The Latest LED Technology Improvement in Thermal Characteristics and Reliability -

Avago's Moonstone 3-in-1 RGB High Power LED

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White Paper

Illumination Market Trend for LEDs

The range of applications for light emitting diodes (LEDs) continues to grow significantly. One of the fastest-growing and most promising uses for LEDs is in illumination applications. The LED is penetrating this market rapidly due to its combination of excellent color saturation, energy savings to meet today's demand for reduced-energy "green" products, and long life characteristics.

Both white and color LEDs are playing important roles in a number of market segments including architectural lighting, entertainment, wall washing, decorative lighting, outdoor façade lighting, and video walls. The use of red, green and blue (RGB) combinations will become increasingly popular in these segments due to the resulting flexibility of color selection and the simplification of the optical aspects of lighting designs.

Figures 1 and 2 summarize the LED lighting market by application and color for 2006 [2]. The largest application in 2006 was Architectural, at $93 million, or 45 percent of the overall market. This was followed by channel letters/contour lighting and consumer portable applications (flashlights, lanterns, bicycle lighting and similar devices), at $34 million (17%) and $30 million (15%), respectively. All other applications accounted for less than 10% of the lighting market.

By color, white accounted for 43 percent ($89 million), blue and green for 35 percent ($72 million), and red, orange and yellow for a combined 22 percent ($44 million). White represents the largest share, mainly due to its large penetration in channel letter, consumer portable, architectural, and retail display lighting. Blue and green is the next-highest color usage in terms of revenue, mainly in RGB applications where the ratio of blue and green units to red units is at least 2:1.

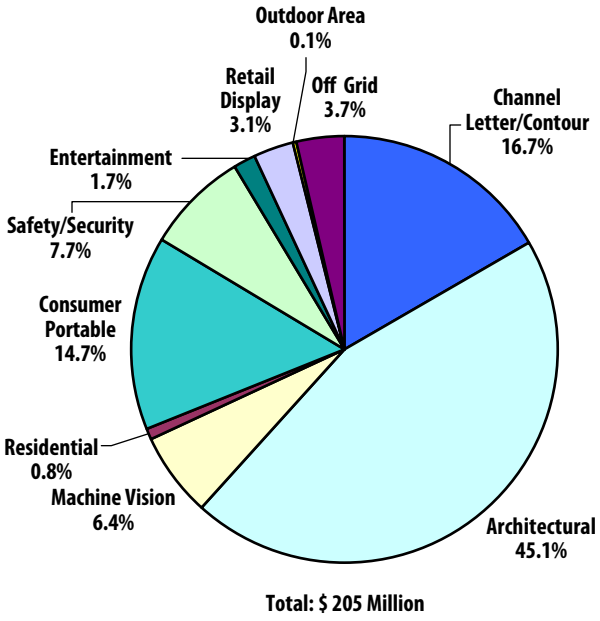

Figure 1. LED Lighting Market by Application (2006)

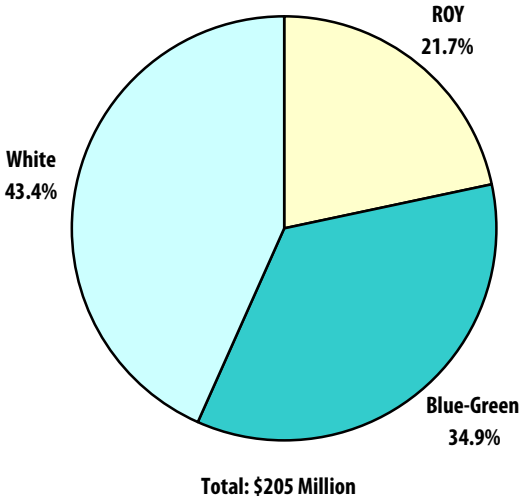

Figure 2. LED Lighting Market by Color (2006)

One of Avago's innovative approaches to the lighting market was the development of the Moonstone® LED package.

Avago's Moonstone LED emitters are available in one of the industry's thinnest packages (15.85 mm x 8.5 mm x 3.3 mm) , and are encapsulated in a heat- and UV-resistant silicone compound for high reliability and long life. The competitively priced Moonstone LED emitters provide designers of solid-state lighting with many features, such as a wide viewing angle radiation pattern, superior heat dissipation, and thin packaging. All this makes them ideal for use where height is a constraint. Typical applications include architectural façade lighting, track lights, spot lights, and decorative lighting applications.

With an exposed pad design on the back of the package, the Moonstone emitter package has low thermal resistance and is able to efficiently transfer heat from the package to the motherboard to maintain long term reliability. These emitters are compatible with standard SMT reflow soldering processes to provide lighting designers with more freedom and flexibility in designing their applications. In addition, the package is qualified to a JEDEC moisture sensitivity level (MSL) rating of 2A. (For manufacturers, this rating means that the devices can be kept in the open air (30°C, 60 percent relative humidity) for up to four weeks after being removed from their sealed package without the need to remove absorbed moisture). The Moonstone LEDs are specified for operation in the –40°C to +95°C temperature range, and are capable of withstanding electrostatic discharge (ESD) levels of 16 kV (class 3b) per ESD Association standard ESD STM5.1, Electrostatic Discharge Sensitivity Testing -- Human Body Model.

Moonstone 0.5 W LED emitters are supplied in warm white (2600 K to 4000 K) and cool white (4000 K to 10,000 K color temperature), with a choice of non-diffused or diffused package and an option of electrically-isolated or non-isolated slug. They provide 30 lumens (lm) (typical) and up to 43 lm cool white light output at 150 mA drive current, with a 110° viewing angle.

Moonstone 1 W LED emitters are supplied in warm white and cool white, with a drive current rating of 350 mA and a choice of 110° or 120° viewing angle. The cool white versions provide up to 80 lm output.

They are also available in AlInGaP:

- amber (582–595 nm wavelength/ 35 lm typ. luminous flux)
- red (620–635 nm/ 40 lm typ.),

InGaN:

- green (515–535 nm/ 40 lm typ.)
- blue (460–480 nm, 10 lm typ.).

Moonstone 3 W LED emitters in warm white and cool white are capable of

being driven to 700 mA, providing a light output of up to 161 lumens, and are available with a 110° or 120° viewing angle.

The newest version is the 3-in-1 Moonstone emitter, combining red, green and blue LED chips into a single package (Figs 3 and 4). Each color can be driven at up to 350 mA, for a typical flux output of 108 lm (40 lm red, 55 lm green and 13 lm blue). Color mixing provides hundreds of thousands of colors, making the 3-in-1 emitter ideal for applications including instrumentation, interior or exterior illumination, mood lighting and special effects.

Figure 3. The 3-in-1 RGB Moonstone LED package (ASMT-MT00)

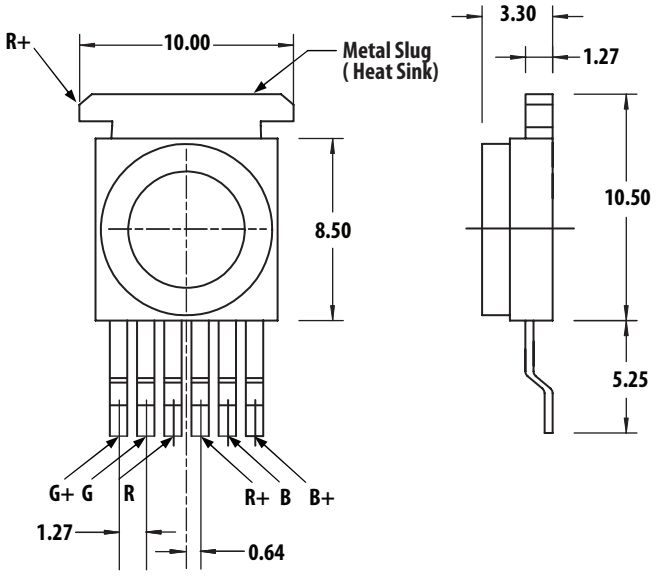

Figure 4. Outline drawing of the 3-in-1 RGB Moonstone LED package (ASMT-MT00), showing dimensions.

Benefits of Integrated 3-in-1 RGB LED Packaging

The conventional approach to assembling RGB LEDs for illumination applications is to use separate, discrete packages for each color, arranging the packages on a printed circuit board to achieve an RGB light source. In applications such as architectural, entertainment, outdoor facade and decorative lighting this will be more challenging for secondary optic designs, including a collimated lens for RGB that is used to illuminate an area some distance away. The lens and printed circuit board sizes will have to be enlarged once the pitch size between the LEDs increases. At the same time, the cost of a secondary optic design and material also will increase.

In contrast, the 3-in-1 approach directly mounts the RGB LED die into the same package. Each die can be individually addressed, which means that each has its own electrical channel to provide a range of colors. This enables the light source to be compact, compared with separately packaged devices, and the pitch between individual light sources to be significantly reduced, which is important in achieving the best color quality. The minimum pitch required for LED light sources to achieve good color mixing is approximately 5 mm. The 3-in-1 approach reduces the pitch to as close as 1.5 mm [Figure 5]. Once the pitch is reduced, the area required for effective color mixing also is reduced. The effect of RGB stray light also will be minimized when approaching white color [Figure 6].

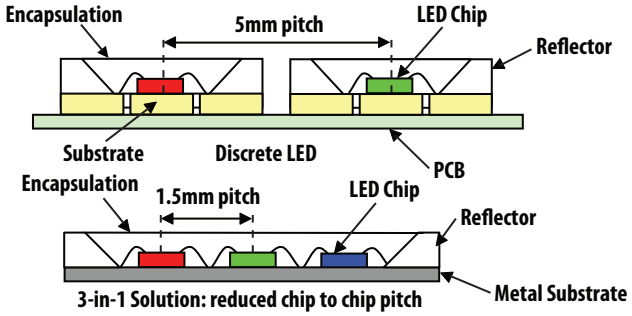

Figure 5. Pitch size comparison between discrete component solution and 3-in-1 solution

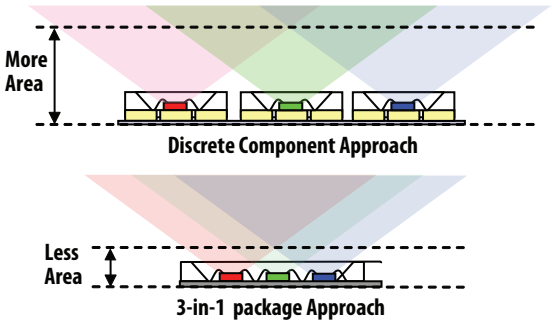

Figure 6. 3-in-1 package approach reduces the required color mixing area

In the Avago 3-in-1 package, high performance polyphthalamide plastic is used as both the package housing and the reflector. This material can operate under conditions of high-temperature, high-UV light levels for long periods while maintaining surface reflectivity. If the wrong material is chosen as a reflector, however, the light output performance can drop significantly because of its white surface, which becomes yellow or brown over time after experiencing high temperatures.

A copper lead frame (substrate) enables the lowest thermal resistance. The heat generated by the operating LED chips can be efficiently transferred to the heat sink through the frame; copper's thermal conductivity is superior to ceramic, mild steel and aluminum [Figure 7].

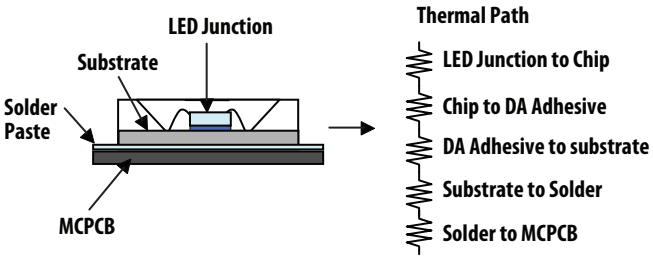

Figure 7. 3-in-1 RGB package thermal path

Good Thermal and Reliability Performance

The thermal resistance has been verified using the FLOTHERM computational fluid dynamics (CFD) program from FLOMERICS Group PLC. In the simulation model, the reflector, lead frame, encapsulation, die attach layer and dice are created. A 1W power source is created on top of each die. The simulation visualization result can be seen in Figure 8.

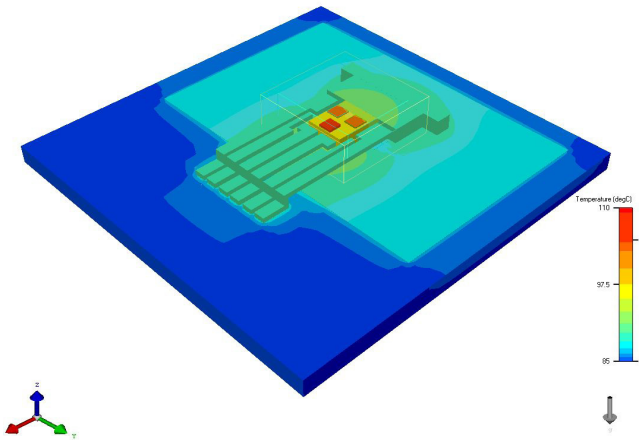

Figure 8. Simulation visualization results for 3-in-1 RGB LED package

The simulated thermal resistance from junction to pin (Rjp) for the red, green and blue die are 23°C/W, 20°C/W and 20°C/W respectively. These thermal resistance values have also been verified by actual measurement using the forward voltage method. The results of actual measurements are very close to the simulation.

Furthermore, the package thermal performance has also been validated through operating life tests of up to 5000 hours.

Reliability testing was performed in a temperature chamber and showed low degradation after 5000 h at +100°C operation [Figure 9]. The InGaN die show an approximately 12 to 18 percent I_V drop and the AlInGaP die, an 10 percent I_V drop.

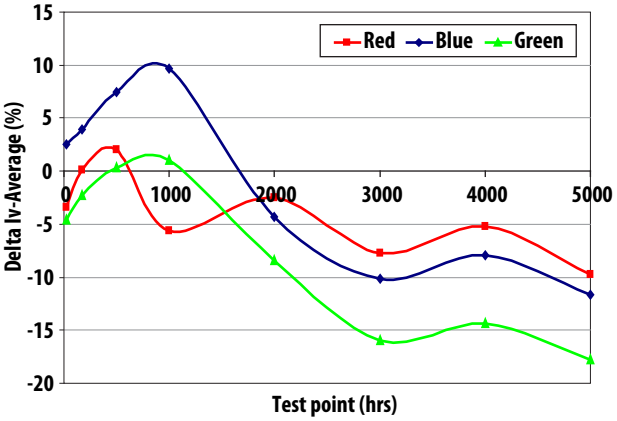

Figure 9. Degradation of LEDs during high temperature operation

Conclusion

The 3-in-1 package solution provides better performance than conventional discrete LED packages in terms of characteristics such as color mixing and space requirements, while featuring good thermal performance and reliability characteristics. It also provides greater flexibility for system designers in developing their applications.

Avago Technologies offers extensive technology and products in the LED illumination field, providing mid- and high-power LED devices ranging from mid-power PLCC surface-mount emitters in both warm and cool white and a range of colors to the Moonstone emitters, Star-1 and Star-2 PC assemblies, 3.5 and 5-watt multi-chip white LED modules and 24-watt multi-chip LED modules. For detailed information on these or other Avago lighting products, go to http://www.avagotechlighting.com/.

Acknowledgement

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References

[1] T. L. Mok, "Ultra Thin Profile RGB LED Module for LCD Monitors and TV Backlighting", *International Display Workshop*, Otsu, 2006

[2] Strategies Unlimited, *HB LED Market Review and Forecast 2007* (illumination market forecast)

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