellent, polyimide resin and AlN powder (0, 0.5, 1.0, 1.5, 2.0 wt%) with excellent heat conductivity, were mixed to form an insulating layer rather than the epoxy previously used. An LED module was fabricated and its thermal resistance characteristics were analyzed. As the AlN powder content increased, the heat resistance of the metal PCB decreased. The heat resistance of the metal PCB without AlN powder was approximately 12 °C/W, whereas that of the metal PCB containing 2.0 wt% AlN powder was 8 °C/W, which showed a lower heat resistance by approximately 30% compared to that of the metal PCB without AlN powder.

Keywords: Light Emitting Diodes, Metal Printed Circuit Board, AlN Composite
1. INTRODUCTION

Currently, technology development is being carried out to increase the output of an individual device to replace general LED lighting with power consumption in the range of tens to several hundreds of Watts. A high LED output is needed, which requires suitable packaging technology. An LED is an optical semiconductor device, and 70 % to 80 % of the input power is converted to heat energy, in contrast to other light sources such as fluorescent lamps and incandescent bulbs. Thus, in LEDs, it is extremely important to achieve effective heat dissipation. While the temperature of an LED light source is affected by the external temperature, it is affected more significantly by the internally accumulated heat. If the heat at LED light sources is not controlled, serious problems can occur such as shortened life, changes in characteristics (luminous flux, color temperature, etc.), reduced reliability of surrounding parts, and changes in power consumption because of changes in temperature, studies to control the heat at LED light sources are therefore needed\textsuperscript{1-2}.

An LED module consists of an LED chip, a PKG substrate, a PCB, a Thermal Interface Materials(TIM), and a heat sink. The PCB has the lowest heat emission among those parts that dissipate heat in the LED module. This is a printed circuit substrate that requires insulation and heat conductivity simultaneously. If the insulating layer becomes thick, the heat conductivity is degraded but the dielectric strength is increased. On the other hand, if the insulating layer becomes thin, the heat conductivity is increased so that the heat dissipation performance rapidly improves, thereby lowering the interface temperature significantly. Thus, the development of high heat dissipation materials that not only have excellent insulating characteristics but also high heat conductivity is crucial for improving the heat dissipation performance (Fig. 1-a)\textsuperscript{3-8}.
In this study, an insulating layer was formed by mixing a polyimide resin (PI), which improves the dielectric strength, an Al metal substrate of which the heat conductivity is excellent, and AlN powder, which improves the heat dissipation characteristics, in other to dissipate the heat generated in the LED chip effectively. An LED module was then fabricated in which a metal PCB was mounted using the above insulating layer (Fig. 1-b)\textsuperscript{9-15}.

The fabricated metal PCB maximized the insulation and heat dissipation effects, which can be useful not only in LED modules but also in PCBs of power devices used in high power applications to solve the existing heat dissipation problem, thereby, improving device performance and life.

2. EXPERIMENT DETAILS

In order to fabricate an LED module with excellent heat dissipation characteristic, a Metal Core Printed Circuit Board(MCPCB) was fabricated using a 10XX-based Al metal as a substrate of which the heat conductivity is excellent (Table 1). An Al metal substrate with a size of 2.5 cm × 2.5 cm × 0.2 cm was prepared, and the organics and impurities remained on the metal surface were removed by etching in NaOH (1.0 M) solution for approximately 5 min at 60 °C.

To coat polyimide resin and AlN powder on the prepared Al substrate, the two materials were mixed. Polyimide resin (PICOMAX Company, 10 wt%) of 8000 cps viscosity was prepared and AlN powder, with an average particle size of approximately 50 nm, was prepared and mixed with the polyimide resin at 0 wt%, 0.5 wt%, 1.0 wt%, 1.5 wt%, and 2.0 wt% (Fig. 2-a). In order to increase the mixing efficiency of the high viscosity polyimide resin and powder, the two materials were mixed for 60 min at 3000 rpm using a planetary mixer that used centrifugal force for stirring. (Fig. 2-b)
Spin coating was used to coat the stirred polyimide resin + AlN powder on the Al metal substrate. To enhance the adhesiveness between the polyimide resin and the Al metal substrate, hexamethyl-disilazane (HMDS), which is an adhesion promoter layer, was coated at 3000 rpm for 30 s. The mixed polyimide resin + AlN powder was spin coated at 500 rpm/10 s and then at 2000 rpm/30 s. Then, to cure the polyimide resin, it was baked at 180 °C for 30 min on a hot plate (Fig. 3). In order to reduce the roughness of the first coating surface, a second polyimide layer was coated at 500 rpm/10 s, then at 4000 rpm/30 s and then cured at 180 °C/2 h followed by 320 °C/1 h on a hot plate, thereby forming an approximately 18 µm-thick polyimide resin + AlN powder layer.

Prior to forming an electrode layer over the coated PI layer, the roughness of the PI resin layer surface was increased using O2 plasma ashing. The plasma surface treatment was performed at 500 W for 30 s to improve the adhesion to the Au electrode by making the surface hydrophilic. The electrode was formed by depositing 20 nm Ti, which acted as a seed layer, using sputter equipment. A 200 nm Au electrode was then deposited, thereby, fabricating an Al metal PCB, which had excellent heat conductivity and dielectric strength. In order to evaluate the heat conductivity of the fabricated metal PCB, analysis was conducted using LFA 457 equipment.

The LED module was built using the fabricated Al metal PCB substrate. An Al metal package substrate (Point Engineering Co. Ltd, South Korea), which had a vertical insulating layer and excellent heat dissipation characteristic, was used in the LED package substrate. Prior to the Ag plating to improve reflectivity and heat dissipation for cavity formed package substrates, the surface was etched for approximately 5 min in NaOH (1.0 M) solution to remove impurities and organics, and cleaned in deionized(DI) water followed by electroplating. To form a Ag plating
layer, a seed layer was plated for 2 min under Ni 0.3 um at a current density of 10 mA/cm2 and 3 um of Ag was plated for 10 min to form an electrode.

Before forming an LED chip over the PKG substrate where the Ag plating layer was formed, Ar plasma cleaning was conducted to increasing the surface energy and remove organic contamination on the package substrate. This was performed to change the package substrate into a hydrophilic surface using Ar plasma cleaning, thereby, improving the adhesion between the substrate and the encapsulation resin, as well as improving the wire bonding adhesion. Plasma cleaning was conducted using Ar gas at a radio frequency (RF) power of 100 W for 30 s. In addition, EZ1000 (vertical type/3 W) (Cree) was used as the LED chip and die bonding was conducted using the Ag paste T-3100 (Sumitomo). Furthermore, wire bonding was conducted to change the 25-um-diameter Au wire into the Ball Bond on Stitch (BBOS) type using “Woowon 4524” equipment. To emit white light, silicone encapsulant material OE6370HF (Dow Corning) and phosphor material YAG4-3-2 (3 wt%, Nemoto) were mixed, and the encapsulation process was conducted after the deformation process was complete. For drying, the processing conditions used were 70 °C for 30 min, 110 °C for 20 min, and 120 °C for 120 min, and the fabricated LED PKG substrate was mounted in the LED module, which was bonded with the Au electrode formed as aPCB substrate to analyze the thermal resistance using Thermal Transient Tester (T-3ster) equipment. (Fig. 4)

3. RESULTS AND DISCUSSION

3-1 Analysis of thermal conductivities of PCBs fabricated using different AlN contents.

As shown in Fig. 5, the thermal conductivity analysis clearly indicates an improvement in thermal conductivity with an increase in the AlN content. Thus, for MCPCB, the thermal
conductivity was approximately 160 W/mK when there was no AlN, and with 2.0 wt% AlN, a high thermal conductivity of 220 W/mK was observed. The thermal conductivity of the Al metal substrate was high, at approximately 230 W/mK, but because of the PI layer, that had a low thermal conductivity of 0.22 W/mK, its thermal conductivity degraded slightly. However, since the AlN powder, of which the thermal conductivity is approximately 270 W/mK, was distributed inside the PI resin, it facilitated heat transfer, the thermal conductivity of MCPCB therefore increased as the AlN powder content increased. That is, as the AlN powder content increased, the amount of material in a certain area of the PI resin increased so that the gap between the powder particles decreased, thereby, improving the thermal conductivity.

3-2 Analysis of thermal resistivity of LED module with metal PCBs containing AlN in different amounts

Heat transfer in an LED package usually relies on thermal conduction. Hence, each material constituting the package must have high thermal conductivity, and the contact surface between materials must have low thermal resistance for effective thermal emission. Thermal resistance is defined the change in temperature from the initial by the heat from the applied power, where high resistance implies that the heat generated cannot easily be emitted.

Thus, the equation for thermal resistance is as follows:

\[ R_{jx} = \frac{\text{temperature difference and thermal resistance between junction and exterior (°C/W)}}{T_j} = \text{Junction temperature at stable state (°C)} \]
Tx= Exterior temperature(℃)

PH= Consumed power(W) = Current(I) * Voltage(V)

The evaluation of thermal resistance confirmed that with increasing AlN powder content, the thermal conductivity increased, as shown in the thermal conductivity analysis. We used three different amounts of AlN powder: 0 wt%, 1 wt%, and 2 wt%. Thermal resistance was measured after preheating for approximately 10 min with an applied current of 350 mA. The measurement result of the thermal resistance of the fabricated LED module, as shown in Fig. 6, shows that the thermal resistance was 22.5 °C/W, 20 °C/W, and 17.5 °C/W, for AlN powder contents of 0 wt%, 1.0 wt%, and 2.0 wt%, respectively. The thermal resistance of only the fabricated metal PCB, as shown in the figure, implies that when the AlN powder content was 0 wt%, 1.0 wt%, and 2.0 wt%, its thermal resistance was 12 °C/W, 10 °C/W, and 8 °C/W, respectively. When the AlN powder was not present, the thermal resistance was high because of the polyimide resin with a low thermal conductivity. As the amount of AlN powder, with excellent thermal conductivity was, increased, the amount of AlN powder distributed over the same area also increased, thereby, facilitating heat transfer, resulting in a reduction in the thermal resistance.

4. CONCLUSION

In this study, MCPCB was fabricated to improve the heat dissipation characteristics of PCB, which has the largest heat transfer loss in the LED module structure. For the MCPCB, the 10xx-based Al metal substrate was used, which has excellent thermal conductivity. In addition, AlN powder was added to the polyimide resin, which improves insulation and electric strength, by
mixing and distributing the using a planetary mix equipment. The result showed that when the polyimide resin of which the insulation characteristic was excellent but had low thermal conductivity (0.22 W/mK) was mixed with increasing amounts of AlN powder, of which the thermal conductivity was high (270 W/mK), the thermal resistance of the LED module decreased because the thermal conductivity increased. In the MCPCB, when the AlN content was 0 wt%, its thermal resistance was approximately 12 °C/W, and when the AlN content was 2.0 wt%, its thermal resistance was 8 °C/W, resulting in a 32% reduction in the thermal resistance. In other words, as the amount of AlN powder increased in a certain area of the MCPCB Al substrate, the number of powder particles increased, thereby, decreasing the gap between the particles, which facilitates the heat transfer, resulting in an increase in the thermal conductivity and a reduction in the thermal resistance. In this study, the maximum AlN powder content was set to 2.0 wt%. However, if the AlN content, that has excellent thermal conductivity, is increased, and other materials such as SiC and boron nitride (BN) with excellent thermal conductivity are used, a greater reduction in the thermal resistance of the LED module can be obtained. In addition, if a heat pipe and fan are used for Chip on Board (COB) PKG application and heat sink improvement, excellent heat dissipation characteristics can be obtained so that the thermal resistance of the LED module will be reduced, thereby improving the LED chip life and optical characteristics.

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References and Notes

Fig. 1. (a) Heat-dissipation path of the LED module. (b) The structure of the metal PCBs with an insulation layer of a polyimide resin and AlN powder.

Table 1) Thermal conductivity characteristics of each material

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<tr>
<th>Thermal Conductivity (W/mK)</th>
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<tr>
<td>Au</td>
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<tr>
<td>Al (10XX)</td>
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<td>AlN powder</td>
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<td>Epoxy</td>
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<td>Polyimide resin</td>
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Fig. 2. (a) Image of the AIN powder (b) Image of the mixture of the polyimide resin and the AIN powder.

Fig. 3. Surface morphologies of the coated poly-imide resin layers with different AlN contents.

Fig. 4 LED module fabrication process and thermal resistance evaluation (a) LED PKG substrate (b) Au electrode formed PCB substrate (c) LED PKG substrate soldering (d) Evaluation of thermal resistance
Fig. 5. Thermal conductivities of metal PCBs containing AlN in different amounts.

Fig. 6. Thermal resistivities of the LED modules with metal PCBs containing the AlN powder in different amounts.
Currently, technology development is being carried out to increase the output of an individual device to replace general LED lighting with power consumption in the range of tens to several hundreds of Watts. A high LED output is needed, which requires suitable packaging technology. In this study, a metal PCB was fabricated to improve the heat dissipation characteristics of the PCB of which the heat dissipation efficiency was the lowest in the LED module. For a metal PCB with an Al substrate, whose heat conductivity was excellent, polyimide resin and AlN powder (0, 0.5, 1.0, 1.5, 2.0 wt%) with excellent heat conductivity, were mixed to form an insulating layer rather than the epoxy previously used. An LED module was fabricated and its thermal resistance characteristics were analyzed. As the AlN powder content increased, the heat resistance of the metal PCB decreased. The heat resistance of the metal PCB without AlN powder was approximately 12 °C/W, whereas that of the metal PCB containing 2.0 wt% AlN powder was 8 °C/W, which showed a lower heat resistance by approximately 30% compared to that of the metal PCB without AlN powder.