Thermal analysis of high power LEDs

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Abstract

Solid-state lighting is a technology which uses semiconductor materials to convert electricity into light. In the earlier discovery, the LEDs emitted low-intensity light with limited colour and were mainly used as signal components or indicators in electrical system. In order to increase the brightness, intensity and luminous flux of LEDs, improvements in materials and crystal-growth techniques were incorporated in the production of high power LEDs, which have improved reliability and efficiency of the devices. But due to the power increase, thermal related problems were encountered during the design and applications. So, the thermal analysis of high power LEDs became an essential factor for designing, reliable and efficient LEDs. In this paper, we used TRM software to study the heat dissipation across the various components of an LED circuit when mounted on different types of substrates. Different PCB materials were used for the simulations, FR4 and diamond. The use of a diamond PCB decreases the operating temperature of the components without requiring additional heatsinks. This results show the importance of PCB materials with high thermal conductivity in the case where the size and volume of the electronic boards is a constraint.

Introduction

Visible Light Communications (VLC) uses visible light to transmit data [1]. High-brightness white LEDs contributed to the improvement of lighting systems due to their faster modulation capability. VLC technology has the benefit of the unregulated high bandwidth availability, high data rates due to LED high modulation capability, absence of electromagnetic interference, improved security and lower power consumption [2]. Using white LEDs for both communication and illumination will increase the efficiency of both systems.

Since the lifetime of an electronic component decreases with the operating temperature, it is important to identify the heat sources and to develop solutions that guarantee an efficient heat removal. The heat sources of a VLC system are the LED (since the junction temperature is directly proportional to forward current [3]) and the driver. On one side, the LED driver must have high current output capability in order to maintain the output modulating voltage level. Since low voltage modulating signals applied to the LED require high current values, the output stage of the amplifier will be forced to dissipate a considerable amount of power that produces high amount of heat concurrently. This heat leads to an increase in output stage biasing currents of the driver. This generates even more heat and thereby more current is drawn to a point of saturation where the driver can no longer perform accordingly to specifications. This high increase in heat also could lead to total failure of its components. On the other side, the junction temperature has a huge impact in the lifetime of an LED [3]. For most of the commercially available high power LEDs this value should not be larger than 150°C. In order to keep this parameter within an acceptable value, efficient heat removal methods are required. One of the ways to extract the heat generated by the LED is to connect a heatsink to the dissipation pad of the LED or, in alternative, to use large copper dissipation pads and a large printed circuit board (PCB). However, both these methods lead to bulky electronic boards. An alternative approach would be the use of a PCB board with a large thermal conductivity, such as a metal core PCB or an alumina PCB.

Diamond has all the properties required to make this material attractive for thermal management applications: high thermal conductivity (~2000 W/(m-K)), high band-gap (~5.4 eV) and high breakdown field (~2×10^7 V/cm) [4]. Synthetic HPHT (high pressure high temperature) diamond is used routinely in some industrial applications; however this material is not available in large area substrates. Diamond can be deposited by chemical vapour deposition in the form of thin films with a thermal conductivity between 1000-1600 W/(m-K). It is already possible to purchase metallized diamond plates from a few vendors around the world, however the price of such a plate is extremely high (> 1700€ for a 10×10 cm^2 plate). It is therefore important to predict the real benefit of replacing common PCBs with diamond PCBs in terms of device lifetime and efficiency.

In the present work we have analysed the thermal dissipation of a LED circuit wherein both LED and driver were mounted on the same FR4 PCB. In order to isolate the LED from the heat generated by the LED driver, similar analysis was performed when the LED was mounted on a separate PCB. In order to get an insight of the influence of the PCB material, substrates with completely different thermal conductivities were chosen, FR4 and diamond.

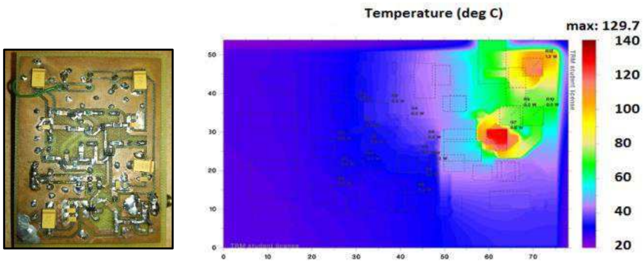
Experimental

TRM ("Thermal Risk Management") is a software tool developed by Adam Research group; Germany [5] designed to perform thermal analysis of PCBs. It calculates the detailed board temperatures with respect to heat by electrical currents and by components. The temperature of the components is calculated based on the components power and electric current. The LED temperature can be calculated according to $T_{LED} = T\text{-}P\times R_{Th}$, where P is the dissipated thermal power and R_{Th} is the LED thermal resistance [6].

The driver and the OSRAM 1 A LED (schematics not shown) were initially mounted on a 78×54 mm^2 FR4 PCB 127 µm-thick. Thermal images were obtained with an infrared (IR) camera.

Results and discussion

The thermal profile of the circuit was obtained at 25°C ambient temperature with TRM for different input voltages (V_S). Figure 1b shows the temperature profile obtained with 1 V input voltage. Table 1 shows the steady state temperature of the driver transistor and the LED for 0.1, 0.5 and 1 V input voltage. As V_S increases from 0.1 to 1 V, the LED temperature increases from 99.1 to 118°C. For the same voltage span, the transistor temperature increases sharply from 41.9 to 128°C. It can easily be concluded that at larger signal levels the transistor operation influences the LED temperature as well.



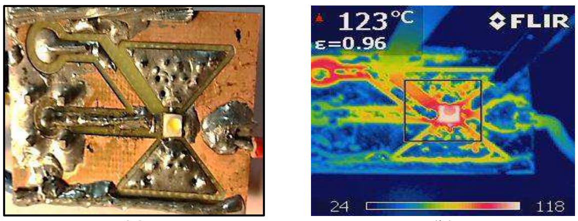
(a) (b)

Figure 1. (a) LED driver circuit. (b) Thermal simulations @1 V.

Table 1. Temperature of FR4 PCB for different voltages.

#	V_S (mV)	LED Power (W)	Transistor Power (mW)	Transistor Temperature (°C)	LED Temperature (°C)
1	100	1.096	102	41.9	99.1
2	500	1.107	503	84.9	103.6
3	1000	1.153	897	128	118

In order to remove the influence of the transistor, the LED was mounted on the top layer of a 38×24 mm^2 FR4 PCB 127 µm-thick (Figure 2a). Larger dissipation pads were included. The transistor driver was connected on the back side of the PCB. The LED was fed with a steady 700 mA current and the thermal profile was obtained with an IR camera – Figure 2b. The thermal contributions of both the LED and the transistor are clearly seen.



(a) (b)

Figure 2. (a) LED PCB. (b) IR image obtained with 700 mA.

In order to depict the influence of the thermal conductivity of the PCB on the LED temperature, thermal simulations were performed for different values of the LED forward current from 100mA to 700mA. The LED was mounted on a 38×24 mm^2 PCB of 127 µm thicknesses and the dielectric was (a) FR4 and (b) diamond.

Table 2 shows the LED temperature for different powers. The temperatures measured for the FR4 PCB with the IR camera are in close match to the simulated values.

Table 2. LED temperature for FR4 and diamond PCB.

#	Electrical power (W)	Thermal power (W)	LED temperature (°C)		
			IR (FR4)	TRM (FR4)	TRM (diamond)
1	0.292	0.1898	34.78	35.5	30.7
2	0.596	0.3874	45.38	46.4	36.7
3	0.909	0.59085	54.32	57.6	42.8
4	1.228	0.7982	69.73	69	49
5	1.555	1.01075	83.49	80.8	55.4
6	1.878	1.2207	95.28	92.4	61.8
7	2.219	1.44235	109.16	104.6	68.4

Figure 3 shows the thermal profile for 700 mA current. When diamond was used as the dielectric material, the PCB temperature distribution was uniform. The junction temperature of the LED was reduced to 68.4°C for a forward current of 700 mA with a diamond PCB, in comparison to 104.6°C with an FR4 PCB considering the internal LED thermal resistance, R_{Th} = 9.6 K/W [6].

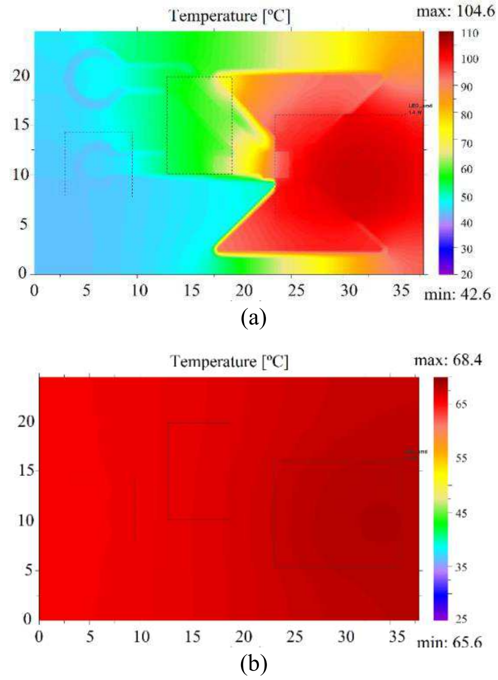


Figure 3. Temperature profile obtained with (a) FR4 (104.6°C at 700 mA) and (b) diamond (68.4°C at 700 mA).

Conclusions

In order to avoid the increase of the LED temperature due to the thermal dissipation of the driver circuit, a careful design is required. The use of a high thermal conductivity PCB, such as diamond, can improve the heat extraction from the LED, thus increasing its lifetime and efficiency. Using TRM, the temperature profile of an LED mounted on FR4 and diamond PCBs was calculated. When diamond is used, the thermal distribution is uniform and the temperature decreases. If the diamond is mounted on a metal heatsink the temperature is expected to decrease even further. It can be concluded that the use of a diamond PCB improves the heat dissipation from power LEDs without the need of further heatsinks.

Acknowledgments

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