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Model of Accelerated Degradation Test for LED Module

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***Abstract* – In comparison to traditional life testing, even under accelerated conditions, the degradation modelling yields more useful data. For light emitting diode modules (LEDM), where failures are rare or take a long time to occur, this is the only effective approach. A bivariate constant stress accelerated degradation test model has been proposed to high power chip-on-board LEDM. In order to verify the theoretical considerations which are being made, a special measurement stand was prepared. Tests are accomplished for one stress factor (temperature or electrical current) as well as for two stress factors (temperature and electrical current). The purpose of experiment was to find how much the temperature activated degradation was related with current stress.**

***Keywords* – Accelerated Degradation, LED Module, Reliability, Test Plan.**

I. INTRODUCTION

Due to high reliability of light emitting diodes (LED), it is hard to observe failures under normal operating conditions in a short time. Currently, the LEDs in the market have an efficiency of about 20%. Consequently 80% of the energy is converted into heat [1]. Life of a LED module is based on the combined effect of gradually light output degradation, mostly caused by material degradation and abruptly light output degradation, mostly caused by electrical component failure.

Accelerated life tests (ALT) is widely used in industry to overcome difficulties with long life [1]. Unfortunately, it may not provide helpful information for highly reliable products, which are unlikely to fail during an experiment with strong time constraint. It is known that, electric current and temperature are two suitable accelerating variables not only for LEDs. The degradation data provides more complete information for assessing conformity of physic-chemical models for test acceleration. In an accelerated degradation test (ADT), the performance characteristic degrading over time is measured at several accelerated conditions, and after that is analyzed by using a specified ADT model [2]. Degradation tests can be effective in the evaluation of system reliability when measurements of degradation leading to failure can be observed. They are an alternative to traditional life testing. The purpose of designing degradation experiments is to assess the amount of degradation at stressed use for the operating lifetime of a system. Compared with ALT, little information is available on ADT planning because it involves more design variables and is more complex in methodology development.

In the up-to-day LED industry, there are no uniform accelerated life testing methods and standards for light emitted diode modules (LEDM) yet [3]–[5]. In addition, the accuracy of life perdition is low due to many reasons such as inappropriate field loading and lack of understanding of the failure modes and failure criteria. Different accelerated tests of LEDM are conducted and results are analysed in the present paper.

II. ACCELERATED DEGRADATION TEST

A degradation study on a LED device was conducted to study the effect of current and temperature on light output over time and to predict life at use conditions. Parametric failure and catastrophic failure are two failure modes for LED devices.

LEDM degradation modelling is developed to understand the aging process of a component and it can have many useful applications with potential advantages. Two common assumptions typically are made when performing degradation modelling:

- A parameter can be measured over time that drifts monotonically either upward or downwards towards a specific failure threshold D_f and when it reaches this failure threshold the failure occurs;
- The drift is linear over time with a slope or rate of degradation, which depends on the relevant stress the LED is operating under and also the (random) characteristics of the LEDM being measured.

In order to predict reliability, based on degradation modelling, a clear understanding to failure mechanism is needed. Therefore a fundamental model to characterize propagation of the degradation path should be built. The model parameters or coefficients can then be thought of as random variables for individuals within the propagation. For LEDM the specific failure mechanisms are unknown or there are many competing failure mechanisms [6].

One of the most important advantages of degradation modelling is that multiple degradation measurements can be recorded on each individual unit within the population. In comparison to traditional life testing, even under accelerated conditions, the degradation modelling will sooner yield more useful data. For LEDM, where failures are rare or take a long time to occur, this is the only effective approach.

The degradation of light intensity in lux (lm/m^2) observed in ADT experiment is transformed by taking negative natural logarithm and by shifting the initial degradation measurements of all test LEDM to a common initial degradation value x_0 = -5 and the degradation threshold D_f = -4,3. Tests are accomplished for one stress factor (temperature or electrical current) as well as for two stress factors (temperature and electrical current). Part of transformed degradation data (for electrical current as stresses levels) are presented in Table I.

On Fig.1 an infrared image of a part of LEDM assembly and LEDs for ADT are shown. The LEDM includes 16 LEDs into a package.

In order to verify the theoretical considerations which are being made, a special measurement stand was prepared. The scheme of the experimental set up is shown in the Fig. 2.

It was composed of the examined light source together with the power supply network, an infrared (IR) camera used for the analysis of changes of the intensity (surface temperature) of light-emitting, temperature chamber with the temperature stabilizing circuit and the system of collecting, gathering and analysis of measurement data by means of a PC set-up. Temperature setting and its stabilization is realized by means of programmable PLC-type controller.

Table I: LED light intensity degradation data for Unit 1

Hours	Stress Level 1 I_f = 30mA	Stress Level 2 I_f = 40mA
50	-4,6994	-4,4918
100	-4,4397	-4,0063
150	-4,32	-3,6119

Fig.1. An infrared view of tested LEDM and LED

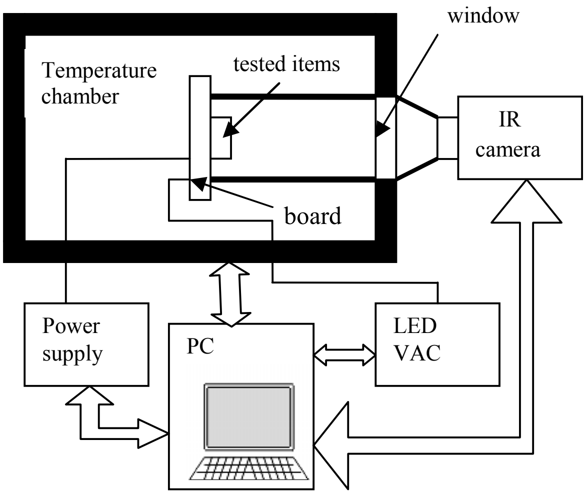

Fig.2. The scheme of the experimental set up

This circuit together with the power supply stabilizes the point of working of light sources. In some periods, measured by the steering network, the image registered by a camera is intercepted and saved.

Collected images are then processed by the Matlab environment. Temperature sensors and lux-meter is also used but they are not shown in the scheme.

III. MATH MODEL OF ACCELERATED TEST

There are difficult practical and statistical issues involved in accelerating the life of a complicated product as LEDM that can fail in different ways. Generally, information from tests at high levels of one or more accelerating variables (e.g., use rate, temperature, current or temperature) is extrapolated, through a physically reasonable statistical model, to obtain estimates of life or long-term performance at lower, normal levels of the accelerating variable(s). The very nature of accelerated tests, however, always requires extrapolation in the accelerating variable(s) and often requires extrapolation in time. This implies critical importance of model choice. Relying on the common statistical practice of fitting curves to data can result in an inadequate model or even nonsense results.

There are different methods of accelerating a reliability test. It turned out that the most informative methods for LEDM are:

- Increase the level of stress (e.g., amplitude in temperature, voltage, or current) under which test LEDM operate;
- Increase the aging rate of the LEDM;
- Combinations of these methods of acceleration are also employed.

In the third situation, when the effect of an accelerating variable is complicated, there may not be enough physical knowledge to provide an adequate physical model for acceleration (and extrapolation). Empirical models may or may not be useful for extrapolation to use conditions.

It was found that the useful types of responses for LEDM are:

- Degradation on a sample of units at different points in time
- Response directly related to the lifetime of the LEDM - typically data are right-censored or interval-censored

An important characteristic of all accelerated tests is the need to extrapolate outside the range of available data: tests are done at accelerated conditions, but estimates are needed at use conditions. Such extrapolation requires strong model assumptions.

Because of the different types of responses, however, the actual models fitted to the data and methods of analysis differ.

In order to compare the degradation mechanism found during thermal storage to operative condition, we submitted a set of LEDs to an accelerated current stress. To achieve degradation kinetic in short times, the LEDs were operated without heat sink for several tens hours. The final purpose of this test was to find how much the temperature activated degradation was related with current stress. Before stress we evaluated the temperature of the junction at nominal current in steady state operation. The final purpose of this test (Fig. 4) was to find how much the temperature activated degradation was related with current stress.

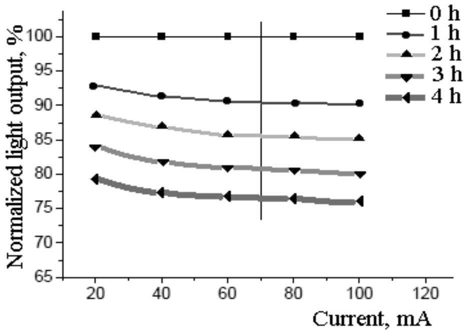

Fig.3. Light output during current ageing is plotted versus current normalized to initial values

A. Temperature-Current acceleration model

Increasing temperature is one of the most commonly used methods to accelerate a failure mechanism. On the other hand high current densities cause atoms to move more rapidly, eventually causing extrusion or voids that lead to component failure. An extended Arrhenius relationship could be appropriate for such data of LED [7].

A LED was said to have failed if its light output was reduced to 60% of its initial value. Two levels of current and six levels of temperature were used in the test. Fig. 4 shows the LED light output data versus time in hours, in the square-root scale. No units had failed during the test. For a simple method of degradation analysis, predicted pseudo failure times are obtained by using ordinary least squares to fit a line through each sample path on the square-root scale, for "hours," and the linear scale for "relative change."

Fig. 5 shows the maximum likelihood (ML) fit of the Arrhenius-inverse power relationship lognormal model (with no interaction) for the pseudo failure LED data. The data at 110^{0}C and 40 mA were omitted in the model fitting because it was determined that a new failure mode had manifested itself at that highest level of test conditions (initial efforts by engineers to use the bad data had resulted in physically impossible estimates of life at the use conditions). Fig. 6 also shows the estimate at use conditions of 20^{0}C and 20 mA.

In some cases, analysts use degradation-level data to define failure times.

B. Stochastic estimated model parameters

A bivariate constant stress ADT model has been proposed to high power chip-on-board LEDM. The experiment includes the next shortly description main steps.

It is assumed that the degradation follows a stochastic process $\{Dk(t), t \geq 0\}$ with drift $\eta_k > 0$ and diffusion $\sigma_k^2 > 0$ at x_k. It is known that the degradation increments, denoted as $D_k(t + \Delta t)$ - $D_k(t)$ are independently normally distributed random variables with mean $\eta_k \Delta t$ and variance $\sigma_k^2 \Delta t$.

If failure is defined as the first time the degradation path crosses a critical value D_c, the failure time of the product under use condition is

$$\mu_0 = \frac{D_c}{\eta_0} \tag{1}$$

at test stress

$$x_k = \frac{s_k - s_0}{s_2 - s_0} \tag{2}$$

k = 0, 1, 2; in which s_k are functions of the applied stresses. With such a transformation next relation is used: $x_0 = 0 < x_1 < x_2 = 1$. This is for easy searching for the intermediate stress within a (0, 1) plane. In order to determine the stress range, a pre-test is needed by testing a few samples at a reasonably high stress level.

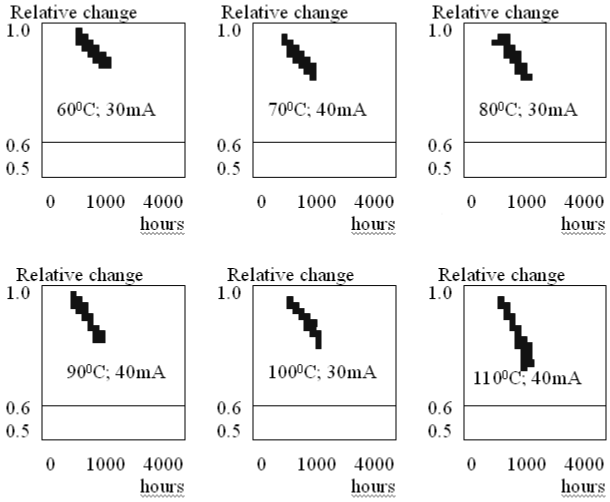

Fig.4. Relative change in light output from 138 hours at different levels of temperature and current. Relative change is in the linear scale and hours is in the square-root scale which linearizes the response as a function of time.

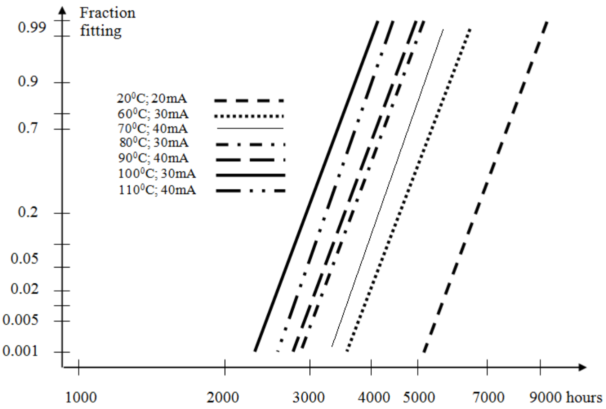

Fig.5. LED device data.

All LEDM samples are inspected simultaneously and continuously with a time interval Δt = 50 hours until the stress changing time T_k at x_k. Unit i is inspected L_k times at x_k and the degradation values observed at time $t_{i,1}$, $t_{i,2}$, …$t_{i,li}$, ti,0 = 0 <$t_{i,1}$ < $t_{i,2}$ <…< $t_{i,lk}$ <T_k are denoted as $D_{i,1}$, $D_{i,2}$, … $D_{\ i,lk}$.

The degradation is governed by a stochastic process $\{D_k(t), t \geq 0\}$ with drift $\eta_k > 0$ and diffusion $\sigma_k^2 > 0$ x_k, in which drift is stress-dependent by:

$$\eta_k = a + bx_k \tag{3}$$

and diffusion remains constant for all stresses:

$$\sigma_k{}^2 = \sigma^2 \tag{4}$$

where a, b, σ^2 are unknown parameters that need to be pre-estimated.

Since $x_0 = 0$, $x_2 = 1$ and drift at use condition is $\eta_0 = a_0$ than (3) can be rewritten as

$$\eta_k = \eta_0 \left(1 + \frac{b}{\eta_0} x_k \right) \tag{5}$$

The advantage of using (3) and (4) also lies in its simplicity in that the stress factor is zero under use stress. Parameters b, η_0 and σ_0^2 are computed by using Matlab. Fig. 6 shows the degradation paths of the standardized light intensity of a LED for one stress level.

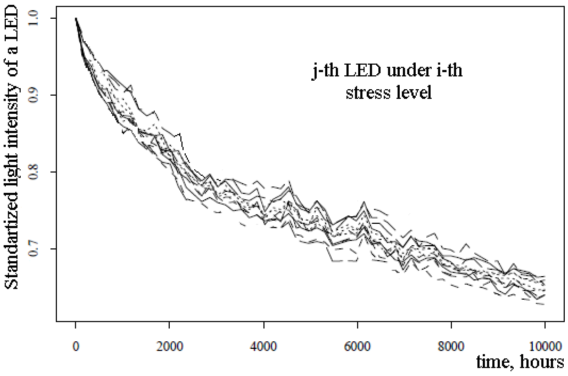

Fig.6. A typical degradation path of an LED product

As a result, only coefficient a has a bearing on the precision constraint. In a final result is life time of 27188 hours while the result for the same conditions and tested LED in physical model (section III.A) was 26596 hours.

IV. CONCLUSION

The failure mechanisms of the LEDs are complicated during the practical applications which can be coarsely divided into chip level and packaging level, if we define packaging to be system in packaging (SiP) so that the whole light fixture system is also a SiP. In the chip level, the degradation of LED devices will occur due to the generation of nonradiative defects, modifications of the electrical properties of the ohmic contacts and changes in the local indium concentration in the quantum wells under electrical and thermal stresses. In the packaging level, the degradation of package materials such as the molding compound, polycarbonate lens, silicone and phosphor and structure damages such as voids in die attach and delaminating at the different interfaces will have significant effects on the thermal, optical and reliability performance of LED devices under the electrical, thermal, moisture, chemistry and mechanical stress.

The ADT models allow lot of score for new research in terms of modelling the degradations, inspection points and the use of data in a dynamic manner to obtain estimates.

The choice of a model requires defining not only the dependency between the value of degradation and its parameters but also defining which parameters will be random variables and which will stay fixed. A continuous control of the process makes it possible to predict the time in which the emitted optical power decreases below the accepted boundary level.

Further study is needed to determine when and how frequently the units should be inspected during given time interval.

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REFERENCES

[1] S. Liu, Y. Liu, *Modeling and simulation for microelectronics package assembly, manufacturing, reliability and testing*, John Wiley and Sons, 2010.

[2] Y. Kan, "Degradatiemodellering van Witte LED tube lights", Afstudeerverslag, Department of Technology Management, Technicsche Universiteit Eindhoven. , 2007.

[3] N. Gebraeel, J. Pan, „Prognostic degradation models for computing and updating residual life distributions in a time-varying environment", *IEEE Transactions on Reliability*, 57, 539-550, 2008.

[4] Projecting Long Term Lumen Maintenance of LED Light Source; IES TM-21-11. Illuminating Engineering Society: New York, NY, USA, 2011.

[5] T. Sutharssan, S. Stoyanov, C. Bailey, Y. Rosunally, "Prognostics and Health Monitoring of High Power LED", *Micromachines*, 2012, no 3, pp.78-100, 2012.

[6] A. Andonova, S. Pleshkova, "Problems of noncontact thermography measurements of HICs", Electronics Technology, ISSE 2011, 11-15 May, High Tatras, Slovakia, pp.241-246, 2011.

[7] H. Yu, S. Tseng, "Designing a degradation experiment with a reciprocal Weibull degradation rate", *Quality Technology & Quantitative Management*, vol.1, no.1, pp 47-63, 2004

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