International Journal of Smart Home
Vol. 9, No. 11, (2015), pp. 225-234
http://dx.doi.org/10.14257/ijsh.2015.9.11.23

Light Fades and Life Prediction of LED Light Source

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Abstract

The life is the most representative parameter in the parameters of LED reliability. But the impact factor of the LED lifetime are numerous and complicated, each factor of the influence degree of each are not identical. If according to the traditional light source life test method, then the cycle is too long to not led update speed. And the majority of the LED accelerated life test by means of increasing the should force experiments to estimate the life of the LED light source, this kind of test is usually elevated led where the ambient temperature or increasing the current through the LED itself. Finally, through the acquisition of data and analysis to predict the service life of LED light source, but did not direct theoretical foundation to justify force and the service life of LED light source specific equivalent relation. Therefore, the accuracy of accelerated stress measured the service life of LED light source is yet to be verified. Through the analysis of the change of the life of LED is a gradient of chemical reaction, with the Arrhenius model, led the life of the weakening is through changes in the flux to the lumen, and for that we can under the normal working condition analysis of LED light attenuation mechanism and rules, the prediction from but realize life led to predict led by degradation of cause and the change of life.

Keywords*: LED;luminous flux;light fades; life test*

1. Introduction

LED has the advantages of high efficiency, long life,low voltage,small size,light weight,fast response,good seismic performance and so on. But lumen of the early LED products is relatively serious, resulting in people of LED, long life characteristics of the question, thus affecting the promotion of LED[1].In recent years, although the LED in the luminous intensity, luminous efficiency, long life and other aspects have been greatly improved, but led manufacturers in the life of the LED still gives only a vague concept, theory think LED life of up to, namely in the case of continuous lighting up to tens of years or even 100 years. If the LED's life is measured in normal circumstances, the time period is too long. when the measured LED life, the product may have already been eliminated. How can you measure the life of LED quickly and accurately? How can you determine the actual life of the LED? While the actual service life of[2] has become one of the industry's most concerned problems LED.

2. Definition of LED Life and Testing Standards

Life is a kind of living time from birth to death, for electronic components, its life refers to its internal physical function from the formation to the disappearance of the continuation time. In theory, the electron hole pair of LED can take a transition to produce a photon, which is an infinitely long process. But any material, even if it constitutes a LED semiconductor material, in the long time of the thermal energy of the load, the final

ISSN: 1975-4094 IJSH
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will be aging decay leading to the loss of the original function and thus failure[3]. Luminous flux is the light generated by a light source in unit time, which is radiant flux can be felt by human visual system (HVS) that part of the effective energy. LED manufacturer defines the LED's lifetime as the time when the light output drops to 70% (some 50%) is the light flux decline used to initial flux of 70% time[4].

At present,the industry has not formed a unified LED reliability test specifications or standards, which also led to the formation of different enterprises to form their own reliability test program. National standards "GB/T24908-2010 general lighting with self ballasted LED lamps-Performance requirements" in a life expectancy test method in accordance with the national standards for the GB/T24824-2009 general lighting LED module test method "in Clause 5.5 requirements and Appendix D method of, the main method is at 25 DEG C environment through the luminous flux measurement products per 300h, until 6000h lumen maintain rate calculated lifetime value of the products. However, the test method does not give a LED luminous quantity with the time changes as a function of matching curve formula or algorithm, so still can not effectively led to estimate the life. In addition, a total of 6000h life test, the test cycle is still very long. Therefore, it is urgent to speed up the test criterion or the forecast model, and make a scientific judgment on the reliability and life of LED lighting products in the shortest possible time.

3. LED Light Attenuation Mechanism

Accelerated life test is the most widely used method to predict the LED life. LED will accelerate the aging of the high current and high temperature conditions. It is for this reason, large current and high temperature working conditions under the luminous flux produced by fast decay for in the normal working current LED light output degradation and its mathematical model is established. But it should be noted that the current and the temperature can not be high to LED damage. But there is no direct theory to prove the acceleration force and the service life of LED light source the exact equivalent relation and increase different should stress the service life of LED light source decay and there will be how many different degrees of impact. It is important to understand that led life the most correct way is in accordance with the traditional light source life test method, under normal circumstances that led to the LED life termination, but due to the LED light source has characteristics of longevity, this approach in practice is clearly not feasible. So we can study the life of the LED light source under normal circumstances, and predict the life of the LED light source from the normal condition. We know that the LED lifetime decay is the direct manifestation of the luminous flux reduce LED light decay, LED light decay is led after a period of time after the light, the intensity will than the original intensity were lower and lower part is the LED brightness. For example, N hours (=1-light flux flux N hours /0 hours). So what is the cause of the failure of LED?

The main components of the ordinary LED is the fluorescent powder, the chip, the organic material[5-6]. The main reason for the LED decline is only from the decay of these materials.

By the amount of fluorescent powder and kinds of different LED light decay affect the learned phosphor will affect the light attenuation of the LED, fluorescent powder with time and environmental temperature affect the performance degradation can cause led decay[7]. From the fluorescent powder making process, it should be is resistant to high temperature, but at higher temperature will accelerate the reaction of fluorescent powder and other surrounding chemical elements, make the structure change, resulting in performance degradation. So that the effect of fluorescent powder on LED decay is one of the main reasons.

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For chip based on the theory of semiconductor physics, the diode in a drive current, composed of semiconductor material in the PN junction of the electron and hole compound, releasing energy in the form of electromagnetic waves, the peak wavelength of the electromagnetic wave by the width of the semiconductor band gap decision, when the peak wavelength in the visible light range becomes LED[8]. So the cause of decay causes and semiconductor material degradation. Never package and a variety of different packaging materials of pure blue light chip lifetimes and decay experiment shows, the life of up to hundreds of thousands of hours, and in practice led the life far less than the time, indicating that the chip material degradation does not affect the decay of the main reasons.

Through daily experience to understand different organic materials in the same conditions the decay is not the same, indicating that organic materials can cause led brightness. Organic material with high molecular structure, under the influence of temperature, short wavelength ray and other factors, the macromolecular chains will be broken and macromolecular structure will change, in the process of fracture, the light transmission characteristics will change gradually until complete failure[9-10].In addition, because the fluorescent powder is generally mixed in plastic packaging, packaging adhesive degradation process will be separated from some of the more active elements, these elements into the lattice structure of the phosphor will lead to the degradation of the fluorescent powder. So the organic material is mainly caused by the decay of LED[11].

In summary, LED is mainly composed of light material degradation caused by[12]. Caused by material deterioration, the main factor is temperature, so that temperature's influence led the life of the main external cause, which is consistent with the heat dissipation LED manufacturers of large-scale research led in recent years to extend the LED life.

4. LED Life Testing Model

Nobel Prize winning Arrhenius through study of ionization phenomena and concludes that the Arrhenius rate law is under constant environmental conditions, the chemical reaction rate can be considered to be a constant, and derive the relationship between chemical reaction rate and temperature. The theoretical basis of the model is proposed by Arrhenius in 1887, which mainly reflects the relationship between the temperature and the lifetime of the electronic components. High temperature can make products such as electronic components, insulation materials, such as to speed up the chemical reaction, to promote products in advance[13]. Therefore, this relationship is essentially a process of chemical change:

$$\frac{\partial \mathrm{M}}{\partial t} = \mathrm{A}_0 \exp(-\frac{\Delta \mathrm{E}}{kV}) \tag{1}$$

M degradation of the characteristic values of the device, $\frac{\partial M}{\partial t}$ the degradation rate of V (temperature), is the Pohl Seidman constant, V is the absolute temperature, A_0 is constant,t is the reaction time, $\Delta \mathrm{E}$ is the activation energy. The activation energy of $\Delta \mathrm{E}$ is an indicator of the influence of temperature stress on the life of the device.It is said that it is the energy barrier that exists in the transformation of the device's failure state to the failure state, the smaller the activation energy, the easier the physical process of failure. Arrhenius believes that the activation energy is not constant with the temperature change, which is the feasibility of the accelerated life test. In fact, when the temperature is greater than 500K, the activation energy is no longer constant. So for electronic products, the

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temperature stress is generally not exceed 500K. For a certain type of reaction, or in a failure mechanism, the activation energy is not constant with temperature.

By previous knowledge the degradation mechanism of LED light source is the packaging material degradation is a gradual process, and actually led the life of generally up to tens of thousands of hours, indicating that the degradation process is in accordance with Arrhenius model. The accelerated life test with temperature as the accelerated stress is very common, because high temperature can make products such as electronic components, insulation materials and other internal accelerate chemical reactions, and promote the advance of product failure[14-15] so the actual acceleration test treatment process used most widely is the Arrhenius model. The LED lifetime decay is shown by the light flux variation of the light output characteristic. By the formula (1) is knowable, flux characteristic value of the degradation rate is a constant in the constant work environment, that led luminous flux change, in any one time decay rate is roughly the same, such as led the first week of luminous flux attenuation is, then the second week is generally is in the first week of longer decay. After a week attenuation on the basis of last week. Light is the main manifestation of life the life of [16-17] LED decreased, so we can through the analysis of the LED decay to study LED. Decay is a of of the: by LED luminous flux of reduced performance, assuming luminous flux with time varying function for, according to experimental data and daily observation shows that, this function should have the following properties:

（under certain conditions）

1、$\Phi(t)$ is continuous in $(0,+\infty)$, that is, the light flux can not be changed;

2、$\Phi'(t)<0$, function is monotonically decreasing， The light flux is not likely to increase,that

is to say $P(0)\geq P(t)$；

3、The initial flux is $\Phi(0)$，The final flux is 0，in other words：

$\lim_{t\to-\infty}\Phi(t)=\Phi(0)$，$\lim_{t\to+\infty}\Phi(t)=0$；

4、According to the life of LED, it is defined as the following relationship.:

$$\Phi(T)=0.7\Phi(0) \quad (2)$$

The mathematical model through the above analysis we can construct LED decay, assuming the flux at the time point of t time is $\Phi(t)$,The flux time point t time is $\Phi(t+\Delta t)$,According to Arrhenius's law, the following relationship was established：

$$\frac{\Phi(t+\Delta t)-\Phi(t)}{\Phi(t)\times\Delta t}=K \quad (3)$$

K is a negative value.When the Δt is very small,that is, when 0 of the equation on the two sides to take the limit:

$$\lim_{\Delta t\to 0}\frac{\Phi(t+\Delta t)-\Phi(t)}{\Phi(t)\times\Delta t}=K \quad (4)$$

so there is：

$$\frac{d\Phi(t)}{d(t)}-K\bullet\Phi(t)=0 \quad (5)$$

$$\frac{d\Phi(t)}{\Phi(t)}=K\bullet dt \quad (6)$$

on both sides of the equation：

$$\int\frac{d\Phi(t)}{P(t)}=\int K\bullet dt \quad (7)$$

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$$\Phi(t) = \Phi_0 e^{K \bullet t} \tag{8}$$

Φ_0 is the initial flux. It is obvious that the calculated flux expressions satisfy the three properties of the flux function.

LED's life experience fluxattenuation to the initial value of 0.7 times the time, so the life of T satisfy the following relations：

$$\Phi(T) = \Phi_0 e^{K \bullet T} = 0.7\Phi_0 \tag{9}$$

$$T = \frac{\ln 0.7}{K} \tag{10}$$

So it is only required that the K can work out the life of LED.

5. LED Life Accelerated Test Platform

Experimental apparatus and equipment：photoelectric comprehensive test system(Integral sphere diameter0.3m）；1w WhiteLED，personal computer，Constant temperature box.Measurement system as shown below:

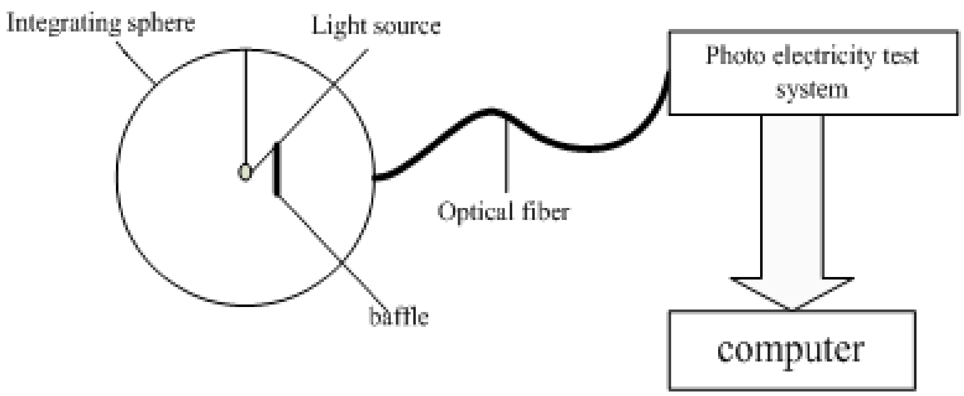

Figure 1. Measurement System

The specifications are the same and are unified batch of 30 1w white LED are divided into three groups, each for a group of 10, in the same situation (stress are rated stress) test and record changes in 30 LED luminous flux. And the maximum and minimum luminous flux of each test two LED removed, the remaining LED flux averaged record in the following table：

time（h）	1 groups of luminous flux（mlm）	2 groups of luminous flux（mlm）	3 groups of luminous flux（mlm）
0	27022	26587	27208
100	26950	26430	27189
200	26898	26412	27153
300	26870	26383	27160
400	26882	26357	27134
500	26824	26258	27094
600	26835	26247	27058

Figure 2. LED Luminous Flux Mean Record

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From the above data can be seen, 1W white LED luminous flux with time overall declining trend, but the downward trend is not obvious, which is consistent with the characteristics of long life of LED, it also explains the LED light decay in the presence of life may not be infinitely long. If the rules of the LED luminous flux satisfy formula (10), using Excel can be quickly obtained (10) k value and draw the curve of luminous flux and seek out the equations

After a set of LED selection time and a set of LED flux data into a chart, select the chart type "x-y scatter plot", after the scatterplot generation, select "Add trend line" in the "trend forecast / regression type" Select type of "index" type, will generate a set of LED flux data trend line in the options bar, choose a "Display formula" and show "R-squared value", the luminous flux curve equation will be generated. As shown below:

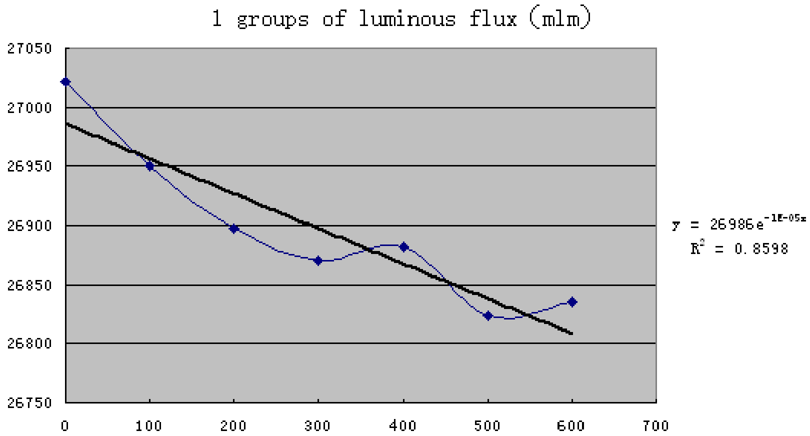

Figure 3. 1 Group of Luminous Flux(mlm)

Blue line is drawn by the acquisition of the flux curve and black lines denote is calculated by computer and luminous flux curve of the similar index curve fitting curve.

For the results of analysis $y = 26986 e^{-0.000011\,x}$, $R^2 = 0.8599$, Where R^2 denotes recorded flux data and curve fitting degree of correlation, R^2 value close to 1 that accord a high degree of fitting curve equation and the luminous flux change trend, the curve fitting equations to approximate on behalf of luminous flux variation.

So for the 1 group LED: $\Phi(t) = 26986 e^{-0.000011\,t}$, $\mathrm{K} = 0.000011$, $\Phi(0) = 26986$

Into the formula, the 1 group of LED life: $\mathrm{T} = \dfrac{\ln 0.7}{\mathrm{K}} = \dfrac{\ln 0.7}{-0.000011} = 32425$

Or directly to the extension of the trend line, "prediction of trend line before pushing the value set in the options, from the curve of readout 0.7 corresponds to the time t is the No. 1 led the life.

Similarly, linear regression analysis of 2 groups and 3 groups of LED using the same method as the following:

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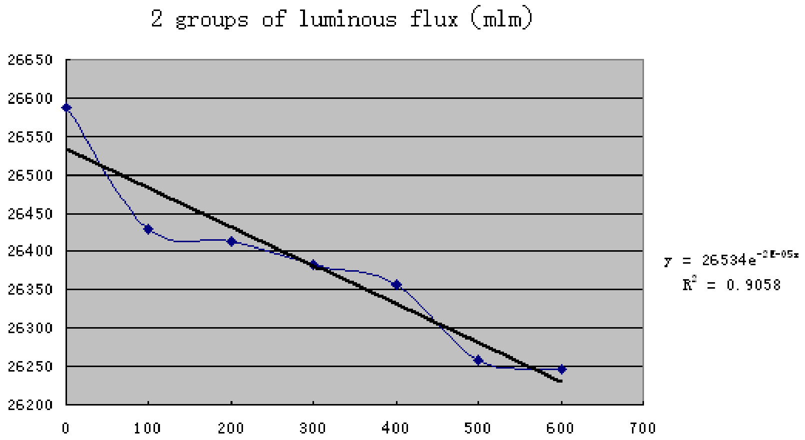

Figure 4. 2 Groups of Luminous Flux(mlm)

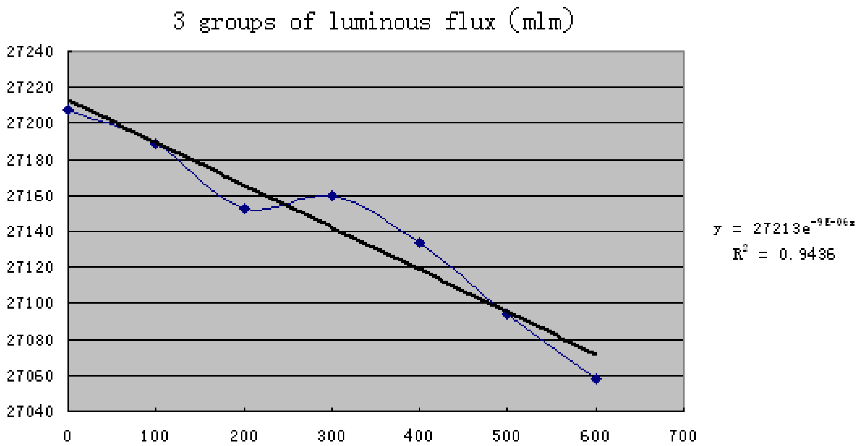

Figure 5. 3 Groups of Luminous flux(mlm)

For 2 groups of LED: $\Phi(t) = 26534\, e^{-0.000019\, t}$, $K = -0.000019$, $\Phi(0) = 26534$

Into the formula, 2 groups of LED life: $T = \dfrac{\ln 0.7}{-0.000019} = 18773$

For 2 groups of LED: $\Phi(t) = 27213\, e^{-0.0000087\, t}$, $K = -0.0000087$, $\Phi(0) = 27213$

Into the formula, 3 groups of LED life: $T = -\dfrac{\ln 0.7}{-0.0000087} = 40997$

From the life analysis of LED, the LED can reach 1×10^4 h,and the life of LED can not reach its theoretical life $10^5 \sim 10^6$ h[18] due to the influence of external and internal factors.

6. Conclusion

LED has a high energy efficiency, long life, for the life of the LED if the traditional measurement method, then the cycle is too long, probably in some measure the life of the LED, this kind of LED may have already been eliminated, and currently used LED accelerated life test methods[18-19] are increased by stress conditions LED normal working hours, through testing, analysis, observation and theory to predict the life of an indirect LED light source, there is no direct theoretical support can not be accurate Restore gradual process LED life. Because the LED's life is mainly determined by the composition loaded material, LED life of decay is caused by degeneration of the composition of the material, and the composition of the material degeneration is a long degradation process, thus weakening the LED life in line with Allen Nieuwpoort Adams model, so under normal circumstances through the LED light output characteristics namely flux build Arrhenius model to study the trend of LED luminous flux is estimated LED life. Under normal circumstances such tests accurately reflects the gradual process LED life, but also to understand the proper changes in the LED life, predictable results than the accelerated stress test LED life is more intuitive and more accurate. Due to the impact of external factors and their own actual life of LED is usually much lower than the theoretical life[20]. Finally, research on the LED luminous flux changes greatly reducing the traditional methods of LED lifetime measurement of time, would be a quick and accurate way to estimate future LED life.

Acknowledgements

This work is supported by Natural Science Foundation of Heilongjiang Province of China under Grant Nos. F201310 and Special fund for scientific and technological innovation talents of Harbin under Grant Nos. RC2013Q0009007 and Research and development project of Heilongjiang Province under Grant Nos. GC13A412

References

[1] H. Liu, S. Xue, "White LED Status and Problems", Lamps and Lighting, no.3, **(2003)**, pp. 4-8.
[2] T.-L. Gui, J. Wei, F.-M. Wu, and X.-L Dong, "Research on Optical and Electrical Properties ITO/NPB/Alq3/LiF/Al OLED", Journal of Harbin University of Science and Technology, no. 5, **(2012)**, pp.104-106.
[3] X. Liu and W. Yan, "White LED life prediction method as defined[J].Lamps and Lighting", no. 4, **(2001)**, pp. 16-22.
[4] Y. Wang, X .V. Linwei and Y. Xu, "InGaN-based light emitting diode light effects advances drop effect", Laser and Optoelectronics Progress, vol. 49, no. 12, **(2013)**, pp. 15-21.
[5] H. Wu and C. Wang, "Experimental Research on Influence of Packing Materials of White LED on Its Luminous Decay, Acta Optica Sinica, vol. 25, no. 8, **(2005)**, pp. 1091 -1094.
[6] J. Zhang, D.-X. WANG and C-D Shi, "Fabrication and Characteristics Test of ITO/CuPc/Alq_3/Al Organic Light-emitting Diodes", Journal of Harbin University of Science and Technology, no. 04, **(2004)**, pp. 79-81.
[7] F. Manyakhin, A. Kovalev and A. E. Yunovich, "Aging mechanisms of InGaN/AlGaN/GaN light-emitting diodes operating at high currents", MRS Internet J of Nitride Semiconductor Research, no. 3, **(1998)**, pp. 53-58.
[8] X. Fan, "Solid light and its application Physics Teaching", vol. 22, no. 9, **(2002)**, pp. 2-6.
[9] Y. Chen, B. Li, G. Fan, "Phosphor white LED in aging research, Journal of Foshan University(Natural Science Edition), , vol. 25, no. 4, **(2007)**, pp. 6-8.
[10] D. Cui, W. Guo, B. Cui, W. Yan and Y. Liu, "Implantation current on GaN-based LED light emitting characteristics", Journal of Optoelectronics.Laser, vol. 22, no. 9, **(2011)**, pp. 1309-1312.
[11] Y. Wu, S. Fen, Z. Dan, G. Wei, "GaN-based white LED phosphor layer Failure Mechanism", Laser and Optoelectronics Progress, vol. 49, no. 10, **(2012)**, pp. 168-173.
[12] X. Li, J Gao and S. Zhang "Polymer Materials natural environment law and mechanism of agin, Beijing:Science Press, **(2001)**, pp. 20-43.
[13] L. Xia, T. Jiang and Y. Chen, "Research Arrhenius model", Product Reliability and Environmental Testing, vol. 23, no. 2, **(2005)**, pp. 12-14.
[14] C. Zhang and X. Wen, "Survey of accelerated life test", Acta Armamentarii, vol. 25, no. 4, **(2004)**, pp. 485-490.
[15] L. Liang and Z. Chen, "Accelerated aging characteristics of white LED", Chinese Journal of Luminescence, vol. 26, no. 5, **(2005)**, pp. 617-621 .
[16] F. Fang, H. Wang and D Song, "White LED attenuation spectroscopy", Chinese Journal of Luminescence, vol. 29, no. 2, **(2008)**, pp. 353-356.

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[17] W. Guo, X. Fan, D. Cui, G. Wu and X. Yu, "LED Reliability rapid evaluation method based on the pseudo-failure life", Chinese Journal of Luminescence, vol. 34, no. 2, **(2013)**, pp. 213-217.
[18] L. Zhang, X. Gao, B. Bo and S. Li. "Experimental study of accelerated aging high-voltage white LED's", Journal of Changchun University of Science and Technology, no. 3, **(2013)**, pp. 1-4.
[19] J. HU, L. Yang and L. Kim, "The aging mechanism of high-power InGaN/GaN light-emitting diodes under electrical stresses", Semiconductor Science and Technology , vol. 22, no. 12, **(2007)**, pp. 1249-1252.
[20] L. Zhang, Z. Li, J. Zhang, Z. Luo and Y. Cui, "Research on Mechanism of High-Power LED Luminous Attenuation", Semiconductor Technology, vol. 34, no. 5, **(2009)**, pp. 474-477.

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