Numerical Analysis and Modeling of LED Luminaries

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HAND’S ON FINAL REPORT

Numerical Analysis and Modeling of LED Luminaries

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1. **Background**

LED is short for Light Emitting Diode, a small device that converts electricity in light and heat. LED technology is based on the semiconductor technology, the first LEDs in 1962 [1] emitted light in the red color spectrum, now days LEDs emit light across the visible, ultraviolet and infrared wavelengths, with very high brightness.

When a light-emitting diode is forward biased (switched on), electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence and the color of the light (corresponding to the energy of the photon) is determined by the energy gap of the semiconductor. An LED is often small in area (less than 1 mm^2), and integrated optical components may be used to shape its radiation pattern.[2] LEDs present many advantages over incandescent light sources including lower energy consumption, longer lifetime, improved robustness, smaller size, faster switching, and greater durability and reliability. LEDs powerful enough for room lighting are relatively expensive and require more precise current and heat management than compact fluorescent lamp sources of comparable output.

Light-emitting diodes are used in applications as diverse as replacements for aviation lighting, automotive lighting (particularly brake lamps, turn signals and indicators) as well as in traffic signals. The compact size, the possibility of narrow bandwidth, switching speed, and extreme reliability of LEDs has allowed new text and video displays and sensors to be developed, while their high switching rates are also useful in advanced communications technology. Infrared LEDs are also used in the remote control units of many commercial products including televisions, DVD players, and other domestic appliances.

Electroluminescence as a phenomenon was discovered in 1907 by the British experimenter H. J. Round of Marconi Labs, using a crystal of silicon carbide and a cat's-whisker detector.[4][5] Russian Oleg Vladimirovich Losev reported on the creation of a first LED in 1927.[6][7] His research was distributed in Russian, German and British scientific journals, but no practical use was made of the discovery for several decades.[8][9] Rubin Braunstein of the Radio Corporation of America reported on infrared emission from gallium arsenide (GaAs) and other semiconductor alloys in 1955.[10] Braunstein observed infrared emission generated by simple diode structures using gallium antimonide (GaSb), GaAs, indium phosphide (InP), and silicon-germanium (SiGe) alloys at room temperature and at 77 Kelvin.

In 1961, American experimenters Robert Biard and Gary Pittman working at Texas Instruments.[11] found that GaAs emitted infrared radiation when electric current was applied and received the patent for the infrared LED.
The first practical visible-spectrum (red) LED was developed in 1962 by Nick Holonyak Jr., while working at General Electric Company.[2] Holonyak is seen as the "father of the light-emitting diode".[12] M. George Craford,[13] a former graduate student of Holonyak, invented the first yellow LED and improved the brightness of red and red-orange LEDs by a factor of ten in 1972.[14] In 1976, T.P. Pearsall created the first high-brightness, high efficiency LEDs for optical fiber telecommunications by inventing new semiconductor materials specifically adapted to optical fiber transmission wavelengths.[15]

Until 1968, visible and infrared LEDs were extremely costly, on the order of US $200 per unit, and so had little practical use.[16] The Monsanto Company was the first organization to mass-produce visible LEDs, using gallium arsenide phosphide in 1968 to produce red LEDs suitable for indicators.[16] Hewlett Packard (HP) introduced LEDs in 1968, initially using GaAsP supplied by Monsanto. The technology proved to have major uses for alphanumeric displays and was integrated into HP's early handheld calculators. In the 1970s commercially successful LED devices at fewer than five cents each were produced by Fairchild Optoelectronics. These devices employed compound semiconductor chips fabricated with the planar process invented by Dr. Jean Hoerni at Fairchild Semiconductor.[17] The combination of planar processing for chip fabrication and innovative packaging methods enabled the team at Fairchild led by optoelectronics pioneer Thomas Brandt to achieve the needed cost reductions. These methods continue to be used by LED producers.[18]

The first commercial LEDs were commonly used as replacements for incandescent and neon indicator lamps, and in seven-segment displays,[19] first in expensive equipment such as laboratory and electronics test equipment, then in such appliances as TVs, radios, telephones, calculators, and even watches (see list of signal uses). These red LEDs were bright enough only for use as indicators, as the light output was not enough to illuminate an area. Readouts in calculators were so small that plastic lenses were built over each digit to make them legible. Later, other colors grew widely available and also appeared in appliances and equipment. As LED materials technology grew more advanced, light output rose, while maintaining efficiency and reliability at acceptable levels. The invention and development of the high power white light LED led to use for illumination, which is fast replacing incandescent and fluorescent lighting.[20][21] (see list of illumination applications). Most LEDs were made in the very common 5 mm T1¾ and 3 mm T1 packages, but with rising power output, it has grown increasingly necessary to shed excess heat to maintain reliability,[22] so more complex packages have been adapted for efficient heat dissipation. Packages for state-of-the-art high power LEDs bear little resemblance to early LEDs.

The first high-brightness blue LED was demonstrated by Shuji Nakamura of Nichia Corporation and was based on InGaN borrowing on critical developments in GaN nucleation on sapphire substrates and the demonstration of p-type doping of GaN which
were developed by Isamu Akasaki and H. Amano in Nagoya. In 1995, Alberto Barbieri at the Cardiff University Laboratory (GB) investigated the efficiency and reliability of high-brightness LEDs and demonstrated a very impressive result by using a transparent contact made of indium tin oxide (ITO) on (AlGaInP/GaAs) LED. The existence of blue LEDs and high efficiency LEDs quickly led to the development of the first white LED, which employed a Y3Al5O12:Ce, or "YAG", phosphor coating to mix yellow (down-converted) light with blue to produce light that appears white. Nakamura was awarded the 2006 Millennium Technology Prize for his invention.[23]

The development of LED technology has caused their efficiency and light output to rise exponentially, with a doubling occurring about every 36 months since the 1960s, in a way similar to Moore's law. The advances are generally attributed to the parallel development of other semiconductor technologies and advances in optics and material science. This trend is normally called Haitz's Law after Dr. Roland Haitz. [24]

In February 2008, 300 lumens of visible light per watt luminous efficacy (not per electrical watt) and warm-light emission was achieved by using nanocrystals.[25]

In 2009, a process for growing gallium nitride (GaN) LEDs on silicon has been reported. Epitaxy costs could be reduced by up to 90% using six-inch silicon wafers instead of two-inch sapphire wafers.[26]

**Advantages**

- **Efficiency**: LEDs emit more light per watt than incandescent light bulbs. Their efficiency is not affected by shape and size, unlike fluorescent light bulbs or tubes.
- **Color**: LEDs can emit light of an intended color without using any color filters as traditional lighting methods need. This is more efficient and can lower initial costs.
- **Size**: LEDs can be very small (smaller than 2 mm^2) and are easily populated onto printed circuit boards.
- **On/Off time**: LEDs light up very quickly. A typical red indicator LED will achieve full brightness in under a microsecond. LEDs used in communications devices can have even faster response times.
- **Cycling**: LEDs are ideal for uses subject to frequent on-off cycling, unlike fluorescent lamps that fail faster when cycled often, or HID lamps that require a long time before restarting.
- **Dimming**: LEDs can very easily be dimmed either by pulse-width modulation or lowering the forward current.
- **Cool light**: In contrast to most light sources, LEDs radiate very little heat in the form of IR that can cause damage to sensitive objects or fabrics. Wasted energy is dispersed as heat through the base of the LED.
- **Slow failure**: LEDs mostly fail by dimming over time, rather than the abrupt failure of incandescent bulbs.
• Lifetime: LEDs can have a relatively long useful life. One report estimates 35,000 to 50,000 hours of useful life, though time to complete failure may be longer. Fluorescent tubes typically are rated at about 10,000 to 15,000 hours, depending partly on the conditions of use, and incandescent light bulbs at 1,000–2,000 hours.

• Shock resistance: LEDs, being solid state components, are difficult to damage with external shock, unlike fluorescent and incandescent bulbs which are fragile.

• Focus: The solid package of the LED can be designed to focus its light. Incandescent and fluorescent sources often require an external reflector to collect light and direct it in a usable manner.

**Disadvantages**

• High initial price: LEDs are currently more expensive, price per lumen, on an initial capital cost basis, than most conventional lighting technologies. The additional expense partially stems from the relatively low lumen output and the drive circuitry and power supplies needed.

• Temperature dependence: LED performance largely depends on the ambient temperature of the operating environment. Over-driving an LED in high ambient temperatures may result in overheating the LED package, eventually leading to device failure. Adequate heat sinking is needed to maintain long life. This is especially important in automotive, medical, and military uses where devices must operate over a wide range of temperatures, and need low failure rates.

• Voltage sensitivity: LEDs must be supplied with the voltage above the threshold and a current below the rating. This can involve series resistors or current-regulated power supplies.

• Light quality: Most cool-white LEDs have spectra that differ significantly from a black body radiator like the sun or an incandescent light. The spike at 460 nm and dip at 500 nm can cause the color of objects to be perceived differently under cool-white LED illumination than sunlight or incandescent sources, due to metamerism, red surfaces being rendered particularly badly by typical phosphor based cool-white LEDs. However, the color rendering properties of common fluorescent lamps are often inferior to what is now available in state-of-art white LEDs.

• Area light source: LEDs do not approximate a “point source” of light, but rather a lambertian distribution. So LEDs are difficult to apply to uses needing a spherical light field. LEDs cannot provide divergence below a few degrees. In contrast, lasers can emit beams with divergences of 0.2 degrees or less.

• Blue hazard: There is a concern that blue LEDs and cool-white LEDs are now capable of exceeding safe limits of the so-called blue-light hazard as defined in eye safety specifications such as ANSI/IESNA RP-27.1–05: Recommended Practice for Photo biological Safety for Lamp and Lamp Systems.

• Electrical Polarity: Unlike incandescent light bulbs, which illuminate regardless of the electrical polarity, LEDs will only light with correct electrical polarity.
• Blue pollution: Because cool-white LEDs (i.e., LEDs with high color temperature) emit proportionally more blue light than conventional outdoor light sources such as high-pressure sodium vapor lamps, the strong wavelength dependence of Rayleigh scattering means that cool-white LEDs can cause more light pollution than other light sources. The International Dark-Sky Association discourages using white light sources with correlated color temperature above 3,000 K.

• Droop: The efficiency of LEDs tends to decrease as one increase current.

2. Introduction

Computational power has allowed us to model LEDs and entire components with cost saving methods from which an end product can be achieved. With the increase in lumens and efficiency of Light-emitting Diodes their application in the light industry has opened a new market into the development of lamps. This investigation discusses the use of Focal Diffusion films and the most appropriate arrangements in an LED desk lamp for its efficient use. Use of all these recommendations accounts into the construction of a highly efficient low watt consumption LED desk lamp of less than 10 watts of power.

High power LEDs have reached above 100 lm/W making them suitable for replacing light bulbs in conventional desk lamps [26,27], yet their light distribution, efficiency and heat problems are what hold them from taking over the market. To produce a highly efficient LED desk lamp all these problems must be overcome, our method will consist of use of reflectors [28], FD films, heat sinks, collected data and simulations done with commercials software of the likes of TracePro [29] and Comsol[30].

The LED desk lamp should be able to meet the required standards set by governments and other organizations such as Illumination Engineering Society of North America (IESNA). According to IESNA at least a minimum 70 Foot candle of luminance is required at an Office setup. Average wall luminance of at least 30 to 100 cd/m² is preferred in typical office work spaces (where 300 to 1000 lx [30 to 100 fc] is provided on the work plane) [31, 32]. Although illumination requirements vary on application, perceived illumination varies on distances, angles, color, and reflectance from many different surfaces, therefore in this experiment we only analyze the irradiance distribution over a flat area parallel to the surface of the LED array [33].

Current LED luminous efficiency is about 15% ~ 25%, in other words, about 75% to 85% of energy is converted into thermal energy [34], when the heat fails to disperse, high-temperatures will lead to a fast aging chip, And accelerate the decay and reduce the emission efficiency of LED life; therefore high power LED must effectively disperse heat to maintain chip Junction temperature in the normal temperature range, to avoid the decrease of its illumination efficiency and life expectancy [35], so the management of LED heat is of more significant importance because of the heat dissipation problem, therefore it is necessary to further explore and study this area.
If the thermal design is not good for the PN junction light-emitting chips when the heat generated reaches high temperatures, LED brightness, lifetime and wavelength will start decaying and even at high temperatures the LED may damaged; Therefore, demand for LED cooling is necessary to achieve the advantages of the necessary conditions for the maintenance of component life, by possible control of the junction temperature under 110 °C. Parts and components must be under the controlled junction temperature of 110 °C for the maintenance of life following [36].

With the use of the LED, illumination efficiency will start to reduce time after time; excessive junction temperature will accelerate the decay of LED light efficiency and life [37-39]. Narendran [40] and other scholars conducted experiments on the LED in different environments, which pointed out that the higher ambient temperature the more intense decay of its life. Ambient temperature and package type directly affects the effective cooling and useful life of LED. Petroski [41] used analysis to improve the thermal performance of LED, and used ANSYS analysis software, to discover that ambient temperature and LED spacing is a key factor affecting junction temperature due to the heat source spacing, spacing will create a small heat concentration. Wei-Guo Han and others [42] modeled cooling LED chip into thermal resistance, making thermal diffusion substrates, heat sink and ambient temperature into thermal resistance of three parts, application of thermal resistance calculation obtains the total overall heat sink thermal resistance, by computer simulation it is possible to predict the temperature of the cooling module, in order to assess the status of LED chip cooling. Huang Zhen Kang et al [43] using COSMOSFloWorks simulated and experimented film symptoms of heat sink under natural convection, using the chimney effect to increase the flow rate so that the heat transfer capability can be improved. Hu et al [44] used numerical analysis from experiment measured data of ceramic thermal cooling temperature distribution channel, to verify measurement accuracy of each part of the LED thermal resistance. Adam and Samuel [45] established a three-dimensional finite element model.

Analyses of the thermal effect on the package body of high power DC / AC LEDs reveal that the dissipation of heat on high power DC / AC LEDs directly impact the device’s performance; the overall module design requires effective cooling structure that will eliminate heat in order to effectively increase luminescence efficiency and lifetime of future devices.

AC LED system is formed through a special manufacturing process so that a combination of multiple particles exist, through a direct supply of AC alternating current, but does not need an external DC converter, however the LED is not reduced in size and weight, yet converter components space are eliminated and cost is down. There is also savings between 15 to 30% of the electricity loss for the conversion process between the traditional AC and DC LED.
It is necessary to judge the junction temperature specifications in order for proper operation. Therefore this study used a number of experimental measurements and computer analysis, to solve DC / ACLEDs experiments and conduct numerical calculation with a software package, to determine a reasonable solution to ensure the LED product performance. The experimental measurements and simulation results of the main structure of the LED chip, slug, lens, leg, heat sink and star shaped MCPCB plate. In order to be able to reduce development costs, using simulation software, as long as substituting the correct boundary conditions, the results will have very little difference between the actual experiments.

In the recent development of LED technologies and market growth of LED luminaries, further study is needed in order for LEDs to replace the current incandescent bulb. Because of the LED radiation pattern, and it being a point-type light source, LED luminaries must employ similar and different methods than those of other luminaries in order to achieve a uniform irradiance. The methods presented in this paper can fasten the production of luminaries while cutting cost and still make luminaries with over 80% uniform irradiance. To achieve these methods reflectors, of 97% reflectivity, of multiple shapes and angles are combined with different arrays of LEDs. All luminaries are constructed using SolidWorks, and then ray data is simulated in TracePro commercial software. The final luminaries are then manufactured and the simulated results are compared and verified with experimental results. The purpose of this paper is to create luminaries for different situations that are affordable to produce while maximizing light efficiency.

3. **LED Modeling with TracePro**

First choose the Led for your application, the following characteristics must be considered in order to make the right choice:

- LED color
- LED Flux
- LED angle type:
  - I. Side Emitting
  - II. Lambertian
  - III. Batwing
- LED Manufacturer

For demonstration we will use a cool white LED with a flux of 80 lumens with a lambertian angle distribution from Edison Opto.

Find the LED data Properties: its wavelength and its radiation pattern.
Figure 1. LED Wavelength

Figure 2. Polar Radiation Pattern

Next open TracePro Source Property Generator copy and paste your image and select your reference points and input the data.
Figure 3. Set your Reference points

Figure 4. Select your data points

Select your LED properties and units in this case Photometric:
LED angular intensity distribution is of much importance as well, it will be used to verify if our LED model is accurate or not. There are two types of angular distribution Polar and Rectangular copy and paste your image, then select your reference points and input data.
Remember to put your number of points. The more points the more accurate.

Figure 7. Select Polar Radiation Data Points

Select Export and save the data in TracePro.

Figure 8. Export and save data

Open TracePro and import data file you just created.
Figure 9. Import Surface Properties

Figure 10. Select your surface Properties

Your data should look like the image below:
Now it is time to test your source data, to verify if the LED intensity is accurate and the irradiation angle is along the range of our LED. To begin we first create an LED using the CAD tools in TracePro.

The Chip is modeled as a block with a length and width of 1mm and a thickness of 200e-6 mm. Add the surface properties to the LED face that you want the light to be emitted from as shown in Figure 13.
To apply surface properties select a catalog and name under which you have stored your Led data and then click apply.

Select the Led Light units for ray tracing in this case Photometric
Figure 15. Select LED units.

Apply Surface Source Properties, the source type is Flux the flux is 80 lumens the total rays are 1000 (the more rays the more accurate is the solution) the Angular distribution is Lambertian, finally click apply.
It is now time to Trace Rays, Select Analysis, Trace Rays, Select Surface Source ALL click Apply and Trace Rays.
Figure 17. Trace Rays

Plot the candela plots to verify the LED simulation is accurate with the datasheet provided by the manufacturer.
4. **Experiment Methods and Laboratory Equipment**

All models were first established in Solidworks and then analyzed using TracePro for ray tracing. Edison Opto LEDs point type series of 0.5 watt LEDs with 40 lumens and 1 Watt LEDs with 90 lumens were used in this paper. All LEDs have a radiation pattern of 120° degrees. Fig. 19 shows the model setup which consist of an LED luminary, reflector, and a perfect absorber of 550mm at a distance, \( H \), of 380mm from the luminary.

Figure 18. Verify LED data with plots.

Step procedures for creating LED luminaries are the following:
1. Finding LED to LED distance that has the most efficiency for different LED arrangements.
2. Adding a Reflector to increase light intensity and uniform irradiance.
3. Adding a Diffusion Film.
4. Testing final product.

Where the uniform irradiance represented by luminance ratio is calculated by

\[
\text{Luminance Ratio} = \frac{\text{Maximum lux}}{\text{Average lux}}
\]

In this paper we will compare four types of LED arrangement patterns: Linear, Staggered, Triangular, and Circular as shown in Fig. 20. To begin modeling an LED luminary, one must first consider LED to LED spacing. From previous research on LED heat dissipation, it is safe to assume that for 1 watt LED a distance of 10 to 20 mm between LEDs is enough to ensure the proper function of the LED without hindering LED life and light output. The LED to LED distance will be increased by 0.5 mm in order to find which distance produces the highest and most uniform light output.
Figure 20. Arranged LED patterns from top to bottom are linear, staggered, triangular and circular.

The LED to LED distance that has most efficiency is then combined with a reflector of 97% reflectivity for each of the arrangement patterns. The reflective surface has an absorption of 3%, making it suitable for our application. For the sake of comparing and understanding the effects reflectors have on light rays, five types of reflectors will be compared: Conic, Elliptical, Faceted, Linear, Parabolic, and Spline.

A diffusion film will then be added because of its many benefits: elimination of hot spots and glare, removing the point-type effect of LEDs, increasing light output and uniform irradiance. A diffusion film from Sun Pro Optronic Co., LTD. and the Industrial Technology Research Institute in Taiwan was selected for the experiments because of its ability to increase up to two times the maximum light output and its high efficiency in achieving uniform irradiance. The diffusion film has the ability to transmit 95% of the light and has a thickness of 0.5mm. The only drawback of using a diffusion film is that it has a constraint (1) in order to maximize its performance, as shows

0.33 \leq \frac{d}{D} \leq 2. \quad (1)

Where $d$ is LED spacing, and $D$ is the height from LED to diffusion film. The Diffusion film will be placed on top of our reflector. If the spacing-height ratio is not within the range, the diffusion film cannot achieve its characteristics.

In order to understand the effect of reflectors and LED radiation pattern an LED luminary is modeled according to the three rectangular arrangements (a)-(c) shown in Fig. 21 and combined with a linear reflector in Fig. 22. $d$, will be fixed at 12 mm in order to show the relationship of reflector angle and length, and because a diffusion film will be added on top of the reflector. At this value we respect the diffusion film equation and let us vary $D$ with respect to the angles of the reflector. $L$ is fixed at its minimum and maximum value 8 mm and 14 mm respectfully. By fixing $L$ and varying $\theta$ from 0 to 60 degrees a new $D$ will be generated each time.
Ray tracing equations are used for modeling and predicting the outcome. This example provides easy and clear understanding of the most important factors in LED light design applications. Snell’s Law for ray tracing in vector form are shown (2)-(6),

\[
\hat{n}_1 \sin \theta_1 = \hat{n}_2 \sin \theta_2 ,
\]

\[
\cos \theta_1 = \hat{n} \cdot (-1) ,
\]

\[
\cos \theta_2 = \sqrt{1 - \left(\frac{\hat{n}_z}{\hat{n}_2}\right)^2 \left(1 - (\cos \theta_1)^2\right)} ,
\]

\[
\hat{V}_{\text{reflect}} = \hat{i} + (2\cos \theta_1)n \hat{n} ,
\]

and

\[
\hat{i} = \hat{V}_{\text{reflect}} - (2\cos \theta_1)\hat{n} .
\]

Where \( \hat{i} \) is the normalized light vector, \( \hat{n} \) is the normalized plane normal vector, \( \theta_1 \) and \( \theta_2 \) are the incident angle and reflected angle, respectively. \( \hat{V}_{\text{reflect}} \) is the reflected vector ray. \( \hat{n}_1 \) and \( \hat{n}_2 \) are the index of refraction for each medium. Since in reflection \( \hat{n}_1 \) is equal to \( \hat{n}_2 \), therefore \( \theta_1 \) and \( \theta_2 \) are the identical. The unit vector form of \( \hat{n} \), \( \hat{i} \) and \( \hat{V}_{\text{reflect}} \) are represented by \( \hat{N} \), \( \hat{i} \) and \( \hat{R} \), respectively and are shown in (7)-(9).

\[
\hat{N} = N_x \hat{i} + N_y \hat{j} + N_z \hat{k} \tag{7}
\]

\[
\hat{i} = I_x \hat{i} + I_y \hat{j} + I_z \hat{k} \tag{8}
\]

\[
\hat{R} = R_x \hat{i} + R_y \hat{j} + R_z \hat{k} \tag{9}
\]

The direction cosines of the unit vector of the reflected or incident ray can be calculated from (7)-(9), and (10) is obtained as result.

\[
R_x = I_x - 2N_x (N_x I_x + N_y I_y + N_z I_z)
\]

\[
R_y = I_y - 2N_y (N_x I_x + N_y I_y + N_z I_z) \tag{10}
\]

\[
R_z = I_z - 2N_z (N_x I_x + N_y I_y + N_z I_z)
\]
The final product was then tested and measured with and without diffusion film. To be able to compare the simulation results with experimental result, a perfect absorber of same dimensions of the XY table is also simulated in TracePro. The model was set on top of a 400 mm by 400 mm XY table where light and temperature measurement devices and data acquisition collected the necessary data. The devices used were Agilent 34970A Data Acquisition system, 40 gauge k-type thermocouple, PC, DC Power supply and a luminance meter (TES 1339R Data Logger Light Meter Pro). The results are then compared with the simulations.

### 4.2 Application of Comsol Mutiphysics.

The application of the governing equations and boundary conditions for Comsol is as follows:

\[
\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + Q_{LED} = \rho C_p \frac{\partial T}{\partial t} \tag{1}
\]

LED exterior boundary conditions:

\[
k_x \frac{\partial T}{\partial x} + k_y \frac{\partial T}{\partial y} + k_z \frac{\partial T}{\partial z} = h(T_a - T) \tag{2}
\]

Contact points between various materials boundary conditions:

\[
k_p \frac{\partial T_p}{\partial x} = k_q \frac{\partial T_q}{\partial x} \tag{3}
\]

Where, \( k_x, k_y \), and \( k_z \) are thermal conductivity direction values from material table, the \( i \) represents different material types, \( Q_{LED} \) is the heat source that is generated from the chip, and \( h \) is the natural convection heat transfer coefficient, \( T_a \) and \( T_o \) represent the ambient surrounding temperature and the initial temperature respectively. In addition, Comsol simulation is used for a 1W DC LED heat setting, the heat flux is about 5-6W/m²·K, and at each time step between the grid points, using iterative algorithms to converge to prove the transient numerical calculation and experimental accuracy.

### 5. Results and Discussions

#### I. LED to LED Distance Results

In the matter of LED to LED distance it can be observed that for a range of 10 to 20 mm light output decreases or increases by an insignificant value without the use of any reflector or diffusion film. Also uniform irradiance cannot be achieved without some external aid. The results are shown in Fig. 22. The only critical factor in LED to LED distance is heat dissipation, if the arrangement is too clustered together for example in
triangular arrangement heat accumulation is inevitable and heat will not dissipate properly causing improper function of LED. Using the range of 10 to 20 mm is safe for all arrangements.

Figure 22. LED to LED distance light units measured in foot candles.

II. LED arrangement patterns

LED arrangement patterns do prove that different arrangements produce better results. For the rectangular model shown in Fig. 22, linear arrangement had the poorest performance; it had the worst uniform irradiance and lowest light intensity. Staggered and Triangular arrangement proved to be the best, although triangular arrangement had better performance over staggered the difference is not much. Staggered and Triangular had about 20% better uniform irradiance over Linear without any external aid. In the case of circular patterns there is barely any difference in the results from both arrangements. Results are shown in Fig. 23.

Figure 23. Results of the changes in light intensity by varying LED arrangement and reflector angle as well as reflector length.
**Light changes due to Reflector**

When a reflector is added to an LED luminary many changes are produced in light intensity and uniform irradiance. From the five types of reflectors, they all showed different application possibilities.

The effect reflector has on LED light source is solely dependent on LED radiation pattern, LED angle, incident angle, and the distance between the reflector and the LED. If the same reflector is used, but the distance of the LED is changed the entire outcome is changed. It is the same if LED radiation pattern is changed. A reflector created for LEDs with radiation pattern of 120 degrees cannot have the same light intensity and uniform irradiance if using a LED with a different radiation pattern. Equations (11)-(14) below demonstrate why LED distance to reflector is important.

\[
R = \sqrt{d_{\text{incident ray}}^2 + H^2} \quad (11)
\]

\[
\gamma = \tan^{-1}\left(\frac{d_{\text{incident ray}}}{H}\right) \quad (12)
\]

\[
\alpha = 90 + \gamma - \beta \quad (13)
\]

\[
\alpha = 90 + \tan^{-1}\left(\frac{d_{\text{incident ray}}}{H}\right) - \beta \quad (14)
\]

R is the ray vector, dincident ray is the distance from the LED source to the incident point, and H is the height of the incident point. \(\gamma\) is the angle produced by the triangle R, dincident ray, and H. \(\alpha\) is the incident angle, and \(\beta\) is the reflector’s angle. Equation (14) clearly states the relation between the distance of LED and reflector and the incident, and reflector angle. Another important factor is modeling the LED. Because any change in LED dimensions from the simulated model and the experimental model will have completely different results. This relationship is clearly stated in the LED simplified two dimensional drawing of the angles involved in ray tracing shown in Fig. 24.

Figure 24. Angles involved in ray tracing between an LED light source and reflectors.

Therefore it is of extreme importance that when creating a three dimensional representation of the LED it must be the exact with the existing LED, or else the value of the angles in Fig. 24 will not concur. LED to LED spacing does not have any change on
lighting because it does not change the angles that interact with the reflector. From Fig. 21 the larger L the higher the light intensity, as the angle θ varies so does the uniform irradiance. Fig. 23 and Fig. 25 shows how L and the angle θ affect the uniform irradiance and light intensity. It can be noticed that the best uniform irradiance is achieved for triangular arrangement for an angle θ between ten and fifteen degrees.

Figure 25. Results of the changes in uniform irradiance by varying LED arrangement and reflector angle as well as reflector length.

Conic, Elliptical and Parabolic reflectors produced the effect of a concentrator. Using ray tracing equations it is easy to see that the main factor in these three types of reflectors is the focus point. Using lens equations it is easy to find the focus point of each reflector. In order to create a uniform irradiance using these three reflectors the focus point must be at a center distance or near the center between the LED luminary and the Absorber surface. Due to its concentrator characteristics the three reflectors increased the light intensity to extremely high values that would make reading, office task, or any visual task under such LED luminary very unpleasant. Also in order to achieve a uniform irradiance large and tall reflectors must be employed which make the LED luminary have a bulky aspect.

Faceted and Spline reflectors had the best results in achieving over 70% uniform irradiance while spreading the light intensity to an acceptable value that complies with IESNA requirements to perform certain tasks. But creating Faceted and Spline reflector involves using more complicated mathematical equations. For cubic B-spline reflectors refer to reference [46]. Fig. 26 shows a circular faceted reflector created from the equations provided in this paper. From the linear reflector example clearer understanding is provided making it easier for modeling more complicated pieces. A circular arrangement provides great example of LED flexibility due to its radiation pattern, and how to maximize it with the use of more complicated reflectors modeled with some mathematical equations.
First two circular arrangements as shown in Fig. 20 were tested. Then all possible solutions were modeled to show best output, these included varying LED angle as well as LED spacing. The best outcome was then combined with the five types of reflectors. Using knowledge from ray tracing equations we used inverse ray tracing to model our reflector. A simple two dimensional model was used to select were we wanted a light ray vector to hit, then we traced the ray vector back to the intersection point with our reflector, which can be any point in three dimensional space. From the reflected ray we traced the incident ray and incident angle which must be the same as the reflected angle, in order to model accurately the angle our reflector needs for this position. Finally the incident ray was then traced back to the LED source. Providing enough spacing in the illuminated region for inverse ray tracing allows modeling a very uniform irradiance. From the intersection point mathematical equations can be applied to model the reflector to any shape. The more intersection points and the more flexible reflector shape the better uniform irradiance. In this paper for circular arrangement line and spline equations were used to create such reflectors.

This example is good because it combines all the main factors, LED arrangement, spacing, and angles, and correct use of the inverse ray tracing equations. This luminary used nine LEDs each of 0.5 watts and 40 lux, one in the center, four in the inner circle, and four in the outer circle. The spacing between LEDs was 10 mm. The center and inner circle LED illuminate the center area of the perfect absorber, while the outer circle LEDs
were slanted outward at an angle of 60 degrees making the rays of the same angle perpendicular to the absorber surface while the rest are reflected at different angles by linear segments of 5 mm length with specific angles to create an uniform irradiance on the outside of the absorber. Figure 9 shows the uniform irradiance pattern created by the circular faceted lamp. Fig. 27 is the true uniform irradiance pattern with very little smoothing, in TracePro smoothing option is available in order to curve fit the data. Using a high smoothing in order to curve fit the data will provide a wrong uniform irradiance and will create discrepancies between the simulated data and experimental results. This is the reason why the data presented in Fig. 27 uses a small amount of smoothing. Using this type of arrangements makes good use of space and allows creating a small luminary. Each line segment can be calculated using simple linear equations for line segments and line continuity. The simulation of the faceted lamp has a 1.5:1 luminance ratio without the use of a diffusion film.

![Figure 27. Uniform irradiance pattern created by the circular faceted lamp (Photometric units are Lux).](image)

**Comsol Numerical Analysis**

Transient simulation performed with Comsol, with an interpolated Tj. temperature function achieves results of great accuracy. The design heat sink for this LED luminary can assure that the LED lamp is operating below 56 degrees Celsius, with a Tj. temperature under 75 degrees Celsius, as displayed in Figure 28 and 29.
Comparing Simulation and Experimental Results

Fig. 20 arrangements where manufactured and combined with the arrangement in Fig. 22, data was collected from the XY table and then compared to the simulation. Simulation results do concur with experimental; the difference was only in that the luminance ratio calculated from experimental was lower than simulation. This is good
because in the end we must attain to reach a 1:1 ratio. Simulation results were of 1.5-1.6:1, but when the diffusion film was added the luminance ratio was 1.2-1.3:1. Heat analysis also concurs as shown in Figure 28 and 29. This is the goal this paper presents: To make cost-effective LED luminaries with uniform irradiance and moderate operating temperatures.

6. Conclusions and Future Prospect

This paper presents a step by step procedure of the most important factors in achieving uniform irradiance in short time without many complications with the use of ray sketching equations, two dimensional analytical drawings and simulation software. At the same time it provides a method to ensure LED luminary is operating at a moderate temperature. Different types of reflectors were combined with different LED arrangement, to successfully demonstrate the effect LED spacing, reflector length, distance, and other characteristics of light reflection. With clear understanding of ray behavior a faceted circular lamp of 1.5:1 luminance ratio was created to demonstrate the efficiency of this method. Heat analysis was performed to this faceted circular lamp in order to demonstrate the reliability of numerical analysis. The experimental data agrees with the simulated data, providing a cost effective way of designing many LED luminaries that one day every home in this world can afford or benefit from.

It is important to shape the path of this future technology with a bright start. By 2020 LED lighting will have replaced more than 90% of all the existing lighting technologies. The packaged LED market grew from $6.1 billion in 2009 to $10.2 billion in 2010, a revenue growth of 67%, according to IMS Research’s new report, “The World Market for LEDs”. The $4.1 billion increase in 2010 versus 2009 is by far the largest in the history of LEDs. By 2013, the global LED market will reach $14.3bn, says iSuppli, nearly double from 2009. From 2013, LEDs in general lighting are forecast to account for most growth.

The biggest market by far eventually will be the general lighting market. It is actually LEDs replacing fluorescent and incandescent lighting in consumer, commercial, residential applications. Today, that size of the market on the LED side is around somewhere in the $4 billion to $5 billion range, and the size of the lighting market is around $90 billion which is still only at a 4%, 5% penetration rate.

Future work from this project would be to further improve lighting methods with higher efficiency free-form reflectors, and devising ways to manufacture LED luminaries of low cost by reducing unnecessary material used in traditional luminaries.
7. **Acknowledgement**

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8. **References**

4. Margolin J. "The Road to the Transistor".
6. SU 12191
18. "LEDs cast Monsanto in Unfamiliar Role".
24. Warm light and high efficiency
25. Colin J. Humphreys' cheap LED production method
34. 呂宗蔚，高亮度 LED 散熱系統之熱傳及效益研究，國立成功大學機械工程學系，台南，台灣，2007。
42. 韓偉國，譚瑞敏，”LED 散熱模組之熱阻模型”,中國機械工程學會第二十五屆全國學術研討會論文集，0429，彰化，台灣，2008。


9. **Appendix**
PLCC Series

ET-5050W-3F1W Cool White Datasheet

Ultra high luminous efficacy, combined with the flexibility in design due to its slim and miniature size, PLCC LED Series are optimized to be used as lighting for building.

Features:
- High luminous Intensity and high efficiency
- Based on InGaN / GaN technology
- Wide viewing angle: 120°
- Excellent performance and visibility
- Suitable for all SMT assembly methods
- IR reflow process compatible
- Environmental friendly; RoHS compliance

Typical Applications:
- Signal and Symbol Luminaire
- Indoor and Outdoor Displays
- Backlighting (illuminated advertising, general lighting)
- Interior Automotive Lighting
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Product Nomenclature

The following table describes the available color, package size, and chip quantity.

<table>
<thead>
<tr>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
<th>X6</th>
<th>X7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>Type</td>
<td>Code</td>
<td>Type</td>
<td>Code</td>
<td>Type</td>
<td>Code</td>
</tr>
<tr>
<td>ET</td>
<td>Edison Top LED</td>
<td>3528</td>
<td>3.5x2.8mm</td>
<td>W</td>
<td>Cool White</td>
<td>1</td>
</tr>
<tr>
<td>5050</td>
<td>5.0x5.0mm</td>
<td>H</td>
<td>Neutral White</td>
<td>3</td>
<td>3pcs</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>Warm White</td>
<td>A</td>
<td>0.5W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Red</td>
<td>B</td>
<td>1W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Amber(615nm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>Yellow(590nm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>True Green</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Blue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTB</td>
<td>RGB 3chips</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. PLCC 5050 series Nomenclature

Environmental Compliance

PLCC 5050 series are compliant to the Restriction of Hazardous Substances Directive or RoHS. The restricted materials including lead, mercury cadmium hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ether (PBDE) are not used in PLCC 5050 series to provide an environmentally friendly product to the customers.
LED Package Dimension and Polarity

Figure 2. PLCC 5050 series Dimension

Figure 3. PLCC 5050 series circuit diagram and recommended soldering pad

Notes:
1. All dimensions are in mm.
2. Tolerance: ± 0.2 mm
## Absolute Maximum Ratings

The following table describe absolute maximum ratings of PLCC 5050 series.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rating</th>
<th>Units</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward Current</td>
<td>30</td>
<td>mA</td>
<td>( I_F )</td>
</tr>
<tr>
<td>Pulse Forward Current ((t_{p} \leq 100\mu s, \text{ Duty cycle}=0.25))</td>
<td>100</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>Reverse Voltage</td>
<td>5</td>
<td>V</td>
<td>( V_R )</td>
</tr>
<tr>
<td>Forward Voltage</td>
<td>3.8</td>
<td>V</td>
<td>( V_F )</td>
</tr>
<tr>
<td>Power Dissipation</td>
<td>115</td>
<td>mW</td>
<td></td>
</tr>
<tr>
<td>LED Junction Temperature</td>
<td>125</td>
<td>°C</td>
<td>( T_J )</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-30 ~ +85</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>-40 ~ +100</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Soldering Temperature</td>
<td>255~260</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Manual Soldering at 350C(Max.)</td>
<td>3</td>
<td>Sec</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
1. Proper current derating must be observed to maintain junction temperature below the maximum at all time.
2. LEDs are not designed to be driven in reverse bias.
3. \( t_p \): Pulse width time
**Luminous Intensity Characteristic**

The following table describes luminous intensity of PLCC 5050 series.

Table 2. Luminous intensity characteristics at $I_f=20\text{mA}$ (each chip) and $T_a=25^\circ\text{C}$ for PLCC 5050 series

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Color</th>
<th>Luminous intensity</th>
<th>Luminous Flux Typ.(lm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Min.</td>
<td>Typ.</td>
</tr>
<tr>
<td>ET-5050W-3F1W</td>
<td>Cool White</td>
<td>5,000</td>
<td>6,300</td>
</tr>
</tbody>
</table>

Note:
Luminous intensity is measured with an accuracy of $\pm$ 10%

**Forward Voltage Characteristic**

The following table describes forward voltage of PLCC 5050 series.

Table 3. Forward voltage characteristic

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Color</th>
<th>$V_f$</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Min.</td>
<td>Typ.</td>
</tr>
<tr>
<td>ET-5050W-3F1W</td>
<td>Cool White</td>
<td>2.8</td>
<td>--</td>
</tr>
</tbody>
</table>

Note:
Forward Voltage is measured with an accuracy of $\pm$ 0.1V

**Color Temperature Characteristic**

Table 4. Color Rendering Index Characteristic at $T_r=25^\circ\text{C}$ for PLCC 5050 series

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Color</th>
<th>CRI Typ.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET-5050W-3F1W</td>
<td>Cool White</td>
<td>68</td>
</tr>
</tbody>
</table>

Note:
CRI is measured with an accuracy of $\pm$ 5
JEDEC Information

JEDEC is used to determine what classification level should be used for initial reliability qualification. Once identified, the LEDs can be properly packaged, stored and handled to avoid subsequent thermal and mechanical damage during the assembly solder attachment and/or repair operation. The present moisture sensitivity standard contains six levels, the lower the level, the longer the devices floor life. PLCC 5050 series are certified at level 2a. This means PLCC 5050 series have a floor life of 4 weeks before PLCC 5050 series need to re-baked.

<table>
<thead>
<tr>
<th>Level</th>
<th>Floor Life</th>
<th>Soak Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>Conditions</td>
</tr>
<tr>
<td>2a</td>
<td>4 weeks</td>
<td>≤30°C / 60% RH</td>
</tr>
</tbody>
</table>

Note: The standard soak time includes a default value of 24 hours for semiconductor manufacturer’s exposure time (MET) between bake and bag, and includes the maximum time allowed out of the bag at the distributor’s facility.
Reliability Test Items

The following table describes operating life, mechanical, and environmental tests performed on PLCC 5050 series.

Table 6. Reliability Test 1

<table>
<thead>
<tr>
<th>Stress Test</th>
<th>Stress Conditions</th>
<th>Stress Duration</th>
<th>Failure Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature and Humidity</td>
<td>60°C / 60%RH</td>
<td>120 hours</td>
<td>No catastrophics</td>
</tr>
<tr>
<td>IR Reflow</td>
<td>Peak temp.=255~260°C*3 times</td>
<td>3 times</td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Reliability Test 2

<table>
<thead>
<tr>
<th>Stress Test</th>
<th>Stress Conditions</th>
<th>Stress Duration</th>
<th>Failure Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room Temperature Operating Life</td>
<td>25°C, IR= max DC (Note 2)</td>
<td>1000 hours</td>
<td></td>
</tr>
<tr>
<td>High Temperature and high Humidity Life</td>
<td>85°C / 85%RH, IR= 5 mA</td>
<td>1000 hours</td>
<td></td>
</tr>
<tr>
<td>Low Temperature Storage</td>
<td>-40°C</td>
<td>1000 hours</td>
<td>No catastrophics</td>
</tr>
<tr>
<td>High Temperature and high Humidity Storage</td>
<td>85°C / 85%RH</td>
<td>1000 hours</td>
<td></td>
</tr>
<tr>
<td>Ambient Temperature Life</td>
<td>25°C, IR= 20 mA</td>
<td>1000 hours</td>
<td></td>
</tr>
<tr>
<td>Temperature Cycle</td>
<td>-40°C/100°C, 30 min dwell&lt;15 min transfer</td>
<td>200 cycles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-40°C / 100°C, 15 min dwell&lt;10 sec transfer</td>
<td>200 cycles</td>
<td></td>
</tr>
<tr>
<td>Thermal Shock</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Reliability test 2 is performed after reliability test 1.
2. Depending on the maximum derating curve.
3. Failure Criteria:
   - Electrical failures
   - Vf Shift >=10%
   - Luminous Intensity
   - I–Decay >= 35%
Color Spectrum and Radiation Pattern

Beam Angle Characteristic

Table 8. Beam angle for PLCC 5050 series

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Color</th>
<th>20% (Typ.) Lambertian</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET-5050W-3F1W</td>
<td>Cool White</td>
<td>120</td>
<td>Deg.</td>
</tr>
</tbody>
</table>

Figure 4. Beam pattern diagram for PLCC 5050 series

Color Temperature or Dominant Wavelength Characteristics

Table 9. Dominant Wavelength or Peak wavelength or Color Temperature Characteristics at Ta=25°C for PLCC 5050 series

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Color</th>
<th>CCT Min.</th>
<th>CCT Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET-5050W-3F1W</td>
<td>Cool White</td>
<td>5,000</td>
<td>10,000</td>
<td>K</td>
</tr>
</tbody>
</table>

Notes:
Color Temperature is measured with an accuracy of ± 200K

Figure 5. Wavelength & relative intensity for PLCC 5050 series

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Optical and Electric Characteristics

Figure 6. Ambient temperature & forward current for PLCC 5050 series

Figure 7. Forward current & relative intensity for PLCC 5050 series

Figure 8. Ambient temperature & relative intensity for PLCC 5050 series

Figure 9. Forward current & forward voltage for PLCC 5050 series
Product Soldering Instructions

Figure 10. Pad Dimension

Notes:
All dimensions are measured in mm.
Reflow Profile

The following reflow soldering profiles are provided for reference. It is recommended that users follow the recommended soldering profile provided by the manufacturer of the solder paste used.

Table 10. Table of Classification Reflow Profiles

<table>
<thead>
<tr>
<th>Profile Feature</th>
<th>Sn-Pb Eutectic Assembly</th>
<th>Pb-Free Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preheat &amp; Soak</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature min (T_smin)</td>
<td>100°C</td>
<td>150°C</td>
</tr>
<tr>
<td>Temperature max (T_smax)</td>
<td>150°C</td>
<td>200°C</td>
</tr>
<tr>
<td>Time (T_smin to T_smax) (ts)</td>
<td>60-120 seconds</td>
<td>60-120 seconds</td>
</tr>
<tr>
<td>Average ramp-up rate (T_smax to T_p)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquidous temperature (T_L)</td>
<td>3°C/second max.</td>
<td>3°C/second max.</td>
</tr>
<tr>
<td>Time at liquidous (T_L)</td>
<td>183 °C</td>
<td>217 °C</td>
</tr>
<tr>
<td></td>
<td>60-150 seconds</td>
<td>60-150 seconds</td>
</tr>
<tr>
<td>Peak package body temperature (T_p)*</td>
<td>230 °C –235°C *</td>
<td>255 °C –260 °C *</td>
</tr>
<tr>
<td>Classification temperature (T_c)</td>
<td>235°C</td>
<td>260 °C</td>
</tr>
<tr>
<td>Time (t_p)** within 5 °C of the specified classification temperature (T_c)</td>
<td>20** seconds</td>
<td>30** seconds</td>
</tr>
<tr>
<td>Average ramp-down rate (T_p to T_smax)</td>
<td>6°C/second max.</td>
<td>6°C/second max.</td>
</tr>
<tr>
<td>Time 25°C to peak temperature</td>
<td>6 minutes max.</td>
<td>8 minutes max.</td>
</tr>
</tbody>
</table>

Notes:
* Tolerance for peak profile temperature (T_p) is defined as a supplier minimum and a user maximum.
** Tolerance for time at peak profile temperature (t_p) is defined as a supplier minimum and a user maximum.
Product Packaging Information

Taping Reel

Figure 12. Taping reel dimensions
Packaging

Figure 13. Packaging diagram

Package Label

Figure 14. Package label

Table 11. Package dimensions and quantity

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Total</th>
<th>Dimensions(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reel</td>
<td>1,000pcs</td>
<td>1,000pcs</td>
<td>Diameter=178</td>
</tr>
<tr>
<td>Box</td>
<td>5 reels</td>
<td>5,000pcs</td>
<td>240<em>235</em>67</td>
</tr>
<tr>
<td>Carton</td>
<td>10 boxes</td>
<td>50,000pcs</td>
<td>500<em>260</em>335</td>
</tr>
</tbody>
</table>
Precaution for Use

Storage

1.1 Before opening the package
The LEDs should be kept at <40°C & <90%RH. The LEDs should be used within a year. When storing the LEDs, moisture proof package with absorbent material (silica gel) is recommended.

1.2 After opening the package
The LEDs should be kept at <=30°C & <=60%RH. The LEDs should be soldered within 4 weeks after opening the moisture proof package.
If unused LEDs remain, they should be stored in moisture proof packages, such as sealed containers with moisture proof package within absorbent material (silica gel). It is also recommended to return the unused LEDs to the original moisture proof package and to seal the moisture proof package again.
If the moisture absorbent material (silica gel) vapors or expires the expiration date, baking treatment should be performed by using the following conditions: 60°C for 20 hours.
The LEDs electrode and leadframe comprise a silver plated copper alloy. The silver surface may be affected by environments. Please avoid conditions which may cause the LEDs being corroded or discolored. The corrosion or discoloration might lower solderability or affect optical characteristics.
Please avoid rapid transition in ambient temperature, especially in high humidity environments where condensation can occur.

Static electricity
The products are sensitive to static electricity and highly taken care when handling them. Static electricity or surge voltage will damage the LEDs. It is recommended to wear an anti-static wristband or an anti-electrostatic glove when handling the LEDs.
All devices, equipments and machinery must be properly grounded. It is recommended that measures be taken against surge voltage to the equipment that mounts the LEDs.

Pick and Place
Recommended conditions: Outer nozzle>ψ4.0 mm
*Avoid direct contact to the encapsulant with picking up nozzle. Failure to comply might result in pick and place processes or damage to encapsulant. In the worst cases, catastrophic failure of the LEDs due to wire deformation and/or breakage.

Notes:
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EDISON OPTO reserves the right to make changes at any time without notice to any products in order to improve reliability, function or design.
EDISON OPTO products are not authorized for use as critical components in life support devices or systems without the express written approval from the managing director of EDISON OPTO.
### Forward Voltage Ranks

Table 12. Forward voltage rank at \( T_a = 25 \degree C \)

<table>
<thead>
<tr>
<th>Bin</th>
<th>Condition</th>
<th>Min</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>UJ</td>
<td></td>
<td>2.8</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td></td>
<td>3.0</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>UL</td>
<td>( I=20\text{mA/ chip} )</td>
<td>3.2</td>
<td>3.4</td>
<td>V</td>
</tr>
<tr>
<td>UM</td>
<td></td>
<td>3.4</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>UN</td>
<td></td>
<td>3.6</td>
<td>3.8</td>
<td></td>
</tr>
</tbody>
</table>

Note:
Forward voltage measurement allowance is ± 0.1V.

### Luminous Intensity Ranks

Table 13. Luminous intensity rank at \( T_a = 25 \degree C \)

<table>
<thead>
<tr>
<th>Bin</th>
<th>Condition</th>
<th>Min.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZL</td>
<td></td>
<td>2,650</td>
<td>3,250</td>
<td></td>
</tr>
<tr>
<td>ZM</td>
<td></td>
<td>3,250</td>
<td>3,950</td>
<td></td>
</tr>
<tr>
<td>ZN</td>
<td>( I=20\text{mA/ chip} )</td>
<td>3,950</td>
<td>4,850</td>
<td>mcd</td>
</tr>
<tr>
<td>ZO</td>
<td></td>
<td>4,850</td>
<td>5,950</td>
<td></td>
</tr>
<tr>
<td>ZP</td>
<td></td>
<td>5,950</td>
<td>7,250</td>
<td></td>
</tr>
</tbody>
</table>

Note:
Luminous Intensity Measurement Allowance is ± 10%.
CIE Chromaticity Diagram

Figure 15. PLCC 5050 series chromaticity diagram
### Table 14. Color Bin Y1-W5 at I=20mA/chip, T=25°C for PLCC 5050 series

<table>
<thead>
<tr>
<th>Bin</th>
<th>Chromaticity Coordinate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Y1</td>
<td>0.3040</td>
</tr>
<tr>
<td></td>
<td>0.2850</td>
</tr>
<tr>
<td>Y2</td>
<td>0.2990</td>
</tr>
<tr>
<td></td>
<td>0.3010</td>
</tr>
<tr>
<td>Y3</td>
<td>0.3040</td>
</tr>
<tr>
<td></td>
<td>0.2850</td>
</tr>
<tr>
<td>Y4</td>
<td>0.2920</td>
</tr>
<tr>
<td></td>
<td>0.3210</td>
</tr>
<tr>
<td>X1</td>
<td>0.3075</td>
</tr>
<tr>
<td></td>
<td>0.3107</td>
</tr>
<tr>
<td>X2</td>
<td>0.3075</td>
</tr>
<tr>
<td></td>
<td>0.3107</td>
</tr>
<tr>
<td>X3</td>
<td>0.3051</td>
</tr>
<tr>
<td></td>
<td>0.3223</td>
</tr>
<tr>
<td>X4</td>
<td>0.3030</td>
</tr>
<tr>
<td></td>
<td>0.3327</td>
</tr>
<tr>
<td>W1</td>
<td>0.3292</td>
</tr>
<tr>
<td></td>
<td>0.3202</td>
</tr>
<tr>
<td>W2</td>
<td>0.3292</td>
</tr>
<tr>
<td></td>
<td>0.3313</td>
</tr>
<tr>
<td>W3</td>
<td>0.3290</td>
</tr>
<tr>
<td></td>
<td>0.3450</td>
</tr>
<tr>
<td>W4</td>
<td>0.3290</td>
</tr>
<tr>
<td></td>
<td>0.3450</td>
</tr>
<tr>
<td>W5</td>
<td>0.3147</td>
</tr>
<tr>
<td></td>
<td>0.3444</td>
</tr>
</tbody>
</table>

Note:
Color coordinates measurement allowance is ± 0.01
Table 15. Color Bin V0-V4 at I=20mA/chip, T=25°C for PLCC 5050 series

<table>
<thead>
<tr>
<th>Bin</th>
<th>X</th>
<th>Y</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>V0</td>
<td>0.3433</td>
<td>0.3320</td>
<td>0.3293</td>
<td>0.3293</td>
</tr>
<tr>
<td></td>
<td>0.3425</td>
<td>0.3208</td>
<td>0.3105</td>
<td>0.3200</td>
</tr>
<tr>
<td>V1</td>
<td>0.3292</td>
<td>0.3444</td>
<td>0.3433</td>
<td>0.3293</td>
</tr>
<tr>
<td></td>
<td>0.3313</td>
<td>0.3442</td>
<td>0.3320</td>
<td>0.3200</td>
</tr>
<tr>
<td>V2</td>
<td>0.3292</td>
<td>0.3290</td>
<td>0.3457</td>
<td>0.3444</td>
</tr>
<tr>
<td></td>
<td>0.3313</td>
<td>0.3450</td>
<td>0.3591</td>
<td>0.3442</td>
</tr>
<tr>
<td>V3</td>
<td>0.3290</td>
<td>0.3288</td>
<td>0.3469</td>
<td>0.3457</td>
</tr>
<tr>
<td></td>
<td>0.3450</td>
<td>0.3569</td>
<td>0.3717</td>
<td>0.3591</td>
</tr>
<tr>
<td>V4</td>
<td>0.3288</td>
<td>0.3286</td>
<td>0.3481</td>
<td>0.3469</td>
</tr>
<tr>
<td></td>
<td>0.3569</td>
<td>0.3689</td>
<td>0.3856</td>
<td>0.3717</td>
</tr>
</tbody>
</table>

Note:
Color coordinates measurement allowance is ± 0.01