Influence of the injection current on the degradation of white high-brightness light emitting diodes

Sebastien Bouchard, Hugo Lemieux, Marie-Pier Côté, Simon Thibault
Laboratoire de Recherche en Ingénierie Optique
COPL, Univ. Laval, 2375, rue de la Terrasse, Quebec, Canada, G1V 0A6

ABSTRACT

Since high-power LEDs show great potential in reducing energy consumption worldwide, a great deal of research has been performed to understand their degradation rate. As reported in many publications, temperature is of critical importance so lifetests are mainly based on the internal temperature of the junction (T_j). A common testing method is to overdrive the LED with high current in order to cause self-heating. However, by doing so, it is assumed that current does not produce self-degradation. This topic is of great importance nowadays because of the recent development of LEDs used to increase operating current. We have conducted a lifetest on LEDs to isolate the influence of current by using a thermally-controlled heatsink to keep the same T_j for different driving currents. This paper presents the experimental setup with the associated protocol used in the experiment. We also present preliminary results obtained from two high-power white LEDs. These were stressed at currents ranging from 350 mA to 1000 mA and at temperatures ranging from 75°C to 150°C. To our knowledge, this type of measurement has not been reported in the literature. In the future, we would like to use a Weibull statistical model to study the combined effects of temperature and current on the degradation of LEDs.

Keywords: light emitting diodes, LED degradation rate, injection current, lifetest

1. INTRODUCTION

High power light emitting diodes (LED) are being used increasingly for lighting in all kinds of applications such as commercial advertising, automobile lights, exit signs, traffic signals and more recently for exterior and interior lighting. Since their lumen output and efficiency have improved greatly in the last few years, LEDs have now become the most attractive low power consumption light source. Their low energy consumption combined with their extremely long lifetime make them a good option for newly installed light fixtures or retrofits. Deployed in the field to replace conventional sources, such LEDs will result in enormous benefits that include energy saving, reduction in global warming CO_2 emissions, reduction of pollutants and long term financial savings. LEDs can also provide additional benefits because they can be controlled to a great extent. That is why they are called *smart lighting sources*. The specific parameters that can be controlled include the emission spectrum (color temperature), dimming (modulation) and spatial emission pattern.

However, all electric light sources experience a decrease in light output over time. LEDs also suffer from aging. The primary cause of LED light output depreciation is heat generated at the LED junction. Because the LEDs do not emit heat as infrared radiation, the heat must be removed by conduction or convection. The LED package or the lamp fixture must be engineered to extract the over heat from the LED ounce the continous high temperature operation will cause permanent light reduction which reduce the energy saving. The LED package or the lamp fixture must be engineered to extract the excess heat from the LED before continuous high temperature operation causes permanent light reduction resulting in reduced energy saving. A great deal of research has been performed in recent years to be able to predict with a consistent model the exact lifetime of these new lights. These models are of critical importance in commercial lighting since they will enable manufacturers to guarantee the lifetime of the lighting fixture. The problem is that lifetime data is hard to obtain since technological advancement greatly exceeds the life of a LED. For this reason, we propose to study the relationship between the LED characteristics and the operating conditions.

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1.1 State of the research

It has been shown in many studies that the fundamental parameter in the degradation rate of the LED, which affects lifetime, is the operating temperature. To be able to predict correctly the degradation rate of the LED, a common approach is to accelerate the lumen degradation by using extreme operating conditions. One way to do this is by driving the LED with a high current without heat management. This produces self-heating at the junction well over normal operating conditions, which reduces the lumen output and creates a wavelength shift of the emission spectrum over time. The common explanation for this degradation in LED performance is that nonradiative recombination centers are created at the p-n junction [1, 2].

Another method commonly used to accelerate LED degradation is to put the LEDs in the oven at a temperature that can be as high as 150°C. Again, this causes degradation of the emission characteristics of the LEDs, which can serve as a background to predict lifetime at normal operating conditions. With this type of experimentation, some studies have shown that phosphor degrades [3], which produces rapid light output degradation at the beginning of the test. After this initial fall-off, a slower rate degradation occurs which is associated with the p-n junction.

1.2 New approach

By using high current to produce self-heating at the junction of the LED, we assume that the current itself does not cause degradation. This assumption can be risky since, to our knowledge, no proof of that has been presented. To produce a better model for the LED degradation rate, it would be better to separate the effect of the operating current from the effect of the junction temperature. In this work, we achieved this by using a temperature-controlled heatsink to drive LEDs at different currents but at comparable junction temperatures. As given in the equation 1[4], the rise in the junction temperature comes from the pads temperature (T_p), the input power (P_j) and the thermal resistance (R). By using the same LEDs with the same mounting technique, the only difference between two diodes driven with different currents is the power at the junction.

$$Tj = Tp + Pj * R \tag{1}$$

This will allow us to extract the different degradation processes involved. To build a complete model, we also used different currents to drive the LEDs without heat control. This caused an elevation in the junction temperature that is different for each operating current. Finally, we placed the LEDs in the oven at two different temperatures that provided the degradation rate when there is no current in the process. The goal of these experimentations was to find the degradation rate produced by all the parameters involved in the process. This will help to build a robust LED degradation model based on the driving conditions.

2. METHODOLOGY

The different devices tested were commercial high-brightness white LEDs obtained from two different manufacturers. The important specifications of each LED can be found in table 1. The devices were mounted on a copper plate with three LEDs from the same manufacturer on each plate as shown on Fig. 1. It can be seen that the two LEDs have different pads. As it can be seen on the left, it was easy to connect the LED model A with a wire directly soldered on the pad of the LED. For the model B, we had to solder each pad of the LED on a small printed circuit board (PCB). This was necessary to be able to drive the LED while keeping the pin at the copper plate temperature.

The heatsink of each LED was thermally-coupled to the copper plate without allowing electric contact. For the two types of LED, the ten copper plates were then separated into four groups. The number 1-3 were all mounted on a heatsink with a thermoelectric controller to manage the pads temperature for different driving currents. The operating currents that were used are around 1000 mA, 800 mA and 500 mA. These current values can be compared to the maximum recommended values given by the manufacturer, which are 1000 mA for LED model A and 400 mA for model B. Numbers 4-6 were driven with the same current as numbers 1-3 but without active thermal control. This is similar to a LED mounted on a PCB where the junction heat is removed by air convection, which is common in solid-state lighting fixtures. The plate number 7 was degraded in the oven at a temperature of (140 ± 10) °C and the plate number 9 was degraded in another oven at a temperature of (76 ± 3) °C. This must be compared with the maximum recommended storage temperature for each model of LED. This temperature is 110°C for model A and 100°C for model B, so we chose two that are over and under these values. The plate number 10 was driven with the current of 350 mA without active thermal control. This is the value used for the LED measurements and is typical of the manufacturer's datasheets. The summary of the degradation parameters used for every plate is presented in Table 2.

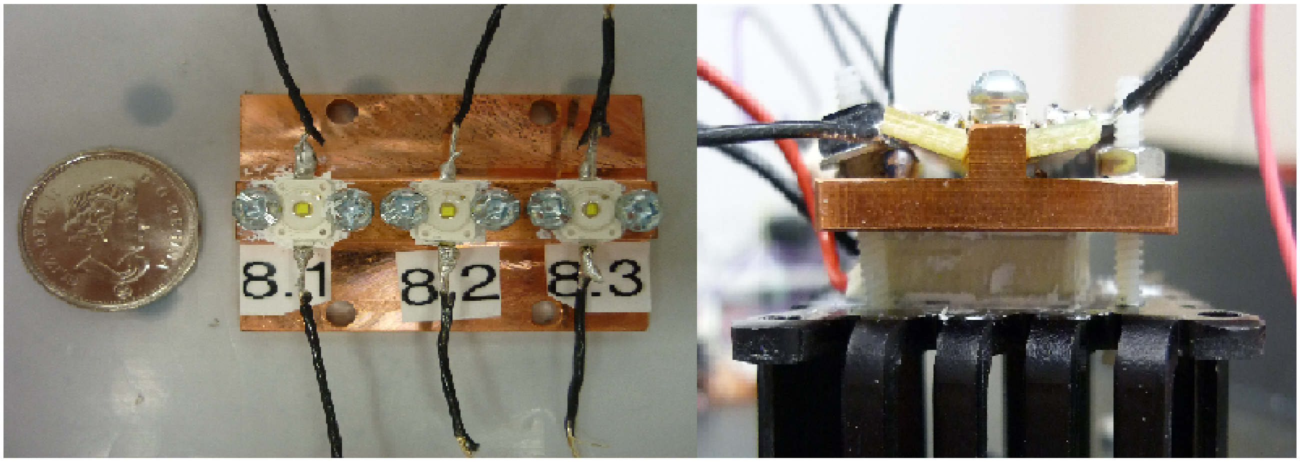

Fig. 1: LEDs mounted on the copper plate. On the right, the complete setup for temperature control with the copper plate mounted on the heatsink with thermal grease, a thermoelectric controller and a thermistor.

Table 1: LED characteristics for the two models used in the degradation test

Characteristics	**Model A**	**Model B**
Maximum forward current (T_A = 25°C)	1000 mA	400 mA
Storage temperature range	-40…+110 °C	-40…+100°C
Maximum junction temperature	125 °C	135 °C
Typical color temperature (CCT)	6500 K	5600 to 9000 K

Table 2: Degradation conditions used in the experiment for each plate and LED model

Copper plate	**Model A**	**Model B**
1	I = (1,0±0,1) A; T_{pin} = (44±3)°C	I = (0,95±0,05) A; T_{pin} = (42±3)°C
2	I = (0,80±0,05) A; T_{pin} = (43±3)°C	I = (0,80±0,05) A; T_{pin} = (44±3)°C
3	I = (0,50±0,05) A; T_{pin} = (41±3)°C	I = (0,50±0,05) A; T_{pin} = (41±3)°C
4	I = (1,0±0,1) A, T_{pin} = (59±3)°C	(1,0±0,1) A, T_{pin} = (80±5)°C
5	(0,8±0,2) A, T_{pin} = (58±3)°C	(0,80±0,05) A, T_{pin} = (60±5)°C
6	(0,50±0.05) A, T_{pin} = (48±4)°C	(0,50±0,05) A, T_{pin} = (44±4)°C
7	T_{oven} = (140±10) °C	T_{oven} = (140±10) °C
9	T_{oven} = (76±3) °C	T_{oven} = (76±3) °C
10	(0,3±0,1) A, T_{pin} = (30±3)°C	(0,35±0,05) A, (37±3)°C

Before the beginning of the accelerated degradation test, each single LED was characterized with typical measurements in the field of solid-state lighting like current-voltage curve, emission wavelength spectrum, light flux, correlated color temperature (CCT) and x-y color coordinates. Also, an emission profile of the LED was done using a homemade goniophotometer built in our laboratory. These measurements were then repeated periodically during the degradation process. It is worth noting that we were only interested in relative measurements. The data and their uncertainty cannot be related to absolute values. For the uncertainty associated with the light flux, the 7% value refers to the maximum difference obtained for the same measurement taken twice. For every measurement, the LEDs were cooled until the junction temperature reached the ambient temperature of (21±1) °C. For this reason, all measurements are comparable since they were taken in the same conditions. By doing so, we may have caused degradation by heating and cooling the junction many times. This topic will need further investigation. However, this allowed us to plot the evolution of the parameters over time.

3. RESULTS

For each graph presented, the three curves represent the three similar LEDs on the same plate. The relative light flux degradation for LED model A stressed in the oven at a storage temperature of (140±10) °C is shown in Fig. 2. It can be seen that there is around 25% loss of light flux after 1000 hours in the oven. The LED 7.2 suffered catastrophic failure, so the measurement stopped around 947 hours. The pads of the LED became too fragile and broke.

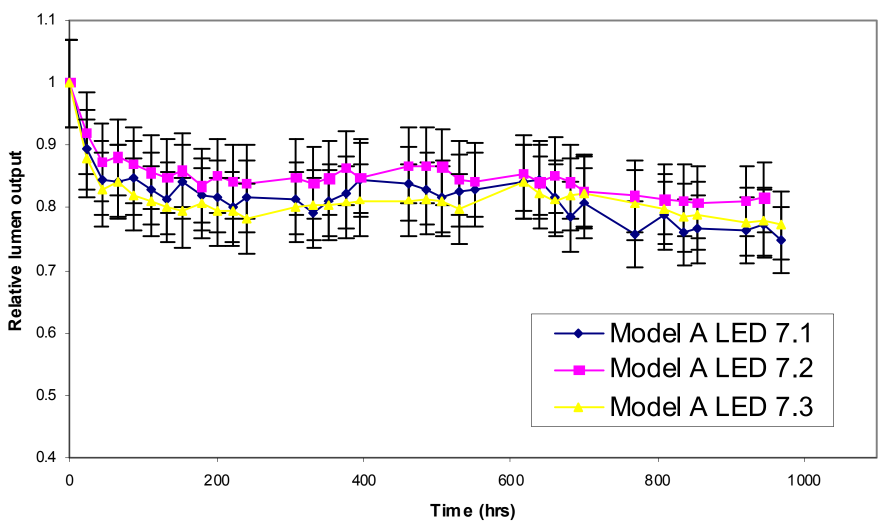

Fig. 2: Lumen output degradation for LED model A in the oven at (140±10) °C

For the sake of comparison, the same experimentation was done on LED model B. The results are shown in Fig. 3 where it can be seen that the lumen degradation is much more important. Also, there was no catastrophic failure for these LEDs so the measurements are plotted over a longer period. In fact, this experience is still running to determine if there is any change in the degradation rate. It can be seen that after 1000 hours in the oven, the lumen output is about 32% of its initial value.

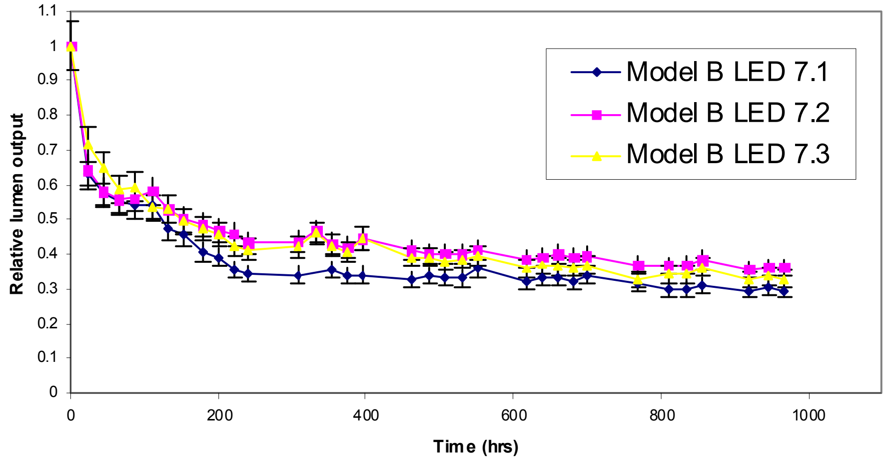

Fig. 3: Lumen output degradation for LED model B in the oven at (140±10) °C

Similar measurements have been performed on plate 9, which was put in the oven at a temperature of (76±3) °C. This temperature is well below the maximum storage temperature for both LED models, so there should be no important degradation under these conditions. The results obtained for the relative lumen output for model A is presented in Fig. 4. After about 1000 hours in the oven, the light flux is about 80% of the initial value. So, there is not much difference between the two temperatures for the same LED model. This test is still running and the results will be presented in another paper.

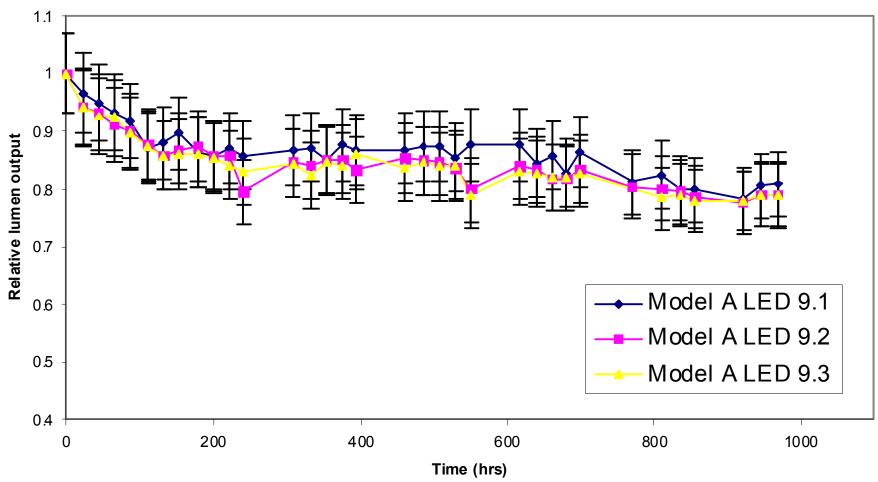

Fig. 4: Lumen output degradation for LED model A in the oven at (76±3) °C

Again, the same measurements were taken for the other types of LEDs. For LED model B, the result of a reliability test performed by the manufacturer was presented on the LED datasheet. They claim that out of 22, no LED reached 70% of the initial light flux after 1000 hours of degradation at a temperature of 100°C. In Fig. 5, it appears that after 1000 hours at 76°C, the lumen output is much less than the result obtained by the manufacturer. The two LEDs that were still working at this time had about 38% of the initial lumen output. There is not much difference with the higher temperature used in Fig. 3. The LED 9.2 was broken during handling at the beginning of the test and further measurements were not possible. This test is still running to look for a possible change in the degradation rate.

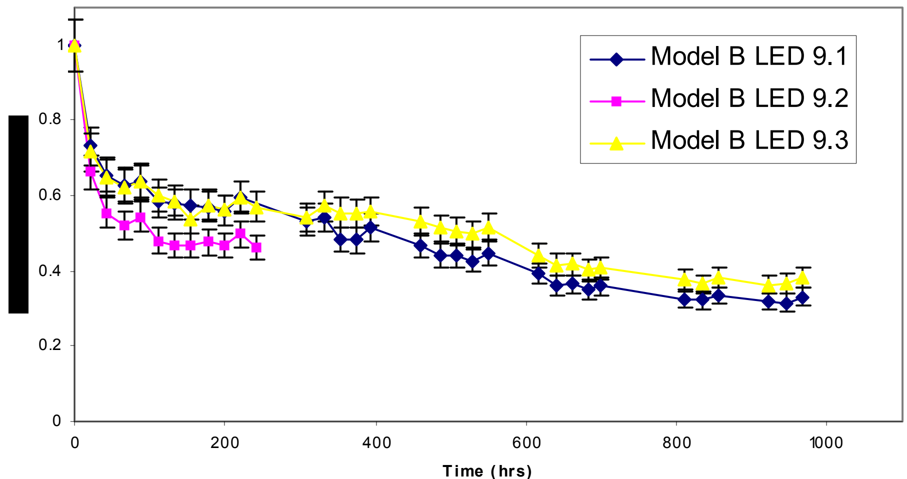

Fig. 5: Lumen output degradation for LED model B in the oven at (76±3) °C

We can now look at the effect of the two heat stresses on the CCT. This parameter was calculated by the software used with the spectrometer. The variation of the CCT for the two LED models when degraded with an ambient temperature of (140±10) °C is presented in Fig. 6 and Fig. 7 respectively. In Fig. 6, there is a small increase of a few hundred degrees after 1000 hours. Also, there is significant disparity in CCT among LEDs from the same batch.

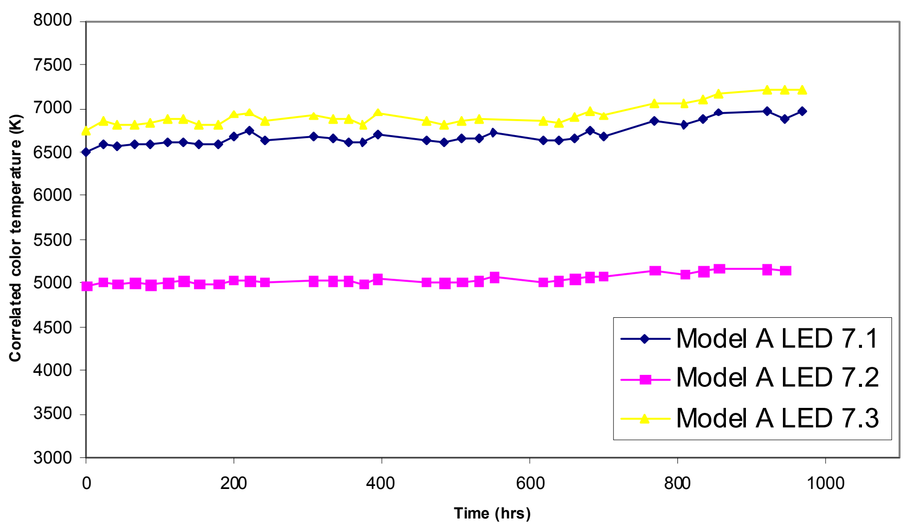

Fig. 6: CCT variation for LED model A during stress in the oven at (140±10) °C

In Fig. 7, a few hundred degrees of increase was observed for LED 7.3 while LED 7.2 and 7.1 stayed at the same CCT after 1000 hours in the oven. Therefore, it is hard to identify any trend in this test for this specific model. Also, there is less variation in the color temperature for this type of LED than for the model A.

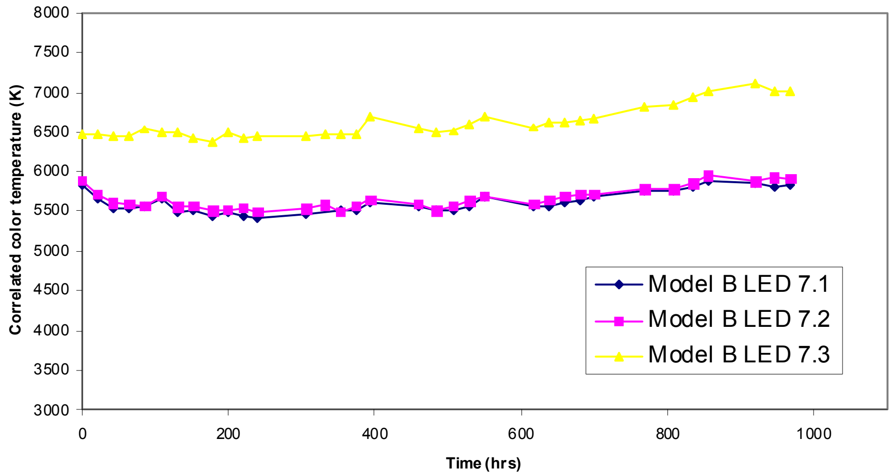

Fig. 7: CCT variation for LED model B during stress in the oven at (140±10) °C

The same measurements were made on plate 9. As shown in Fig. 8, the same increase for model A was observed. There is still considerable disparity in the initial CCT value for the different LEDs used on the same plate. This fact could be a problem when LED color is an important factor since there is so much variation in a single batch. This corresponds to a great change in the color coordinates of the light output.

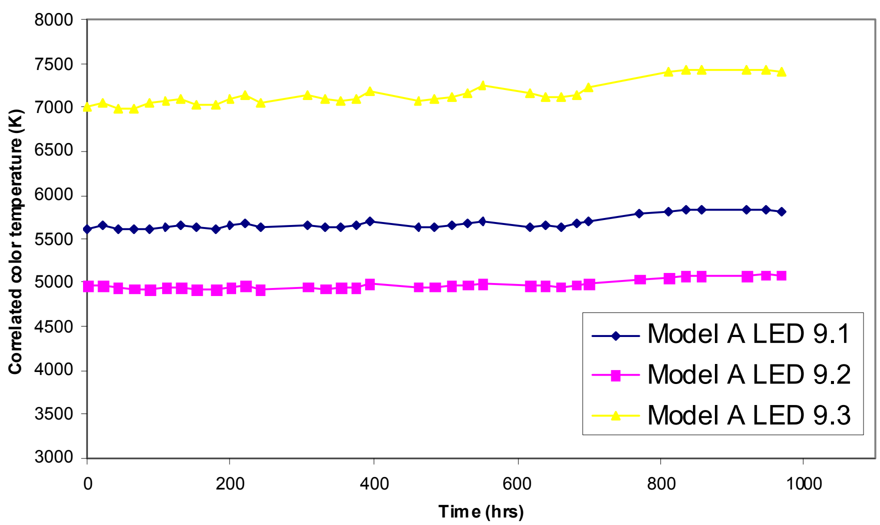

Fig. 8: CCT variation for LED model A during stress in the oven at (76±3) °C

In Fig. 9, no variation of the CCT was observed during the test. This is the same result as obtained for the other temperature with the same type of LED. Again, the color temperature is constant from one LED to the other, which is an advantage in the design of a solid-state lighting fixture. There will be further measurements performed to look for possible variation in the CCT for this specific type of LED.

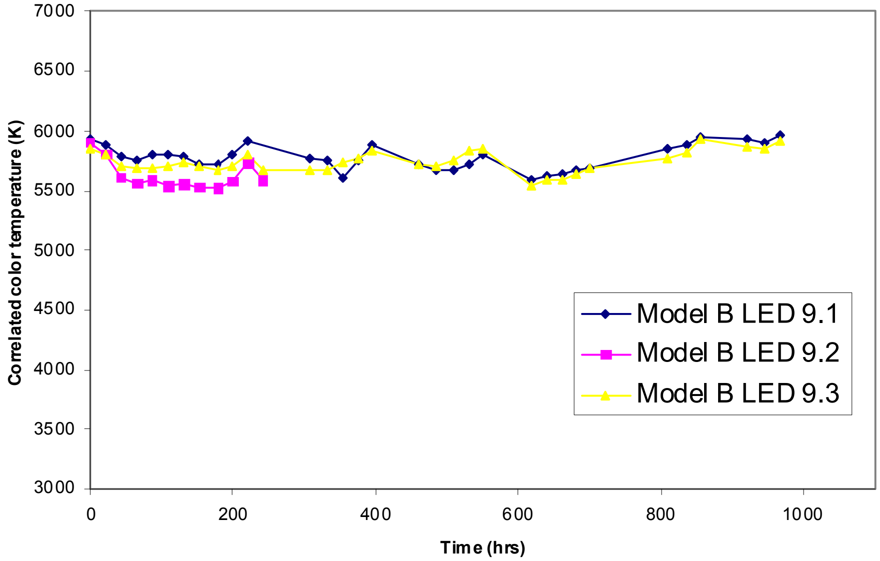

Fig. 9: CCT variation for LED model B during stress in the oven at (76±3) °C

4. CONCLUSION

The preliminary results presented in this paper indicate that the LED storage temperature is of critical importance in the degradation process. This should be a concern for manufacturers for handling and shipping of production. Also, this is of critical importance in the design of solid-state lighting fixtures. If the LEDs in the lamp suffer lumen output degradation without current injection, this is a major concern since the lifetime will be greatly reduced. In the same way, the change in CCT could cause problems in light uniformity.

These experiments are still running at this time and a longer measurement series will help to extract a trend in the evolution of the parameter. We would like to determine if the light flux stays almost constant after the fast initial decrease, as shown in the results or if there is a change in the rate. The effect of current injection will also be evaluated through a new experiment with and without active temperature control. The results will be presented in a future publication. All of these results will serve as a background to build a model for LED degradation.

In the future, we plan to continue the degradation tests already started. We will also test other LEDs from various manufacturers. In order to complete the preliminary tests presented, we will perform a new series of test on the same LEDs with power on in the oven to compare the results with figures 2, 3, 4 and 5. These measurements will help to understand the additional impact of the injection current on LED degradation.

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