Seeking solutions to color binning in the LED value chain

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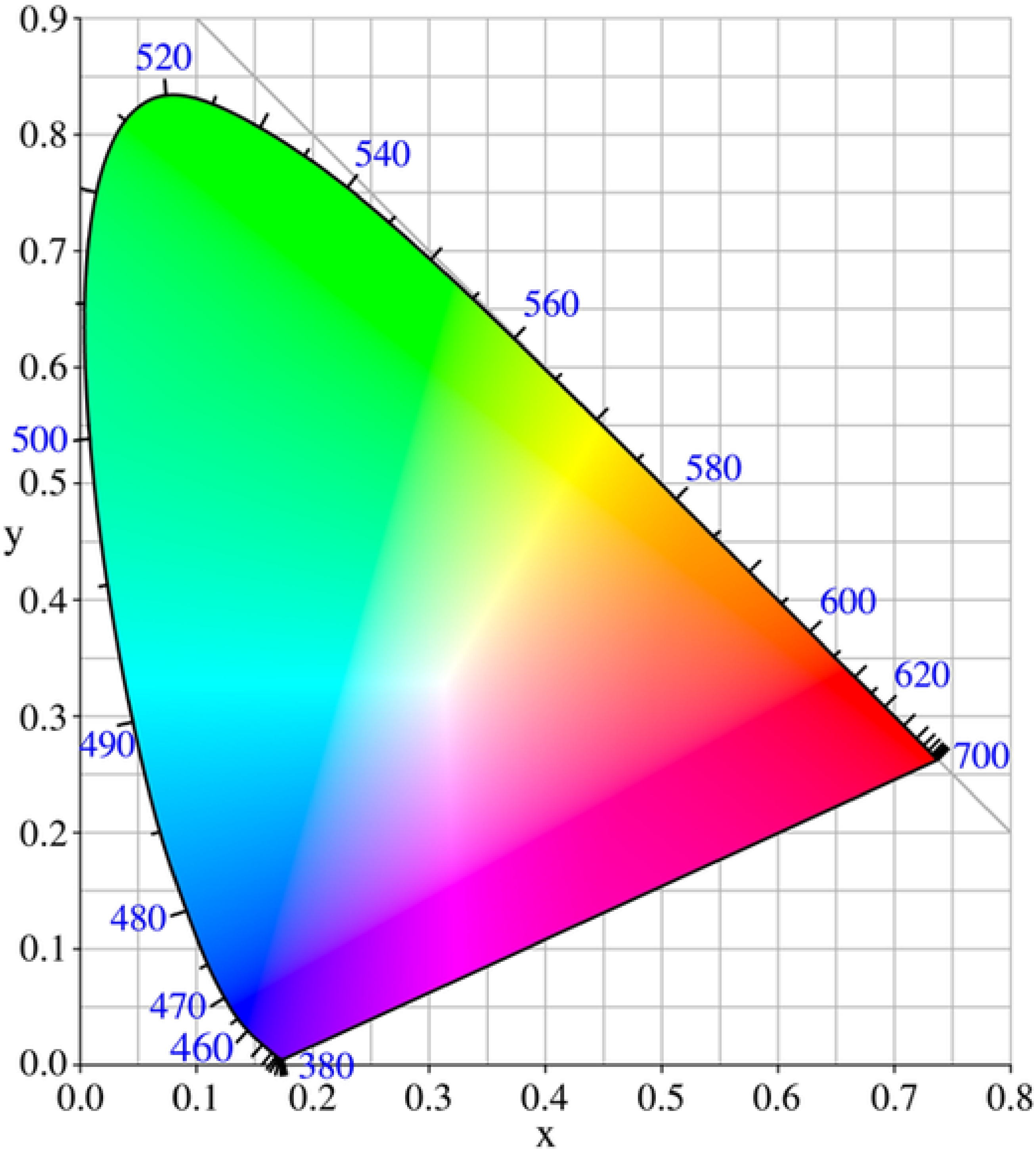
The semiconductor technology that underlies solid-state illumination represents the epitome of precision manufacturing. Production of these devices begins with creation of blue light-emitting diodes (LED chips) through the nanoscale deposition of semiconductor materials onto a wafer, which is then sliced into rectangular dies. Microscopic wires are bonded, and the LED chips are encapsulated by polymeric materials such as silicones in which phosphors are dispersed in order to convert blue light into white light.

Yet, despite years of research and production at nanometer and micron scales, manufacturers of next-generation illumination sources still struggle to provide spatial phosphor distribution with enough uniformity to avoid significant variation in the color temperature of finished LEDs. These variations may have minor impact in some applications, such as streetlights. But they present significant challenges for back lighting for liquid crystalline displays, and LED bulb and luminaire designers who need to tightly limit variation in their designs. Although an imperfect solution, color binning enables LED manufacturers to quickly and accurately select LEDs within an acceptable performance range. It also maximizes the commercial yield for suppliers, allowing them to sell products according to bin ranges.

Part of the challenge in finding a solution arises from the lack of industry standards that would establish a universal package design, and thereby invite a universal fix. Indeed, there are multiple packaging architectures, including through-hole, surface mount, chip-on-board, flip chip and others. Plastic leaded chip carrier (PLCC) devices bridge several of these packaging architectures and are the dominant LED device design today. Yet, the diversity of package options still presents multiple proprietary LED designs that can influence application of phosphors to the LED die.

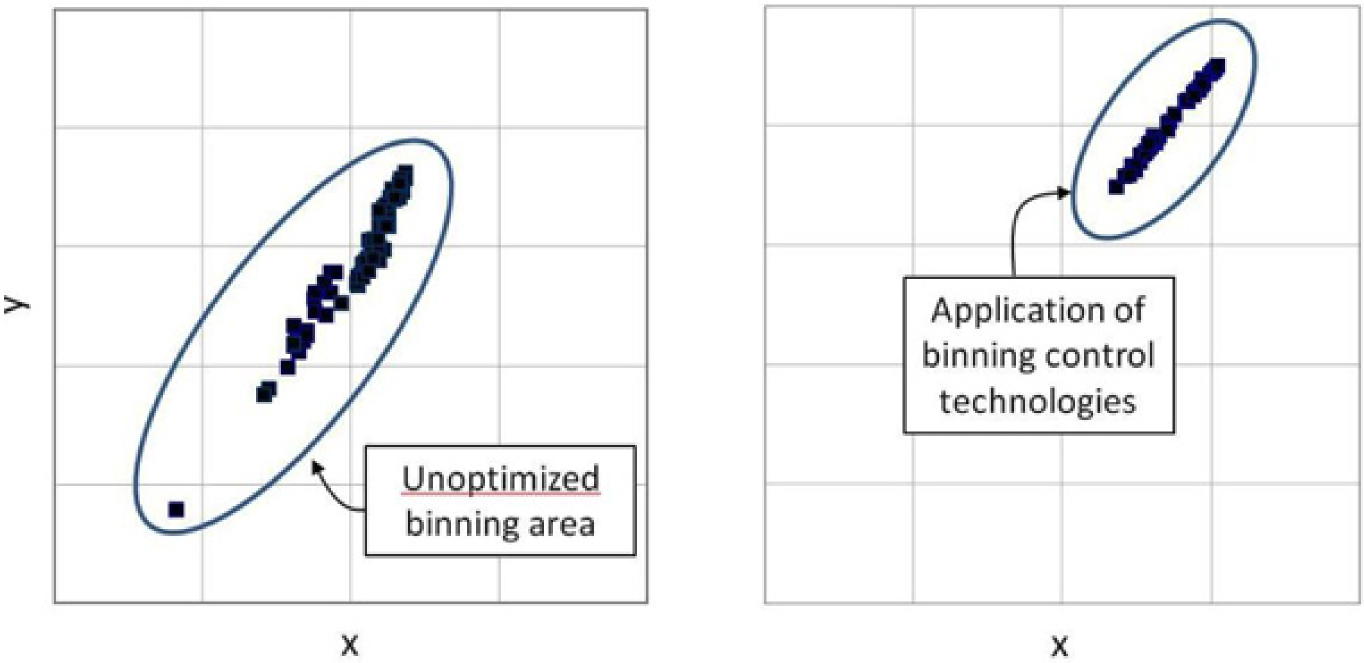
In the absence of a universal fix, the industry has resorted to binning finished LEDs according to their variations in color warmth. Although still an evolving solution, color binning enables LED manufacturers to quickly and accurately select finished LEDs within an acceptable performance range. It also maximizes the commercial yield for suppliers, allowing them to sell products according to bin ranges.



In addition, binning provides some basis for standardization. For example, the American National Standards Institute (ANSI) has established tolerances under its C78.377 standard for grouping white LEDs within certain color temperature bins based on a 7-step McAdam ellipse within the CIE color space. Many LED manufacturers group LEDs into micro-bins, sorted by even more stringent tolerances in color variation. Larger bins permit more variation in color temperature, whereas smaller bin sizes ensure tighter control over color variation.

Yet, the LED industry largely regards color binning as a necessary evil that introduces an added layer of complexity and cost to the design process. As a consequence, manufacturers have sought greater control over variations in LED hue and flux.

One approach is color mixing, whereby LED manufacturers avoid the use of phosphors altogether. Instead, they incorporate multiple LEDs within the same package – regardless of color variations – and allow the collective light to average out as a perceived uniform white light. But this is a limited solution in that the averaged light can appear yellowish. Plus, it relies on additional secondary optics to more evenly blend the variable hues of multiple LEDs.



Consequently, many LED manufacturers have instead sought to maintain greater control over the consistency in phosphor distribution in common LED packaging materials such as silicone. This is no small feat.

One early challenge was applying silicone encapsulants in a consistent film thickness across a wafer's surface to minimize variations in phosphor volume. However, this has been largely addressed by advances in precision dispensing equipment. A more persistent challenge has been controlling sedimentation of phosphors within silicone before cure. This can be managed to some degree through greater control over pot life and process conditions. Yet, phosphors are comparatively large particles measuring 10 to 15 microns, with specific gravities around 4. So, some sedimentation in low viscosity liquids is difficult to avoid.

Recently, companies have approached this problem directly by optimizing surface interactions between the phosphor and silicone mixture. The end goal is to better ensure suspension of phosphor particles in silicone's pre-cured state to maximize potential pot life, and minimize variations in hue and flux in the finished LED.

Though still in the early stages there are several promising approaches to achieving this. In very generic terms, we are working to:

1. Address the surface interactions between phosphor particles and the silicone matrix to prevent them from settling;

2. Ensure the pre-cured silicone maintains a consistent dispersion before use; or
3. Take a molecular approach to control the agglomeration of phosphors to ensure that smaller particles separate out evenly in the silicone matrix.

Given the diversity of LED package designs, it is unlikely in the near term that there will be any single comprehensive way to improve phosphor dispersion. The eventual solution may leverage one or more of these approaches. In addition, the predominance of PLCC phosphor-dispersed packages offers a good place to begin to apply the innovative methodologies listed above. However, any color binning solution for these architectures will require the correct selection of polymers and resins to maximize the suspension of phosphor particles in the precured state.