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Performance of Light Emitting Diode on Surface Machined Heat Sink

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ABSTRACT

In the point of efficient heat removal from light emitting diode (LED) package to ambient, the surface of the heat sinks must be finished based on required condition. The surface finishing plays an important role in efficient heat dissipation. In our work, the top surface of heat sink was machined like two different shapes (slotted and 'W' shaped) and tested the thermal performance for 3W green LED. The total thermal resistance was high for 'W' shaped surface at 100 mA. Surface modification was not influenced much on the thermal resistance (R_{th}) value at higher operating current. Noticeable increase on junction temperature was observed for 'W' shaped surface at 100 mA than slotted surface. In optical properties, low lux values were recorded for 'W' shaped surface at all operating current. In addition, 'W' shaped surface showed low value in CRI than other two surfaces (plain and slotted). The observed CCT value was decreased as the measuring time increased. High value in CCT was observed for 'W' shaped surface at higher operating current (> 350mA). Slotted surface showed good performance on both thermal and optical properties of the given 3W green LED.

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1. INTRODUCTION

Apart from the special illumination, high power light emitting diodes (LEDs) will soon be used in general illumination because of its distinctive advantages including high efficiency, good reliability, long life, variable colors and low power consumption. An expectation about high power LED is that it will be the dominant lighting technology by 2025 [1]. Theoretically, the higher operating current delivers more light output from LED. Unfortunately, the light output power of the LED decreases as the temperature of the LED increasing as a result of increasing junction temperature (T_J) [2]. Increased junction temperature will induce thermal activation of non-radiative recombination of electron-hole recombination. The number of defects responsible for non-radiative recombination increases with temperature [3]. Therefore, the junction temperatures of LEDs significantly influence the reliability and durability [4].

As electronic packaging becomes more compact and processing power continues to increase, engineers are looking for alternatives that provide more efficient thermal transfer in a smaller space. Machining heat sink is a popular alternative in meeting today's thermal challenges. Machining is most appropriate for prototypes, short run and low volume production; and the performance characteristics will be similar to a forged heat sink. [5]. Since the optical power degradation occurred as a result of increasing T_J, proper thermal management is a key issue in power LED based lighting applications. The surface geometry of heat sink is an important and influences more on heat transfer from the LED package to ambient [6]. In literature, improvement of convective heat transfer for passive cooling using extended surfaces has been extensively investigated [7].

An increase to the surface area of a heat sink will almost always result in improved thermal performance and increase cycle time with add to the cost. Most of the researchers have been concentrated the surface modification on fins side of the heat sink [8-10]. No literature is available in machining of top surface of the heat sink where the real surface contact exists. It is expected that the surface contact area of applied TIM to top surface of the heat sink is increased. In this work, the surface of heat sink (top) is machined in different shape in order to increase the surface contract area and reduce the material quantity of the heat sink. The thermal and optical properties of 3W green LED with respect to modified surfaces are reported here.

2. RESEARCH METHOD

2.1. Theoretical background

The device junction temperature in the test condition can be determined by:

$$T_J = T_{J0} + \Delta T_J \qquad (1)$$

where T_{J0} = initial device junction temperature before heating power is applied [ºC]
ΔT_J = change in junction temperature due to heater power application [ºC]

It should be noted that the relationship between ΔT_J and power dissipation is usually linear over some specific range of conditions and may vary considerably at the extremes of device operation. The method itself is independent of the environment of the device under test (DUT), thus requiring careful and detailed attention to environmental conditions in order to assure that the test produces meaningful results. Static mode was applied using still air box for the all measurement which applies heating power to the DUT on a continuous basis while monitoring the T_J through measurement of the temperature-sensitive parameter.

2.2. Surface modification

In order to test the surface influence, three identical heat sinks (see figure 1) are selected (23 x 25 x 9 mm). One among them is considered as plain surface, and the other two is machined as given in the figure 2. Figure 2(a) and Figure 2(b) named as slotted surface and 'W' shaped surface for throughout this paper. The specification of the modified surface is given in figure 2 itself. The area of the heat sink (top) is 575 mm^2, 850 mm^2 and 610 mm^2 for plain, slotted and 'W' shaped surface respectively.

Figure 1. Photograph of ideal heat sink used (plain surface)

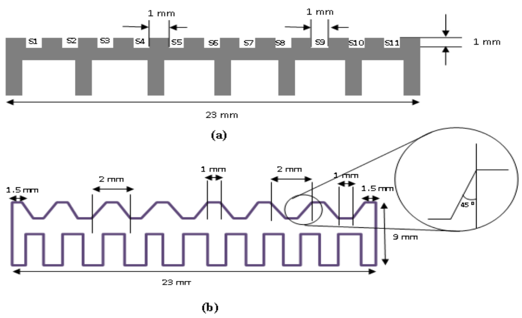

Figure 2. Schematic diagram of surface machined as (a) slotted surface and (b) W shaped on heat sink top surface.

In this study, 3W green LED package attached with Metal Core Printed Circuit Board was used for all measurements and placed over the heat sink as shown in Figure 3(a). Alumina thermal paste kit was used as TIM in this study. The thermal transient characterization of the LED for above said three conditions is captured based on the electrical test method JEDEC JESD-51. The thermal behavior of the LED is captured by the Thermal Transient Tester (T3Ster) in still air box as given in photograph in Figure 3(b). In order to get the optical behavior with respect to modified surface, MK350 LED meter (Make:UPRtek) was used to measure the optical behavior of given LED such as correlated color temperature (CCT), Color Rendering Index (CRI), and Lux was measured and reported here.

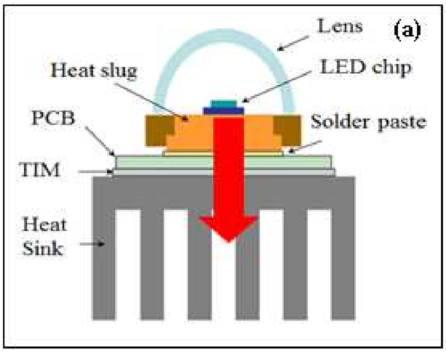

Figure 3. (a) Schematic diagram of the LED on a heat sink and (b) Measurement setup for thermal transient analysis of LED fixed within a still-air chamber.

2.3. K factor calibration

Before the real measurement, the LED was thermally calibrated using dry thermostat and T3Ster as the power supply. The product of K and the difference in temperature-sensing voltage (referred to as ΔV_F) produces the device junction temperature rise:

$$\Delta T_J = \Delta V_F \, K \quad (2)$$

$$K = \Delta T_J / \Delta V_F \quad (3)$$

During the calibration process, the LED was driven with lower operating current at 1mA to prevent self-heating effect at the junction. The ambient temperature of the LED was fixed to 25˚C and the voltage drop across the junction was recorded once the LED reaches thermal equilibrium with the temperature of the thermostat. Later, the ambient temperature of the LED was varied from 35˚C, 45˚C, 55˚C, 65ºC, 75˚C and 85˚C and the voltage drop across the junction was noted at each ambient temperature. From the calibration process, the K-factor of the LED was determined (2.289) from the graph of junction voltage (voltage drop) against ambient temperature as shown in Figure 4.

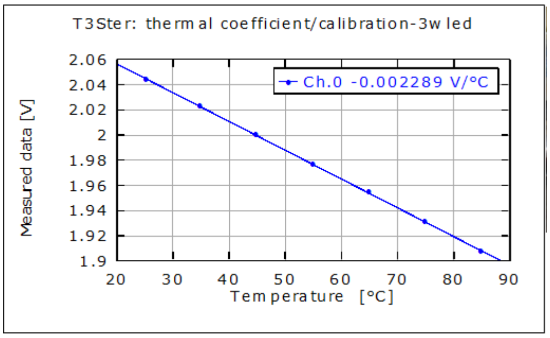

Figure 4. K factor calibration curve for given 3W green LED

2.4. Thermal transient analysis

During the thermal test, the LED was driven at three different currents 100 mA, 350mA and 700 mA in a still-air chamber at room temperature of 25˚C ± 1 ˚C as shown in Figure 3 (b). The LED was forward biased for 900s. Once it reaches steady state, the LED was switched off and the transient cooling curve of heat flow from the LED package was captured for another 900s. The obtained cooling profile of the LED for plain, slotted and 'W' shaped surface of the heat sink was processed for structure functions using Trister Master Software.

3. RESULTS AND DISCUSSIONS

3.1. Thermal properties

The thermal resistance (*Rth*) analysis of 3W green LED with different surface modified heat sink was performed and the results are given in Table – 1. T_J values were derived from the smooth curve observed during transient analysis (see figure 5 a-c). It shows that the variation in T_J as well as R_{th} is comparatively small for all modified surface. Noticeably, T_J value slightly decreases for modified surface (slotted and 'W' shaped) at high operating current (700mA). It attributes the increased surface contact area of TIM on top of heat sink surface [11]. Unfortunately, noticeable increase in T_J could be observed at 350mA operating current. It reveals that the results shows that the modified surface does not show much influence on decreasing T_J values and especially a small increase in T_J could be observed at 100mA for 'W' shaped surface since the surface contact area was comparatively less than slotted and plain surface surfaces. Since the removal of material on surface and extended the surface area, the machined surface area has made more bond line thickness for applied TIM via slotted and 'W' shaped surface and it has high thermal path from MCPCB to heat sink surface (see figure 6) and hence the thermal resistance is high [12,13].

The following thermal resistance equation realizes the above said statement as the resistance increases with the thickness of TIM increases.

$$R_{TIM} = L/kA \quad (4)$$

where L – thickness of TIM (m), k - thermal conductivity of TIM (W/mK) and A – contact area of TIM (m^2) [14]

Table 1. Junction temperature and thermal resistance of plain and modified surface heat sinks from cumulative structure function

	Plain surface			'W' shaped surface			Slotted		
	100	**350**	**700**	**100**	**350**	**700**	**100**	**350**	**700**
T_J	9.8	36.98	80.36	10.75	37.55	79.86	9.8	37.86	79.92
Rth-tot	35.41	34.09	34.79	36.18	34.61	34.55	35.00	34.47	34.63
Rth-b-hs	22.17	21.00	20.43	23.00	21.43	20.18	21.81	21.3	20.43

To measure the R_{th}, the cumulative structure function was derived from the cooling curve using T3ster software and given in figure 7 (a-c). On considering total R_{th} (R_{th-tot}), the surface modified heat sinks showed low value when compared with plain surface. But the difference is comparatively small. In order to confirm the repeatability, the measuring of transient cooling curve is repeated for 3 times and the difference in R_{th} is observed less than 0.02 K/W. The R_{th-tot} value of both modified surface (slotted and 'W' shape) increases as the input current increases upto 350 mA and slightly decrease when measured at 700 mA. It is attributed to the effect of low heat capacity and high TIM thickness in slotted and W shapped surface [12]. In order to test the interface material resistance, the thermal resistance between board and heat sink ($R_{th-b-hs}$) is measured from the cumulative structure function. The $R_{th-b-hs}$ value increases for slotted and 'W' shaped heat sink surface when measured at 100 and 350mA and slightly decreases for high operating current (700 mA) as observed for R_{th-tot}.

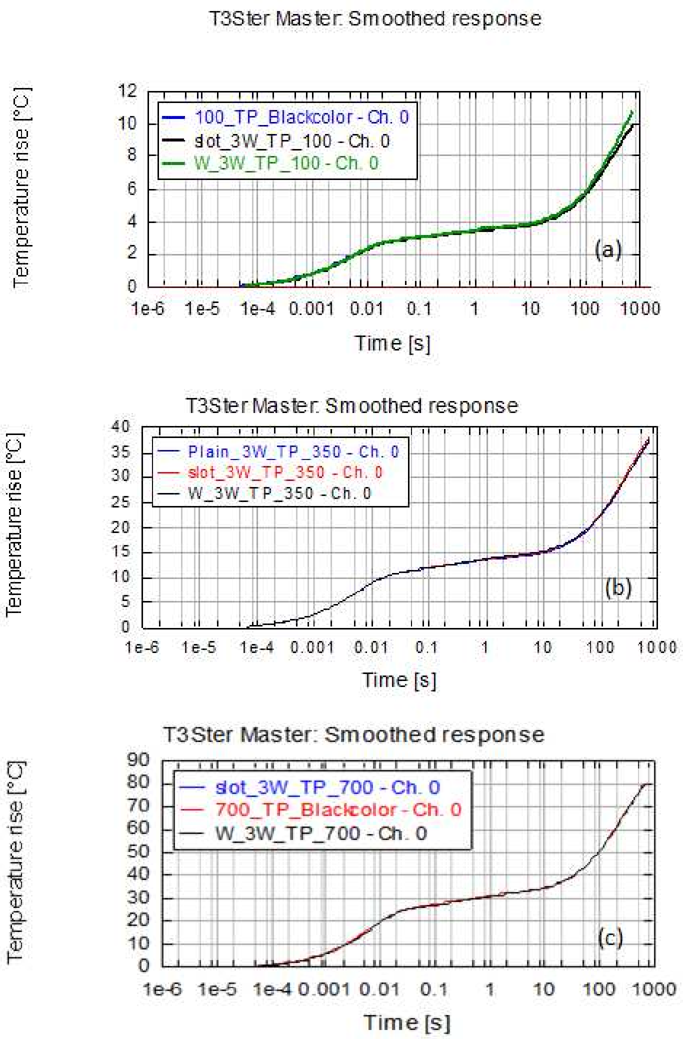

Figure 5. Transient cooling curve of 3W green LED for plain and surface modified heat sink recorded at (a) 100 mA, (b) 350 mA and (c) 700 mA

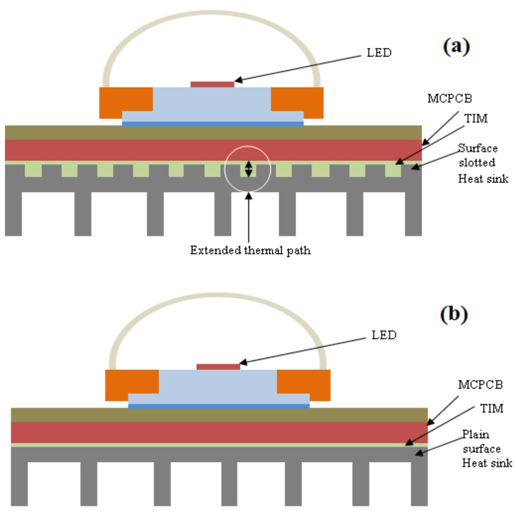

Figure 6. (a) Illustration of increased bond line thickness (TIM) for the LED attached on slotted surface of heat sink and (b) Schematic diagram of LED attached with heat sink by TIM

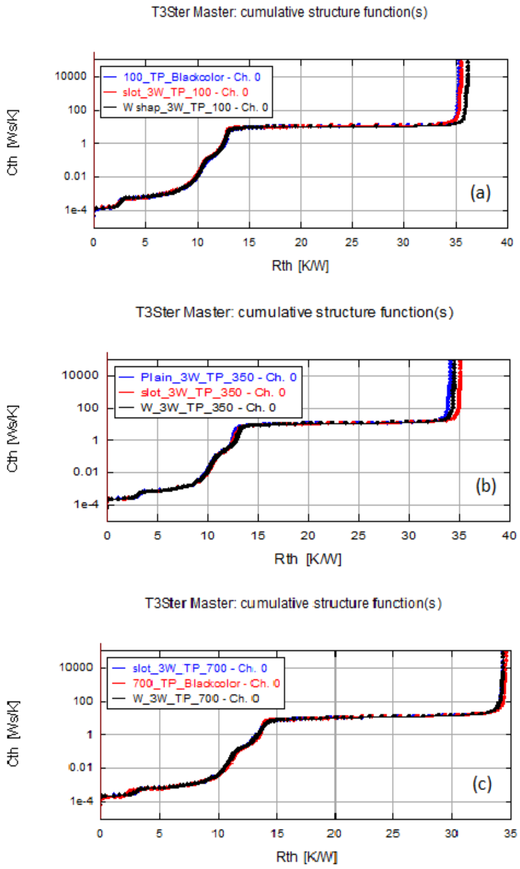

Figure 7. Cumulative structure function of plain and surface modified heat sink recorded at (a) 100 mA, (b) 350 mA and (c) 700 mA

From the all observed results, it is concluded that the slotted and ‘W’ shaped surface help to reduce the thermal resistance at high operating current. It is attributed that the molecular agitation (free electrons) within the material is more at high T_J than the LED operates at low operating current [15]. From the figure 7a, it is observed clearly that the ‘W’ shaped surface gives high R_{th} value than plain and slotted surface. From the figure 2, the surface area of heat sink contact with MCPCB via TIM is low for ‘W’ shaped surface (225 mm^2) than slotted surface (300 mm^2). The figure 7b reveals that the surface modified heat sink restricts heat transfer from board to ambient at 350 mA operating current. But the results in Figure 6c depicts that the operating at 700mA supports the surface modification on heat sink to enhance the heat removal since the contact surface area is high compared with plain surface.

3.2 Optical properties

The optical behavior of 3W LED was also characterized by measuring the parameters like CCT, CRI, Wavelength and Lux using the LED meter. The measured CCTs for plain and modified surfaces are given in Figure 8. The color temperature or color coordinated temperature over 5000 K are called cool colors, while lower color temperatures (2700-3000K) are called warm colors [16]. According to Wien's displacement law, the spectral peak is shifted towards shorter wavelengths for higher temperatures. The observed results are obeyed the Wien’s concept and the CCT value increases as the current input increases and hence the λ_{peak} shifted to lower wavelength from 542 – 539 nm [17]. It is clearly described in fig 8. It reveals that the CCT varies with respect to input current as we know. At 100mA, ‘W’ shaped surface maintain the value from start up to end time of the measurement. But plain and slotted surface shows similar results at starting point. No big difference in CCT is observed for plain and slotted surface measured at 100mA. In addition, linear behavior as CCT decreases as running time increases could be observed for both 350 mA and 700mA input current for all surfaces. But at higher input current, ‘W’ shaped surface show higher value than other two surfaces.

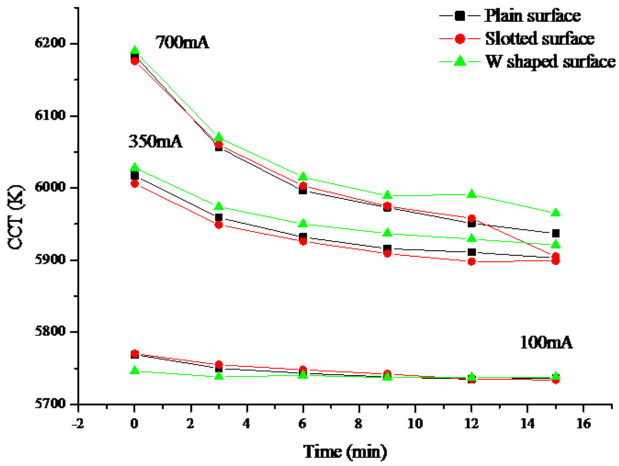

Figure 8. Variation of CCT values with respect to measuring time for 3W green LED fixed on plain and surface modified heat sink.

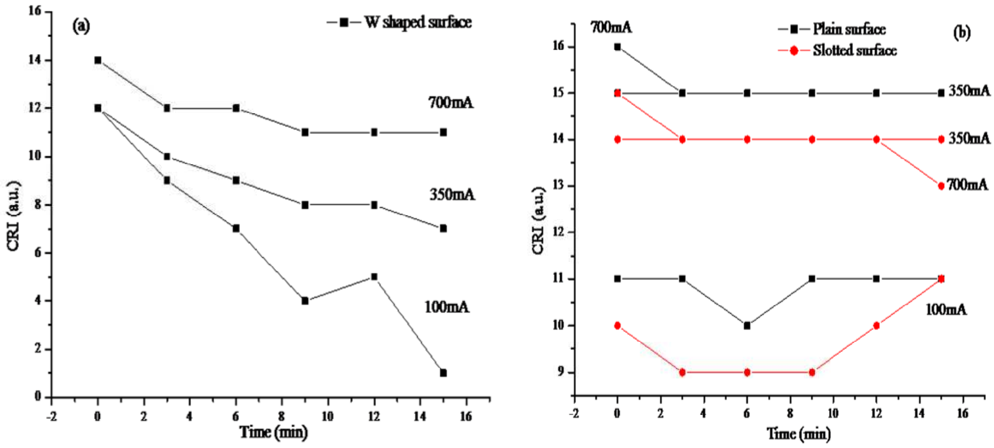

Figure 9. Variation of CRI values of 3W LED against measuring time at various driving current fixed on (a) ‘W’ shaped surface and (b) plain and slotted surface.

Especially, the results observed at 700mA show high value at initial stage and decrease drastically over period of time. It is indirectly related to the raise in T_J as well as R_{th} of the LED package. The fig.8 shows that the CCT values measured at 350 and 700 mA are very close to each other at the end of the measurement (15^{th} min). Finally, the CCT values are within the cool region (>4000 K) even though the surface modification done. Color rendering index (CRI) is a measure of how accurately an artificial light source displays colors. The higher the CRI, the better the artificial light source is at rendering colors accurately. According to published results [18], the differences in CRI values of less than five points are not significant. In order to study the influence of surface modification on CRI for the given 3W green LED, the CRI values are recorded for modified surfaces at different driving currents.

The observed results are given in figure 9(a–b). Figure 9a clearly indicates that the CRI values drastically decreases as the running time increases at 100mA operating current than other driving currents (350 and 700mA) for ‘W’ shaped surface. Fig.9b shows that the slotted surface shows a noticeable change in CRI value when the LED operated at 100 mA. In addition, CRI values observed as low for slotted surface at all driving currents. Overall, ‘W’ shaped surface show low value than other two surfaces (plain and slotted) even at higher operating current. But liner behavior for both plain and slotted surface could also be observed at operating current above 350 mA.

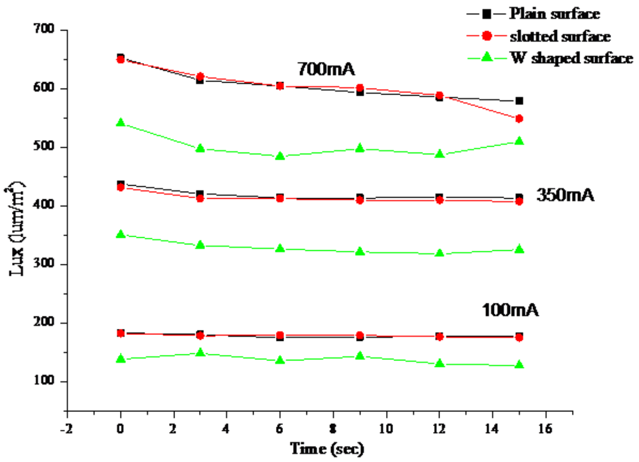

Figure 10. Change in Lux of 3W LED against measuring time at various driving current for plain and modified surface.

Figure 10 shows the influence of surface modification on the light output at various driving current. It shows that the 'W' shaped surface shows low lux level for all driving current when compared to other two surfaces. It may be due the effect of increase in T_J as well as R_{th} of the LED package. Also, it reveals that the slotted surface doesn't influence much on the light output for 3W LED at different operating current and the observed values are very close to the values of plain surface. This observation supports the possibility of reduced material quantity of heat sink without affecting the optical properties of the LED. In peak wavelength measurements, we could not observe much difference and the values were in between 539 – 541 nm.

4. CONCLUSION

Thermal conductivity behavior of surface modified heat sink was tested for 3W green LED at different driving currents. Machined surface had more contact surface area than the plain heat sink. Low R_{th} was observed with modified surface at 700 mA. The increased thermal performance coupled with the ability to expand the surface area without increasing the size of the heat sink could be achieved. Machined surface had low materials quantity than the plain surface. Interface resistance between MCPCB and heat sink was varied with respect to surface modification. Optical properties reflect the surface modification and show low lux value for 'W' shaped surface than plain and slotted surface at various driving currents. Good optical behavior was achieved for slotted surface with increased surface area and reduced material content. The observed CCT values for 'W' shaped were high at operating current > 350 mA.

REFERENCES

[1] M. Alan, "Lighting: The progress & promise of LEDs", *III-Vs review*, vol 17 (4), pp. 39-41, 2004.
[2] András Poppe and Clemens J.M. Lasance, "On the Standardization of Thermal Characterization of LEDs", *IEEE SEMI-THERM Symposium*, 2008, pp. 151-158.
[3] S. L. Chuang, "Kinetic model for degradation of light emitting diodes", *IEEE J. Quant. Elec*, Vol. 33, No. 6, 1997, pp. 970-979.
[4] Robert V. Steele, "High-brightness LED market overview", *Proceeding of SPIE*, Vol. 4445, 2001, pp. 1-4.
[5] http://www.cooliance.com/pdfs/Discover_the_Benefits_of_A_Precision_Forged_Heatsink.pdf
[6] http://en.wikipedia.org/wiki/Thermal_management_of_high-power_LEDs
[7] A. Bar-Cohen, M. Iyengar, and A. D. Kraus, "Design of optimum plate-fin natural convective heat sinks", *Journal of electronic packaging*, 125, pp. 208-216, 2003.
[8] J. Concepcion, Master Thesis: Passive heatsinking for Recessed Luminaries. *Lighting Research Centere, Rensselaer Polytechnique Institute*. 2004
[9] Feenstra, "*Heat sink utilizing the chimney effect*," U.S. Patent 5, 781, 411, 1998.
[10] V. R. Rao, S. P. Venkateshan, "Experimental study of free convection and radiation in horizontal fin arrays", *International journal of heat and mass transfer*, 39 (4): 779-789, 1996.
[11] F. P. Incropera, and D. P. De Witt, *Introduction to heat transfer*, John Wiley and sons, NY. 1985.

[12] http://www.electronics-cooling.com/2003/11/thermal-interface-materials/
[13] http://www.dowcorning.com/content/publishedlit/11-1712-01.pdf
[14] http://www.cree.com/~/media/Files/Cree/LED%20Components%20and%20Modules/XLamp/XLamp%20Application%20Notes/XLampThermalManagement.pdf
[15] http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/heatra.html#c2
[16] http://www.handprint.com/HP/WCL/color12.html
[17] A. Vial, "Fall with linear drag and Wien's displacement law: approximate solution and Lambert function", *European Journal of Physics*, vol. 33, pp. 751-755, 2012.
[18] http://cool.conservation-us.org/byorg/us-doe/color_rendering_index.pdf

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