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ABSTRACT

Two life tests were conducted to compare the effects of drive current and ambient temperature on the degradation rate of 5 mm and high-flux white LEDs. Tests of 5 mm white LED arrays showed that junction temperature increases produced by drive current had a greater effect on the rate of light output degradation than junction temperature increases from ambient heat. A preliminary test of high-flux white LEDs showed the opposite effect, with junction temperature increases from ambient heat leading to a faster depreciation. However, a second life test is necessary to verify this finding. The dissimilarity in temperature effect among 5 mm and high-flux LEDs is likely caused by packaging differences between the two device types.

Keywords: Light-emitting diodes (LEDs), white LEDs, degradation, life, junction temperature

1. INTRODUCTION

White light-emitting diodes (LEDs) are rapidly evolving for use in general illumination applications. LED manufacturers are now designing more efficient and reliable white LEDs than ever before. However, there is no easy way to estimate the life of white LEDs. Therefore, the goal of this study was to investigate how different types of commercial white LEDs degrade over time and to compare the effects of drive current and ambient temperature on the degradation rate. In the long run, this information will be useful in developing a life predictor that can reduce the need for time-consuming life tests.

Typically, LED performance is affected by the drive current and by the ambient temperature surrounding the LED. Both of these parameters contribute to the junction temperature of the LED, which is known to be a good predictor of LED life.[1, 2] Therefore, our objective was to determine whether drive current and ambient heat have similar effects on the degradation of white LEDs. To understand how the different LED packages are affected by these parameters, LED arrays were tested at different operating conditions using either the same current but different ambient temperatures, or the same ambient temperature but different currents. The details of the experiment and the results are presented in this paper.

2. EXPERIMENT

Two life tests were conducted to compare the effects of drive current and ambient temperature on white LED degradation. The first experiment investigated 5 mm white LEDs arrays, and the second experiment studied high-flux LED arrays.

The two LED life tests explored light output depreciation as a function of time. Figure 1 illustrates the experimental setup (see Reference 3 for more setup details). Because each LED type has to operate at a particular ambient temperature, all were tested in specially designed individual life-test chambers. These test chambers were designed to keep the ambient temperature constant and to act as light-integrating boxes for measuring light output. Each individual LED array was mounted at the center of the inside top surface of a life-test chamber, a 9 in. by 9 in. (22.86 cm by 22.86 cm) square box constructed of wood laminate. The inside of the chamber was painted matte white. A photodiode attached to the center of the left panel continuously measured the light output. A small white baffle placed over the photodiode shielded it from the direct light, allowing only the reflected light to reach the photodiode. A resistance temperature detector placed on top of the baffle measured the chamber's ambient temperature and controlled the heater through a temperature controller. The temperature inside the box remained within ± 1°C. The heater was attached to a raised aluminum plate with a matte-white cover that sat on the chamber floor. The LED junction temperature was estimated using a J-type thin wire thermocouple soldered to the cathode pin of one LED in the array. The junction temperature of the LED was estimated from the cathode pin temperature, the power dissipated at the p-n junction, and the thermal resistance coefficient of the white LEDs.[4] For each chamber, an external LED driver controlled the current flow through the LEDs. Each chamber was calibrated at regular intervals throughout the life test using a halogen light source placed at the inside top left corner. The chambers were calibrated to ensure that the light output degradation was from the LEDs only and not due to degrading paint inside the box.

All life-test chambers were placed inside a temperature-controlled room, as shown in Figure 2. The life-test chambers were staggered vertically and horizontally to ensure that heat rising from the bottom chambers did not affect the chambers above them.

Fig. 1: LED life-test chamber.

Fig. 2: LED life-test laboratory.

Before beginning the experiments, the LEDs were operated in their individual chambers for 1000 hours for an initial seasoning. Prior experiments in the laboratory have shown the need for seasoning because of the rapid changes that LEDs experience initially (probably due to annealing factors) before they settle into a steady decline over time.

2.1 Experiment 1

The goal of the first experiment was to determine the effects of ambient heat and drive current on the degradation rate of 5 mm white LEDs. Two groups of white LEDs were life-tested. The LEDs in Group 1 were operated at similar currents but at different ambient temperatures, and the LEDs in Group 2 were tested at similar ambient temperatures but at different currents. Thirty 5 mm white LEDs were selected from the same batch, acquired in April 2003. Six LEDs with the same peak wavelength for the short-wavelength emission were connected in series to form an array. Altogether, five LED arrays were constructed and each one was mounted inside its own life-test chamber. The operating conditions of the five arrays and their estimated junction temperatures are shown in Table 1. These conditions were achieved by adjusting the LED drive current and the ambient temperature inside the chambers.

Table 1: Testing conditions and estimated junction temperatures for the 5 mm LED arrays in Experiment 1.

	Array #	Ambient Temperature (°C)	Drive Current (mA)	Estimated Junction Temperature (°C)
Group 1	Array 1	41	15	56
	Array 2	55	16	70
	Array 3	69	15	85
Group 2	Array 1	41	15	56
	Array 4	40	28	70
	Array 5	37	45	85

2.1.1 Results of Experiment 1

Figure 3 shows the relative light output as a function of time for the five LED arrays. For each array, the relative light output over time was normalized to its initial value. The horizontal axis is on a log scale. The light output decrease over time is exponential in nature and therefore, the light output, L, can be expressed as:

$$L = L_0 \cdot e^{-\alpha t} \qquad \text{(Eq. 1)}$$

where α is the light output degradation rate, t is the operation time measured in hours, and L_0 is the initial light output which is normalized to 1.

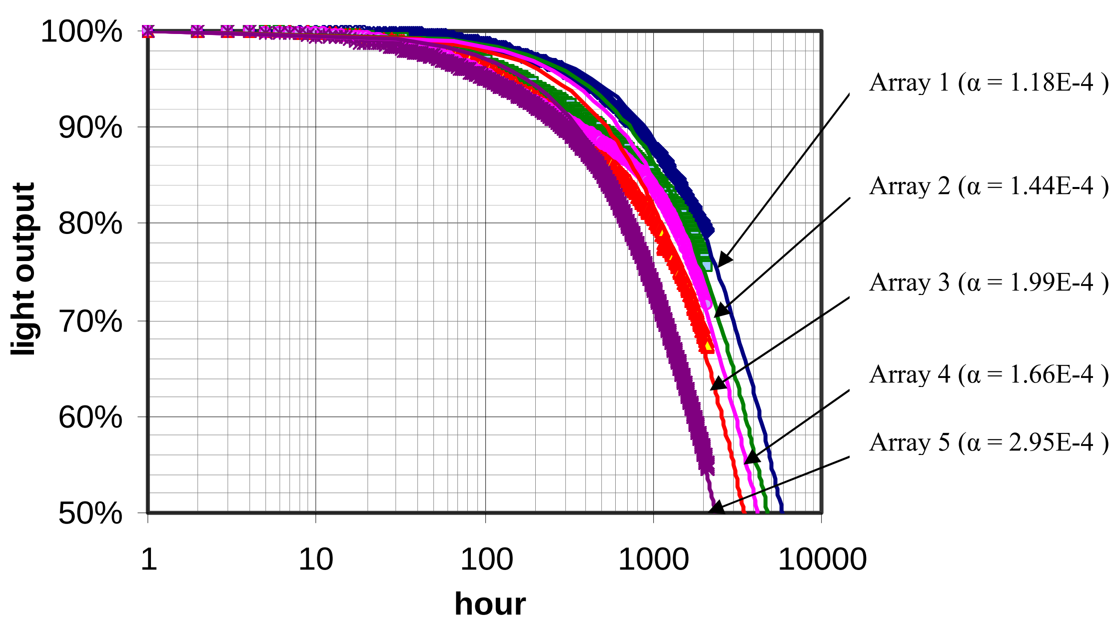

Fig. 3: Light output variation as a function time for the 5 mm LED arrays in Experiment 1.

Exponential curve fits yielded different degradation rates for each LED array. Figure 4 illustrates the variation of the degradation rate as a function of LED junction temperature. A higher degradation rate means a faster light output depreciation. As the junction temperature increased, the degradation rate also showed an increasing trend. However, Figure 4 shows that the junction temperature increase caused by drive current had a larger effect on the degradation rate than the junction temperature increase caused by ambient temperature.

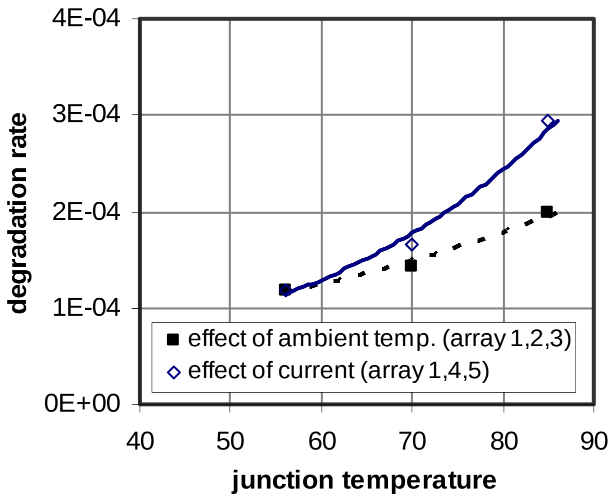

Fig. 4: Degradation rate α as a function of junction temperature for the 5 mm LED arrays in Experiment 1.

2.2 Experiment 2

The goal of the second experiment was to determine the effects of ambient heat and drive current on the degradation rate of high-flux white LEDs. Ten high-flux single-die white LEDs, acquired in 2004, were selected from the same batch, and two LEDs with the same short-wavelength peak were connected in series to form an array. As before, five arrays of white LEDs were life-tested. The LEDs were operated at their rated current of 350 mA but at different ambient temperatures. The operating conditions of the five arrays and their estimated junction temperatures are summarized in Table 2.

Table 2: Testing conditions and estimated junction temperatures for the high-flux LED arrays in Experiment 2.

Array #	Ambient Temperature (°C)	Drive Current (mA)	Estimated Junction Temperature (°C)
Array 1	35	350	56
Array 2	45	350	59
Array 3	50	350	65
Array 4	55	350	68
Array 5	60	350	76

2.2.1 Results of Experiment 2

Figure 5 shows the relative light output as a function of time for the LED arrays, which had the same drive current but different ambient temperatures. Here, too, the light output decrease over time is exponential in nature. As before, exponential curve fits yielded the degradation rate for each LED array. Figure 6 illustrates the variation of the degradation rate as a function of junction temperature. With increasing junction temperature, the degradation rate increased exponentially, except for Array 3 at the ambient temperature 50°C (Figure 6). A repeat test of the 50°C and 55°C ambient temperature conditions is under way. This repeat test will verify that abnormal point.

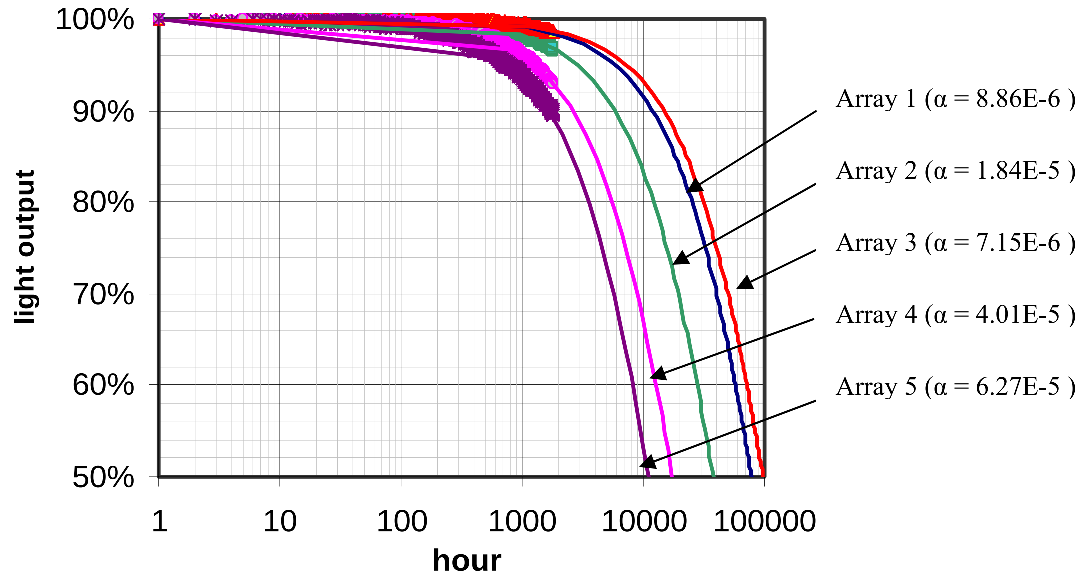

Fig. 5: Light output variation as a function time for the high-flux LED arrays in Experiment 2.

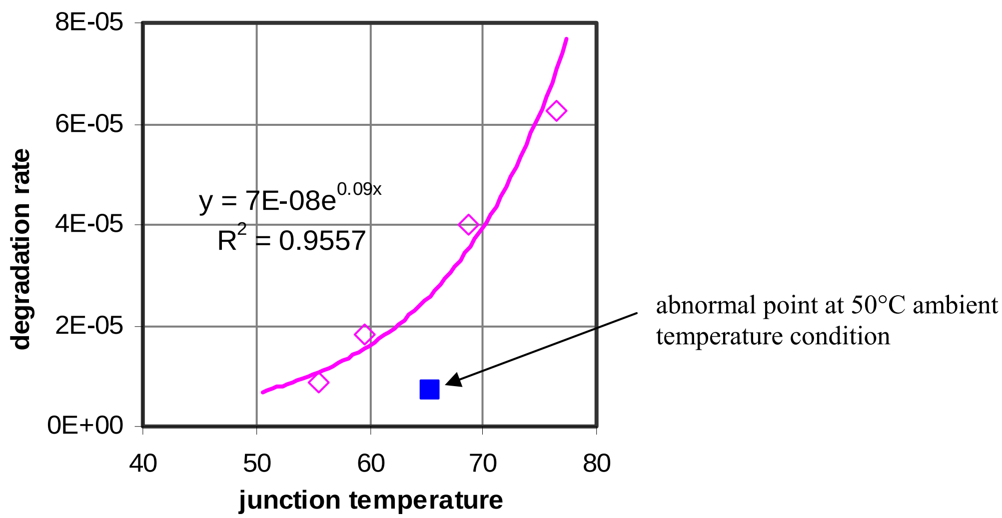

Fig. 6: Degradation rate α as a function of junction temperature for the high-flux LED arrays in Experiment 2.

3. DISCUSSION

As described in our preliminary study [5], high-flux LEDs show greater sensitivity, and thus faster degradation, to a junction temperature rise produced by ambient temperature than by drive current. Figure 7 shows the hypothesized degradation rates under the effects of ambient temperature and drive current. This is opposite of the effect observed in 5 mm LEDs (Figure 4), which degrade more quickly with current heat. Based on our 5 mm LED life study [3], this dissimilarity could possibly be induced by the package differences between 5 mm LEDs and high-flux LEDs. The silicon-based encapsulant of high-flux LEDs is less sensitive to short-wavelength radiation, which contributes to the yellowing of the encapsulant of 5 mm LEDs and thus causes faster light output depreciation. However, to verify the two curves in Figure 7, one more life test is needed for the high-flux LEDs. In that life test, the high-flux LEDs should operate at the same ambient temperature but at different drive currents.

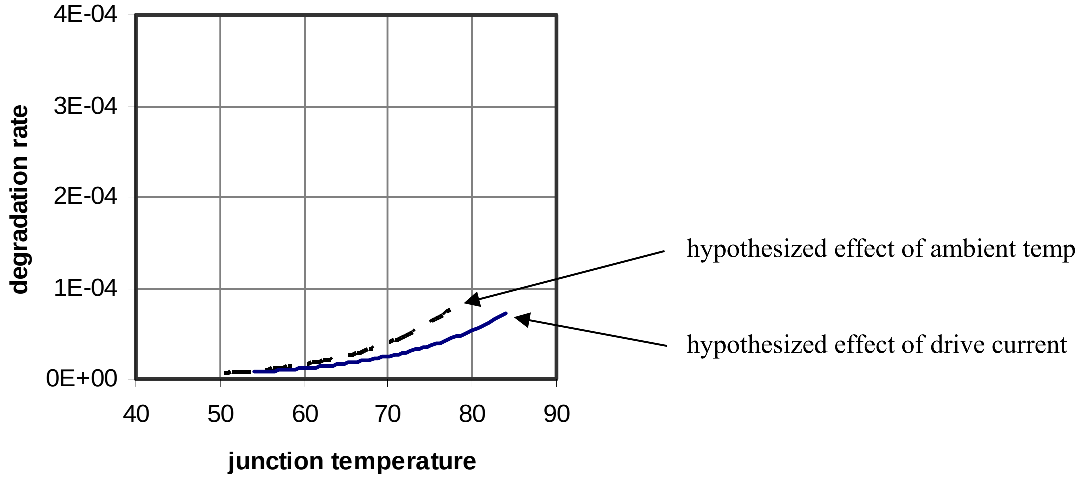

Fig. 7: Hypothesized degradation rate α as a function of junction temperature for high-flux LEDs by the effects of ambient temperature and drive current.

4. SUMMARY

The two experiments showed that the degradation rate changes as a function of junction temperature depending on the source of increasing heat (drive current or ambient heat). However, for 5 mm LEDs, current-induced junction temperature rise has a greater effect on the degradation rate than ambient heat-induced junction temperature rise. From a preliminary study, it was observed that for high-flux LEDs the ambient temperature has a greater effect than the current. Nevertheless, one more life test is needed to verify this.

Currently, other types of high-flux white LEDs are being life-tested at 35°C and 50°C common ambient temperatures. Even though it is too early to make conclusions about their life, different packages will likely produce different performance characteristics. The results will be discussed in a follow-up paper. By testing different commercial white LEDs, we can understand the degradation mechanisms for different types of LEDs and finally develop a metric for predicting the life of white LEDs.

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