Broadband LEDs enhance colour fidelity

White LEDs are efficient, robust, long lasting and dimmable, but they are often let down by a colour quality that is inferior to incandescents. How can this weakness be addressed? By introducing a range of phosphors that deliver broadband emission and ultimately enhance colour fidelity, argues Faiz Rahman from Electrospell.

Makers of TVs, smartphones and in-car navigation systems continually exploit our weakness in perceiving colours. What appears as yellow on these screens is not a single band of narrow emission, but the combination of light produced by closely packed red and green pixels. This is wonderful in one regard, because it allows us to see 'full-colour' images from screens based on just red, green and blue sources. However, it is a completely different story when a real world object is lit with artificial illumination.

In this situation, it is only possible to capture all the nuances of colours and shades by illuminating objects with light containing all possible colour components – in other words, a full-spectrum light source. Everyday objects have complicated chromatic reflectivities, so it is essential to use incident light with a broad, balanced spectrum to capture all the colour detail (see Figure 1 for several examples of ordinary objects and their surface reflection spectra).

The technology employed for lighting objects is in the midst of a revolution. Tungsten filament incandescent bulbs, the incumbent technology of the twentieth century, have recently faced strong competition from compact fluorescent luminaires, and LED-based lighting systems are just starting to make an impact. Each of these light sources offers a different quality of colour reproduction, because each technology is naturally predisposed towards a

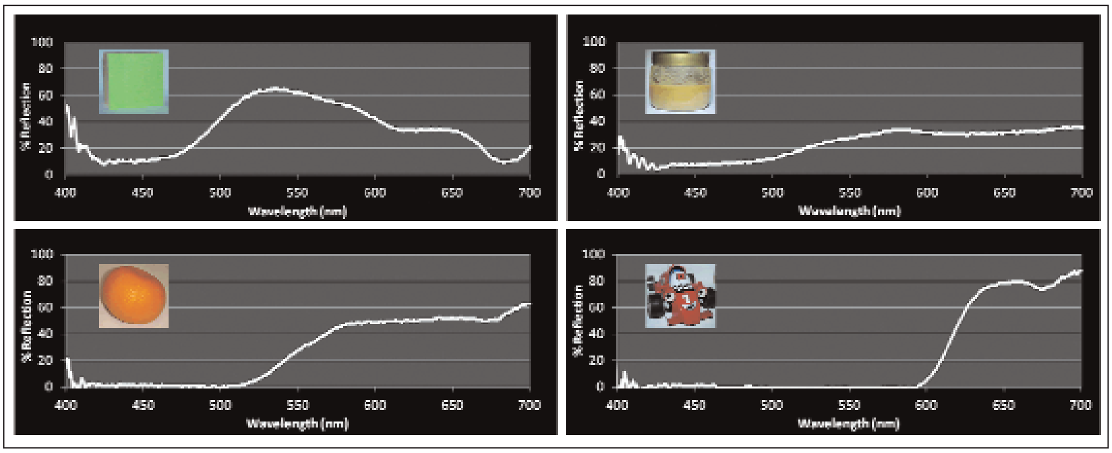

Figure 1. Surface reflection spectra of some common everyday objects. Most surface colours display complicated spectral details that cover large parts of the visible spectrum. Faithful rendering of the colours of such objects then requires a light source with a balanced spectrum that fills the entire visible region from 400 nm to 700 nm

certain spectral distribution. For example, the incandescent bulb is a thermal source that generates a black-body-like spectrum, which appears as yellowish-white light. This is pleasing to the eye and, despite its low efficiency, is still a popular technology for indoor lighting in developed countries.

Efforts to promote greater use of more efficient light sources have spurred sales of fluorescent sources, such as tube lights and cold cathode fluorescent lamps (CCFLs), which generate emission when a phosphor is excited by ultraviolet radiation. Traditionally, light from such sources has been described as 'cold white', due to the distinct bluish hue that stems from deficiencies at longer visible wavelengths.

Today, LED-based bulbs are starting to appear in hardware stores, with sales tipped to rocket in the next few years. White light is produced by using a blue InGaN LED to pump a yellow-emitting phosphor, such as cerium-doped yttrium aluminium garnet (Ce:YAG). The spectrum of light that results has a prominent blue peak somewhere in the region of 450-470 nm and a somewhat broader yellow emission.

A superior, but more complex alternative is to generate white light by mixing differently coloured LEDs – usually, red, green and blue. This produces colour-tuneable light, with hues that can be adjusted to meet the wishes of the user. If the LEDs are hooked up to a microcontroller, it is possible to digitally control individual colour channels to 8 or 16 bits of precision, enabling the generation of millions of colour shades. RGB luminaires, however, require drive electronics and colour mixing optics. These are not difficult to integrate into a complete lighting system, but they do increase the cost and complexity of the final product.

Gauging colour quality

Several metrics are used to compare the quality of white light produced by the combination of blue LEDs and yellow phosphors, and the colour mixing of red, green and blue LEDs. One of the most common is the colour rendering index (CRI), which provides a measure of the ability of a given light source to produce the same reflection spectrum as that produced by an ideal light source, such as natural sunlight. As this is a relative scale, CRI's are quoted in percentages – a light source with a CRI of 100 percent will reproduce colour details as faithfully as light from the sun, under ideal conditions. In practice, CRI values are determined by measuring the surface reflectivity of a set of coloured reference cards. Usually 16 cards are used, with the relative reflectivity for each colour in

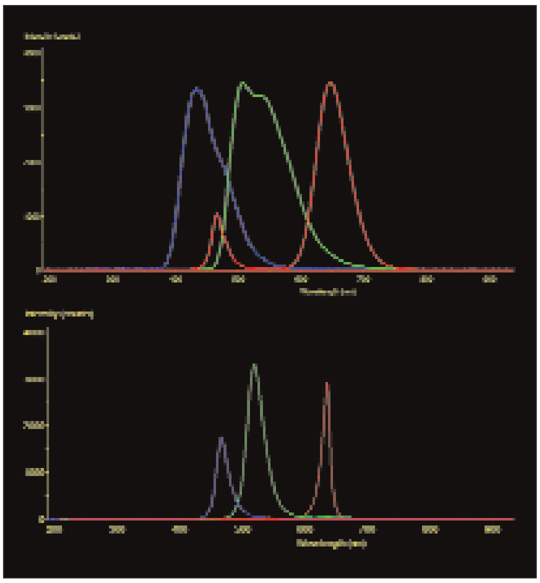

Figure 2. Spectra of Electrospell broadband RGB LEDs (top) compared with the spectra of ordinary RGB LEDs. The secondary emission from broadband red LED is residual blue pump light

the set quoted as a separate value. These, so called, R16 values can then be combined to arrive at a single value for CRI.

More recently, approaches such as the Gamut Area Index (GAI) have been developed to address certain flaws in the CRI scale. Combining these two approaches is now considered satisfactory for quantifying the colour rendering properties of LEDs. The National Institute of Standards and Technology (NIST) in the US has also developed a colour-rendition quality scale called the colour quality scale (CQS), which may become the standard metric for judging illumination quality in the coming years.

The combination of a blue-emitting chip and yellow phosphor delivers the highest efficacy when it produces a cool white light. This emission, which closely resembles that emanating from a CCFL source, is not particularly pleasing to the eye. What's more, it is bad at colour rendering because its spectral makeup lacks emission at many wavelengths in the visible region.

It is possible to trade losses in efficacy for better colour rendering by using LEDs with phosphors that emit at slightly longer wavelengths. These warm-white LEDs have a reduced blue peak and significantly broader emission in the green, yellow and orange parts of the spectrum. This translates into a lower colour temperature – the spectral output is below 4000K, compared to more than 6000K for a cold-white source – and the emission is closer to the characteristics of an 'ideal' light source. However, although these devices have higher CRIs when compared with cool-white LEDs, their light still falls far short of what is needed for accurate colour rendering of real world objects.

To address this issue, at Electrospell of Glasgow, UK, we have been developing superior full-spectrum LEDs that are enabling the production of outstanding solid-state light sources. We have adopted a two-pronged approach: By combining broadband red LEDs with their green and blue cousins, we can create light sources that are suitable for making full-spectrum tuneable luminaires; and by utilising mixtures of broadband phosphors, we can generate exceptionally good white-light spectra.

The phosphors that we use often contain gadolinium, europium and terbium, in combination with cerium, either hosted in an oxide or oxy-nitride matrix. This set of rare-earth ions ensures a broad, balanced emission with diminished prominence of sharp peaks (see figure 3). The advantage of employing a multiplicity of rare-earth ions is that it creates several sets of so-called 'crystal field split' energy levels, which combine to deliver a dense set of wavelength peaks that coalesce into a flat spectrum. White light systems made from such LEDs produce CRI values in excess of 92, exceeding the benchmark for high-performance lighting systems.

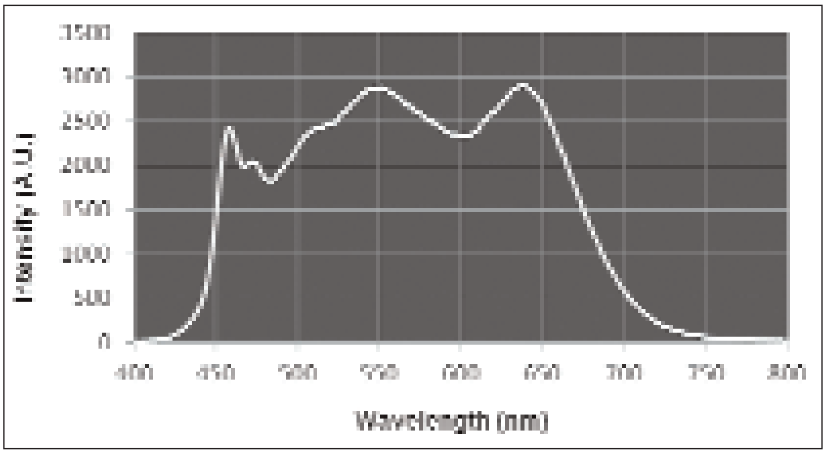

Figure 3. Spectrum of light from a full-spectrum Electrospell white LED

Improving stability

LEDs are renowned for their long lifetimes – they range from 20,000 hours to over 50,000 hours. However, performance varies over lifespan. That's partly because powerful LEDs used for lighting generate copious amounts of heat, which must be removed quickly to prevent overheating that ultimately shortens device lifetime. A good thermal management system addresses this issue, but even with efficient heat removal, LEDs operate at least a few degrees above ambient temperature, causing variations in output over time. This includes a gradual reduction in light intensity. There is no universal definition for LED lifetime, but typically quoted values are for periods of continuous operation at full power over which device output falls by either 70 percent or 50 percent of its initial brightness.

In addition to declining output power, the colour point of an LED shifts with age due to various phosphor ageing effects, such as changes in oxidation state and thermal degradation. For commodity white LEDs, this shift can be 10 percent or more of the specified initial colour point. This means that in colour-critical applications, changes in chromaticity can be a far bigger problem than the gradual dimming of the LEDs.

Dimming and colour shifts cannot be avoided, but they can be reduced by running LEDs at lower temperatures and switching off the system when not in use. Turning to high-quality LEDs also helps, because these are built with higher quality phosphors and other optical materials, which

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together trim thermal and ageing-related colour shifts so that the chromaticity shifts are reduced to only around 2 percent. Another trend is to physically separate the phosphor from the heat-generating LED chip. Turning to a remote phosphor delivers many important benefits, including a significantly longer life, increased wavelength conversion efficiency (and hence perceived brightness) and reduced colour shifts.

This architecture is appearing in several retrofit LED bulb designs, which feature a phosphor coating deposited on the bulb envelope. Product lifetimes in excess of 50,000 hours are then possible, which are limited by the electronic drive circuit that powers the LED, rather than the performance decline of a battalion of solid-state emitters.

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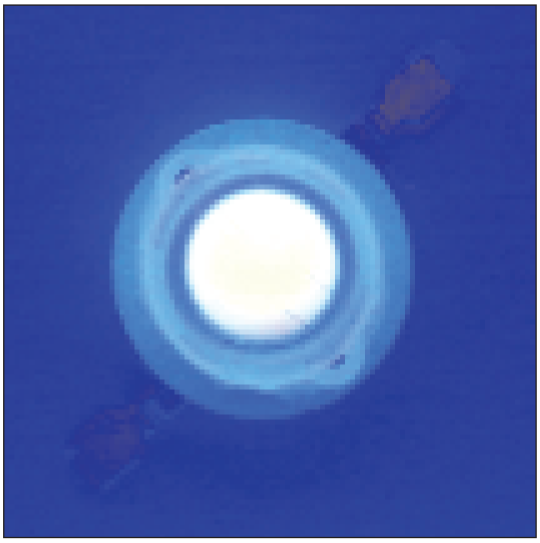

Electrospell produces LEDs with a broader emission spectrum than conventional devices, thanks to the incorporation of a wide range of phosphors

Another area where flat-spectrum LEDs are to make an appearance is that of backlighting liquid crystal displays (LCDs). If this class of display is to deliver great picture quality, it requires a flat backlight positioned behind the main LCD panel that can uniformly light a surface. Light from the backlight selectively passes through colour filters at each pixel of the LCD panel, creating a mosaic of multi-coloured light points that constitute an LCD image. Flat-spectrum LEDs are better suited to this task, because these devices generate roughly equal intensities in the red, green and blue parts of the spectrum, making colour filtration more efficient and consequently the display more power-efficient.

There are a handful of other applications where broadband colour LEDs can also offer an advantage over their conventional, lower CRI cousins. This includes indoor plant growth: Photosynthesis requires wavelengths from the infrared to the yellow spectral region, plus blue wavelengths. Installing white LEDs in these greenhouses fails to provide the ideal wavelength profile, and narrowband red and blue LEDs are not up to the task. What's needed are LEDs that emit broadly in the red and blue regions.

It is not just plants that appreciate wide spectrum light - human skin therapists are also considering broadband LEDs for various dermatological treatments. Other technical and industrial applications of broadband, solid-state sources include document scanners, flat-spectrum light sources for colourimetry and machine vision systems.

Thanks to the capability of LEDs to deliver a very high quality light, solid-sate lighting is already penetrating many existing and new illumination applications. However, as spectrally rich light from the new generation of white and colour LEDs establishes itself in the market place, the adoption of LEDs as the technology of choice for all lighting applications will accelerate – hastening the transition to an LED-dominated world.