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LED Performance and Heat Sink Technology

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LED Performance and Heatsink Technology

Introduction

The purpose of this report is to provide the results of the exploration of novel heat-sinking technologies for use in LED-integrating fixtures, specifically the desktop task-lamp.

As a transition is made from standard 5mm LED packages to high-power lamps, operating at powers of 1-5 watts, the issue of thermal management becomes increasingly vital to the efficiency and lifetime of the diodes. Increased junction temperatures can degrade the wiring used in connecting the LED chip to the package, the phosphor used in converting the blue or UV light to white emission, and the encapsulant material used in the lens. Furthermore, an increased junction temperature results in both reduced luminous efficiency (particularly for AlInGaP based red and amber LEDs) and a red shifting of the emission wavelength.

It is essential that heat be removed from the LED package – LumiLeds rates the maximum temperature of the junction at 120°C and the package at 105°C. This is typically accomplished by mounting the LED onto a larger, thermally conductive heat-sink. The use of fiber-core PCBs is common in surface mounting electronic components, but results in junction temperatures well above the recommended values. In this study, we compare standard fiber-core boards to two types of metal-core boards, aluminum and copper, as well as to more novel structures, incorporating graphite and carbon wires.

Experimental Setup

The LEDs used in this study were off-the-shelf 1W white Luxeon packages from LumiLeds. The emission pattern was either batwing or Lambertian, although there should be no effect of that pattern on the thermal characteristics of the device. The packages were then mounted onto the boards using a thermally conductive, yet electrically insulating silicone joint compound (Ther-o-link 1000, Aavid Thermal Technologies, 0.73 W/(m°C)).

To begin analyzing the thermal characteristics of an operating device, a calibration is made of the voltage drop across the LED as a function of ambient temperature. The device is placed in an oven, and 1mA of current is passed through the diode. The voltage across the junction is measured as the temperature of the oven is varied, allowing for the device to reach an equilibrium temperature at each point. Figure 1 shows the experimental setup used in generating the calibration curves.

To determine junction temperature at an operating current of 300-350mA, the device is pulsed, with the current in the LED varying between the desired final operating current and 1mA. The period of the pulse is set at 100msec with an off-time (I = 1mA) of 6.8msec. It is assumed that the off-time is sufficiently short so that no cooling occurs during that interval. The voltage drop across the device at a current of 1mA is then compared to the calibration curve to back-out the operating temperature – a specific voltage drop is correlated to a specific junction temperature. Figure 2 shows a calibration curve for a Luxeon Lambertian package. The schematic of the split-current circuit diagram is shown in Figure 3.

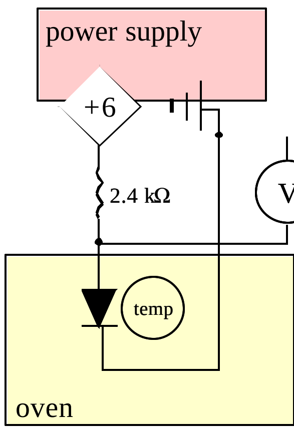

Figure 1: Thermal calibration setup layout

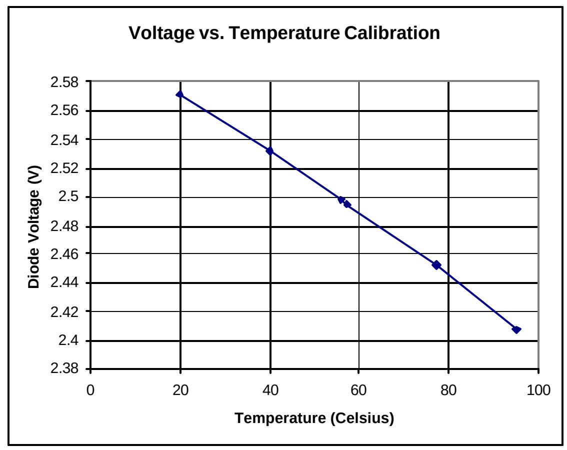

Figure 2: Sample calibration curve

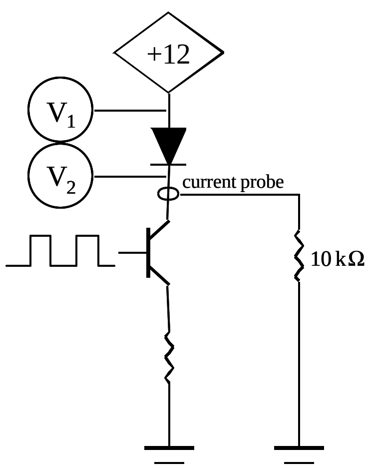

Figure 3: Differential voltage measurement circuit

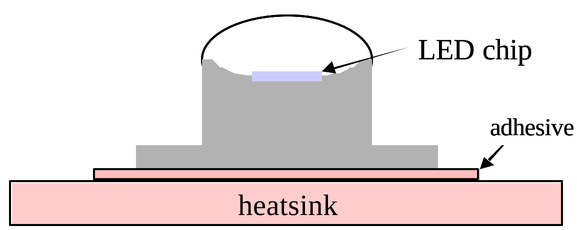

Figure 4: Experimental schematic; adhesive is Ther-o-link compound, approximately 0.5mm thick.

Results

Baseline Material: Fiberglass-core PCB

The most common PCB material is a fiberglass-core board with a copper trace for mounting. Luxeon LEDs were mounted on this board using the Ther-o-link material (Figure 4), and the junction temperature measured in the manner detailed in the previous section for both 50mA and 300mA operation.

At 50mA (92% duty cycle), the ΔV was 2.56V, corresponding to a junction temperature of 40°C. At 300mA (d.c. = 92%), the voltage difference was 2.44V, corresponding to a junction temperature of 120°C. Extrapolating this to 350mA yields a junction temperature of 136°C at that current.

Metal-core PCB: Copper (Bergquist Co.)

The metal-core board consists of a copper trace laid upon a thin insulator layer on top of a thicker metal heatsink. The insulator should be as thermally conductive as possible while providing electrical isolation. The underlying metal core is typically either copper or aluminum. Copper offers a better thermal conductivity (260 W/m°C, versus 173 W/m°C for Al) and a smaller thermal expansion coefficient (18 ppm/°C vs. 24 ppm/°C for Al). The drawback for using Cu is the added weight penalty.

Measurement of a Luxeon LED mounted to a Copper-core board using the ther-o-link compound yielded a ΔV of 2.34V (at 350mA), corresponding to a junction temperature of 126°C.

Permlight Board

Through collaboration with Permlight, LBNL has acquired 1.5x1.5 in^2 boards with a graphite core surrounded by an insulating Si/Al composite. Mounting the LED using the ther-o-link compound yielded a ΔV of 2.42V (at 350mA), corresponding to a junction temperature of 127°C. However, a problem arose when a Luxeon LED was soldered to a copper pattern on the Permlight board. Upon probing, it became apparent that the circuit was shorted – likely due to the porosity of the Si/Al film, which allowed for a conduction path to be formed via the underlying graphite layer.

Additional comparison between Permlight and copper

A comparison between the Permlight board and a Bergquist copper-core board of similar area showed nearly identical thermal spreading characteristics. Heat was applied to the center of each board by using a soldering iron, and the temperature measured at a corner via thermocouple. During the measurements, each board was placed on a large Aluminum block that served as a heatsink. The temperature of the Aluminum did not change significantly during the course of the measurement. Figure 5 shows the temperature at the corner as a function of time for the copper-core, Permlight, and fiber-core boards. Additionally, a measurement of the temperature at the center of the board was made at the 5-minute mark. For both the copper-core and Permlight board, the value was 29.4°C – the same as at the corner – while for the fiber-core board, the center temperature was higher: 33.9°C as compared to 31.0°C at the corner.

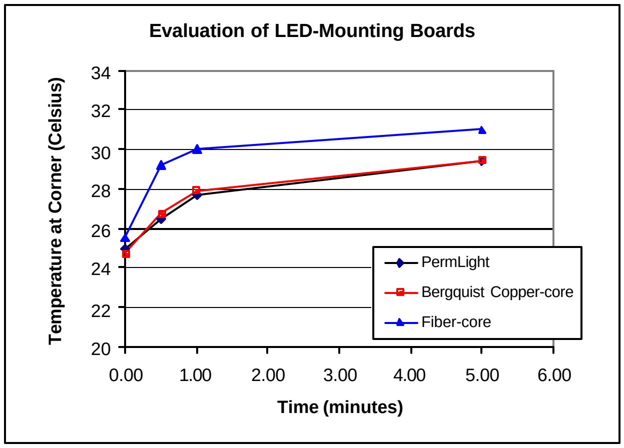

Figure 5: Comparison of different mounting boards

Given the expense of the Permlight board, its similarity in performance to a copper-core board, and the problem of porosity in the insulating layer, it is unclear whether it is worthwhile to incorporate this material in the final design of the task-lamp.

Additional Materials

Nisvara

Nisvara Inc. offers a potentially better mounting material with its carbon fiber based heat transport system. The company's IP revolves around both the production of the carbon fiber matrix in a variety of shapes, and the ability to connect to the fibers via a copper interface. Theoretically, the transport system (connecting to a spatially removed thermal ground) is lighter in weight than aluminum, and can conduct 4 times better than copper. A number of challenges remain for the company to go into full production of these products, but a sample for testing should be provided by the end of April 2004.

Optimized Aluminum Package

Measurements were made on a Luxeon Star package, which incorporates an aluminum base. For the Star, a ΔV of 2.49V (300mA, 92% duty cycle) was recorded, corresponding to a junction temperature of 80°C. It should be noted that the thermal conductivity of aluminum is lower than that of copper, and as such one could expect a higher operating junction temperature. However, given that in the preceding experiments the mating between the LED and the board was accomplished by using a poor thermal conductor, this value is not surprising. In their package, LumiLeds uses a 0.01" thick adhesive with a thermal conductivity of around 1 W/m°C. The Ther-o-link (0.73 W/m°C) used in our experiments was approximately 0.5mm thick (0.02"). It is likely that a better mounting design – both in terms of material used and thickness – will yield junction temperatures below 80°C (at 300mA).

Conclusions and Suggestions for Future Work

Based on the measurement shown in Figure 5, it is clear that, for the case of non-integrated mounting boards, copper is the best available choice. The Bergquist board shows properties on par with the Permlight board, but at a lower cost and greater (and easier) availability. Measurement of the junction temperature on the different boards confirms this assessment, although it also indicates that the best design is one in which the LED is properly mounted onto the board, as in the case of the Luxeon Star. It is quite likely that the resulting high junction temperatures (well above 100°C at 350mA) are due to the Ther-o-link compound used in the mounting. One possible solution is to incorporate a high thermal conductivity epoxy. Tra-Con Inc. for example, produces a diamond epoxy (Supertherm 2003) with a thermal conductivity of 2.57 W/(m°C) – a factor of 3 higher than the Ther-o-link compound – while remaining electrically insulating. The drawback in using this material is that it must be kept at -40°C for storage. In the use of the Cree packages, it may be possible to solder the base of the lamp to the board directly (assuming that, unlike in the Luxeon lamp, the base is isolated from the diode). A typical thermal conductivity of solder is around 50 W/m°C, almost 2 orders of magnitude better than Ther-o-link, and 20 times better than an epoxy.