BY MIKE WOOD

Better phosphors = better whites

YOU'LL, I HOPE, FORGIVE ME if I return once more to the subject of white LEDs. There's little doubt that this is the hot topic in lighting at the moment. With new regulations in Europe and Australia further increasing the legal minimum efficacy required for lamps, and continued controversy about the amount of blue light that's good for you, this is one topic that isn't going away.

> "Our eyes evolved to see in that light, so that's what you need. Anything less is inevitably going to have compromises."

I've discussed white LEDs a number of times in this column before. The advantages and disadvantages of making white light through additive mixing of red, green, and blue (as we commonly do in our industry) as compared to the now almost ubiquitous technique used in domestic and industrial lighting where a blue LED is coupled with a yellow phosphor. Neither of these is ideal, both result in too high a value of peaky blue light around 450 nm, just where we have the biggest problem with blue light disrupting Circadian rhythms. That excess blue light also tends to scatter within the fluids in the eye (just like it does in the sky) resulting in reduction in overall contrast and glare. As well as the blue problem, neither of these techniques do well with deep reds. In addition, they both have almost no output in cyan and an RGB mix is also lacking in yellow, the two areas where our eyes have the highest color discrimination. The end result can be flat cartoonish colors, and poor color rendering. (Note: I'm not talking about theatrical color mixing, where clearly we need red, green, and blue, or even more colors for additive mixing; I am talking about simply trying to make white light.)

Figure 1 shows what I mean, this is a chart of the human eye's ability to discriminate colors plotted against wavelength. The lower the value of the curve, the better we can discriminate colors at that wavelength. There are two minima, one at around 500 nm, in the cyan, and the other at 580 nm, in the yellow.

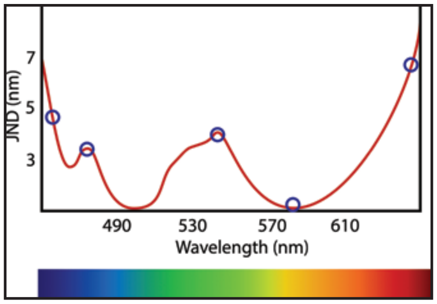

Figure 1 – Human eye color just-noticeable differences

Now compare that with **Figures 2** and **3**, which show maximal efficacy white mixes for a blue + yellow phosphor white LED, and an RGB mix.

In both cases there is a dip in the cyan which almost perfectly matches our position for best color discrimination, and the RGB has a dip in the yellow, where our second maximum discrimination point is positioned!

We've been like kids with new toys with white LEDs. The amazing energy saving has tended to outweigh the poorer quality, but now that a domestic LED lightbulb can be had for not much more than a dollar, that novelty has worn off and, thank goodness,

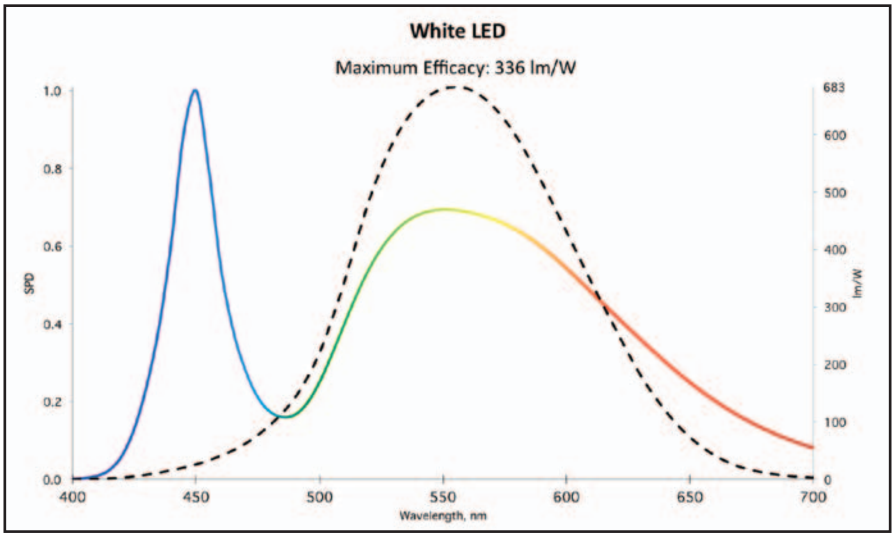

Figure 2 – Maximum efficacy blue + amber for a white LED

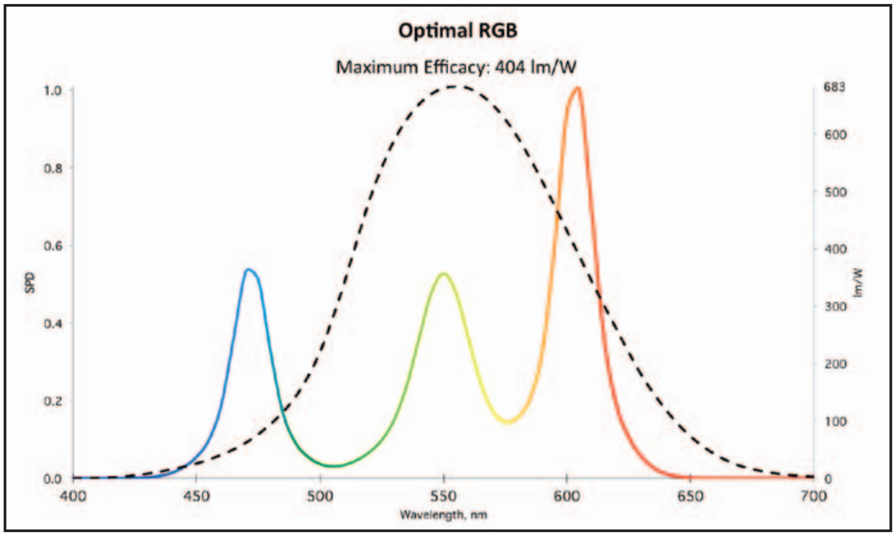

Figure 3 – Maximum efficacy RGB for a white LED

we're becoming more discriminating.

One way we in the entertainment industry have been trying to improve color rendering and color mixing is by adding more colors to the mix. These days it's becoming common to see at least amber or lime added to the RGB, with a number of manufacturers also adding in cyan and other colors. Cyan is way-more important than you think, not only is it a critical wavelength for color discrimination, but it's also important for good skin tones. There's quite a lot of blue in human skin coloring at lower levels in the blood vessels, and cyan gives the skin depth. Without that cyan the light reflected from skin can appear slightly green tinted. I'm sure you've noticed when trying to mix RGB on skin tones how quickly the skin leaps from looking green to looking magenta, and it's almost impossible to get a balance in the middle. Adding cyan and amber makes that balance much easier to achieve.

Similarly, for white LEDs, manufacturers have tried to reduce the blue spike, add more red, and close that cyan gap, but the single (or dual if you add red) phosphor approach has its limitations.

Whatever color rendering metric you use, be it the outdated CRI, CQS, or the newer recommended TM-30, the fundamental issues are still the same. To get the absolute best color rendering from white light, you need to do the best job you can of mimicking sunlight. That means having a continuous spectrum of light all the way from deep blue to deep red covering the entire band that's visible to human eyes. Our eyes evolved to see in that light, so that's what looks right, and that's what you need to emulate. Anything less is inevitably going to have compromises.

> "Why should I care about new white light phosphors?"

I was very interested therefore to see the approach taken by a new partnership between Seoul Semiconductors and Toshiba to produce a white LED with a continuous spectrum. Interestingly enough, they are moving much closer to the RGB mix that we use in color mixing but are using phosphors for all three colors. Three phosphors manufactured by Toshiba, one each in red, green, and blue, all driven by a single pump LED. That pump LED is in a color that Seoul Semiconductor calls purple, but I think I'd call it indigo. (To me "purple" suggests there is some red in the mix, but indigo is a pure short wavelength color.) Toshiba call this technology TRI-R, and Seoul Semiconductor will be marketing the final products under the brand SunLike. The use of an indigo/purple pump isn't new, but Toshiba claim that their phosphors are, and that they've eliminated the purple or blue spikes from the final output.

Figure 4 shows the system compared to a normal white LED. This technique allows the use of broad band phosphors, each producing a much wider band of wavelengths than an LED does on its own. They can also be tuned to slightly overlap, eliminating the dead-bands in the cyan and

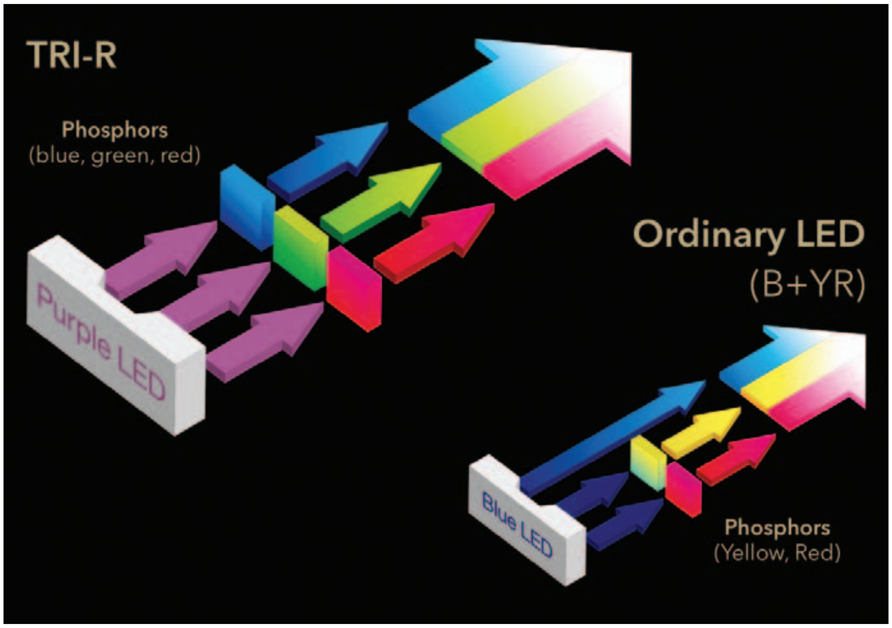

Figure 4 – TRI-R technology

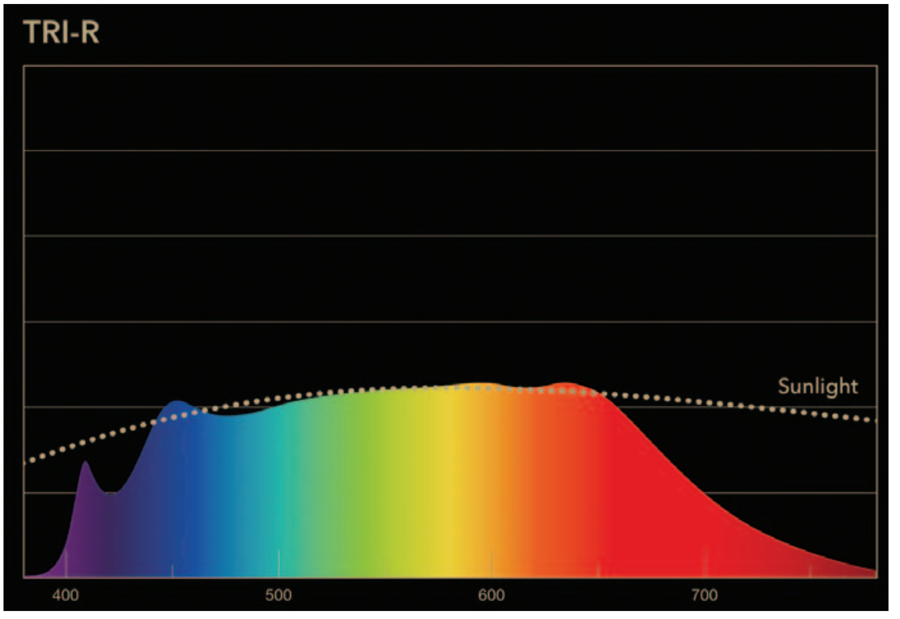

Figure 5 – TRI-R spectrum

yellow. The end result, as claimed by Seoul Semiconductor and Toshiba, closely mimics natural sunlight with much reduced blue spike and a continuous spectrum across the human vision band. **Figure 5** shows the SPD, with just a little of the purple/indigo coming through as a small spike, and then a continuous curve up to about 650 nm. The red drops off more quickly than I'd like after that, but it's still significantly better than the blue + amber white LEDs we have become familiar with.

The manufacturers only announced these products earlier this year and, so far, are being very cagey with the information they release. I'm sure there are lots of patents pending here, so I'm not entirely sure where each of the three phosphors starts and finishes, and how much overlap there is. They claim that color rendering, measured to TM-30, is in excess of 95 and that they match real sunlight better than anything else available. It certainly looks impressive from the data, but I haven't yet seen a real product. They plan to start shipping samples this summer, so I'm looking forward to seeing one.

Who is this technology aimed at? Well, Seoul Semiconductor and Toshiba have great ambition for SunLike. They see it being used anywhere that color rendition is important, specifically in residential, architectural, health-care, and retail lighting. The first products, supposedly shipping in July 2018, are aimed at fluorescent tube replacements. **Figure 6** shows one of the publicity photos released which show an application in Pompeii, lighting some of the murals painted 2,000 years ago. The left image is lit with a regular blue + yellow/red white LED, while the right image is lit using SunLike products. I'm always somewhat skeptical of press photos like this, but I'm certainly interested!

Figure 6 – Murals in Pompeii. Left lit with normal blue + yellow white LEDs, right lit with SunLike.

"Okay, Mike," I hear you saying. "This is all very interesting, but I don't care that much about fluorescent tubes or lighting murals in Pompeii, and this is supposed to be a journal about entertainment technology. Why should I care about new white light phosphors?" There are a number of reasons why I think this is interesting for entertainment lighting. Firstly, we have applications in our industry where white light is important. Anything involving a camera could well benefit from this. Secondly, this phosphor development holds great promise for making additive color mixing luminaires with better color rendition, and no gaps in the spectrum. The SunLike phosphors are broad-band, so primary colors wouldn't be as saturated, but as a way to mix pastels and mid tones, they could be a great improvement. It's an extension of what we are already doing with lime LEDs as a way to fill in the gaps in the middle of the spectrum, into the blue and red as well.

Figure 7 gives a hint of that potential, where various mixes on the new phosphors

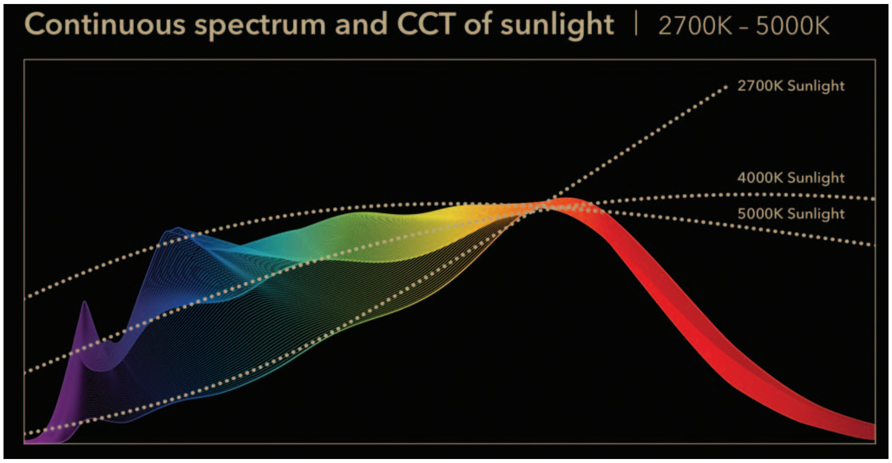

Figure 7 – SunLike phosphor mix options for varying color temperatures

have been used to mimic daylight at 2,700 K, 4,000 K, and 5,000 K. The potential here for color tunability is significant.

One last thing, how efficient is this technology? Seoul Semiconductor claim that, at the moment, they lose about 10% as compared to conventional white LEDs, but that they expect to get that back, and more, over the next year or so. I can believe that. Let me refer you back to a previous article in this series, from the Summer 2014 issue of *Protocol*, where we looked at maximum possible efficacies for LEDs and how an RGB mix could beat a blue + yellow. Tuning a mix of wavelengths to match the sensitivity of the sensors in the human eye maximizes efficacy and these phosphors must be close to that.

For now, we wait and see, but if these LEDs live up to the promises from the manufactures, I'm sure we'll be seeing them, or another manufacturer's version of the same thing, in entertainment lighting products before very long. ■

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 40-year veteran of the entertainment technology industry, Mike is a past President of ESTA and Co-Chair of the Technical Standards Council. Mike can be reached at mike@mikewoodconsulting.com.