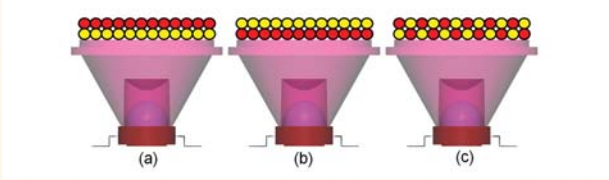
White SPE LEDs with Multi-phosphor Layers

Early phosphor-converted white LEDs produced light with poor color characteristics in terms of CRI and CCT. More recent LEDs have improved their color properties by combining multiple phosphors instead of using a single yellow phosphor such as YAG:Ce. Several manufacturers are now adding a red phosphor to the commonly used YAG:Ce to improve color properties. The common practice is to create a random mixture of multiple phosphors that is spread around the LED chip. In this study, LRC researchers questioned the impact of randomly mixing the phosphors versus stacking different phosphors in layers, as well as the effect of the order of the layers.

Experiment

Commercial red ($SrS:Eu^{2+}$) and yellow ($YAG:Ce^{3+}$) phosphors were applied to three scattered photon extraction (SPE) lenses in different configurations and mounted on three high-power blue LEDs. In all cases, the amount of phosphor was kept the same, 10 mg for each lens. The quantum efficiencies of the phosphors used were 91% for the yellow phosphor and 59% for the red phosphor. Experimental measurements were compared with optical ray-tracing simulations for chromaticity and light output.



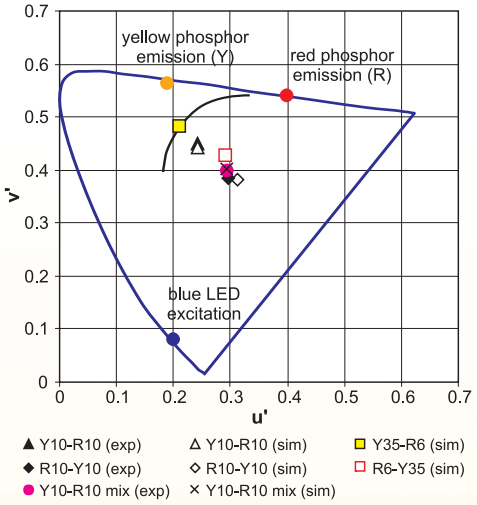
SPE LED packages with multi-phosphor layer configurations: (a) Y-R (yellow first, red second); (b) R-Y (red first, yellow second); (c) Y-R random mixture.

Phosphor	Experiment		Simulation	
	P (W)	Φ (lm)	P (W)	Φ (lm)
Y10-R10	0.102	27.8	0.099	26.6
R10-Y10	0.089	17.5	0.082	15.7
Y10-R10 mix	0.088	18.5	0.088	18.6

Light output results in radiant energy and luminous flux for three phosphor configurations from the experiment and optical ray-tracing (simulation).

Further Information

Zhu, Y. and N. Narendran. 2010. Investigation of remote-phosphor white light-emitting diodes with multi-phosphor layers. *Japanese Journal of Applied Physics* 49(10).



Chromaticity results on CIE 1976 UCS diagram for phosphor configurations of Y10-R10, R10-Y10, and Y10-R10 mixture from experiment and optical ray-tracing (simulation), along with Y35-R6 and R6-Y35 from optical ray-tracing.

Results

The chromaticity values (u', v') of the output light for the Y10-R10 SPE package are different than the other two, even though the amount of yellow and red phosphors is the same. The Y10-R10 SPE package, where the longer-wavelength red phosphor is the outermost layer, yielded the highest light output among all three configurations. Two dominant factors that influenced the outcome include: 1) the amount of the backward emitted light from the first layer, and 2) the forward emitted light from the first layer being reconverted by the second phosphor layer if its spectrum is within the second phosphor layer's absorption region.

Because many applications require white light with chromaticity values on or very close to the blackbody locus, another optical ray tracing study was carried out with different amounts of yellow (35 mg) and red (6 mg) phosphor to achieve ideal chromaticity values. Comparing Y35-R6 with R6-Y35, the results showed Y35-R6 was on the blackbody locus and had 26% more radiant watts and 80% more lumens than R6-Y35, which had chromaticity values far below the blackbody locus. Other studies using phosphor-on-chip configurations also have concluded that layering the phosphors produces higher luminous flux than random mixtures.

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