Today’s market for LCD screens is extremely competitive, driven by quickly evolving technologies that are rapidly deployed in pursuit of granting viewers the most desirable viewing experience at competitive costs. For the makers of televisions, smartphones, tablets and more, keeping pace is both a challenge and the price of doing business.

Brightness, clarity and color are all vitally important in a consumer electronics world where “high-definition” is no longer a selling point but a baseline expectation. That final point—color—is yet the most elusive goal in the pursuit of a more perfect display screen image.

Why? LED-backlit LCD displays took over the consumer electronics market several years ago, almost entirely displacing CFL-backlit displays for televisions and other electroluminescent displays in mobile applications. This occurred for a number of reasons: LED-based LCDs are more efficient, offer better contrast ratios, maintain a far longer lifespan and more.

It’s been well established, however, that displaying red with LED technology has historically been a challenge. “The perfect red” has eluded LED display manufacturers, often necessitating a compromise between brightness and appearance, specifically efficiency and color gamut.

To help LED manufacturers overcome the red conundrum, GE has developed TriGain™, a family of potassium fluorosilicate (PFS) phosphors for use in LED display backlight applications. Grounded in GE’s expertise and capability in material science, TriGain phosphors will be manufactured through GE’s proprietary processes at a Cleveland-based GE Lighting facility. TriGain phosphor improves narrow red band performance in LED backlights—meaning greater overall color, enhanced red enunciation, more unique red generation and better general contrast for all manner of LED-backlit displays.

This white paper explains how the TriGain phosphor technology works and the benefits that can be brought to a range of consumer electronics through a simple yet vital step forward in red emission technology.
Achieving a Better Red with TriGain Phosphor

To understand the advantages of TriGain phosphor, it’s worth a refresher on how LED generates light and color. LED systems generally operate by converting blue light to white light through the use of a phosphor, not entirely dissimilar to how fluorescent lamps convert UV to white light.

Red is a very sensitive, narrow color and difficult to reproduce in displays—it can easily become slightly orange or dim due to infrared components invisible to the human eye. Therefore, the red phosphor is doubly important for LED-backlit LCDs since it strongly impacts color gamut and display brightness.

Typically, generating higher color gamut in LED-backlit LCDs can involve the addition of broad emission nitride red phosphors to the LED and/or the use of stronger color filters. Typical red nitride phosphors produce a broad red spectrum, resulting in a slight orange tint or significant spillage into the infrared. Removing this orange tint can require stronger color filters, which absorb these undesired colors. Consequently, these modifications for higher-gamut LCDs lead to additional energy use and/or the incorporation of additional LEDs to maintain system brightness.

However, even with these drawbacks, phosphor and color filter modifications have proven to be desirable solutions to improved color gamut due to their relative simplicity. This is particularly true for backlight display applications where space is tight. LED manufacturers know this fact well—most smartphones, tablets, laptop monitors or televisions are far thinner or more compact than they were just a few years ago, creating a greater challenge to fit the necessary, sophisticated components inside. Although there is a solution commercially available for high-gamut backlights, the best result comes from a narrow-band red phosphor that meets brightness and color gamut requirements while being easily integrated into typical LED packages.

Creating that narrow red band simply and effectively is where GE’s TriGain phosphor marks a significant breakthrough in phosphor technology versus other solutions currently on the market.

TriGain phosphor brings the right ion (Mn) and the right host (K₂SiF₆) together through the replacement of a portion of silicon in its chemical makeup with manganese (the result: K₂SiF₆: Mn⁺⁺). K₂SiF₆, without the addition of manganese, would be a white powder that doesn’t accomplish much for an LED system; manganese, however, is one of the few doping agents that enable this material to emit that elusive narrow red band.

This discovery is the result of multiple years of research and development at GE Lighting and the GE Global Research Center. GE’s work has shown the potential for TriGain phosphor to enhance LED systems of all types, offering greater color gamut for LCD backlights. For the LED backlight display market—be it LCD televisions, smartphones or tablets—it means sharper, brighter color without compromise.
**TriGain Phosphors vs. Alternative Systems**

Televisions, smartphones and tablets have all grown smaller, thinner and more compact as technology has progressed. Display manufacturers are seeking the simplest solution to enhancing overall color and picture quality. TriGain phosphor incorporated into an LED package enables LED backlights to bring those solutions to bear, more simply and effectively than alternative methods. Phosphor-converted LEDs are the most cost-effective solution in the near term and provide significant advantages across all LED applications.

First, compare TriGain phosphor to alternative phosphors:

![Graph showing spectral comparison of TriGain phosphor-enabled LED vs. industry-standard white LED with YAG and broad emission nitride red phosphor. TriGain phosphors demonstrate significantly more intense red emission at ~631nm.]

This graph shows a spectral comparison of a TriGain phosphor-enabled LED versus an industry-standard white LED with an Yttrium Aluminum Garnet (YAG) with the addition of a broad emission nitride red phosphor. TriGain phosphors clearly demonstrate significantly more intense red emission at ~631nm.

**TriGain phosphors also demonstrate superb color and efficiency compared to state-of-the-art white LEDs:**

<table>
<thead>
<tr>
<th>Standard LED Lo CRI</th>
<th>Standard LED Hi CRI</th>
<th>LED with Mn4+ red line phosphor</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 CRI</td>
<td>90 CRI</td>
<td>90 CRI</td>
</tr>
<tr>
<td>160 LPW</td>
<td>127 LPW</td>
<td>168 LPW</td>
</tr>
<tr>
<td>R9 &lt; 30</td>
<td>R9 &lt; 45</td>
<td>R9 &gt; 90</td>
</tr>
</tbody>
</table>

*3030 2 die 6V LEDs measured under identical conditions

![Figure 2: Comparison between LEDs at 4000K: Lo CRI, Hi CRI and TriGain.]

TriGain phosphors also demonstrate robustness, where comparative phosphors are limited. Until recently, a significant hurdle for PFS in LED systems was emission loss due to sustained exposure to 450nm emission within the LED itself, as well as limited environmental resistance. But GE has made patented and proprietary additions to its PFS to imbue TriGain phosphor with significant robustness, allowing TriGain phosphor to maintain sustained, long-term performance in all applications. This renders the material ideal for high-end displays where deteriorating color would be catastrophic. As a phosphor solution, TriGain phosphor is truly a best-in-class material.
Outside of phosphors, TriGain phosphor remains a far simpler and easier-to-implement solution than other systems that tout sharp color separation and narrow emission. Quantum dots, for instance, are nanoparticles that can be incorporated into a display via tube or an overlaid film—these materials similarly eliminate wasted light, allowing an LCD display to emit color via narrow band.

However, quantum dots can become price prohibitive and have been generally used in television applications due to some of the additional system alterations. TriGain phosphor, comparatively, suits all types of LED-backlit displays and is a simple 1-for-1 red phosphor replacement in the LED package. For the display manufacturer, an LED package that accomplishes superb color, clarity and brightness with TriGain phosphor is a significantly more attractive option.

The TriGain Phosphor Advantage

LEDs have grown in prominence, not just in backlight displays, due to similar advantages displayed across all applications. LED Inside reported in late 2014 that the U.S. market for LED packages accounts for nearly $13 billion, with the television market alone accounting for 20 percent of that figure.

The market appetite for bright, clear, sharply rendered light from LED packages grows—in the backlight market particularly, displays continue to grow more advanced, as we’ve seen in the relatively recent advent of 4K “ultra HD” TVs. With TriGain phosphor, LED manufacturers can take advantage of a simplified, high-quality solution for sharper, clearer, brighter color, backed by the experts at GE.

For more information on TriGain phosphor, contact your GE representative or visit www.gelighting.com/trigain.

1. U.S. Patent Nos. 7,497,973; 7,847,309; 7,358,542; 7,648,649; and 7,653,195 are relevant to the use of a PFS phosphor in an LED package and are available for license from GE.