Red Phosphors for LED Lighting

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DOE SSL Workshop

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Lumenari

Company Snapshot

What we do	We are developing LED phosphors that improve LED efficacy up to 40%
Target Markets	Packaged LED suppliers to the general lighting & display backlighting markets
Employees	2 Founders plus 7 PhD Chemists and Physicists
Founded	January 2013
Headquarters	Lexington, KY

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U.S. DEPARTMENT OF ENERGY

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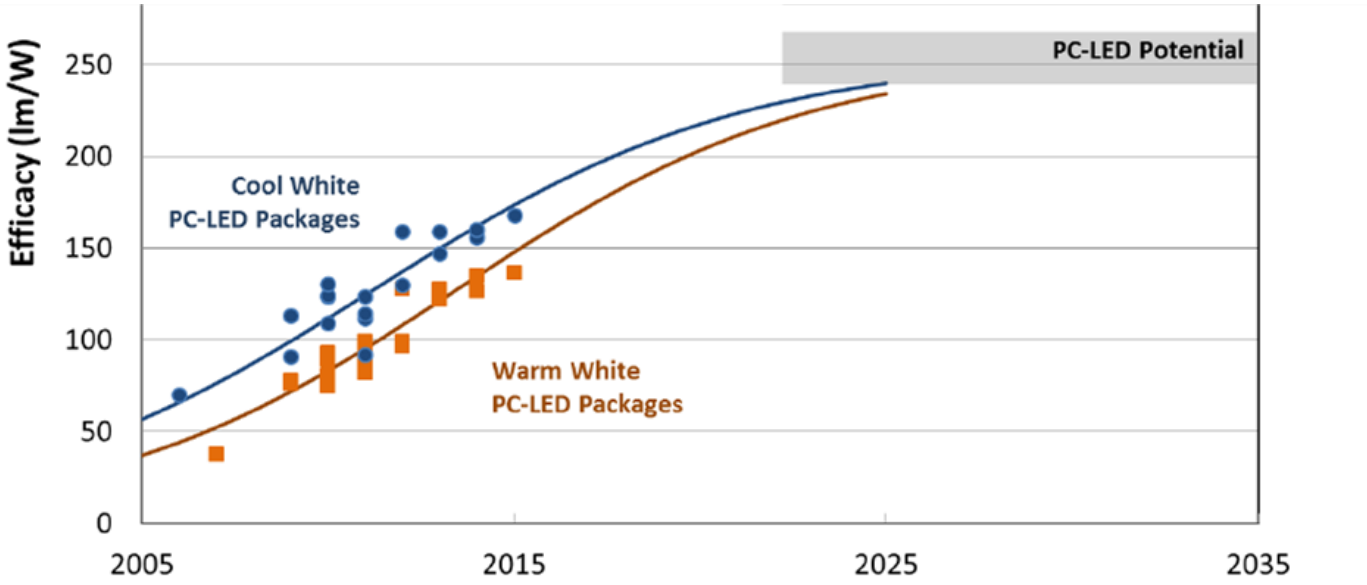
Brighten the world... one particle at a time.

The Efficacy Trajectory

- LED package efficacy has increased steadily
- Warm White packages are slightly more than halfway to theoretical efficacy

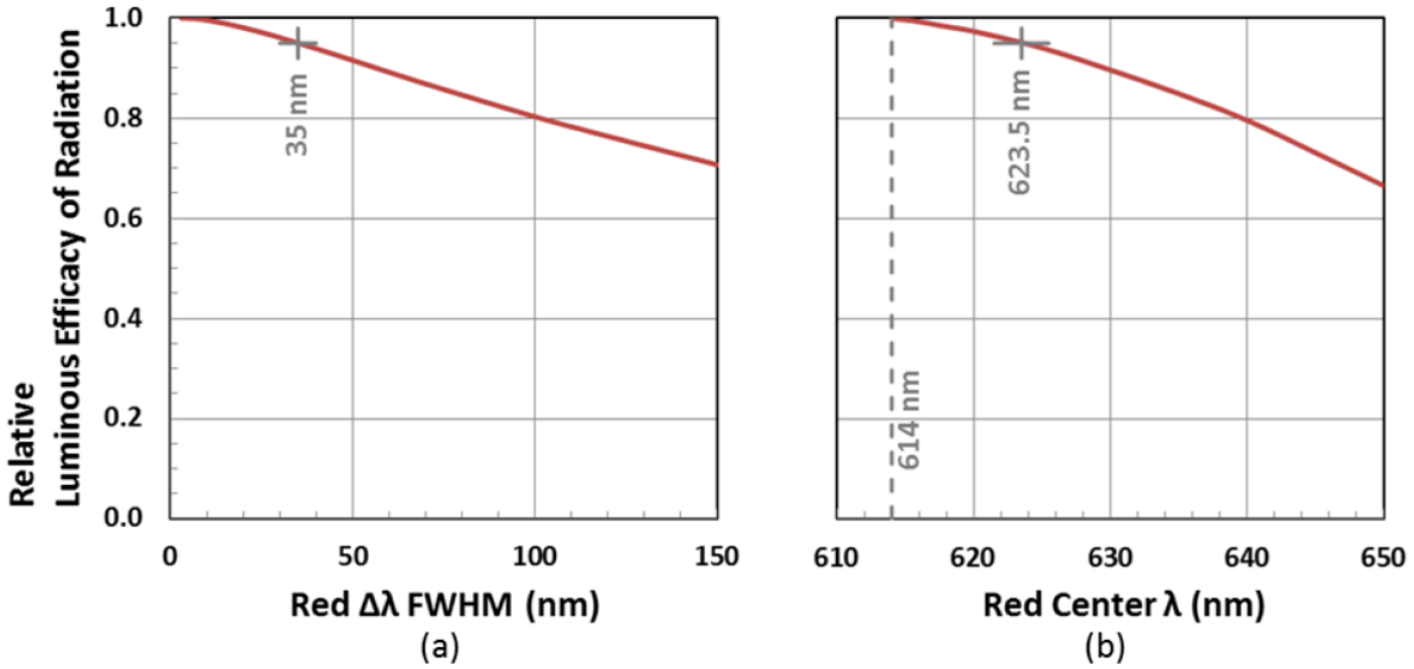


U.S. Dept. of Energy, SSL R&D Plan, 2016

Red Phosphor and LER Impact

Narrower red emission and shorter red wavelength improve LER

– There are λ_{max} – color quality trade-offs, especially R_9

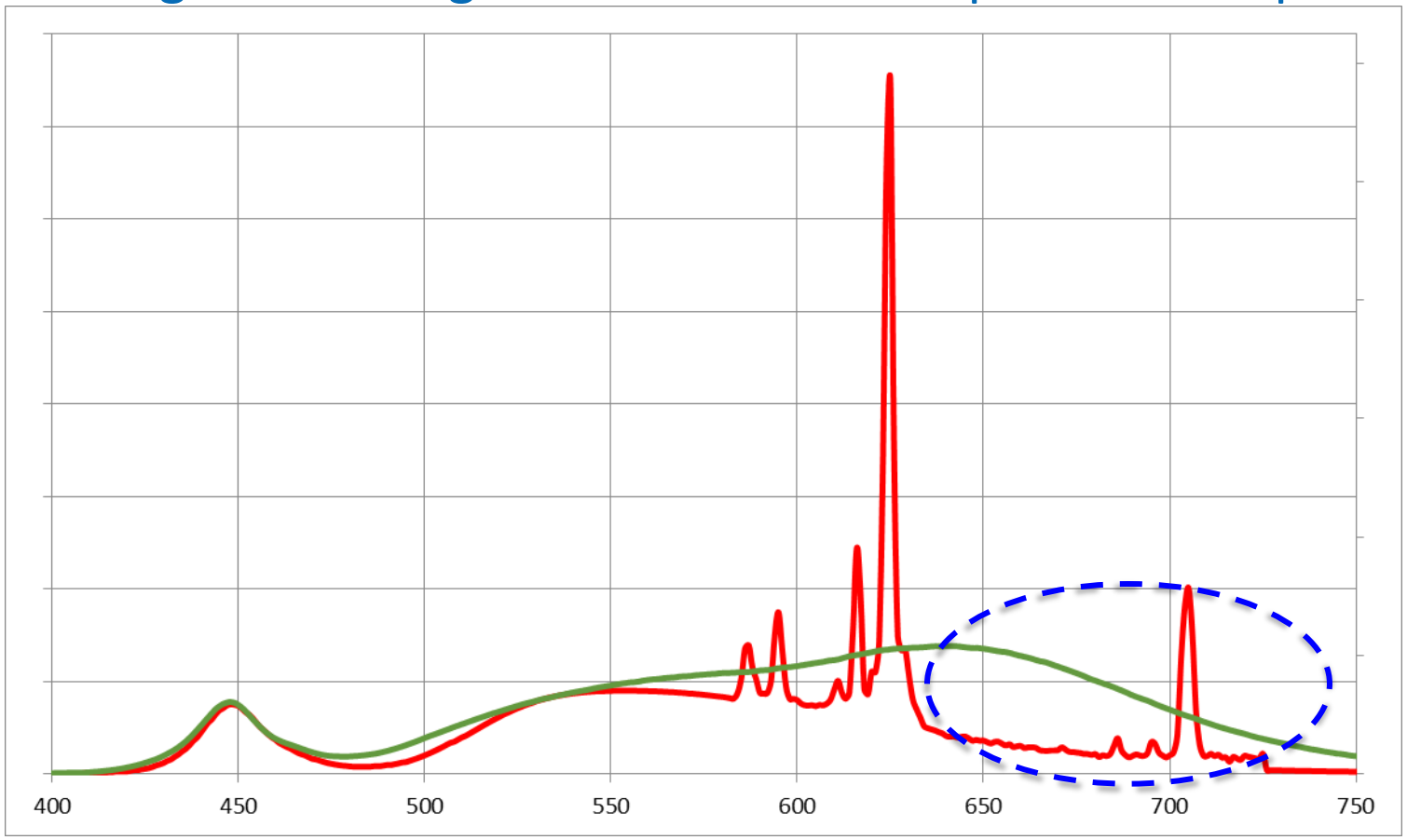


Relative LER 3000K, $R_a = 80$, $R_9 > 0$

U.S. Dept. of Energy, SSL R&D Plan, 2016

Potential for Large Efficacy Gains with Red Phosphor Emission

Eliminating or reducing near-IR emission improves LER up to 40%



Red Phosphor Activators

	Eu^{2+}-activated	Mn^{4+}-activated	Eu^{3+} - activated*	DOE Targets
Peak Emission λ	600-650 nm	631 nm	615-625 nm	615 nm
Excitation Peak/ Edge	~475 nm / ~650 nm	~450 nm / ~500 nm	~450 nm / ~500 nm	
Absorption, α450	>200 cm^{-1}	<60 cm^{-1}	>200 cm^{-1}	
Flux Density Saturation (rel. QY @ 1W_{rad}/mm^2 vs peak QY)	Unknown	Sub-linear > 0.4 W/mm^2	Unknown	95%
PL Decay Lifetime	<3 μs	~8.7 ms	~200 μs	
QY @ RT	~90%	~80%	>55%**	~95%
Spectral FWHM	60-100 nm	<10 nm	<10 nm	30 nm

* Target Specifications

** 55% QE with 625 nm peak yields 5 - 20% increase in efficacy vs. red nitride

Red Phosphor QE

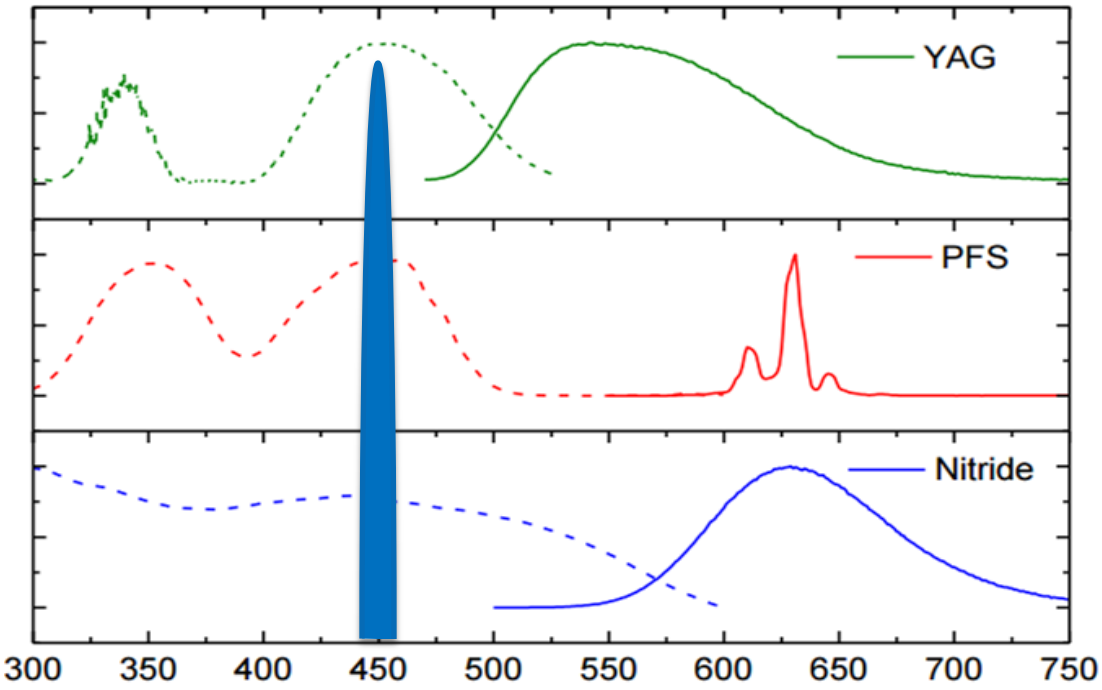
Relative efficacy as a function of phosphor QE (Calculated*)

	Traditional Blend	With Narrow Red (FWHM < 10 nm)			
Phosphor QE	**90%**	**85%**	**75%**	**65%**	**55%**
Relative efficacy Ra>80	100%	122%	118%	112%	106%
Relative efficacy Ra>95	100%	139%	134%	128%	120%

* Thermal effects not considered

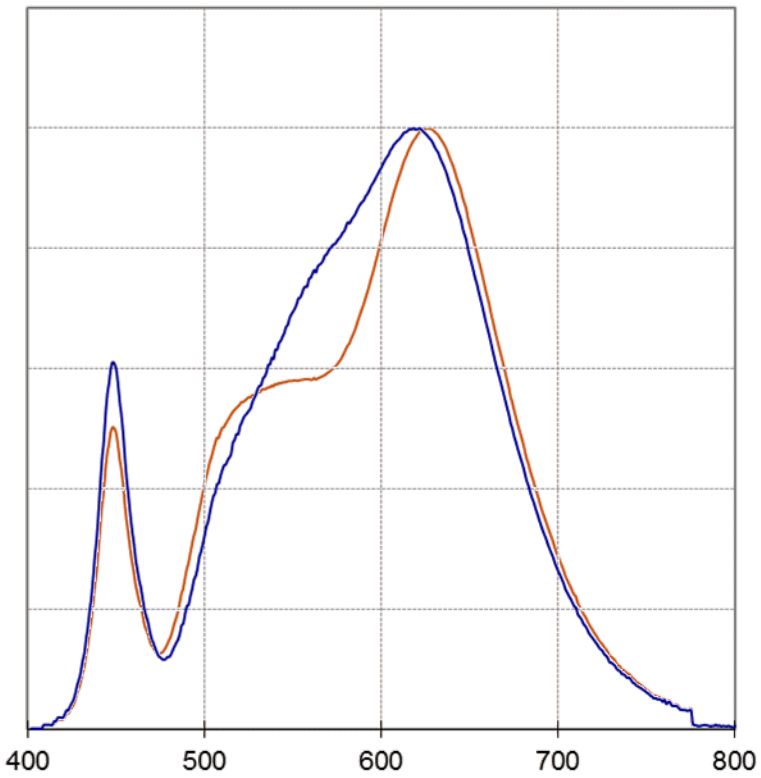
Exciting Phosphors with Blue LEDs

In order to be viable, phosphors must be able to use all photons from the LED



Chowdhury, Phosphors Panel
San Diego May 2014

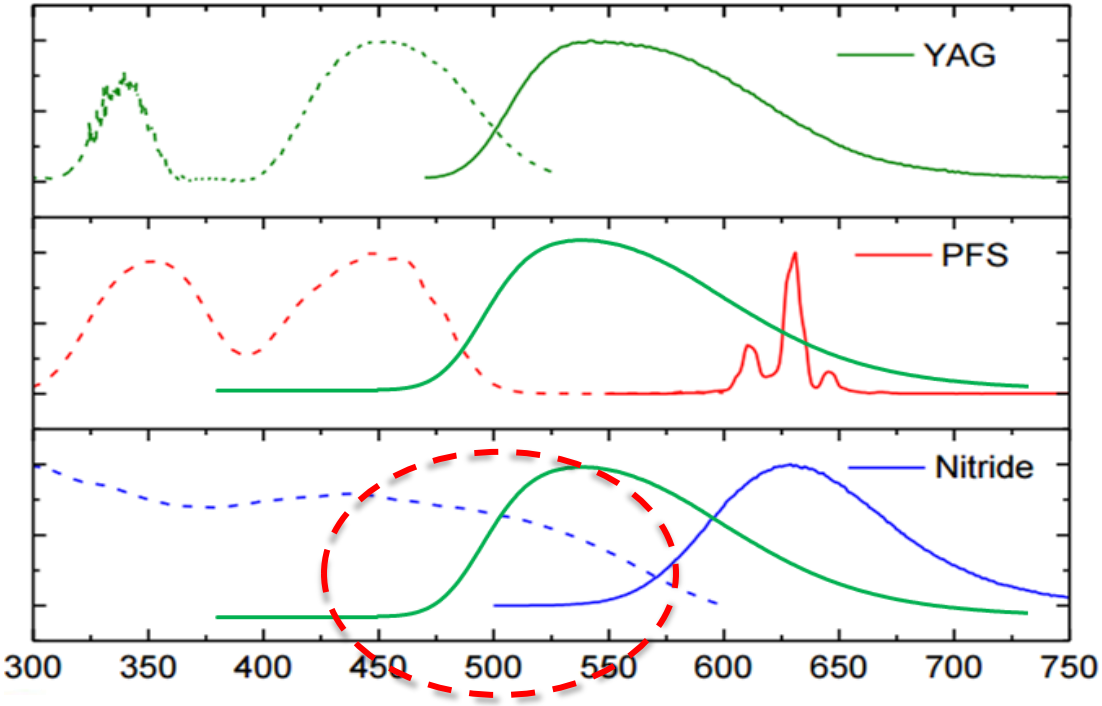
Potential for Efficacy Gains with Red Phosphor Excitation



- Eliminating cross excitation improves overall photon usage, also improves CRI
- LuAG 535 nm and CASN 630 nm
- With CASN absorption Ra ~87 (blue) and without (red) Ra ~96

Exciting Phosphors with Other Phosphors

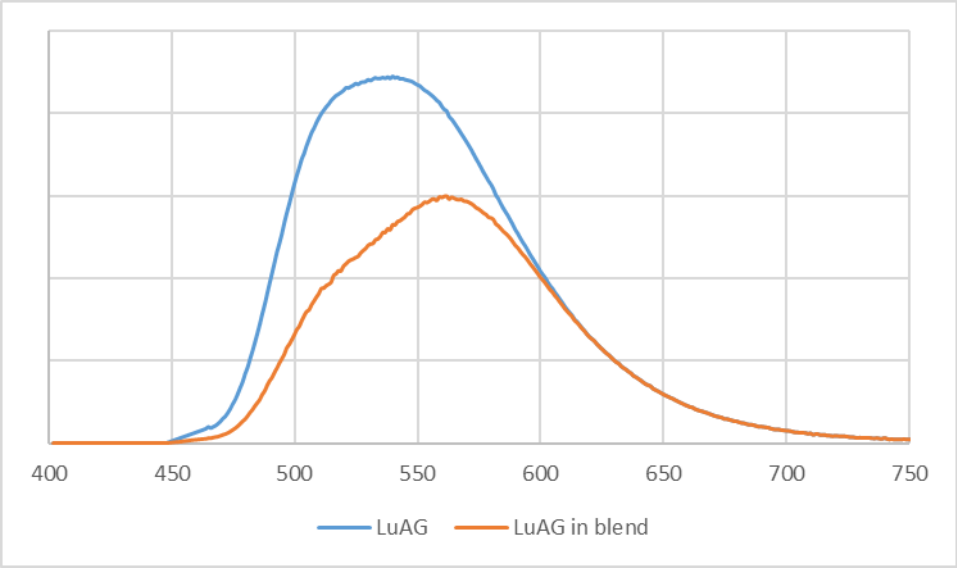
Cross Excitation multiplies QE losses, and reduces CRI by peak shaping



Modified from Chowdhury,
Phosphors Panel San Diego May 2014

Peak shaping

- CASN absorption of LuAG changes peak shape which impacts (lowers) CRI



Conclusions

Large efficacy gains can be realized with continued red phosphor development

- **Primarily driven by narrow emission spectrum**
  - Elimination of longer wavelength red emission improves LER
- Quantum efficiency
  - High QE should remain the long term goal
  - Moderate QE when coupled with narrow emission can enable nearer term efficacy gains
- Parasitic excitation
  - Potential for small efficacy improvement

Thank You

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