BY MIKE WOOD

How do LEDs work? Chip-on-board

OVER THE LAST YEAR OR so, I've written a series of articles in this journal on the mechanics and physics of LEDs and how they operate. This issue, I want to continue that theme and take a look at a method of mounting and using LEDs which is gaining popularity in entertainment lighting products. You'll see it referred to as chip-on-board or COB. What does that mean, and what advantages does it give to the product designer?

> "The closer spacing of the dies improves color homogenization and helps get rid of multi-colored shadows."

The first thing to say is that COB is not actually a new technique. It dates back many years both in LED usage and with semiconductors as a whole. Chip-on-board is a method of packaging and using semiconductors and has nothing to do with the design and manufacture of the semiconductor die or LED itself. We are most familiar with seeing semiconductor dies assembled into a plastic or ceramic housing to create a component. These packages form the familiar computer chips we see on every circuit board and are supplied with standardized leads or connections that make them easy to assemble onto boards. This packaging also provides protection to the semiconductor die. One downside of the chip-style packaging is that it also adds a lot of bulk to the semiconductor. What was a 2 mm x 2 mm die that's 1 mm thick becomes a 10 mm x 20 mm package that's 5 mm thick, perhaps 250x the volume. This potential for extreme reduction in size is one of the first reason COB devices were used. With a COB device, the semiconductor die has no packaging and instead is mounted directly onto the circuit board or substrate.

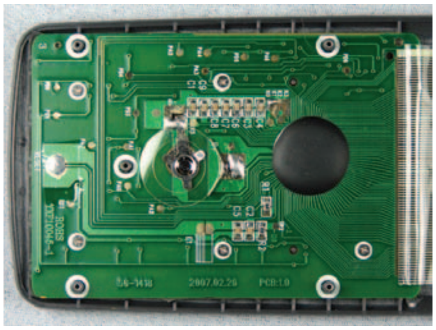


Figure 1 – Chip-on-board processor in a calculator

Figure 1 shows an example of a COB chip in a pocket calculator. The circular black blob to the right in the photograph is the processor that provides all the calculating power. It's a complex digital semiconductor that, if packaged conventionally, might be 3 cm square just to accommodate all the connections. Instead, the silicon semiconductor die is adhered directly to the green circuit board, and the connections are made through fine gold wires that are bonded from the die straight to points on the circuit board with no intermediate connectors. The entire assembly is then encased in the blob of black epoxy that you can see in the photograph that provides protection. The end result is tiny compared to a packaged chip.

Let's take a look at how LEDs are packaged and how they could also take advantage of chip-on-board techniques. To recap from an earlier article, the most familiar and oldest LED package is shown in **Figure 2**.

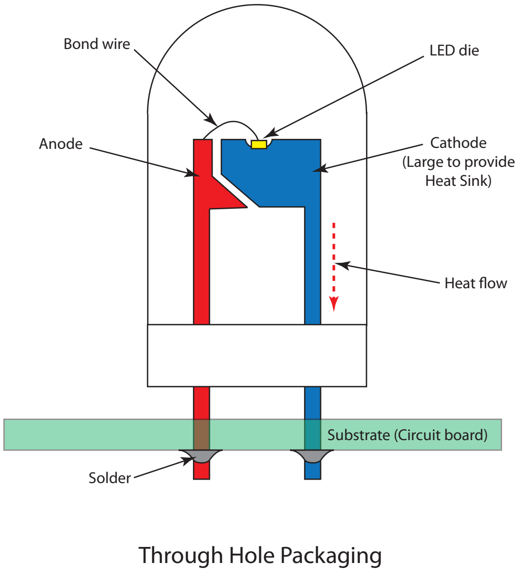


Figure 2

This is a through hole package where the LED die is mounted to one of the lead wires (which also provides the heat sink), and the entire assembly is surrounded by a transparent domed package. The two lead wires pass through holes on a circuit board where they are soldered to copper traces on the board. **Figure 2** is roughly to scale, and you can see how large the package is compared to the tiny die inside.

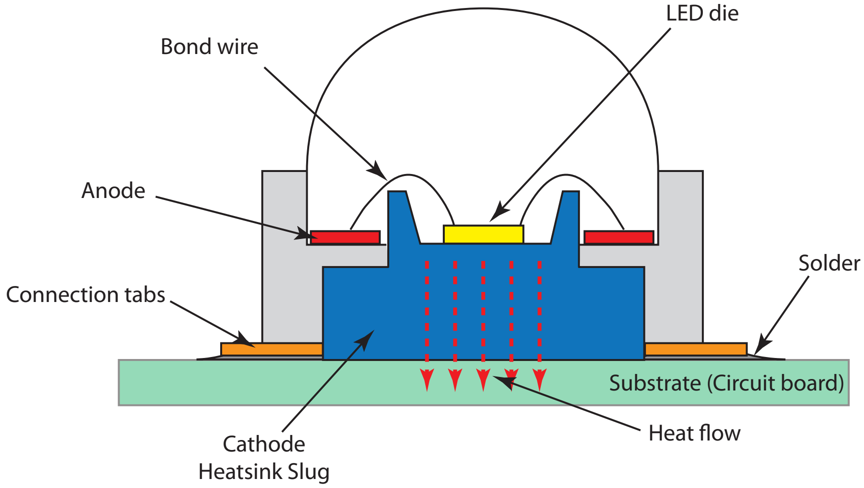
Next up is surface mount packaging, as shown in **Figure 3**.

In this case, the die is mounted to a heat sink slug, which helps in transporting heat out of the LED die and into the substrate or an external heat sink. In this case, the electrical connections are made through tabs around the edge of the package onto the top surface of the board; they don't go through holes. Surface mount packages are simpler for automated pick-and-place machines to handle and provide much better thermal contact for the LED. The connections to the LED die within the package are made through tiny bond wires, which are welded across to internal connection points. As with the through hole package, the packaging is large compared with the size of the die.

Figure 4 shows the same LED die as **Figure 3**, but now as a chip-on-board assembly.

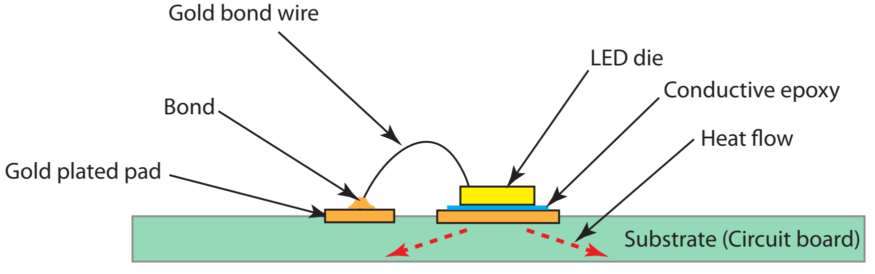
The LED die is bonded directly to a connection pad on the substrate or circuit board using a conductive adhesive of some kind, often an epoxy. This provides both electrical connection for one side of the LED and a path for heat to escape. The second electrical connection comes from a bond wire, just as was used inside the surface mount package, but now used externally directly to a gold plated pad on the substrate. Compare this with **Figure 3**, and you can see how much smaller the assembly is. It also provides the shortest possible path for heat flow into the substrate and, therefore, allows the LED to be run at higher power while still extracting the heat and keeping it cool.

The packaging shown in **Figure 4** is very simple; the LED die is mounted on a flat substrate, which provides little or no optical control of the device. More sophisticated COB packaging can do better than that. **Figure 5** shows a system where the substrate is formed with an optical cup that can act as a reflector to direct the light from the LED die while still retaining the advantage of small size and good heat



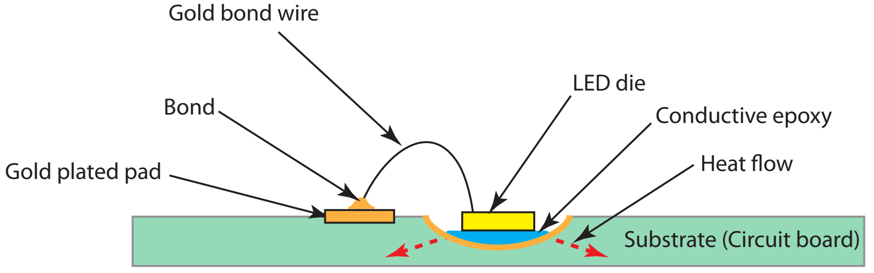
Surface Mount Packaging

Figure 3



Chip on Board Packaging

Figure 4



Chip on Board Packaging with Optical Cup

Figure 5

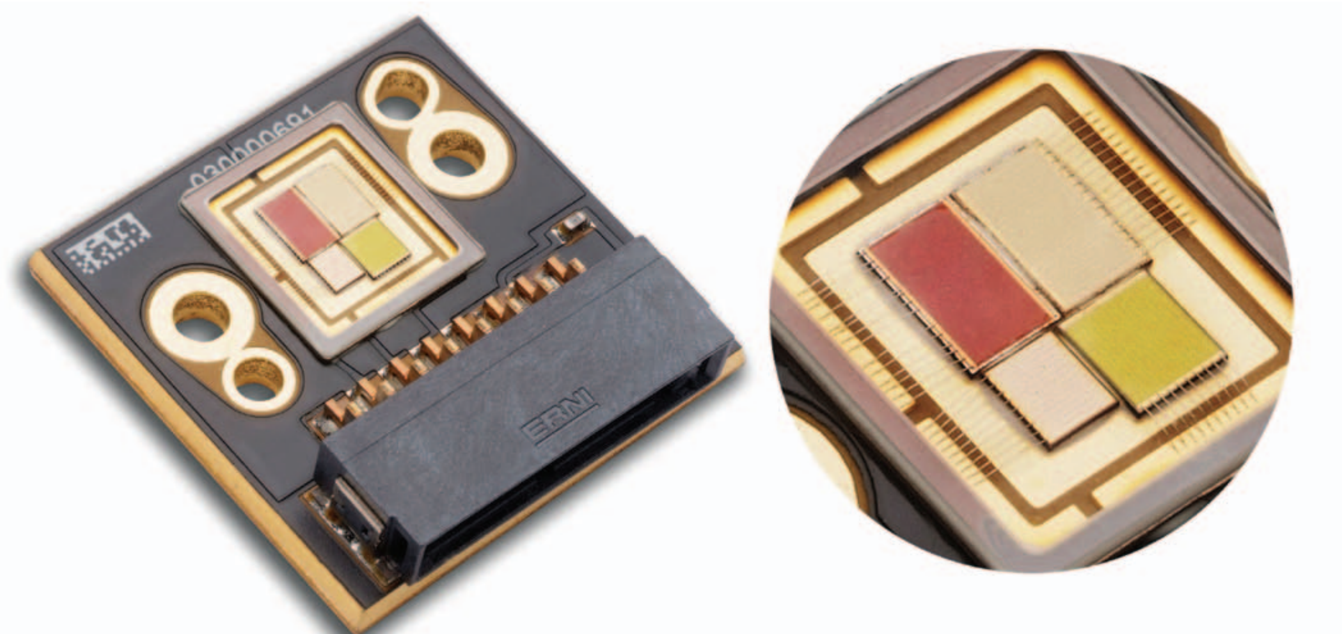


FIGURE 6 - COPYRIGHT LUMINUS DEVICES INC.

Figure 6 – Chip-on-board hybrid device

transfer. Even more sophisticated designs are becoming commonplace, with further optical components being incorporated into the structure.

The most exacting portion of this assembly is the bond wire from the die to the substrate. These wires can be incredibly thin, 15 - 50 µm is typical, and often made of gold, but they also can be made of copper in high power LEDs where significant current flow is required. In those circumstances, you also often see multiple bond wires being used in parallel to carry the necessary current. These wires are extremely delicate and always require some kind of protection. This protection can be transparent silicone or epoxy similar to that shown in the calculator in **Figure 1**, but, with LEDs, it's more likely that protection is provided as part of an external lens assembly, window, or other optical device.

Figure 6 shows an example of a hybrid device where four LED dies—red, green, blue, and white—are bonded in a COB manner to a single substrate. In this case, that substrate is a copper-cored circuit board that also contains a thermistor and all connection traces. The bare LED dies and the bond wires are protected with a clear glass window. You can clearly see the multiple bond wires connecting the top surfaces of each of the four dies to connection pads at the sides of the assembly. The reason I call this a hybrid device is that the entire assembly is provided as a pre-assembled package by the manufacturer and can then be used with conventional circuit boards. This hybrid model helps solve one of the major problems with COB devices: serviceability. A COB device is great when it's working and, because of the reduced number of connection points, should be more reliable than other packages. But it is almost impossible to service if it does have a problem. Removing and replacing COB devices from their substrates is sometimes possible but is very difficult and requires specialist equipment. If a single circuit board contained 50 separate LED COB devices, you may have no option but to replace the entire board if one fails. Hybrid designs avoid this problem.

COB LED assemblies like this have been around for many years from a number of manufacturers, often providing compact, high density arrays of LEDs. I can recall testing them more than ten years ago in high-powered LED products, so the concept isn't new. However, what is new is the widespread use in a wider range of

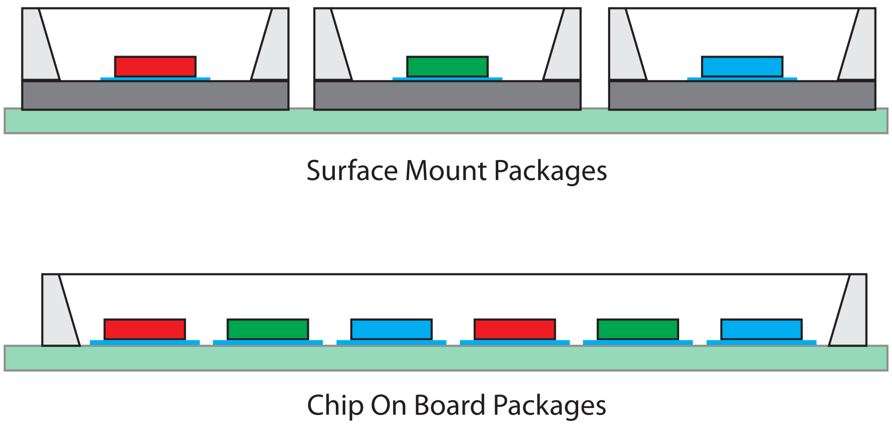


Figure 7 – Packaging comparison

products, not just specialist high-powered devices. The substrate can be a conventional circuit board or something with better thermal properties, such as ceramic. **Figure 7** shows the potential advantages of the technique when used with an LED array.

At the top of **Figure 7** is a typical RGB LED array of the kind comprising surface mount packages used in many current LED products. You'll see this type of arrangement in many wash lights. Each individual package incorporates optics and connections, and they are usually mounted as closely together as possible on the underlying substrate. In contrast, the lower diagram in **Figure 7** shows the exact same LED dies, but this time mounted as chip-on-board. In this example, it is possible to mount twice as many dies in the same space while still maintaining good heat transfer through the substrate. Each die may still have its own optics or may, as illustrated here, share a single large optic over the entire array. This technique is being used extensively in LED backlights for monitors and also is being increasingly seen in entertainment lighting products. The closer spacing of the dies improves color homogenization and helps get rid of multi-colored shadows. The potential downside, as I mentioned earlier, is the lack of serviceability, so you'll likely see hybrid solutions or boards made up of smaller daughter boards to minimize the cost of replacement. The most common hybrids are the single packages containing three or four dies arranged as RGB or RGBW. This allows common lensing for the group. We are also starting to see non-hybrid solutions where multiple dies are mounted in a true COB manner.

I'm sure you are also familiar with the kind of LED package shown in **Figure 8**. These devices are again a hybrid COB package. In this case, there is an array of blue LEDs mounted in COB fashion to the substrate, and then the entire array is covered with a disk of phosphor coated material. This serves both to provide protection of the dies and to phosphor-convert a large proportion of the emitted blue light to a yellow color. The mixed combination of the blue light from the LEDs and the yellow from the phosphor disk produces a white light. The final package is very efficient in the example illustrated—well over 100 lm/W—and easy for the designer to mount and use. The closely spaced array of small dies is cost-effective to manufacture and produces a well homogenized beam that behaves very much like a single large light source.

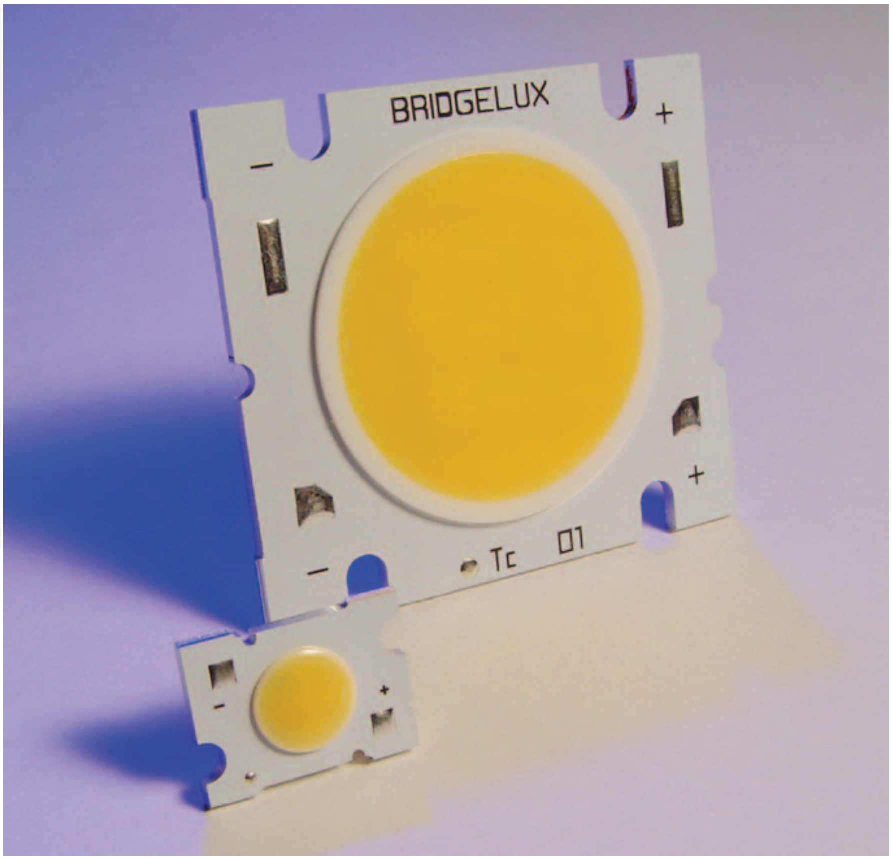


Figure 8 – Chip-on-board white light LED array

"Removing and replacing COB devices from their substrates is sometimes possible, but is very difficult . . ."

Another improvement with COB also looks to be helpful for our industry: direct to metal mounting. Designers often choose to mount LEDs to a metal-backed circuit board that can assist with heat transfer (and heat is always, always the biggest problem). With COB, the die can be mounted directly onto this metal backing through a hole in the top layers of the board. This gives the best possible thermal contact with almost nothing in between the die and the heat sink. There is one layer in the sandwich rather than the four or five you get with a surface-mount device.

Take a look at the next LED luminaire you get. Chances are you'll start to see more and more chip-on-board construction. LED technology continues to develop so rapidly that last year's products are already out of date. This is the fifth article in this column with the title, "How do LEDs Work?", and I'm quite sure it won't be the last. ■

Mike Wood runs Mike Wood Consulting LLC, which provides consulting support to companies within the entertainment industry on product design, technology strategy, R&D, standards, and Intellectual Property. A 35-year veteran of the entertainment technology industry, Mike is the Immediate Past Chair of the PLASA Governing Body and Co-Chair of the Technical Standards Council. Mike can be reached at mike@mikewoodconsulting.com.