SSL Postings
U.S. DEPARTMENT OF ENERGY

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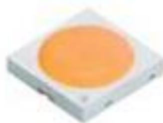
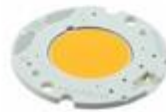
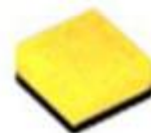
# LED Package Diversity

Central to any LED lighting product is the LED package, because that's where the light is generated. Initially, the goal was to develop one type of LED package that would be suitable for any application — an approach that would reduce costs through high volume. But for the past seven or eight years, it's been increasingly apparent that such an approach is not viable, because the requirements of the various lighting applications are so diverse as to demand a similar diversity in LED package types in order to ensure high performance. That's why the development of new types of LED packages has been a priority in the DOE SSL R&D Plan as well as a focus of our SSL R&D funding.

High-power


Mid-power


Chip-on-board


Chip-scale

It's also why the variety of LED packages for general illumination has literally exploded — from a few types of 1W-class packages to a huge number of form factors, sizes, lumen levels, voltages, and optical patterns. Nowadays, an LED manufacturer can have as many as 50 different package families, with each family having multiple variants based on lumen output, Vf, CCT, CRI, and binning tolerance. This package diversity has given luminaire manufacturers the freedom and flexibility to use LEDs best suited for the targeted lighting application and market. Several main types of LED package platforms have emerged:

- **High-power packages** (1–5W) are typically used in products requiring small optical source size (e.g., directional lamps) or high reliability (e.g., streetlights). They were the original lighting-class products and were used in the early high-performance LED lighting products. They provide high efficacy, high luminous flux, and good reliability based on their thermal management and optical design.

High-power LEDs typically consist of a large 1 $mm^2$ die, or even multiple die for a high-power array, mounted onto a ceramic substrate for thermal management. The phosphor is applied to the chip, and then a hemispherical silicone lens is over-molded onto the package. In addition to the large die, some high-power package designs use numerous small die in series to create a high-voltage package architecture that, when grouped with a boost driver topology, can yield system efficiency improvements.

- **Mid-power packages** (0.1–0.5W) are typically used in products requiring omnidirectional emission (e.g., troffers, A-lamps). Originally used in display and backlighting applications, they found their way into general lighting applications in 2012, as chip performance improvements led to viable lumen levels. Mid-power LEDs are low-cost, plastic-molded lead-frame packages that typically contain one to three small LED die, which are usually mounted on a silver-coated metal lead frame surrounded by a plastic cavity. The cavity is filled with phosphor mixed in silicone, which acts as the downconverter and encapsulant. Mid-power LEDs have gained favor over high-power LEDs in a number of applications, due to their low cost. In recent years, the plastic molding material used in mid-power LEDs has improved and led to new products that can withstand higher operating temperatures, allowing for use at higher power levels.

- **Chip-on-board (COB) packages** are typically used in products needing high lumens from a small optical source or extremely high lumen density. COB arrays typically use a large array of small die mounted onto a metal-core printed circuit board or a ceramic substrate. The LEDs are covered with a phosphor-mixed silicone encapsulant and resemble a fried egg. COB arrays provide high lumen output (up to 14,000 lm) from a small optical source area and are typically used in high- and low-bay lighting but are also found in downlights, outdoor area lighting, and even directional lamps — with applications continuing to expand, as manufacturers are offering a suite of different power levels and light-emitting surface sizes.

- **Chip-scale packages (CSPs)**, also called package-free LEDs or white chips, have more recently gained attention as a compact, low-cost alternative to the mid-power platform. The CSP is essentially a miniaturized high-power package around the LED chip. The current trend in LED CSPs is to use flip-chip die as a base, onto which the phosphor and encapsulant are conformally applied.

The variety of LED packages will continue to grow and evolve to reduce the cost and provide many levels of efficiency, color quality, and reliability required by different applications. New package types also embed more and more luminaire functionality (thermal, optical, electrical) within the component, simplifying integration of the LED package within the luminaire and reducing total system cost. Within a given package platform, there will still be some package designs that become mainstay components, given their ability to work in a variety of applications. The CSP has the potential to become a major package platform, due to its lower cost and smaller size, although there remain challenges with thermal management. Integration at the module level is another trend that will continue to grow, as a way for LED manufacturers to add value to their

products and luminaire manufacturers to simplify their value chain and improve performance.

The growing diversity of LED packaging choices is critical to the development of SSL, because it enables manufacturers to optimize luminaire design for the specific lighting application, improve performance, and reduce cost. This will make it possible to reach the efficacy targets set forth in the DOE SSL R&D Plan and achieve the technology's full potential.

As always, if you have questions or comments, you can reach us at postings@akoyaonline.com.