LED Phosphors

Characterization for Manufacturing Controls, and Usage in High Performance LED Systems

Ashfaq Chowdhury
Chief Engineer - LED
GE Lighting

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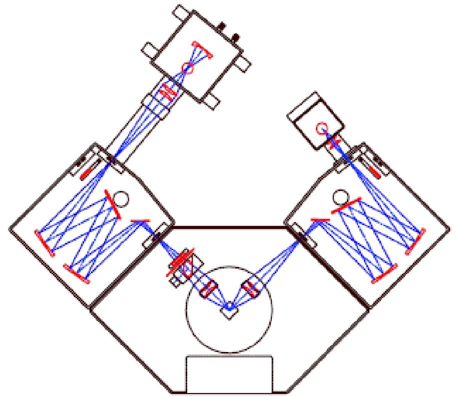
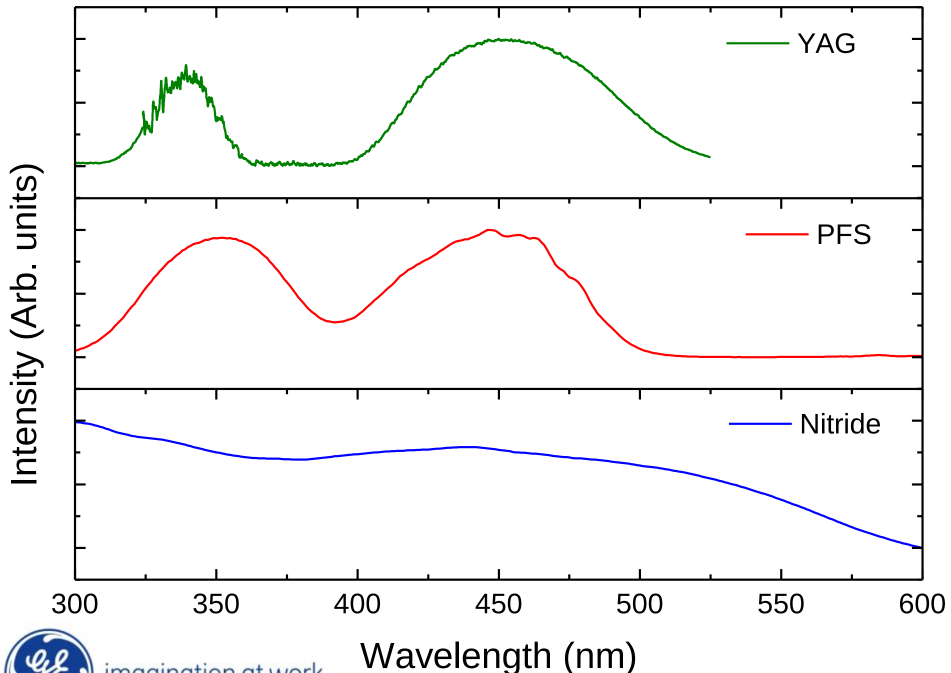
Standard Considerations for LED Phosphors

1. Powder level measurements
   a) Excitation Characteristics
   b) Emission Characteristics
   c) Absorption Characteristics
   d) Phosphor decay lifetime - saturation
   e) Quantum efficiency
   f) Particle size distribution
   g) Reliability at Hi Temperature and Humidity
   h) Reliability under incident flux
2. Interaction with Matrix materials
3. Usage in white LEDs and LED systems

Phosphor Excitation



Spectrometer schematic



Data from measurement

Convolution of phosphor absorption & relative quantum efficiency

Method of measurement

Spectrometer w/fixed emission λ

Potential issues

System calibration/correction vs. λ

Relationship to LED system

Gives appropriate LED λ range

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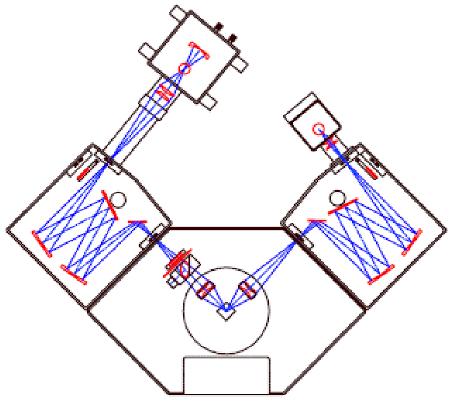
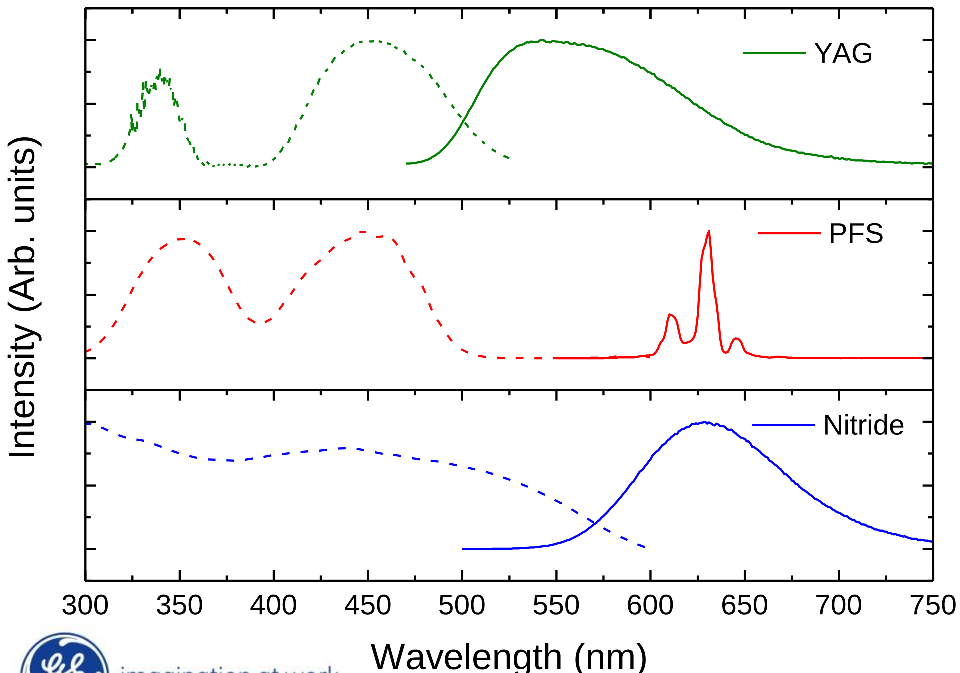
Phosphor Emission



Spectrometer schematic



Data from measurement

Phosphor spectral power distribution

Method of measurement

Spectrometer w/fixed excitation λ

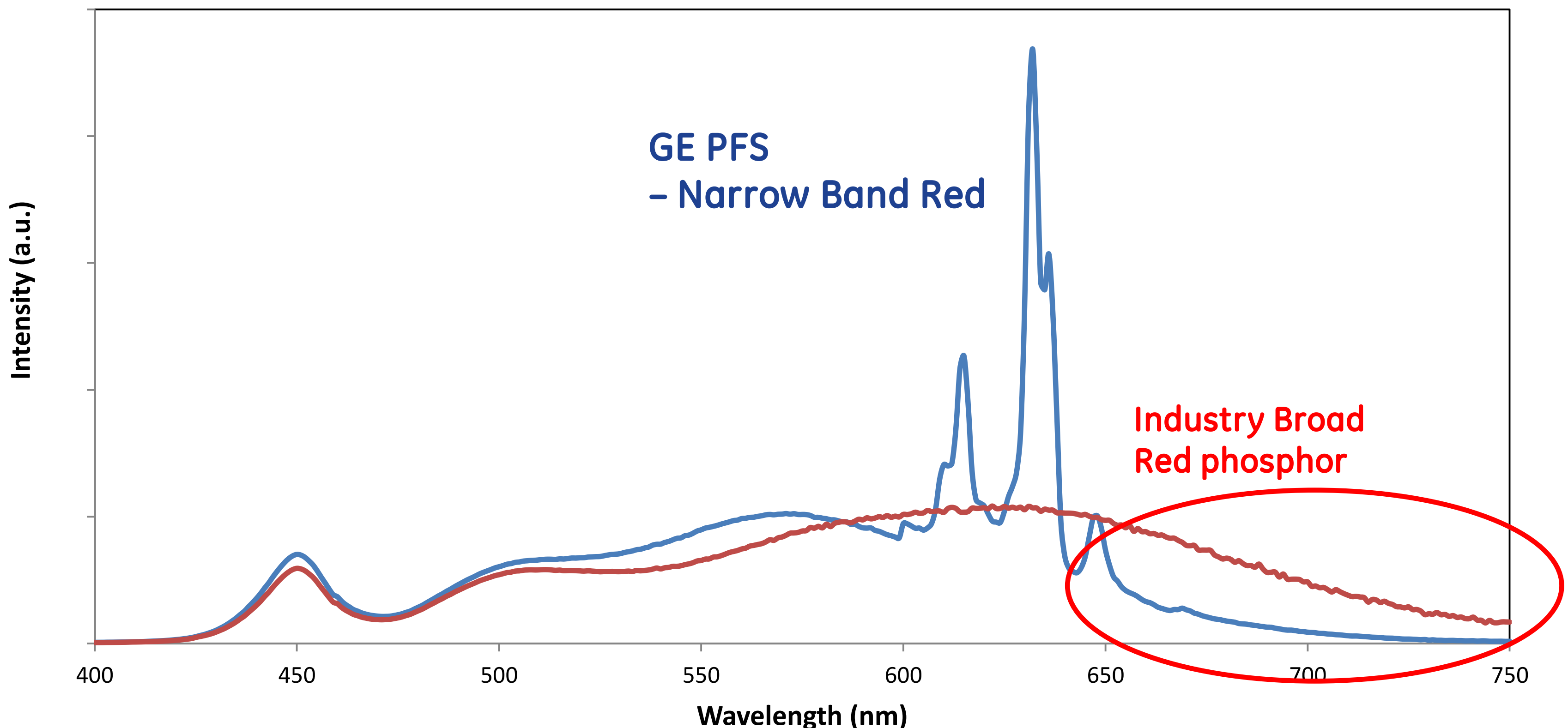
Potential issues

System calibration/correction vs. λ

Relationship to LED system

Estimates lumen equivalent/CRI/CQS

Phosphor Blends for Hi Performance White LEDs Spectral Comparison



Lost Energy in the NIR

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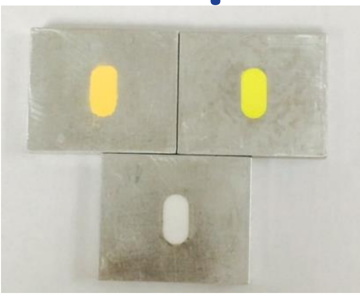
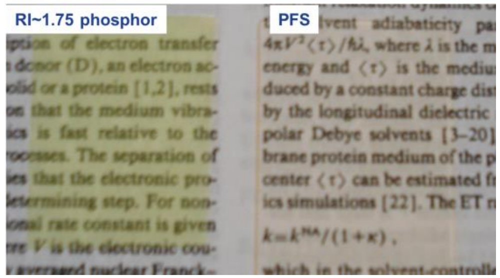
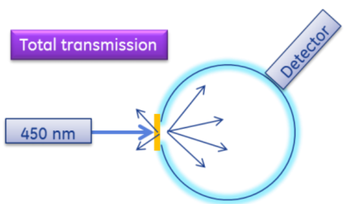
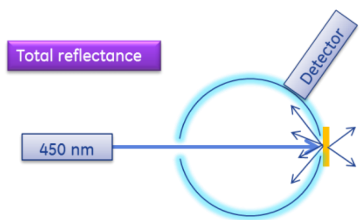
Phosphor Absorption/Scattering









Phosphor	RI	α (cm^{-1})
Garnets	1.82	150-350
Broad red nitride	>1.8	>200
GE PFS	1.4	30-50

Data from measurement

Absorption/scattering coefficient

- Can be relative or absolute

Method of measurement

Spectrometer diffuse reflectance (DR)

Optical properties for phosphor parts & deconvolute α using optical models

Potential issues

DR convolutes scattering/absorption

Phosphor part evaluation outside of powder plaque measurements

Phosphor Refractive Indices less known

Relationship to LED system

Parasitic absorption → lower lumens

Absorption of other phosphors

Phosphor loading in system & "scattering" losses

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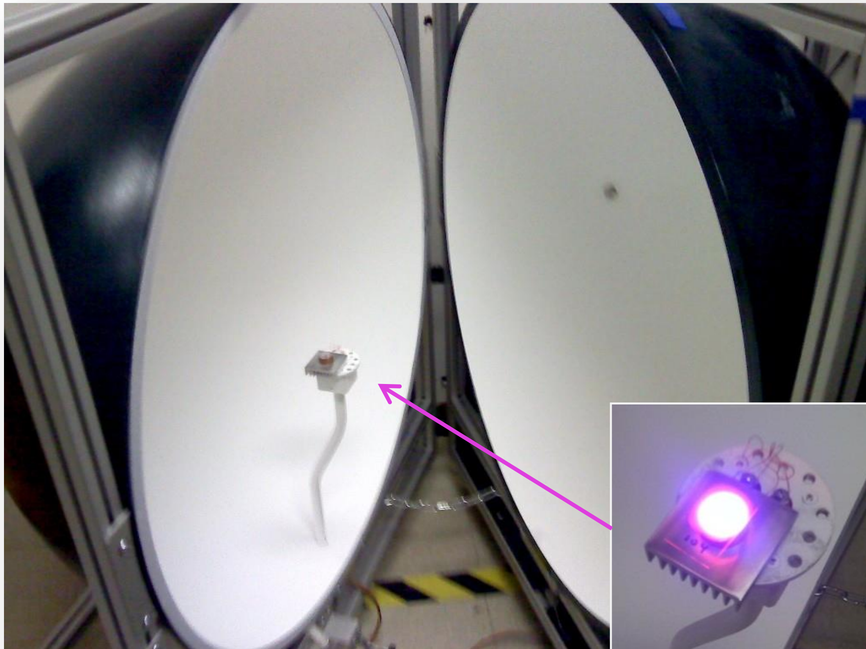
Phosphor Quantum Efficiency



Phosphor	RT QE
Garnets	>90%
Broad red nitride	85-95%
GE PFS	86-93%

Data from measurement

Photons emitted/photons absorbed

Method of measurement

Calibrated spectrometer

- Integrating sphere attachments
- Need reflectance standards

LED light engine w/ known optical properties

Potential issues

Sample prep for measurement

Quality of reflectance standard

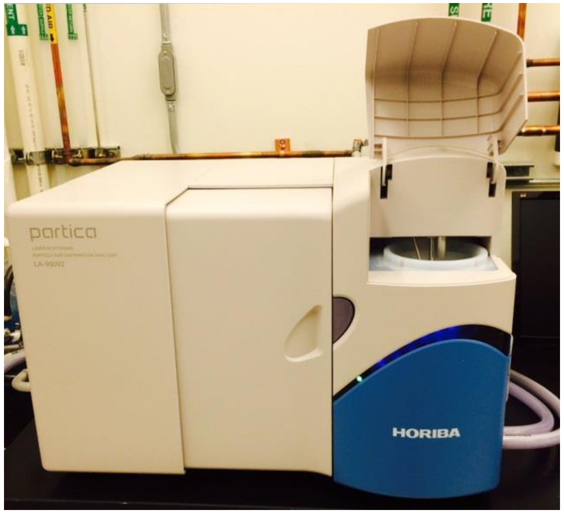
Evaluation of light engine properties

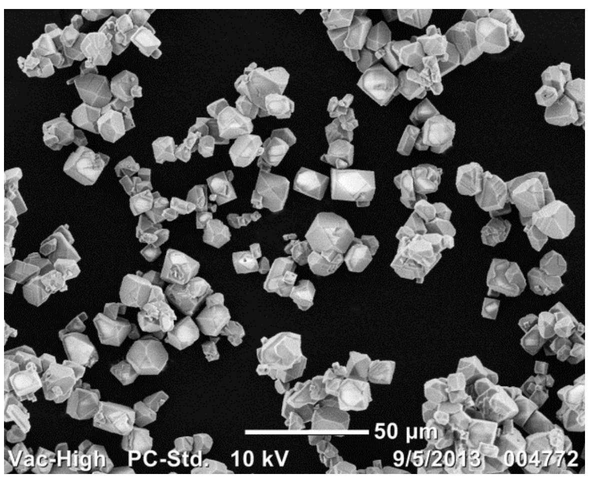
Relationship to LED system

Lower QE → lower lumens & higher phosphor loading

QE vs. T →color shift vs. mA/T

Phosphor Particle Size & Matrix Materials





Data from measurement

Particle size distribution

Method of measurement

Particle size analyzer→light scattering

SEM/optical image analysis

Potential issues

Unknown phosphor RI

Particle agglomeration

Relationship to LED system

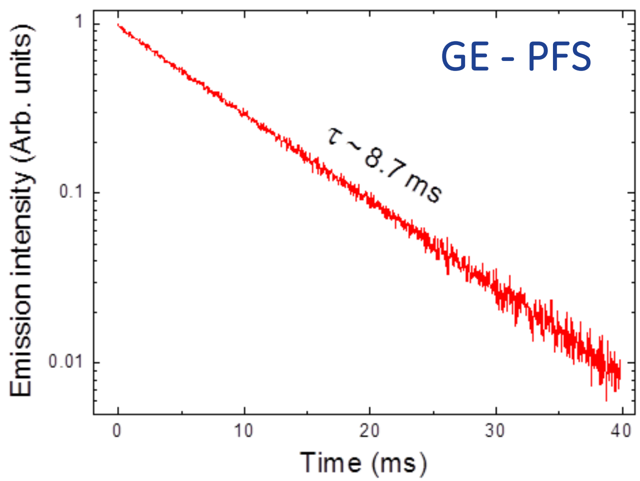
Scattering in LED packages

Settling in phosphor/polymer mixtures

Handling in dispense operation

Reactions with matrix/package?

Phosphor Decay Lifetime



Phosphor	Decay time
Garnets	<100 ns
Broad red nitride	<3 μs
GE PFS	8.7 ms

Data from measurement
Radiative lifetime for emission
Potential phosphor quenching

Method of measurement
Spectrometer w/ pulsed excitation

Potential issues
System-to-system differences
Fitting non-exponential decays

Relationship to LED system
Insight for phosphor saturation & package/system design

Phosphor HTHH Reliability

Phosphor	HTHH losses (85/85, 150 hr)
Garnets	<1%
Broad red nitride	<1%
GE PFS (2010)	>30%
GE PFS (2014)	<15%

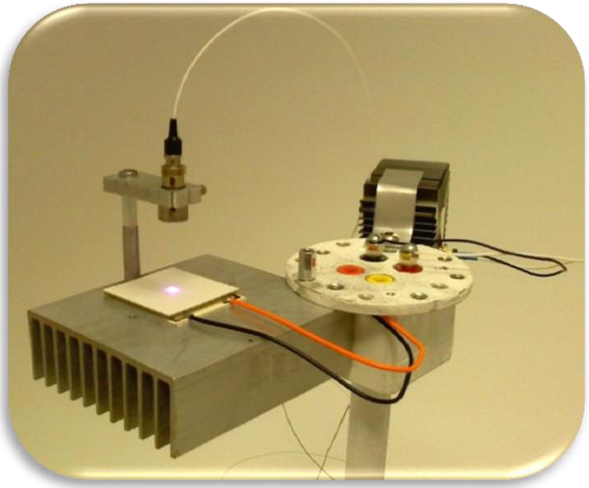
Data from measurement
Stability vs. HTHH conditions

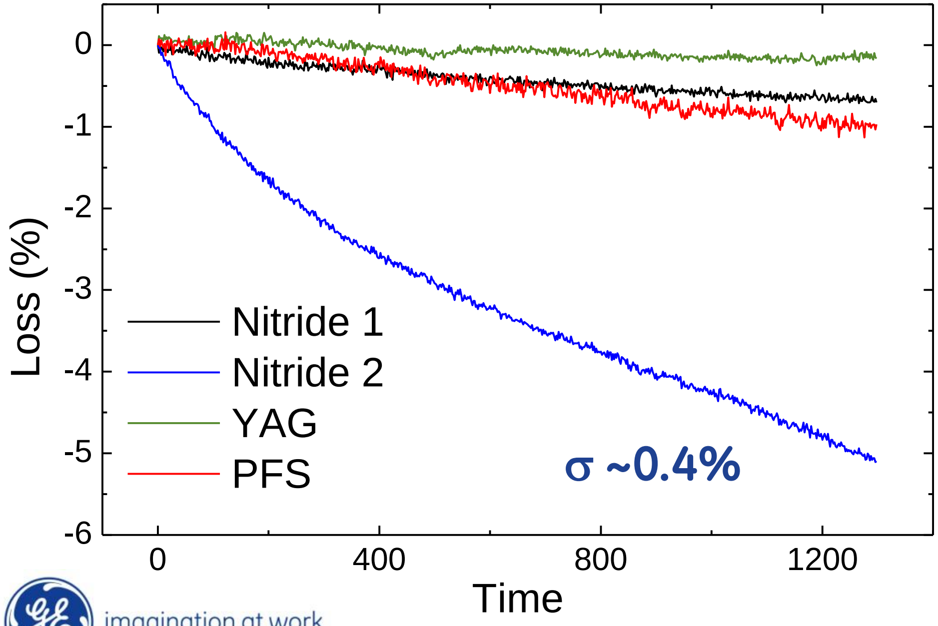
Method of measurement
Phosphor QE vs. exposure time

Potential issues
HTHH chamber variability
Unknown acceleration factors

Relationship to LED system
Storage/operation reliability
System design for environment

Phosphor Reliability Under Incident Flux





Data from measurement
Stability vs. high light flux/T

Method of measurement
High intensity excitation (e.g. laser)

Potential issues
Non-standardized measurement
Unknown acceleration factors

Relationship to LED system
Operation reliability
System design for environment

What do you do with this data?

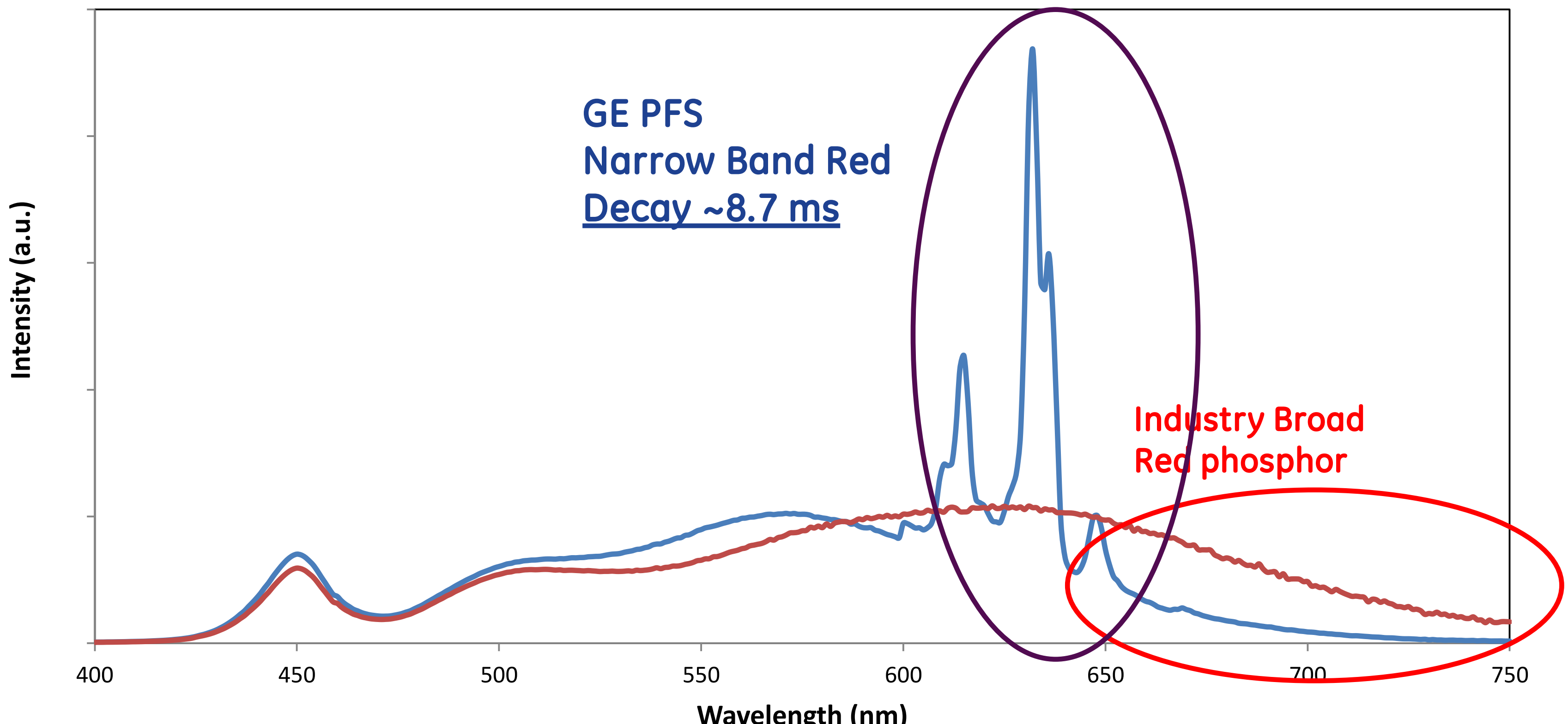
Different LED systems have various requirements…

- Lab-scale measurements initially for screening materials/processes
- May focus optimizing on measurement subset based on initial results

Final tests & relationships →LED package & system testing

- Direct relationships b/w powder & system possible
- Can also use regression-based analysis for multivariate analysis

Phosphor Blends for Hi Performance White LEDs Spectral Comparison



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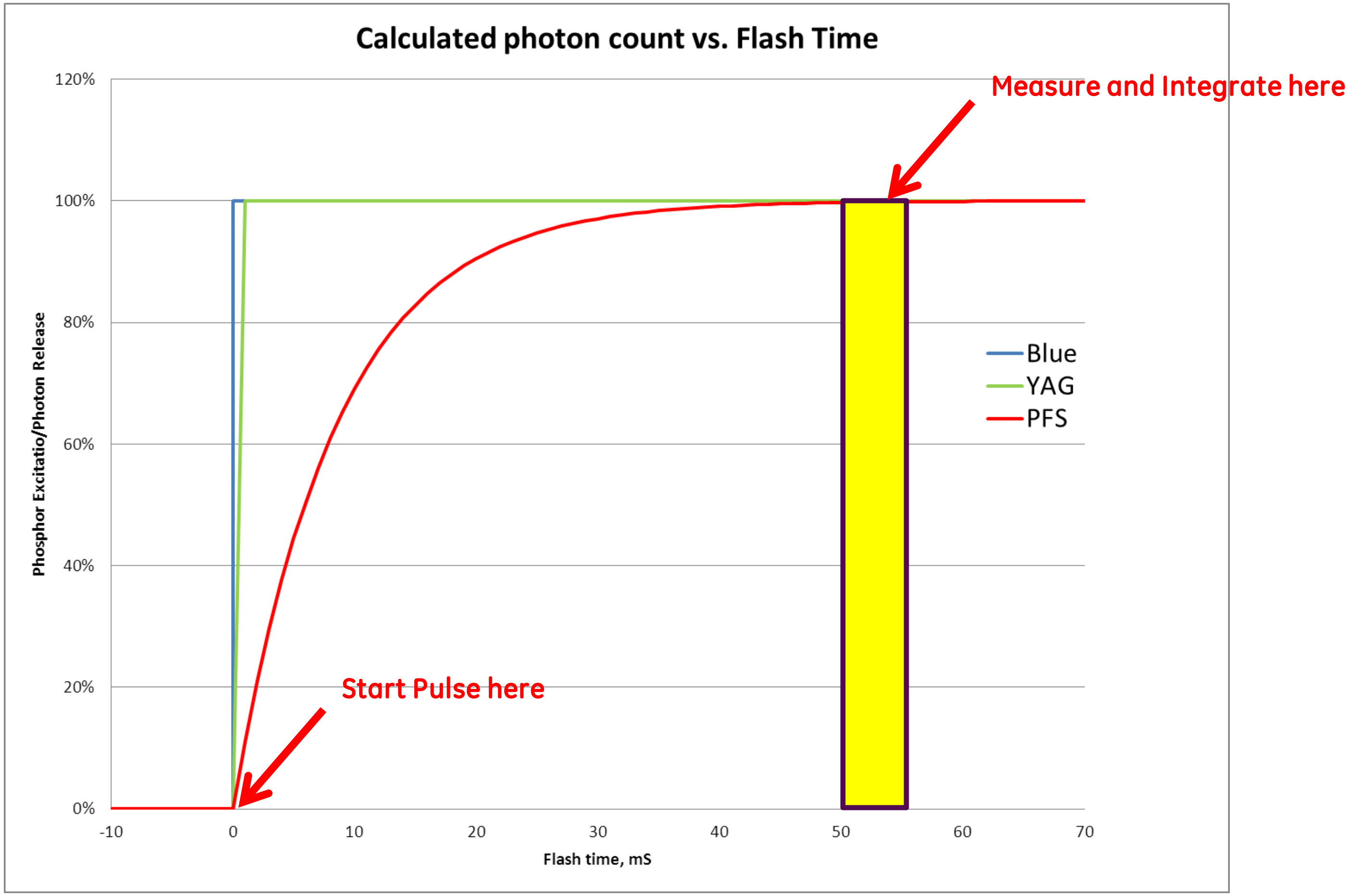
Photon Count vs Flash time



- Minimum Flash time needed >50 ms
- Measure after 50ms

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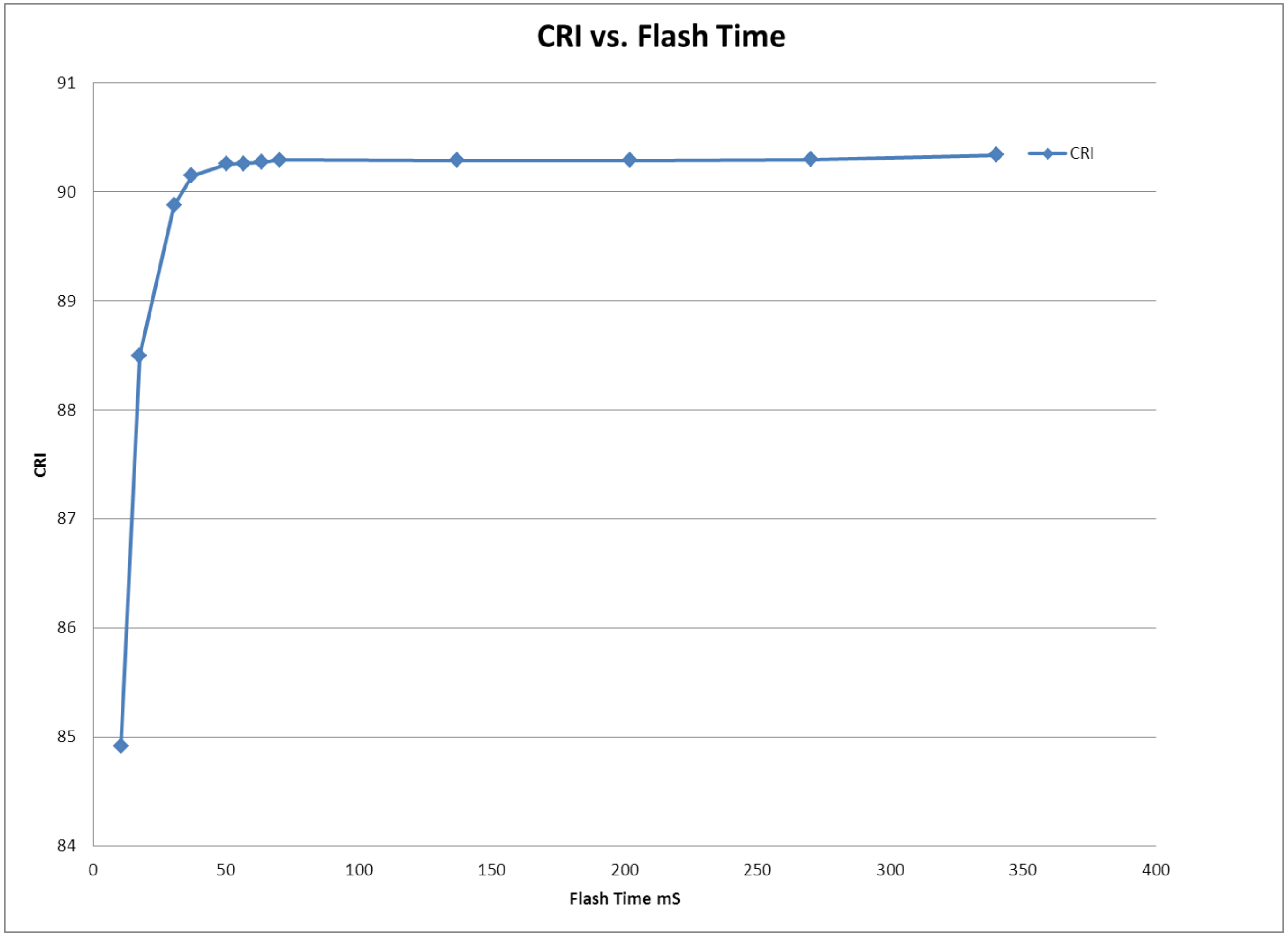
CRI differences vs Flash time



- Minimum Flash time needed >50 ms

Blended Phosphor for Hi Performance White LEDs

Light Engine Steady State Performance Comparison

	LED Efficiency	CRI	R9
Commercial White LED 4000 K, 80 CRI	140	80	<30
Commercial 2 Channel Mixed 4000 K, 90 CRI	160	90+	90+
GE PFS Blend LED 4000 K, 90 CRI	170	90+	90+

Table top demo of a Hi Performance GE PFS Blend Luminaire at the poster session

Acknowledgements

GE Global Research
Florencio Garcia
Ravi Hanumantha
Prasanth Kumar
Bob Lyons
Jim Murphy
Anant Setlur
Srinivas Sista

GE Lighting Solutions
Hanna Alfahel
Gary Allen
Bill Beers
Kevin Benner
Dennis Bradley
Dengke Cai
Bill Cohen
Fangming Du
Jerry Duffy
Cherian Jacob
Emily Martis
Clark Nelson
Kevin Vick

Thank You

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