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Enhancement of light-emitting diode reliability using silicone microsphere in encapsulant

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ABSTRACT

The aim of this study was to prevent the delamination of encapsulant for light-emitting diode (LED) without sacrificing other optical performance. Silicone microsphere was employed to control the properties of shrinkage and hardness of encapsulant during curing process. The effects of microsphere in encapsulant were investigated by using the different concentration of microsphere. After curing reaction, the shrinkage percentage and hardness of both shore A and D encapsulants were reduced and reinforced, as increasing the concentration of microsphere. Despite the addition of microsphere, the LED packages fabricated without/with microsphere showed the similar initial optical efficiencies. It is because the light scattering effect compensated their small difference of refractive indexes between encapsulants and microsphere. Using the silicone microsphere, the improvement of reliability of LED packages could be achieved after 1000 h under condition of temperature (85 °C)/humidity (RH 85%). It is attributed to the synergy effects of shrinkage suppression and hardness improvement.

1. Introduction

Light-emitting diode (LED) is becoming the main next-generation light source for replacing existing types of lighting due to their outstanding features such as low power consumption, compact size, high efficiency, and non-toxic materials. [1–3]. Because of these advantages, LED has attracted much attention in the fields of medicine, backlight unit liquid crystal display, indoor lighting, street lamp, electronic display, vehicle headlight and so on [4–8]. In spite of the high light efficiency and advanced packaging technology, there are some demands for an excellent performance of LED lighting such as a higher color rendering index, more uniform color temperature and longer reliability. Among them, the reliability is an important factor to evaluate the optical performance for a longtime.

The encapsulant is a vital element since it covers and protects the LED chip and wire from physicochemical stimulates and keep phosphors with a high transparency [9]. Moreover, encapsulant was used to increase the refractive index, resulting in a higher light extraction based on Snell's law [10,11]. However, the shrinking issue must be addressed because the delamination and crack of encapsulant lead to permeating external moisture and gas, resulting in the corrosion and discoloration of package. Such interfacial defects are caused by a long-term thermal stress attributed to a low thermal conductivity of encapsulant, leading to a serious decline of lighting performance. There have been a lot of researches for polymerization shrinkage of encapsulant in various fields such as a construction, dental clinics and electro-devices [12]. But there are only few studies for the relationship between shrinkage and filler in LED application. Due to the specific characteristics of the encapsulant, we previously researched into the enhancement of optical efficiency by using microsphere [13]. Also, the relation between the cross-linking density and sulfur gas permeability of encapsulant was investigated [14]. In this paper, our study was focused on the investigation into effects of silicone microsphere for the LED lifetime reliability. The shrinkage and hardness of encapsulant could be efficiently controlled by varying the concentration of microsphere, resulting in the improvement of reliability.

2. Experimental

LED chip (peak wavelength: 451 ± 2 nm) was attached on a 5050 polyphthalamide package (0.5 × 0.5 mm) using an adhesive (KER-3000-M2). Two kinds of silicone encapsulants, having different hardness properties, were adopted. One is EG6301 (shore A, refractive index: 1.40) containing the methyl group. The other is KSS005 (shore D, refractive index: 1.52) which includes phenyl group. Silicone microsphere (diameter: 11 μm, refractive index: 1.42) was employed as a filler. LED light sources were fabricated by the following process: attaching an LED chip to a package, wire bonding and curing reaction. The encapsulants were prepared with different silicone microsphere content and then the mixtures were homogeneously dispersed by using a high-speed revolution and rotation mixer (Mazerustar). Subsequently, the encapsulants were cured in a convention oven at 70 °C for 1 h and then at 150 °C for 2 h. The EG6301 including 0, 1, 3 and 5 wt% of

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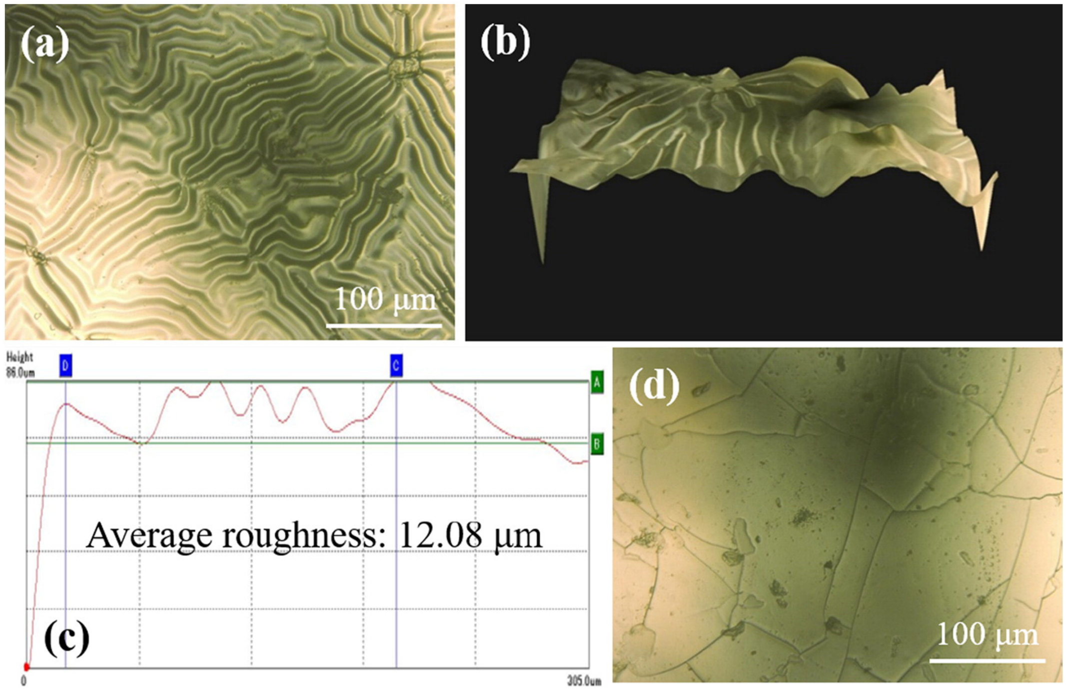

Fig. 1. High resolution images (×500) for front (a) and cross (b) sections of shrinkage in EG6301 and profiling its surface roughness (c). High resolution image for front section of cracks in KSS005 (d).

microsphere was named as E0, ES1, ES3 and ES5. The KSS005 containing 0, 1, 3 and 5 wt% of microsphere was identified as K0, KS1, KS3 and KS5. For facile analysis of degree of shrinkage and hardness of encapsulants after curing process, the cured encapsulant samples were additionally fabricated by using the fabricated rectangular parallelepiped stainless template (30 × 70 × 10 mm) coated with Teflon. The percentage of shrinkage was calculated by comparing between encapsulants before and after curing reaction. The degree of hardness was measured by using a hardness tester (Model HM-211). The penetrator was circular cone type (2 mm in diameter and 1.5 mm in height), and the pressure was 10 gf. The optical property of LED packages was characterized by using a spectrometer system (CAS-140CT).

3. Results and discussion

Fig. 1(a) and (b) presented the front and cross view images of shrinkage phenomenon generated in curing reaction. In the case of encapsulant with a high elasticity, the significant surface roughness (average roughness: 12.08 μm) were indicated by polymerization reaction as shown in Fig. 1(c). If the encapsulant has a too low elasticity, the cracks were occurred through curing process in Fig. 1(d). The serious shrinkage and crack phenomena could damage LED package due to the exposure to external moisture and gas. The schematic illustration of shrinkage phenomenon of LED package was indicated in Fig. 2(a). Generally, the shrinkage occurs through polymerization reaction by the external thermal energy in initial curing process. Moreover, the additional shrinkage happens through the curing reaction by internal thermal energy, which is attributed to the long-term thermal stress the non-radiative transition. For the improvement of LED reliability, it is necessary to suppress shrinkage causing the delamination. The negative phenomenon on encapsulant could be effectively reduced by using microsphere.

In Fig. 2(b), the initial radiometric fluxes of LED packages were analyzed to estimate the variation in optical performance by adding additive. The average values of EG6301 and KSS005 were 116.55 ± 0.69 and 112.41 ± 0.29 mW, respectively. The changes in initial flux of LED

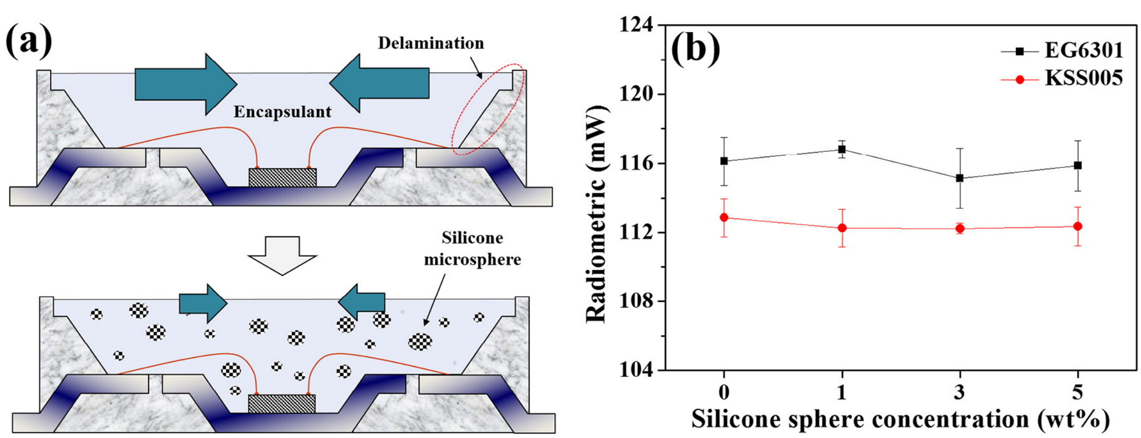

Fig. 2. Schematic illustration for the effects of microsphere (a) and initial radiometric flux (b) of LED packages fabricated by EG6301 and KSS005 with difference concentration of microsphere.

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