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Time evolution of packaged LED lamp degradation in outdoor applications

Preetpal Singh[a], Cher Ming Tan[b,c,d,e,*]

[a] Center for Reliability Engineering, Ming Chi University of Technology, New Taipei City, 24301, Taiwan
[b] Centre for Reliability Science and Technology, Chang Gung University, Wenhua 1st Road, Guishan Dist., Taoyuan City, 33302, Taiwan
[c] Department of Electronics Engineering, Chang Gung University, Wenhua 1st Rd., Guishan Dist., Taoyuan City, 33302, Taiwan
[d] Department of Urology, Chang Gung Memorial Hospital, Guishan, Taoyuan, 333, Taiwan
[e] Department of Mechanical Engineering, Ming Chi University of Technology, 84 Gungjuan Rd., Taishan Dist., New Taipei City, 24301, Taiwan

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ABSTRACT

Degradation of Silicone used in high power white LEDs as molding material has significant impact on the LED's lifetime and efficacy. This work provides a detail study on the impact of moisture, temperature and thermal aging on the packaging materials by tracing its progression of degradation under high temperature and humidity conditions. Silicone degradation via discoloration and cracks formation is identified and its cracks depth is found to decrease as the time progressesdue to diffusion mechanism and this led to highly distorted surface. It is found that Silicone undergo hydrolysis, condensation, thermal oxidation and thermal aging over its lifespan, and discoloration is mainly due to hydrolysis while cracks formation is mainly due to thermal oxidation. The decrease in the crack depth is due to thermal aging where diffusion of silicon oligomer occurs.

1. Introduction

High efficient, high reliable and high brightness LEDs are rapidly developing in many lighting applications. A packaged LEDcomprising of various materials including molding part, encapsulant, heat sink, LED die and interconnects [1]. The outer molding material forms the physical protection to LEDs and also contributed to higher light output due to its reflector shape and special filler addition. While the degradation of the other parts and their effect on LEDs reliability and lifetime are studied in depth by various groups [2,3], the degradation of the molding part under outdoor applications where temperature and humidity are presence is the least studied.

Due to the wide spread applications of high power LEDs, silicone as the outer molding material used for LEDs can experience temperature as high as 135 °C [4], and this can lead to photo/thermal degradation of silicone which can induce chemical structural change as reported in Refs. [5–8]. Material properties such as mechanical strength, color change and transparency can be altered due to the chemical structural change after the degradation [9]. An increase in silicone hardness and cracks initiation are common degradation mechanisms in LEDs under high tempertaure conditions [10].

Recently, the molding part yellowing in white LEDs under high tempertaure and high moisture, and its effect on LEDs luminous efficacy is studied by Singh and Tan [11]. They observed that the molding part fractures into various shapes and develops cracks after degradation. In this work, we investigate the progression of the degradation of the molding part under electrical, thermal and moisture stress. Composition of molding part used for commercial LEDs tested in this work is not revealed by the company. Thus, FTIR and EDS spectroscopy is employed and it is observed that the molding part comprises of poly dimethylsiloxane (hereafter known as silicone in this work) integrated with silica nano fillers.

2. Experimentation

12 High power OSRAM golden dragon LEDs are chosen for the experiments in this work, and initial set of measurements for all the LEDs are done to serve as reference baseline for each test sample. These measurements include optical microscope examination, electrical measurement, luman measurement, electron microscopy, energy dispersive spectroscopy and FTIR spectroscopy. The setting for the electrical measurements is done according to [12] to prevent self-heating during measurement. Optical examination is done using Keyence VHX5000. Electrical measurement is done using Tektronix 2461 Sourcemeter.

Three units are kept un-stressed as fresh samples for comparison, and 9 LEDs are subjected to 85 °C/85%RH environmental condition in a temperature-humidity chamberKD- 162- FUL from KING DESIGN, with

* Corresponding author. Senior member IEEE, IEEE Distinguished Lecturer Professor and Director of Centre for Reliability Sciences and Technologies Chang Gung University, Taiwan.
E-mail address: cherming@ieee.org (C.M. Tan).

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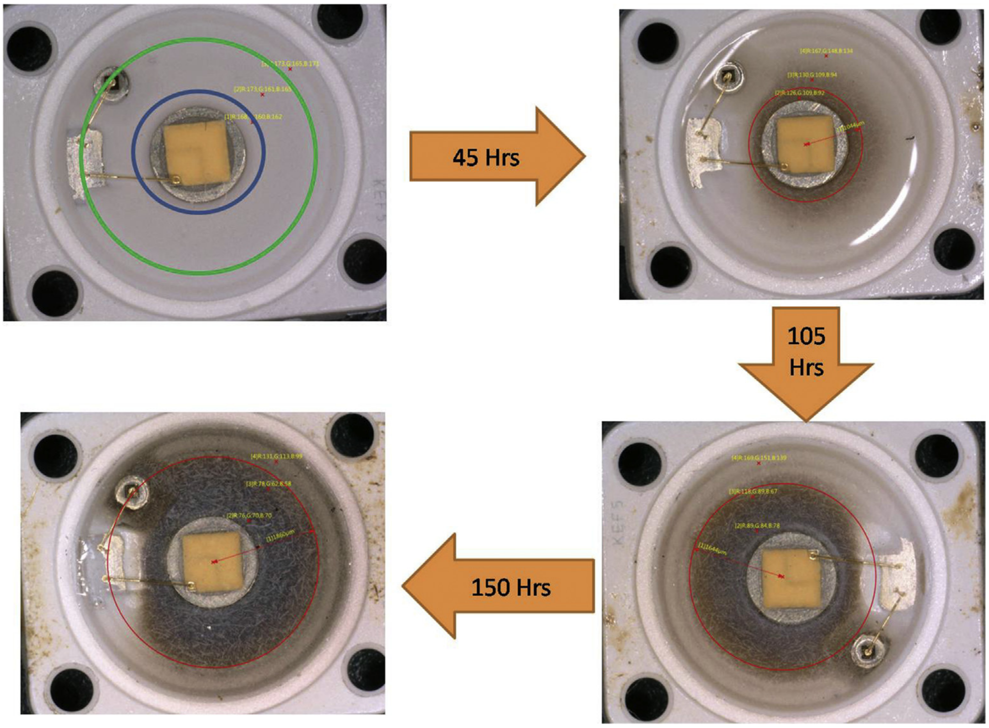

Fig. 1. Optical micrographs of white LEDs with varying test time intervals. The blue color circle in the fresh sample represents the inner molding part close to LED chip periphery and the green color circle represents the outer molding part which is far from the LED chip. This will be used in later discussions. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

350 mA constant current passing to them individually using Keithley power supply model 2651A, according to the manufacturing specification. A group of 3 LEDs is removed from the chamber after respective time interval of 45, 105 and 150 h. After the LEDs are taken out from the chamber, the entire set of measurement as done intially will be performed for their degradation investigation.

3. Experimental results

Discoloration is observed for all the test samples using Optical microscope Keyence VHX5000 as seen in Fig. 1. Initial fresh LED is at the top left side and the arrows represent the samples with various test time progressively. The molding part of the fresh sample is clear white in color showing no yellowing or discoloration whereas the discoloration is vividly observed in all the tested samples. The extent of discoloration is observed to increase as test time increases.

To observe the extent of degradation, the radius of the discoloration is measured using the Keyence microscope, and they are shown in Fig. 2, and one can see that the radius increases with the test time as expected, but the rate of discoloration is the highest in the first 45 h, and then it slows down subsequently.

The molding part discoloration observed affects the light output of LEDs as can be seen from the good correlation of the trend of decrease of the lumen flux shown in Fig. 3 with the trend of increase in the radius of discoloration (Fig. 2). However, the decrease in the luminous flux can also be due to other possibilities such as chip failure, phosphor degradation or package failure under such stress test.

To identify the importance of the above-mentioned possibilities, several measurable parameters and their respective changes are examined with respect to the test time. Blue to yellow ratio is used to observe the phosphor degradation [13], ideality factor change is used to observe the chip level degradation [14,15] and molding yellowing is used to check the molding part degradation [11]. The comparisons are shown in Fig. 4.

From Fig. 4, it is clearly observed that the phosphor degradation and molding yellowing are likely to be the degradation mechanisms as the trends of these degradations are in close correlation with the trend of the lumen flux changes. Among these two factors, molding part

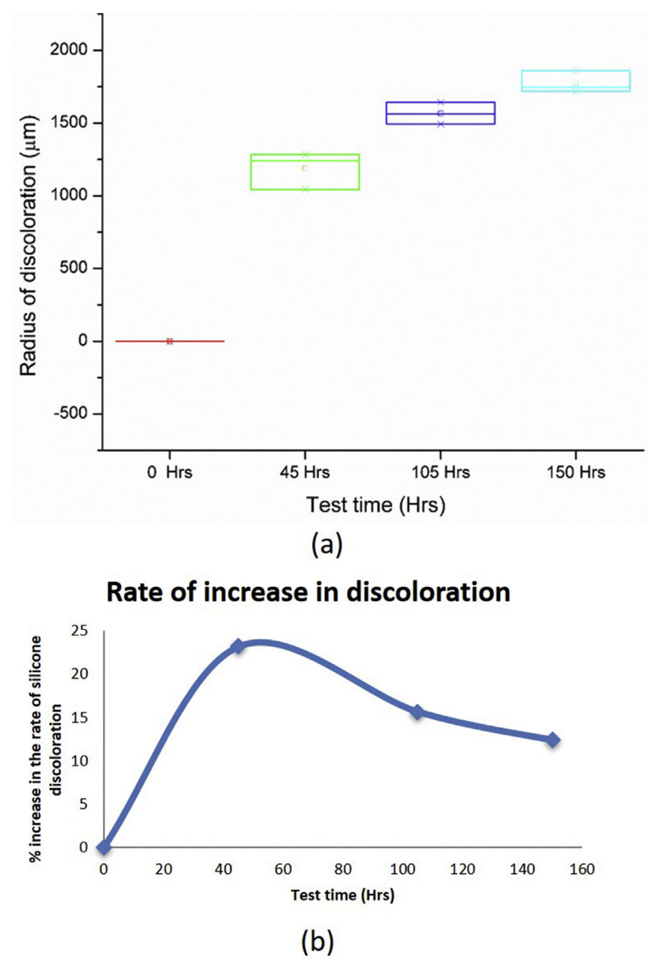

Fig. 2. (a) Radius of discoloration as measured using Keyence microscope for samples with varying test time. (b) Rate of increase in the discoloration radius versus time of testing.