Phosphor Systems for Illumination Quality Solid State Lighting Products

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Project objectives

Develop efficient phosphor platforms to enable efficient, customer-driven solid state lighting.

Overall efficacy & color goals for this program for 1000 lm lamps:

- 96 lm/W at CCT~3000 K & CRI>80
- 71 lm/W at CCT<3100 K & CRI~95

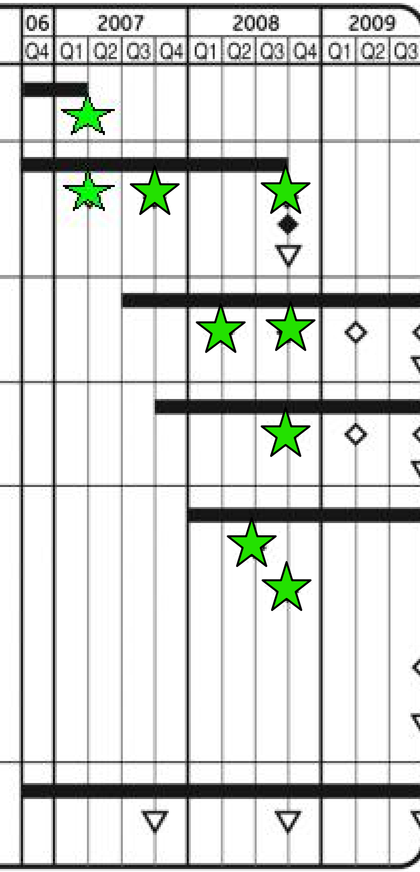
4 W Vio™ product

Lamp	LED WPE	Phosphor Luminosity	Package efficiency	Efficacy
Current CRI~80	30%	280 lm/W-rad	65%	40 lm/W
Future CRI~80	50%	**330 lm/W-rad**	**80%**	**96 lm/W**
Future CRI~95	50%	**260 lm/W-rad**	**75%**	**71 lm/W**

Vio™ platform is testing vehicle & one potential path for commercialization.

Project tasks, milestones, & deliverables

Program Activities	
Task 1	**Determine entitlement for current GE/Lumination phosphors using material selection rules.** ***Milestone:*** *Spectral goals for new phosphor development, refinement of material selection rules.*
Task 2	**Develop new phosphor compositions for violet LEDs.** ***Milestones:*** *Phosphor composition downselection, meeting spectral requirements from Task 1 and spectroscopy tests at UGA.* ***Program Go/No-Go:*** *Are lamp deliverables possible using these phosphors?* ***Deliverable:*** *New phosphor compositions and performance entitlement in LED lamps.*
Task 3	**Synthesis optimization of new phosphor compositions.** ***Milestones:*** *Improvement and optimization of downselected phosphor compositions.* ***Deliverable:*** *Optimized phosphor compositions with quantum efficiencies >85% for integration into polymeric materials.*
Task 4	**Incorporate phosphor materials into polymeric binders and processing of phosphor/polymer composites.** ***Milestones:*** *<5% loss in phosphor efficiency when optimized compositions are incorporated into polymer binders.* ***Deliverable:*** *Phosphor/polymer composites for LED lamp integration.*
Task 5	**Build and evaluate violet LED-based lamps.** ***Milestone:*** *Phosphor blend development using new phosphors with blend luminosity of 330 lm/W-rad at CRI=80 with CCT/CRI trade-offs.* ***Milestone:*** *Lamp testing of new phosphor compositions for package efficiency and accelerated reliability; no loss in lumen output under accelerated reliability. Package efficiency of optimized phosphor compositions 10% greater than current Lumination phosphors in single phosphor tests.* ***Milestone:*** *Package efficiency of individual optimized phosphor compositions 10% greater than current Lumination phosphors. Demonstration of 10% greater package efficiency for new phosphor blends and luminosity of 330 lm/W-rad.* ***Deliverables:*** *Lamp deliverable of >96 lm/W at 3000 K/CRI~80 and >71 lm/W at ~3000 K/CRI~95 when scaled to a 50% EQE LED chip.*
Task 6	**Project management.** ***Deliverables:*** *Technical papers at annual DOE/NETL SSL Meeting and Peer Review Meeting. Briefings to DOE Project Officer as required.*



Legend: ◆ Go/No-Go Decision Point ◇ Milestone ▽ Deliverable

1st year milestones = understanding & discovery
2nd year milestones = discovery & optimization
3rd year milestones = optimization & integration into lamps

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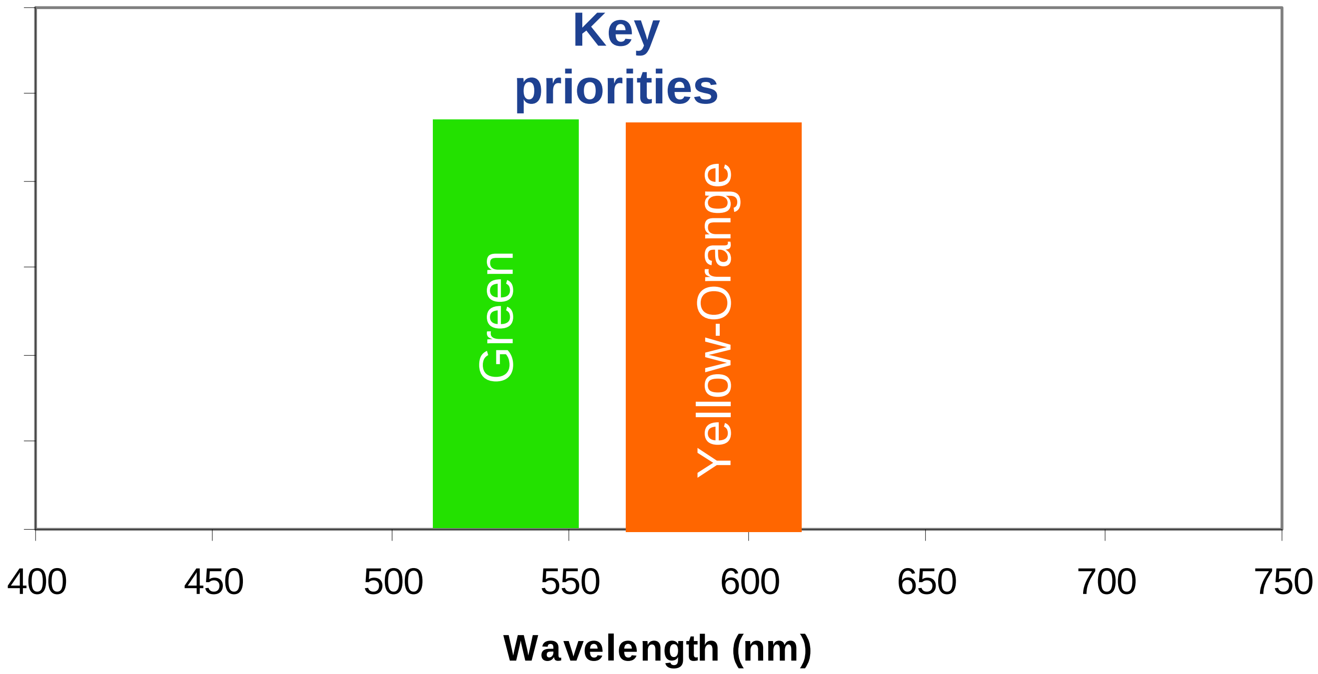
Setting the goals for phosphor discovery

Initial spectral goals via theoretical blend calculations:

– Green spectral goals: λ_{max}=520-545 nm, emission FWHM <80 nm

– Yellow-orange spectral goals: λ_{max}=590-620 nm, emission FWHM <70 nm



Vio™ development & prior DOE program on phosphor quenching:

– Baseline for phosphor performance & quenching processes

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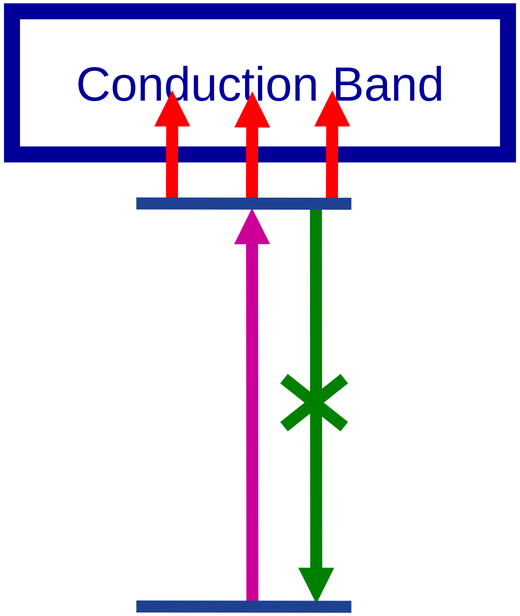
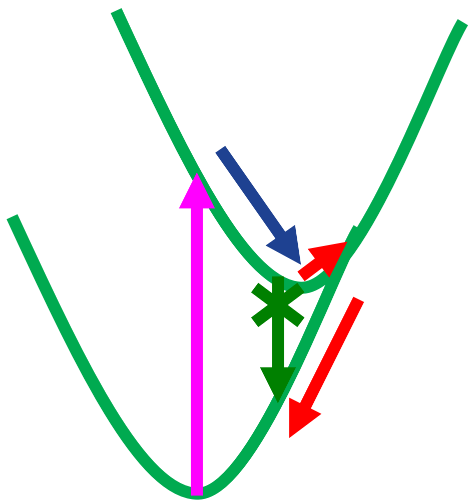
Understanding phosphor quenching

For phosphors w/ fast decay times, three routes for quenching:

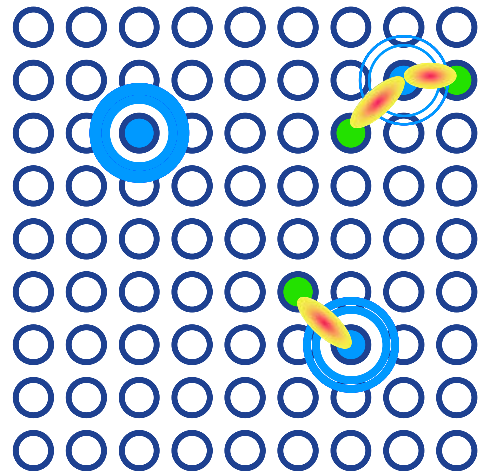
– Thermally activated ionization → ***Intrinsic for a host***
– Thermally activated relaxation to lower levels → ***Intrinsic for a host***
– Energy transfer to lattice defects → ***Can be addressed***



Photoionization



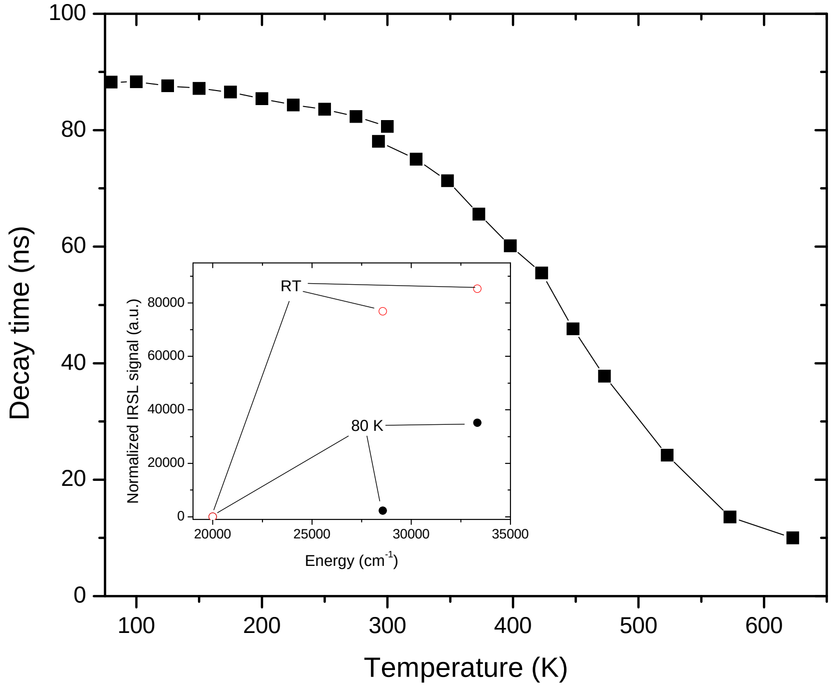
Relaxation to lower levels



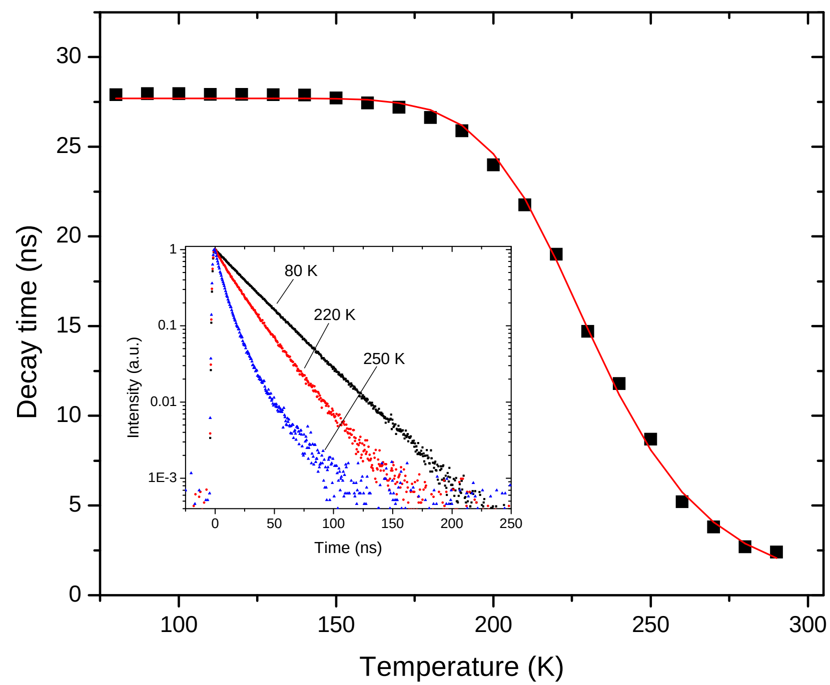
Energy transfer

Experimental assessment of phosphor quenching mechanism

Understanding quenching = phosphor downselection & optimization



Decay vs. T & IR stimulated luminescence: quenching without filling of traps = relaxation to lower levels



Decay time vs. T & Ce^{3+} decay profile: quenching + afterglow @ elevated T = photoionization

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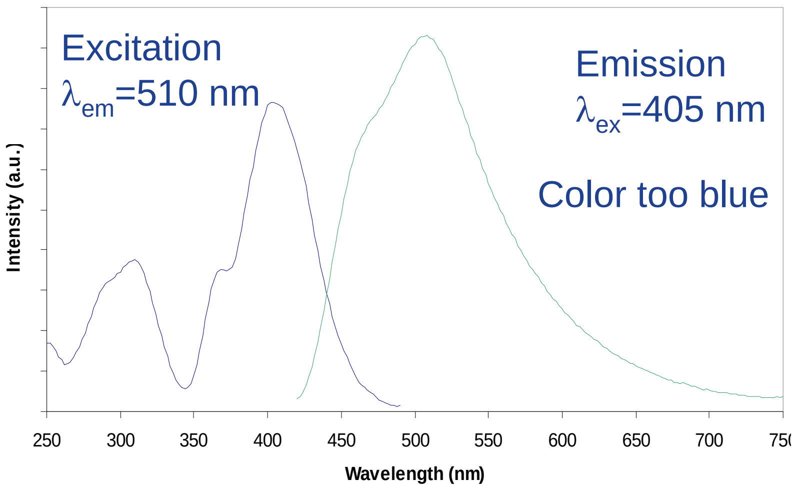
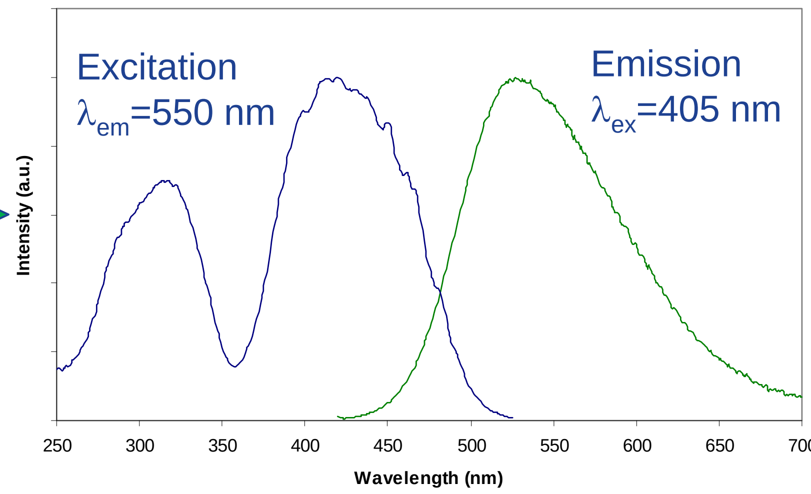
Developing new green phosphors

Using crystal/combinatorial chemistry methods to develop/optimize materials:





Emission/excitation spectra for initial blue-green phosphor → **Emission/excitation spectra for modified yellow-green phosphor**

Current best green phosphor:

– >15% higher efficiency vs. current Lumination green @150^{o}C

– Quantum efficiency = commercial Ce^{3+}-garnets @ 450 nm excitation

– Initial samples: >3,000 hrs w/o efficiency losses or color shift

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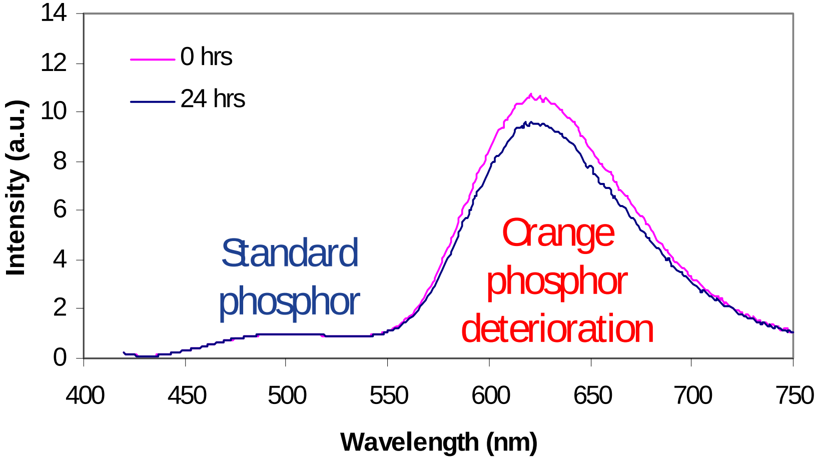
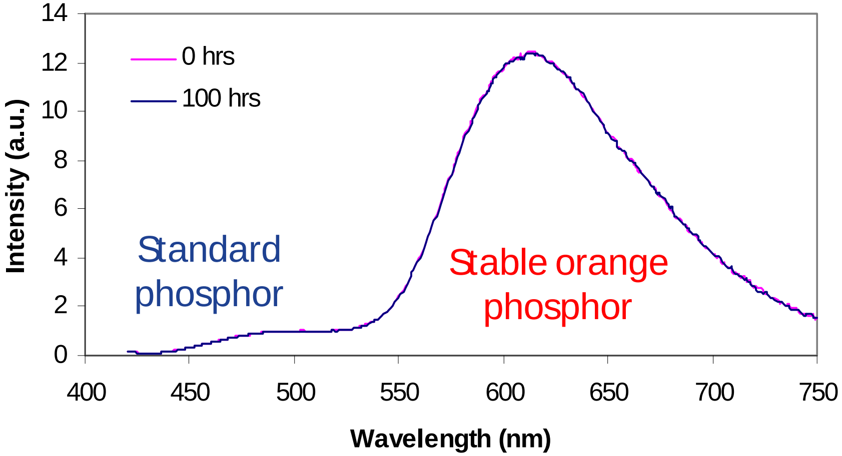
Developing new orange phosphors

Beyond efficiency, also must test/downselect for phosphor reliability:
Use stable Vio™ package/phosphors as internal standard to test new phosphors:





Reliability comparisons between orange phosphors screened in this program

Best orange phosphors @ 2/2009:
– Potentially ~15-20% higher efficiency vs. current Lumination yellow @150^{o}C
– Initial samples passed >10,000 hrs w/o efficiency losses or color shift

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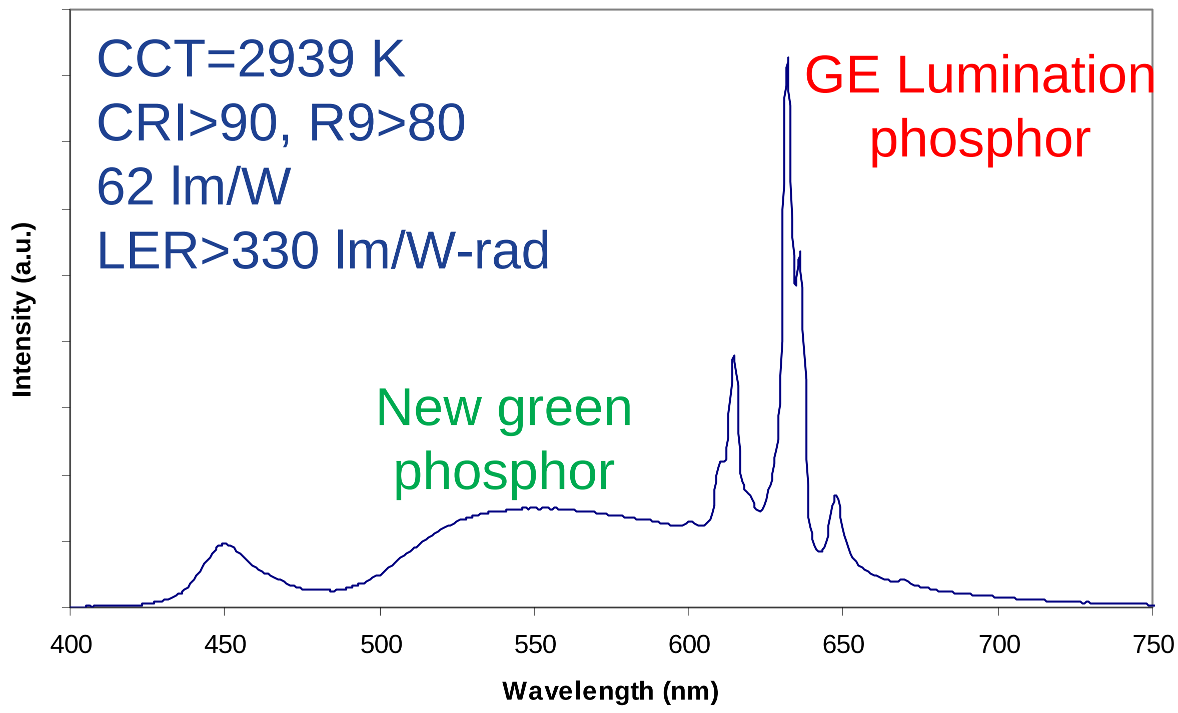
Blend development & lamp testing

Initial blend calculations using new phosphors + GE Lumination portfolio:

Initial lamps using yellow-green phosphor + Lumination red phosphor blends:

– CCT~3000 K & CRI~91; >60 lm/W efficacy

– Lamps in reliability testing for color/lumen stability



Additional blend testing underway for different CCT/CRI combinations

Next steps for Year 3

Continue optimization of new orange & green phosphors

– Further quantify luminescence quenching pathways

– Designed experiments for composition/synthesis parameters

Phosphor incorporation into polymeric materials

– Evaluate efficiency/reliability for phosphors when incorporated in Lumination polymers/silicones; develop methods to retain efficiencies if reactions occur

Lamp testing of new phosphors & blends

– Continue testing of new phosphors & their blends

– Determine quantitative functions for CCT, CRI, lumens, & reliability

– Initial package optimization (coating thickness, blend composition, etc.)

Patents & publications from this program

Patents

Two patent application filed for new phosphor compositions.
One disclosure in process.

Peer-reviewed publications

1. U. Happek, A.A. Setlur, and J.J. Shiang, "Inverse bottleneck in Eu^{2+}- Mn^{2+} energy transfer," J. Lumin., accepted for publication.
2. A.A. Setlur, W.J. Heward, M.E. Hannah, and U. Happek, "Incorporation of Si^{4+}-N^{3-} into garnet hosts for warm white LED phosphors," Chem. Mater., **20**, 6277 (2008).
3. A.A. Setlur, A.M. Srivastava, H.L. Pham, M.E. Hannah, and U. Happek, "Charge creation, trapping, and long phosphorescence in $Sr_2MgSi_2O_7$:Eu^{2+}, RE^{3+}, J. Appl. Phys. **103**, 053513 (2008).
4. A.A. Setlur, J.J. Shiang, and U. Happek, "Eu^{2+}-Mn^{2+} phosphor saturation in 5 mm light emitting diode lamps," Appl. Phys. Lett. **92**, 081104 (2008).

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