Overdriving reliability of chip scale packaged LEDs: Quantitatively analyzing the impact of component

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ABSTRACT
The objective of this study is to quantitatively evaluate the impacts of LED components on the overdriving reliability of high power white LED chip scale packages (CSPs). The reliability tests under room temperature are conducted over 1000 h in this study on CSP LEDs with overdriving currents. A novel method is proposed to investigate the impact of various components, including blue die, phosphor layer, and substrate, on the lumen depreciation of CSP LEDs after aging test. The electro-optical measurement results show that the overdriving current can lead to both massive light output degradation and significant color shift of CSP LEDs. The quantitative analysis results show that the phosphor layer is the major contributor to the failure in early period aging test. For the long-term reliability, the degradations of phosphor and reflectivity of substrate contribute significantly on lumen depreciation. The proposed reliability assessment method with overdriving loadings can be usefully implemented for LED manufacturers to make a cost- and effective-decision before mass production.

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1. Introduction
Phosphor converted white light-emitting diode (LED) packages are the most typical light source in solid state lighting (SSL) applications [1]. The advancement of application design requires the next generation LED package design with small footprint and high lumen density [2]. The chip scale packaged (CSP) LED has been developed in order to fulfill these requirements. One of the extraordinary advantages of CSP LED is their high efficacy operating under high current injection [3,4]. Compared to common SMD LED package, the structure of CSP LED is simplified by removing sub-mount and bonding wires, as shown in Fig. 1. Only a flip-chip LED die and a light converting phosphor layer are kept. This simplified structure enables the volume reduction up to 80% compared with traditional SMD packages [5]. The thermal resistance of the CSP LED is about 2 °C/W, while that of traditional LED is 15–30 °C/W [6].

Yole Développement announced, “The combination of cost reduction and advanced packaging technologies, such as Flip Chip and Chip Scale Package, is changing the LED industry landscape, especially its supply chain” [7].

According to Haitz’s law, SSL lamps will exceed all conventional mainstream lamps by factors of 2 to 10 times in efficacy by 2020 [8,9]. To achieve higher luminous efficacy, CSP LEDs are driven under higher current density [10], especially under overdriving current. “Overdriving current” in this paper means the current is higher than the typical current of the product datasheet (normally is 350 mA [11]). However, the small-size interconnection pads induce the heat being concentrated in a small area, which is particularly sensitive to the reliability of the CSP LED when it is driven by overdriving current. Although the reliability of white LEDs has been attracted great interest by many research groups [12–28], there is limited report on the reliability of CSP LEDs under overdriving current.

In fact, identification of the failure modes, especially quantitative analysis the impact of each component on the CSP LEDs, is essential for further improving CSP technology. Pecht’s groups [12–14,29,30] predicted the reliability of high-power LEDs by using prognostics and health management method. Fan et al. [12,31,32] analyzed thermal, optical and electrical performance of LEDs with experiment and
simulation after a high temperature accelerated degradation test. Cheng et al. [13] presented lumen degradation and chromaticity shift in glass and silicone based high-power LEDs under accelerated thermal tests. Most of their studies indicate that the blue die and the phosphor layer are the critical factors to determine the reliability of LEDs. In order to identify which portion of LEDs is degraded, Wong et al. [3,15] analyzed the change of spectral power distribution of the sample before and after aging test with non-destructive techniques according to IES LM-80-08 [33] and JESD 22-A101-C [34] standard. They found that the color shift of the blue die might not be the major factor because blue radiation makes little contribution to in the lumen. However, the effects of solder joint and substrate on the reliability of CSP LEDs are not considered. Besides, few studies have been conducted on analyzing the impact of components on the lumen depreciation of CSP LEDs.

In this study, the reliability tests under room temperature are conducted over 1000 h on CSP LEDs with overdriving currents at first. Second, the components of the aged samples, including blue die, substrate and phosphor layer, are exchanged separately according to the proposed methodology. Then, the electro-optical performances of each sample are investigated. Finally, the impacts of individual components on the early-period and long-term reliability of CSP LEDs are quantitatively analyzed.

2. Experimental procedures

2.1. Methodology

Lumen depreciation of CSP LEDs is a complex process and is dependent on the interactions of multiple factors, including the effect of the aged solder joint, the degradation of blue die, the reflectivity change of substrate, and the degradation of phosphor layer. The effect of aged solder joint on the reliability can be ignored because CSP LEDs' soldering is in good condition after aging (see Section 3.1). A sample of CSP LED is fabricated by bonding a blue die with a phosphor layer on a ceramic substrate. We quantitatively analyze the data of aged samples in two stages: the early period (24 h) and the long-term aging (>1000 h) (Fig. 2).

Benefited from the simplified structure of CSP LED, we can exchange the individual component separately and avoid the interaction of the whole aged components. The processes are as follow:

1) Before the impact analysis of CSP LED’s components, shear tests are conducted on the packages to analyze the mechanical strength of the package according to the JESD22-B117B standard [35]. The mean shear strength of the samples is about 1689 g, indicating that the CSP package mounted on the ceramic substrate can withstand the mechanical damages out of the environment.

Fig. 1. A SMD white LED package (left) compared to CSP LED (right).

Fig. 2. A series of experiments designed to investigate the impact of various components on the reliability of CSP LED after aging test.
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