

TriGain™ LED phosphor system using red Mn⁴⁺-doped complex fluorides

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1/2015

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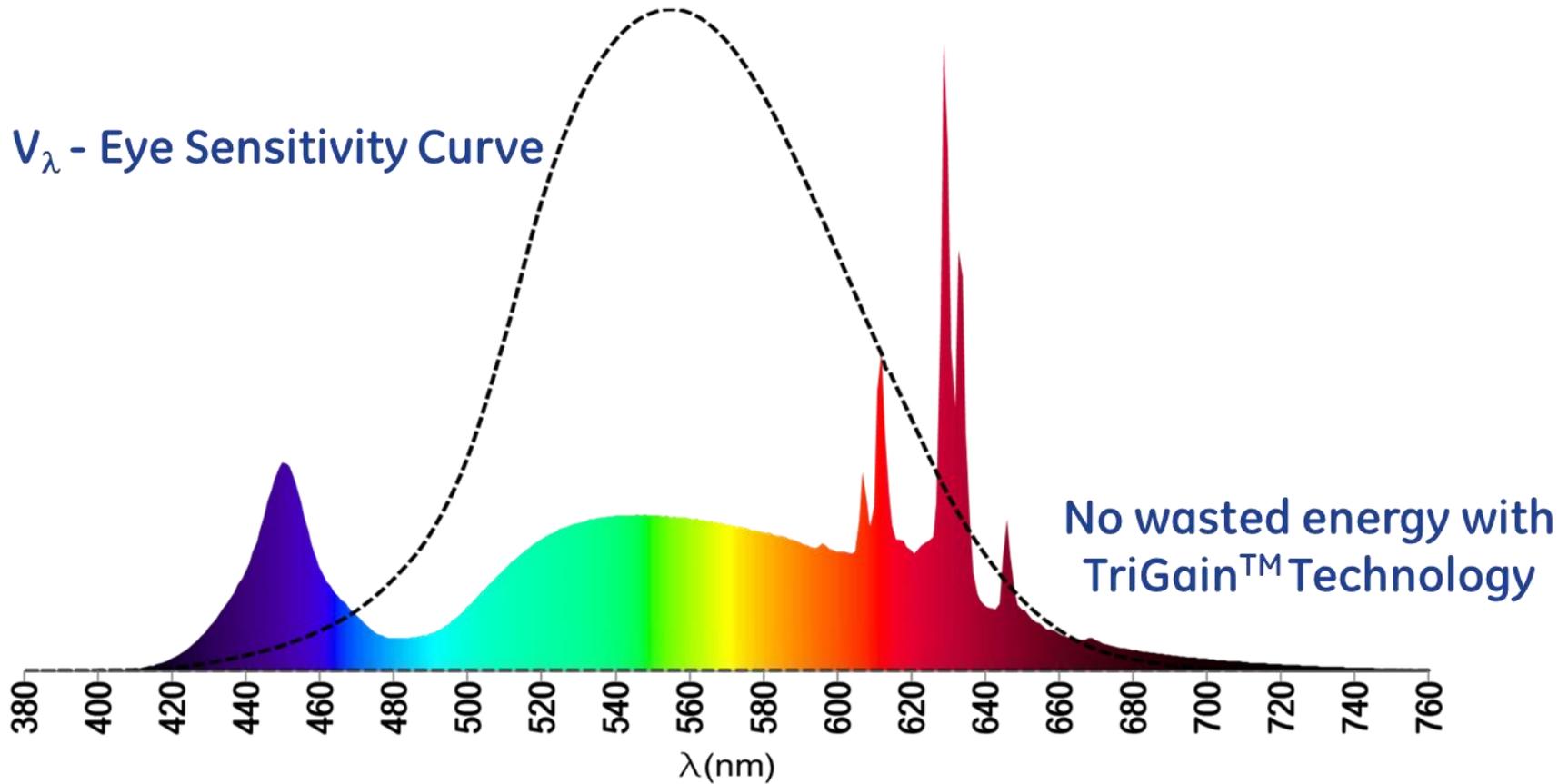
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Acknowledgments

Partially supported by the U.S. Department of Energy through contract #DE-EE0003251 & by
GE Lighting Solutions.

Spectral rationale for Mn⁴⁺-complex fluoride phosphors

Mn⁴⁺ red-line phosphor vs. Eu²⁺ red: +10% lumen equivalent @ 90CRI
Higher gamut for LCD backlighting with reduced lumen losses



Mn⁴⁺-doped fluoride hosts – basic parameters

Mn⁴⁺ emission known to be a red-line emitter: $\lambda_{\text{max}} > 650$ nm in oxides

- Position of ${}^2E \rightarrow {}^4A_2$ dependent on Mn⁴⁺-ligand covalency in octahedral site

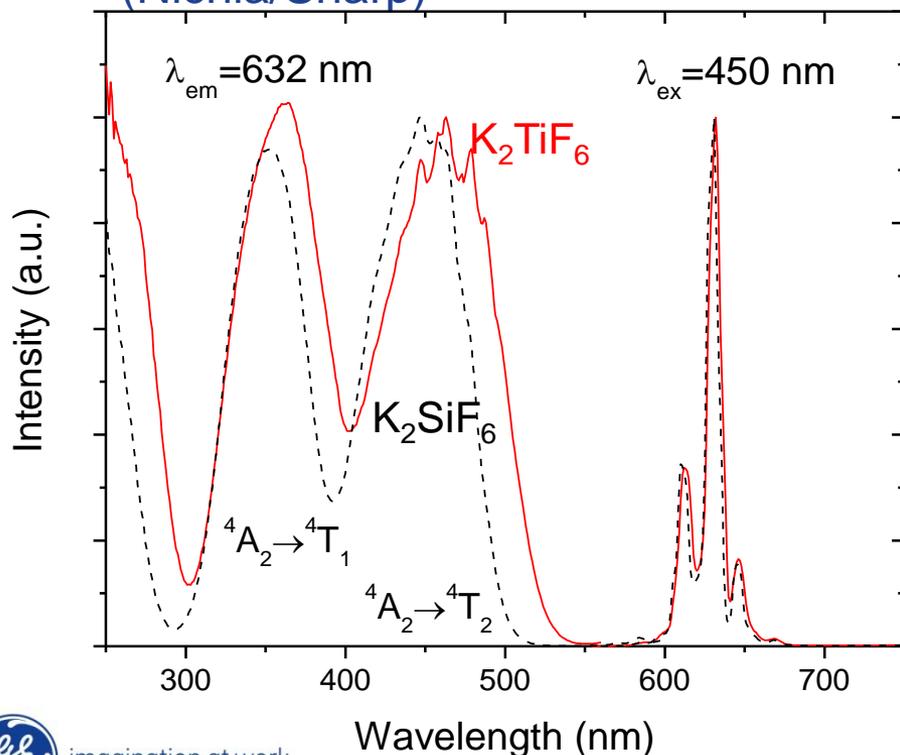
Mn⁴⁺ doped fluoride materials known since 1970's

- Excitation into broad ${}^4A_2 \rightarrow {}^4T_2$ d-d transition & vibronic emission from 2E level

GE-exclusive technology for use in LED-based systems & new compositions/processing

- TriGain™ technology/patents* actively licensed for display backlighting

(Nichia/Sharp)

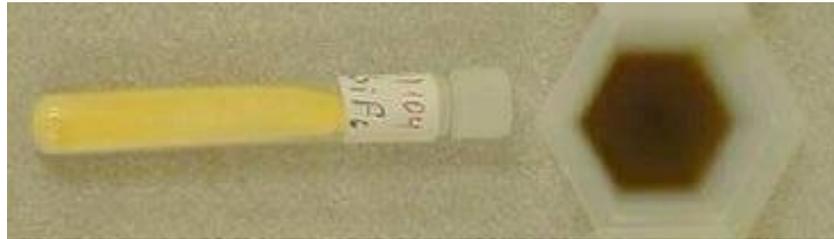


Property	Eu ²⁺ doped Nitride	K ₂ SiF ₆ :Mn ⁴⁺
QY (%)	>90%	~90%
PL Lifetime (1/e)	<3 μs	~8.7 ms (${}^2E \rightarrow {}^4A_2$)
$\alpha_{450\text{nm}}$	>200 cm ⁻¹	<60 cm ⁻¹ (${}^4A_2 \rightarrow {}^4T_2$)
FWHM	>70 nm	5 peaks ≤ 2nm
RI	≥ 2	~1.4
Absorption cut-off	~600 nm	510 nm



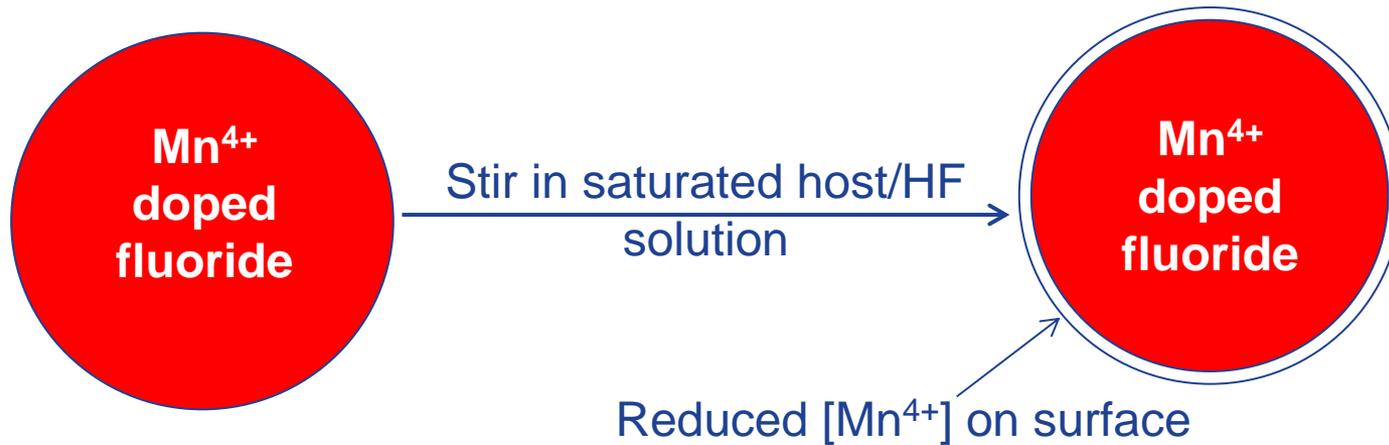
Mn⁴⁺ fluoride hosts – improving phosphor stability

(MnF₆)²⁻ groups can hydrolyze into mixed-valence Mn-oxide/hydroxide



Initial K₂SiF₆:Mn particle

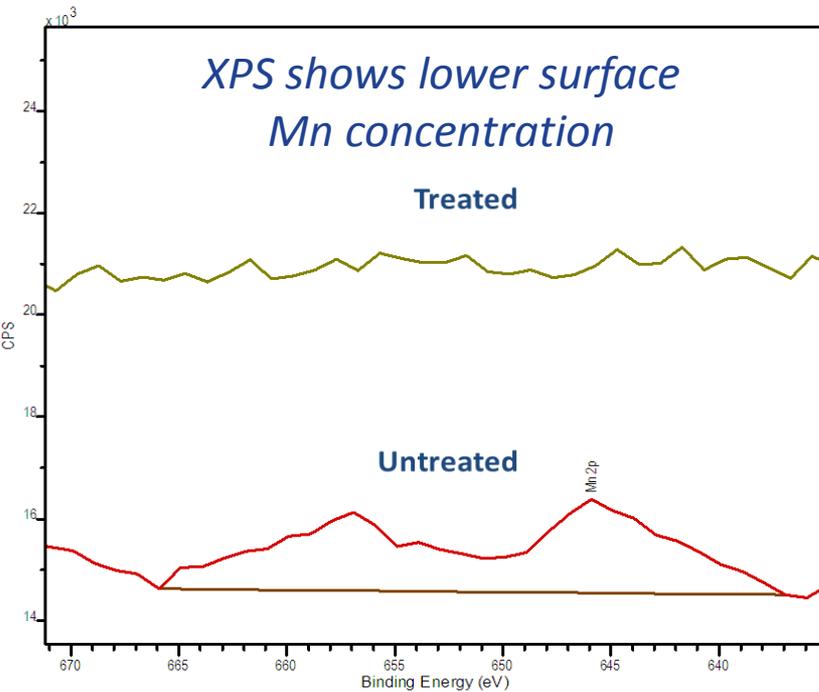
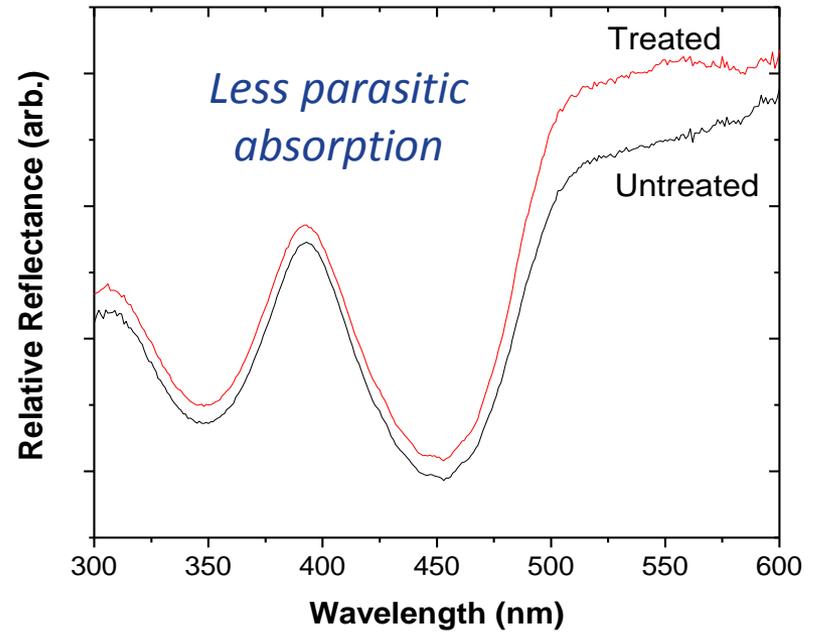
Treated K₂SiF₆:Mn particle



Mn⁴⁺ fluoride hosts – improving phosphor stability

Treated samples have:

- No measurable Mn on surface (<0.1%)
- No parasitic absorption
- improved quantum efficiency
- HTHH Degradation improved 7X



HTHH Testing: 85°C/85%RH at 150 hrs.

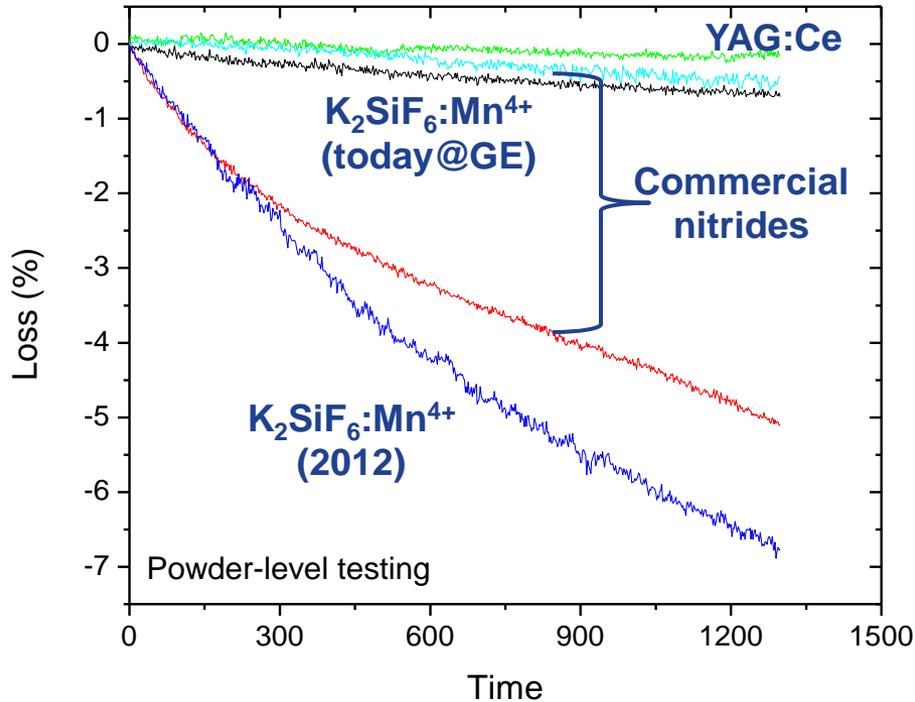
Sample	Initial QE/Abs	$\Delta(QE*ABS)$
PFS	95/72	-14%
Treated PFS	100/70	-2%

Improvement in QE, decrease in HTHH degradation

Mn⁴⁺ fluoride hosts –improving phosphor stability

Composition and/or processing modifications for K₂SiF₆:Mn⁴⁺ → comparable stability to many nitrides

Powder-level testing:



LED accelerated testing:

Red phosphor	MacAdam steps	Δx
K ₂ SiF ₆ :Mn ⁴⁺ (2012)	4.0	-0.0058
K ₂ SiF ₆ :Mn ⁴⁺ (today@GE)	0.5	-0.0011

Enables on-chip use in medium power packages (e.g. 3030)

LED system performance w/ TriGain™ phosphor technology

GE TriGain™ system improves efficacy *and* color rendering

- Light engine efficacy @ 168 lm/W, 4000K, 90CRI
- Suspender troffer system efficacy @ **135-140 lm/W**, 4000K, 90CRI



Next steps for Mn⁴⁺-doped complex fluorides

Bringing properties closer to those of typical red phosphors

Property	Eu ²⁺ doped Nitride	K ₂ SiF ₆ :Mn ⁴⁺
QY (%)	>90%	>90%
PL Lifetime (1/e)	<3 μs	~8.7 ms (² E → ⁴ A ₂)
α _{450nm}	>200 cm ⁻¹	<60 cm ⁻¹ (⁴ A ₂ → ⁴ T ₂)
FWHM	>70 nm	5 peaks ≤ 2nm
RI	≥ 2	~1.4
Absorption cut-off	~600 nm	510 nm

Composition/synthesis modifications must retain good reliability

Summary

TriGain™ phosphor technology using Mn⁴⁺-doped complex fluorides implemented for general illumination & display backlighting

Numerous synthesis & composition improvements to meet requirements including reliability in medium-power LED packages

R&D in progress to accelerate implementation across different LED systems

Materials synthesis challenges (e.g. HF) are being addressed through careful controls & preventative safety procedures

**Thank you to the organizers for the invitation
Thank you for your attention**

