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The investigation of flip-chip eutectic bonding on the performance and lifetime of light emitting diodes

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ABSTRACT

The present study investigated the eutectic bonding on the long-term performance of flip-chip LEDs under varying aging stresses. A direct eutectic bond was used to adhesive the power LED chip to the Al_2O_3 ceramic substrate. The flip-chip structure was capable to perform both high thermal conductance and good light extraction efficiency of the LED device. The varying sputtered copper thickness on the ceramic substrate was investigated to reduce junction temperature. The experimental results showed that flip-chip LEDs using eutectic bonding exhibited superior die shear strength and also performed good long-term reliability after applying 1000 h aging test under various ambient temperature and relative humidity (RH). Thermal resistance decreases as thickness of copper was decreased from 60 μm to 15 μm. The lumen maintenances were above 98.5% and 104% for the eutectic flip-chip LEDs under temperature of 298 K and 358 K, respectively. When the RH was increased from 50% to 90%, lumen maintenance was higher than 100% for all eutectic flip-chip LEDs. However, the luminous decay was at 31.6% for sliver pate LED sample at 90% RH after aging tests. The experimental results are applicable for optimizing the direct eutectic bonding process and for designing highly reliable LED devices.

1. Introduction

Lumen maintenance and production cost are the major drawbacks of using light emitting diodes as a light source. Heat dissipation is still a major issue because of more than 50% of input electrical power converted into waste heat of LED devices. A flip-chip LED structure has higher light extraction efficiency compared to the conventional chip structure [1–2]. A highly reliable lighting module with excellent heat dissipation and long-term reliability is needed. Extremely high heat flux can cause LEDs to have poor efficiency and lifetime [3–4]. Most heat inside LED chip is dissipated through heat conduction from active layer to ambient. Thermal resistance from junction to ambient directly influenced junction temperature of the LEDs. Therefore, heat dissipation design is a severe problem for high-power LEDs [5–7]. High thermal conductive ceramic substrates such as Al_2O_3 and AlN are both superior materials that perform outstanding thermal performance of the LEDs [8–9]. Die attach quality also has a strong influence on the thermal resistance and long-term reliability of the LED devices. Delamination and voids at the die attach layer deteriorate device performance and lumen maintenance during long term aging tests [10]. Hence, the eutectic bond (Au–Sn) became a more promising die attach process compared to silver paste and solder paste [11]. However, the related research about direct eutectic bond on ceramic substrate is still lacking to accurately evaluate long-term reliability for flip-chip LEDs.

This study investigated correlations of thermal resistance, temperature, and humidity on the long-term performance of the direct eutectic flip-chip LEDs. Effects of varying thicknesses of copper coated on the ceramic substrate and the effects of different die attach processes on the lifetime of LEDs were also discussed. The flip-chips LEDs were fabricated on the Al_2O_3 ceramic substrate with different copper thicknesses. Transient thermal analyzer was applied to determine the thermal resistance from junction to environment of the eutectic flip-chip LED devices. Thus, junction temperature could be determined for various test LEDs. The experimental results provide a more comprehensive understanding for optimizing the direct eutectic bonding process and predict long-term reliability for manufacturing high reliable LED lighting fixtures.

2. Experiments

In the present study, the direct eutectic bonding applying 80% Au and 20% Sn was adopted as the die attach material between the blue LED chip (1 mm^2) and ceramic substrate. The Al_2O_3 substrate was first placed on a platform at the set temperature. Then a suction head was used to provide pressure to detach the LED chip from blue tape. Before die bonding, nitrogen was purged on the substrate surface to avoid

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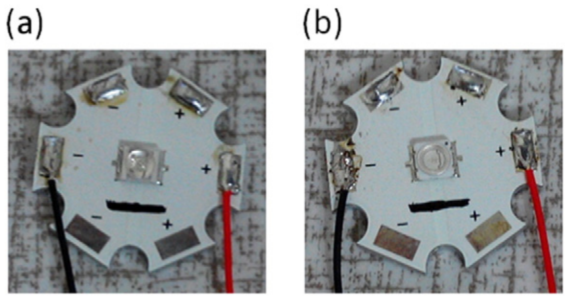

Fig. 1. Top view of the LED devices (a) flip-chip LED with eutectic bond (b) face-up LED with silver paste.

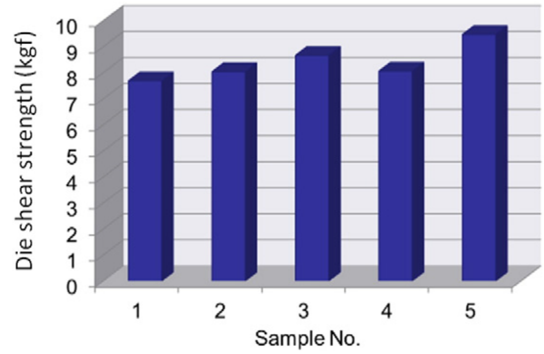

Fig. 3. Shear test results of eutectic flip-chip LEDs using Nordson DAGE 4000 bond tester.

metal oxidation of eutectic alloy. Then, the LED chip was pressed onto the ceramic substrate. The melting point of the direct eutectic bonding was set at temperature 553 K under constant pressure. The intermetallic bond provided superior die bond strength between LED chip and substrate. A flip-chip structure was used to obtain high thermal conductance and high light extraction efficiency of the LED devices. Effects of varying copper thicknesses (15 μm, 30 μm, and 60 μm) on the ceramic substrate were investigated in order to decrease the thermal resistance of the LEDs. The face-up structure with sapphire based blue LED chip (0.25 mm^2) was selected as the control group to compare the difference on the thermal characteristics and long-term performance with flip-chip LEDs. Silver paste was selected as the die attach material. The driving current of face-up LED was set under 0.15 A. Thermal resistances under varying copper thickness were measured using transient thermal analyzer to evaluate thermal impedance from junction to ambient [12]. In order to optimize the eutectic die bond process of the flip-chip devices, the LEDs were then placed into the ovens by controlling different environment temperatures and relative humidity. A 1000 h aging test was performed to compare the effects of environmental temperatures and relative humidity on the long-term performance of the LEDs.

3. Results and discussion

Fig. 1 shows the top view of the flip-chip and face-up LED devices. Two different devices were then placed on the aluminum plate to facilitate long time aging tests. The die attach materials for the flip-chip and the face-up chip were eutectic and sliver paste, respectively. An X-ray was then applied to ensure good uniformity at the die attach layer without obvious delamination and voids before tests, as shown in Fig. 2. Fig. 3 showed the results of die shear strength test using Nordson DAGE bond tester for the five flip-chip LED samples. The die shear strength test is a promising process for inspecting the quality of die attach between the LED chip and substrate. The experimental results showed that die shear strength increased from 7.4 to 10.2 kgf. That is, the shear strength of using eutectic was much higher than that when using silver paste and solder (1–2 kgf).

Thermal resistance of the flip-chip LEDs was measured using thermal transient tester. During the tests, LED was driven under direct current, and the transient thermal response can be treated as a unit step response function [13].

$$T(t) = P_{heat} \times \sum_{i=1}^{n} R_{thi} \cdot [1 - \exp(-t/R_i C_i)] \tag{1}$$

$$\frac{dT(z)}{dz} = \int_0^{\infty} R(\zeta)[\exp(z - \varsigma - \exp(z - \zeta))]d\zeta \tag{2}$$

in which R, C, and $R(\xi)$ represented thermal resistance, thermal capacitance, and time constant spectrum respectively. Fig. 4 illustrated the differential structure function of the flip-chip LEDs under varying copper thickness using driving current of 0.35 A. As shown in the figure, the thermal conduction path of LED from junction to ambient can be analyzed quantitatively. The thermal resistances from junction to ambient were measured at 12.5 K/W, 13.4 K/W, and 14.3 K/W under copper thicknesses of 15 μm, 30 μm, and 60 μm, respectively. The R_{th} values of flip-chip LEDs were much lower than applying face-up LED chip using sliver paste at 59.6 K/W. The corresponding junction temperatures were evaluated under an input electrical power of 1.1 W by using Eqs. (3) and (4) at 311.8 K, 312.7 K, and 313.7 K.

$$\Delta T_j = R_{th} \times P_{input} \tag{3}$$

$$T_j = T_{j0} + \Delta T_j \tag{4}$$

where R_{th}, P_{input}, and T_{j0} represented thermal resistance from junction to ambient, input electrical power, and initial junction temperature, respectively. The maximum junction temperature difference approximated 2 K when copper thickness was decreased from 60 μm to 15 μm. Furthermore, the thermal resistance from junction to substrate $R_{j\text{-}s}$ were obtained at 3.1 K/W, 4.0 K/W, and 4.9 K/W under copper thicknesses of 15 μm, 30 μm, and 60 μm, respectively. The $\Delta R_{j\text{-}s}$ was measured at 1.8 K/W as the copper thickness increased from 15 μm to 60 μm. The copper thickness exhibited an obvious correlation between the thermal resistances of the LEDs.

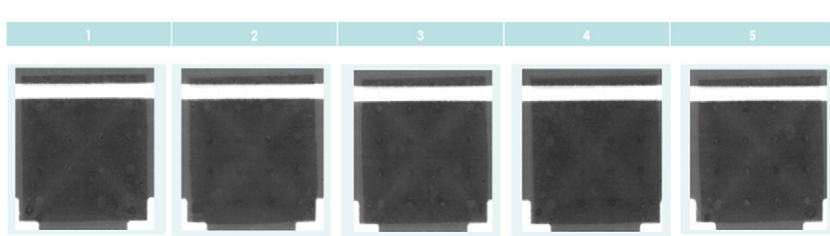

Fig 2. X-ray images at die attach interface of eutectic flip-chip LEDs.