

## Novel High Power Multichip LED Devices Give Customers Flexibility to Design-Their-Own Four-Chip LED Configuration

By Siegmund Kobilke, Engineering Leader, LED Solutions, PerkinElmer Optoelectronics



PerkinElmer recently introduced two new products to its ACULED (All-Color Ultrabright LED) family. The ACULED DY0 (Design-Your-Own) is a high-power multichip LED device that gives the customer the flexibility to “design-your-own” LED configuration from a broad chip selection menu. The DY0 leverages PerkinElmer’s experience with custom-designed LED solutions in Chip-on-Board (COB) technology along with its standard LED offerings. The ACULED VHL (Very High Lumen) uses the next-generation ACULED platform with improved thermal properties and powerful chips to provide standard four-chip high-brightness (HB)/high-power (HP) LEDs with individual control for each chip and available in the UV to IR spectral range.

With the significant efficiency increase of LED chips, the market for high power LED solutions is rapidly expanding. In order to reap the benefits of high power LEDs, special requirements concerning thermal management, optical, electrical and mechanical design have to be met.

### LED Chips

LED chips are available in different sizes. Standard dies with edge lengths of 250  $\mu\text{m}$  to 350  $\mu\text{m}$  are available in nearly all wavelengths from 360 nm to 1,000 nm. Standard chips are limited to small forward currents (usually 20 to 30 mA), thus requiring many chips to achieve a high radiant flux assembly. The resulting high bonding costs and low packing densities make them favorable for different applications that do not require the highest luminous flux.

High-current or high-power chips, with edge lengths ranging from 0.5 mm to 2 mm, are available from a few suppliers for more and more wavelength regions, typically for driving currents of 350 mA to 1 A multi-watt even making multi-kilowatt LED arrays possible.

### Substrate Materials

For high-power LED packages, thermal conductivity is important. High performance can be achieved by utilizing ceramic-based solutions, such as aluminum oxide ( $\text{Al}_2\text{O}_3$ ) and aluminum nitride (AlN) with typical values of 25 W/mK and 180 W/mK or metal core printed circuit boards.



Figure 1. Compares the size of a 16-chip array in COB with a comparable solution that uses single-chip high-power packages

### Chip-On-Board Technology

Chip-on-Board (COB) technology provides a number of distinct benefits as compared to standard single-chip packages offered by multiple LED suppliers.

The main advantage of COB solutions is the high packaging density. COB arrays can reach packaging densities of up to 85 percent (lighting area to board size), enabling a miniaturized, packaging size. In comparison, typical values for standard single-chip packages can be as low as 1-5 percent (See Figure 1). In COB technology, LED chips may be bonded to a substrate that can be directly packaged on a heat sink or any kind of active cooling unit. This optimizes heat-flow and overall LED performance in a COB process. For market applications requiring multi-color LED solutions, the close chip placement in COB technology also offers the benefit of superior color mixing. The close chip spacing (100  $\mu\text{m}$ ) between the chips in the standard ACULED RGB product (Figure 2) underscores the ability to achieve the best color mixture, with or without additional beam shaping optics.



Figure 2. Shows the ACULED High Performance RGB LED (with 4 chips) in COB technology

### Thermal Management

There are many LED chips with dimensions of approximately 1 by 1 mm<sup>2</sup> that require electrical powers of 1 to 3 W per LED and often produce heat. Since the junction

temperature of the chips should not exceed 100°C to 120°C due to lifetime and high optical efficiency, the generated heat must be dissipated. This is done via the carrier, substrate, and heat sink. If heat dissipation is not properly executed, the LED will show chaotic degradation, wavelength shift (Figure 3), loss of radiant flux, and reduction of forward voltage  $V_f$ .

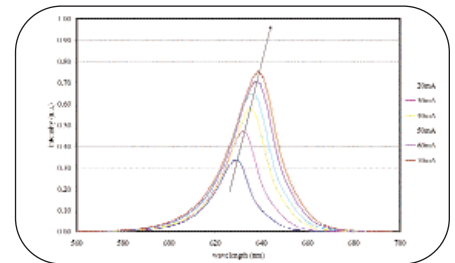


Figure 3. Shows wavelength shift depending on input current  $I_f$

If the chip substrate (PCB) and heat sink are fixed, they must be combined properly. Normally done by soldering, most companies typically use thermally high conductive glues. PerkinElmer uses extremely thin and homogenous adhesive layers - below 10  $\mu\text{m}$  thickness - in order to provide the highest LED-performance.

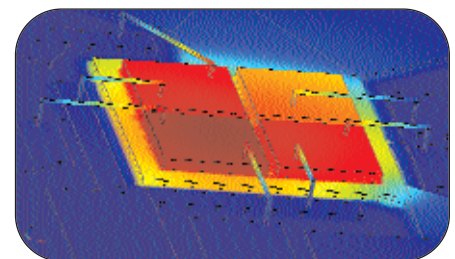


Figure 4. Thermal simulation for ACULED

Thermal simulations are utilized to compare different scenarios, to optimize the materials, the thickness of the different layers, and the layout of the board. Figure 4 shows an example of a thermal simulation for the ACULED (Four - Chip RGB) HB LED on copper substrate.

### Example: Thermal Resistance, Cross-Talk Matrix For the ACULED Structure

The individual thermal resistance of each LED is higher than the total ACULED thermal resistance of 7.8 K/W.

In other words, if all heat power is generated within a single LED, the self-heating of that

LED is stronger than the same total heat power distributed over different LEDs. In order to estimate the temperature rise within an individual LED under the influence of all other LEDs, the following simple formulas can be employed:

Red:  $\Delta T_1 = R_1 P_1 + C_{12} P_2 + C_{13} P_3 + C_{14} P_4$  (1)  
 Green:  $\Delta T_2 = R_2 P_2 + C_{21} P_1 + C_{23} P_3 + C_{24} P_4$  (2)  
 Blue:  $\Delta T_3 = R_3 P_3 + C_{31} P_1 + C_{32} P_2 + C_{34} P_4$  (3)  
 Green:  $\Delta T_4 = R_4 P_4 + C_{41} P_1 + C_{42} P_2 + C_{43} P_3$  (4)

LED	Thermal Resistance
1. red	14.33 K/W
2. green	18.53 K/W
3. blue	19.53 K/W
4. green	18.79 K/W

Table 1. Thermal resistances for individual use of LEDs in ACULED layout

With the single-LED resistance  $R_i$  (Table 1) and heat power  $P_i$ , the coefficients  $C_{ij}$  measures the thermal cross-talk between LEDs  $i$  and  $j$ . All of the cross-talk coefficients are shown below in Table 2. Note that the cross-talk coefficients depend on the direction of the heat flow. For example, the blue LED affects the red LED more ( $C_{13}=2.15$  K/W) than the red LED affects the blue, ( $C_{31}=1.87$  K/W) since part of heat generated by the red LED dissipates into the adjacent metal contact layer.

LED	1	2	3	4
1. red	R1=14.33	C12=3.66	C13=2.15	C14=3.25
2. green	C21=3.42	R2=18.53	C23=4.14	C24=2.03
3. blue	C31=1.87	C32=3.65	R3=19.53	C34=3.73
4. green	C41=2.86	C42=1.93	C43=4.14	R4=18.79

Table 2. Thermal coefficients [K/W] for ACULED layout

Equations 1 - 4 can also be written in form of a matrix equation

$$\begin{pmatrix} \Delta T_1 \\ \Delta T_2 \\ \Delta T_3 \\ \Delta T_4 \end{pmatrix} = \begin{pmatrix} R_1 & C_{12} & C_{13} & C_{14} \\ C_{21} & R_2 & C_{23} & C_{24} \\ C_{31} & C_{32} & R_3 & C_{34} \\ C_{41} & C_{42} & C_{43} & R_4 \end{pmatrix} \begin{pmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \end{pmatrix} \quad (5)$$

As a test, we calculate the temperature rise within the blue LED (Eq. 3) for a power setting of 700 mA, which is very close to the exact simulation result of 68.71 K:

$$\Delta T_3 = 19.53 \times 2.44 + 1.87 \times 1.47 + 3.65 \times 2.52 + 3.73 \times 2.52 = 69.0 \text{ K} \quad (6)$$

LED	350 mA	700 mA
1. red	20.00 K	43.71 K
2. green	29.37 K	66.98 K
3. blue	31.76 K	69.10 K
4. green	29.15 K	66.56 K

Table 3. Estimated temperature of individual LEDs from Eqs. 1 - 4

Table 3 lists all LED temperatures estimated from Eqs. 1 - 4 using the data in Table 2. Thus, the approximate formulas (1-4) can be conveniently used to estimate the temperature rise in individual LEDs for arbitrary heat power values.

### Efficiency Enhancement of COB Packages

More and more lighting applications work with high-power LED arrays and need defined irradiance. The broad aperture angles of most LED types, including the COB LEDs, will require additional optical



Figure 5. Shows several COB solutions with different types of optical beam shaping elements

elements. Using primary optics, reflectors, or secondary optics, these demands can be fulfilled. Figure 5 illustrates several COB examples from PerkinElmer. The first example places LED chips into embedded cavities. The other examples show a custom solution with external reflectors and solutions with lenses on top.

### The Benefits of COB Technology

COB represents an attractive technology for packaging LEDs, particularly for high brightness applications. Excellent thermal management with adopted materials and high efficiency throughout the LED-assembly enables manufacturers to meet the most stringent customer requirements.

Figure 6 shows a PerkinElmer High-Power COB array that represents one of the brightest LED-arrays ever achieved. With nearly 2000 1 mm LED chips contained on a lighting diameter of approximately 120 mm, an LED was produced with a power consumption of more than 3 kW pulsed, or 25 W/cm<sup>2</sup>. For this customized high-speed application, the homogeneous light output of more than 200 W underscores the benefits of COB technology.

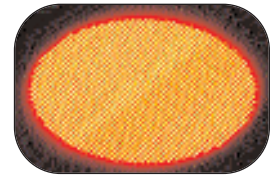


Figure 6. shows an impressive "3 kW-LED" high-power COB array, with nearly 2000 1 mm chips

### Next-generation HB/HP products with COB Technology: ACULED VHL and ACULED DYO

The ACULED VHL is a high-power light source utilizing COB technology with up to four different chip types. With its next-generation platform, the VHL affords an impressive improvement in thermal design, thermal resistance and an improvement in luminous efficacy of up to 90 percent as compared to the first generation platform. With the VHL, each chip has a separate anode and cathode, enabling each to be driven individually, thus increasing flexibility in electrical layout. The ACULED VHL offers a higher color rendering index than the basic RGB version and is available in standard monochromatic as well as multi-color chips, including an RGBY (yellow) version. Additional optics can be easily attached and for ESD-sensitive chip types, ESD protection is included via Z-diodes. The thermal resistance  $R_{th}$  JB of the package can be as low as 4.5 K/W, depending on the chip configuration.

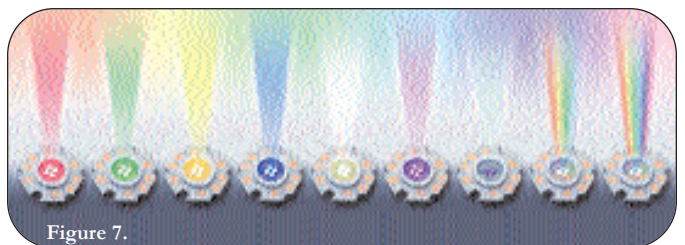
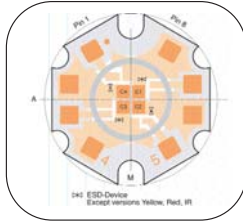


Figure 7.

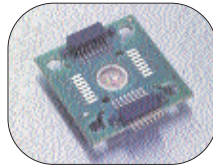
With the ACULED DYO, customers have the flexibility to "Design-Your-Own," four-chip LED configuration to suit specific needs and lighting applications. Design choices include UV, visible, IR and photo diode chips, as illustrated in Tables 4 and 5 on page 36.

**Layout and Mounting**

Figure 7 shows the principal layout of the ACULED VHL and DYO. The chips are placed in the middle of the IMS board, protected by a ring and silicone resin encapsulation. If ESD protection diodes are required, they can be set inside the ring. If one wants to connect the chips serially, neighboring soldering pads can be attached (i.e. #2 - #3, #4 - #5, #6 - #7 or #8 - #1) making the board design as easy and flexible as possible.



**Figure 7. ACULED VHL/DYO - Layout**



**Figure 8. Upside-Down Mounting of the ACULED**

As illustrated in Figure 8, one method of mounting the ACULED is upside down. When mounting it regularly on a heat sink or appropriate board, the pads must be electrically connected by wires or spring contacts. For automatic processing like reflow, soldering by using the upside down method is recommended. Here the ACULED is mounted upside down on a PCB which can be made from FR4 and other non-heat conductive materials. The PCB needs a cut-out of Ø 7.4 mm so as to make the ACULED visible. Thereafter, whole package, ACULED with PCB, can be mounted on a heat sink. The advantage of this method is to provide easy reflow processing and an easy way of using inexpensive PCB materials and standard heat sinks.

**Summary**

The newly expanded ACULED product family takes advantage of COB technology along with the design benefits of the newly enhanced IMS platform including improved thermal management, lower thermal resistance, and high luminous efficacy. The special separated pad-geometry of the next generation LED products reduces thermal cross-talk of the LED chips when operated simultaneously. The design flexibility afforded by the new DYO line is its way to illuminating a range of applications including general illumination, architectural and landscape lighting, entertainment and mood lighting, medical lighting, displays and signs and more.

Wavelength [nm]	Color	Chip code	ESD rec.	Cathode on
445-455	deep blue	D	yes	odd pads
455-470	blue	B	yes	odd pads
490-515	cyan	C	yes	odd pads
515-540	green	G	yes	odd pads
585-605	yellow	Y	-	odd pads
605-620	amber	A	-	odd pads
615-635	red	R	-	odd pads

**Table 4. Chip list with colored VIS chips**

Wavelength [nm]	Radiation	Chip code	ESD rec.	Cathode on
360-410	UV	U	yes	odd pads
830-880	IR1	I	-	even pads
930-1000	IR2	J	-	even pads

**Table 5. Chip list with UV and IR chips**

Reprinted from the July/August Issue of *LED Journal*. © 2007 Webcom Communications Corp.  
 7355 E. Orchard Road, Suite 100, Greenwood Village, CO 80111 USA  
 Phone 720-528-3770. Fax 720-528-3771. www.infowebcom.com