Degradation Mechanisms in GaN/AlGaN/InGaN LEDs and LDs
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Abstract

Our studies of device lifetime and the main degradation mechanisms in Nichia
blue LEDs date back to spring 1994. Following the initial studies of rapid failures under
high current electrical pulses, where metal migration was identified as the cause of
degradation, we have placed a number of Nichia NLPB-500 LEDs on a series of life tests.
The first test ran for 1000 hours under normal operating conditions (20 mA at 23 °C).
As no noticeable degradation was observed, a second 23 °C test was performed with the
same devices but with a range of currents between 20 and 70 mA. For subsequent tests,
the temperature was increased by 10 °C in 500 h intervals up to a final temperature of 95
°C using the same currents applied in the second test. This work presents a thermal
degradation mechanism that dominates degradation at high ambient temperatures.

A. Introduction

In order to investigate the lifetime of the Nichia LEDs, 20 devices were mounted
inside a large environmental chamber that could be maintained at a constant temperature [1].
The light output of each LED was sampled by an optical fiber that was connected to its own
photovoltaic detector located outside the chamber. The LED-to-fiber connection was both
mechanically stable and light tight, eliminating intensity variations due to mechanical
misalignments and ambient light. The system used a switching device to select a single
detector's current, which was fed to a meter for automated reading of each LED's output.

A comparison between the life test data for the early stages of the life test (at low
ambient temperatures) and the data shown in Figure 1 for the eleventh segment of the test (at
95 °C) showed a distinct difference in the degradation rates for the same LEDs. The obvious
explanation is that the increase in the degradation rate in the higher temperature test is an
acceleration of the same degradation mechanism because of the increase in temperature. The
degradation at lower ambient temperatures has been shown to be related to the changes in the
plastic packaging material with exposure to the short wavelength emission from the LED [2].
The problem with this degradation mechanism being responsible for the degradation at high
ambient temperatures was identified in Figure 2. Figure 2 shows how the light output is
reduced at higher temperatures which would cause degradation mechanisms related to light
output to be reduced as the temperature is raised. Thus, a different mechanism must be
responsible.

B. Thermal Degradation of Package Transparency

In order to identify the high temperature mechanism, the degradation rates or the
slopes of the intensity versus time curves shown in Figure 1 were extracted from the data. The
data, as shown in Figure 3, indicates that there is a dramatic increase in the degradation rate for currents greater than 30 mA at an ambient temperature of 95 °C.

![Graph showing relative intensity change vs. time (hours)](image)

Figure 1 - Relative change in intensity of remaining Nichia blue LEDs at 95 °C for the final 510 hours.

Since the life test data suggests that the degradation may be related to a combination of ambient temperature and LED self-heating, the changes in the plastic with temperature were investigated. Figure 4 shows three sections of plastic removed from an Nichia LED control sample. The piece on the left has not been exposed to more than normal room temperature and has a clear appearance. The sample in the middle was placed in a burn-in oven at 150 °C in air for a 133 hours. This sample has turned to a deep brown color. The sample in the right was placed in the same oven at 200 °C for 130 minutes and shows a similar change to the sample exposed to 150 °C only to a lesser degree. This test indicated that at temperatures of around 150 °C (or slightly lower) the plastic can change by a purely thermal effect in such a manner that the light output of the LED could be attenuated. While the LEDs used in the life test did not show plastic that had browned that was visible on the outside of the package, the plastic in contact with the LED may have. This evidence showed that a more accurate junction temperature measurement was needed.

The only way to accurately measure the temperature at the diode is by measuring the junction voltage. To make this measurement, a control LED was placed in a burn-in oven and allowed to come to thermal equilibrium with the oven temperature. The junction voltage was measured when the LED was first turned on to minimize changes in the voltage across the junction due to self-heating. An HP 4145 semiconductor parameter analyzer was used for the measurement allowing the voltage to be accurately measured within 10 ms after the current was applied. This process was repeated at currents from 10 mA to 70 mA (coincident with the range of currents used in the life tests) and at temperatures from 30 °C to 150 °C. The data showed that there was a linear relationship between the voltage measured across the junction and the temperature of the junction. From this data, a better measure of the temperature that the plastic in contact with the diode was at could be made.

To calculate the diode temperatures experienced by the LEDs in test 11 (95 °C), a similar LED was placed in an oven at 95 °C and allowed to come to thermal equilibrium. The same forward currents that were used in the life tests were applied and allowed to stabilize meaning that the final temperature resulting from the ambient temperature and self-heating had been reached. This point was determined by observing the junction voltage and waiting
for it to stop decreasing. Using this data plus the linear fit parameters from the data collected on junction voltage versus temperature at turn on, the junction temperatures were calculated for each forward current. The results are shown in Figure 5. The calculations showed that for forward currents of 40 mA and above, the junction temperature was in excess of 145 °C which is very close to the 150 °C temperature where the plastic was shown to discolor in Figure 4. For currents smaller than 40 mA, the temperature is less than 135 °C where, according to the data in Figure 3, the degradation rate is significantly lower. While the exact temperature at which the plastic begins to discolor has not been determined, the temperature where the degradation begins to affect this material in a time frame important to LED lifetimes has been shown to be between 135 and 145 °C.

![Figure 2](left) - LED output power at various temperatures.  
Figure 3 (right) - Slopes extracted from test 11 data showing a sharp change in degradation rate at 95 °C for currents around 40 mA.

![Figure 4](Sections of Nichia LED package material: (left) unstressed, (middle) 133 hours at 150 °C, (right) 130 minutes at 200 °C.

C. Conclusions

The life tests of Nichia blue LEDs completed have not produced significant degradation on any of the devices in a manner consistent with a degradation mechanism attributable to the diode. These results indicate that Nichia devices enjoy a remarkable longevity in spite of their high density of defects. An analysis of the degradation characteristics of the plastic packaging material demonstrated that a degradation in light output could indeed be caused by the ultraviolet light emitted by the LED at lower temperatures [2]. At higher life test temperatures, the degradation mechanism changed from a light intensity related mechanism to a pure thermal mechanism. By calculating the junction temperature of the diode at the life test temperatures, excellent correlation was made between
the observed degradation rate and the temperatures achieved through the combination of ambient temperature and diode self-heating. This analysis was supported by the observation of plastic discoloration by exposure to temperatures consistent with those calculated from the junction temperature measurements.

![Figure 5 - Calculated junction temperature ($T_j$) at various forward currents (ambient temperature 95 °C).](image)

D. Acknowledgements

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E. References
