LED Color Conversion

Phosphors + Matrix + Application

Jim Neff
Philips Lumileds
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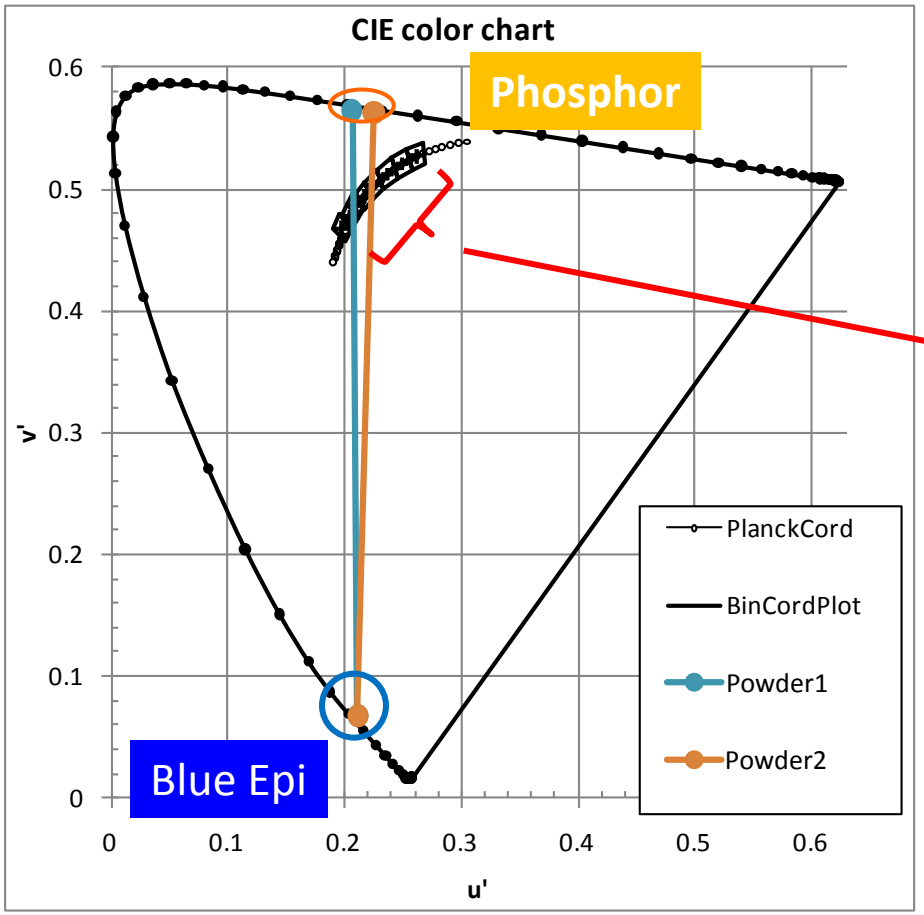
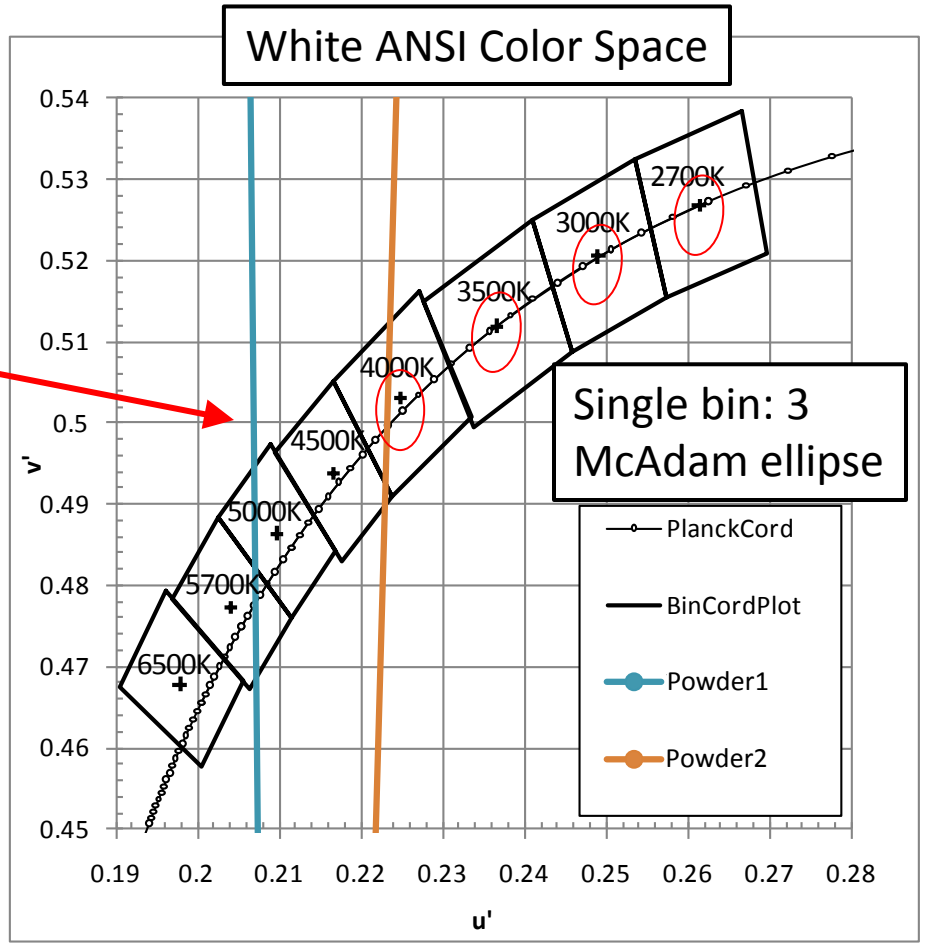
Outline

- Introduction to LED color conversion systems
- Problem of platform scalability
- The quest for single-bin solutions
- Converter cost
- Converter reliability
- Conclusions

Phosphors, Color Control, & Platform Scalability

Combine phosphor & epi to make white LEDs





High-mix manufacturing – a full-range product platform involves:

- (6-8 CCTs) x (2-4 CRI) = ~24 phosphor solutions per LED platform

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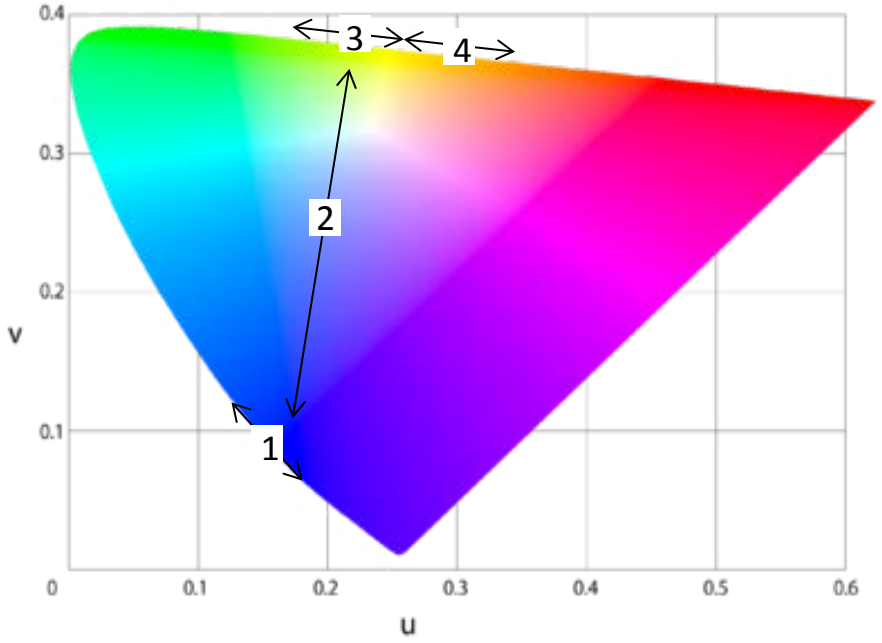
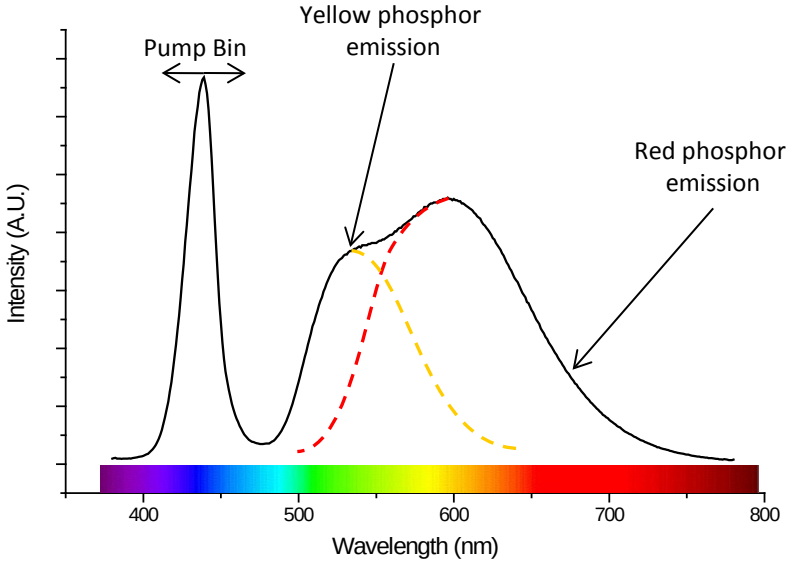
LED Color Point & CRI Control





LED color point & CRI:

1. Choice of pump wavelength (LED Bin)
2. Conversion strength of phosphor: phosphor loading & thickness control
3. Green phosphor color point (yellow/green phosphor choice)
4. Red phosphor color point (red phosphor choice)
5. CRI is improved by ‘filling the spectrum’

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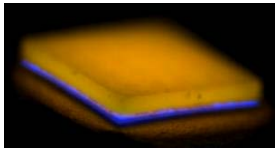
Given A Spoonful Of Phosphor Powder & A Blue LED, How Can You Make A White LED?

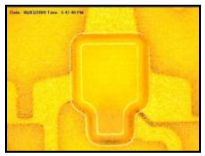
1. Mix phosphor with silicone and dispense onto the LED die


2. Deposit the phosphor using a wet chemical deposition process, infuse with silicone

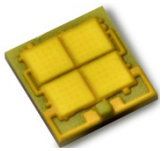
3. Make the phosphor into a platelet, place it on top of LED die



4. Mix it with silicone and mold onto the LED die



5. Mix phosphor with silicone and form a conformal coating on the LED die



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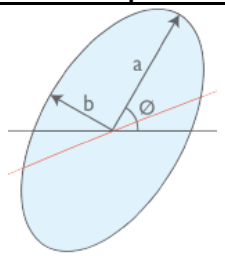
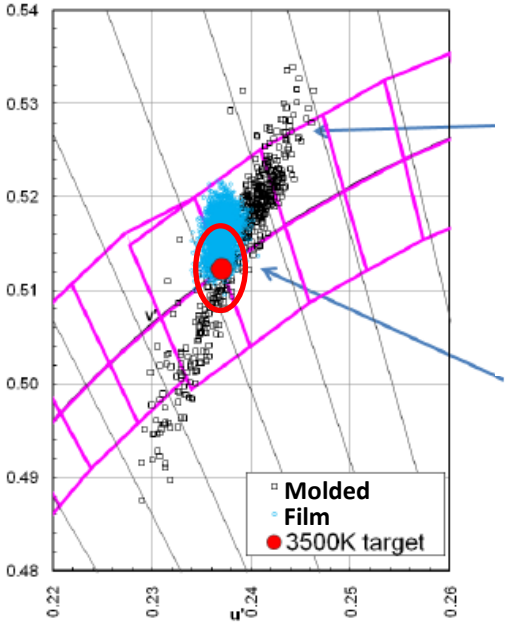
The Quest for Single-Color-Bin Solutions

Customers want this ...

The 3-Step MacAdam Ellipse



At 3000K:
- a: Δxy~0.004
- b: Δxy~0.002

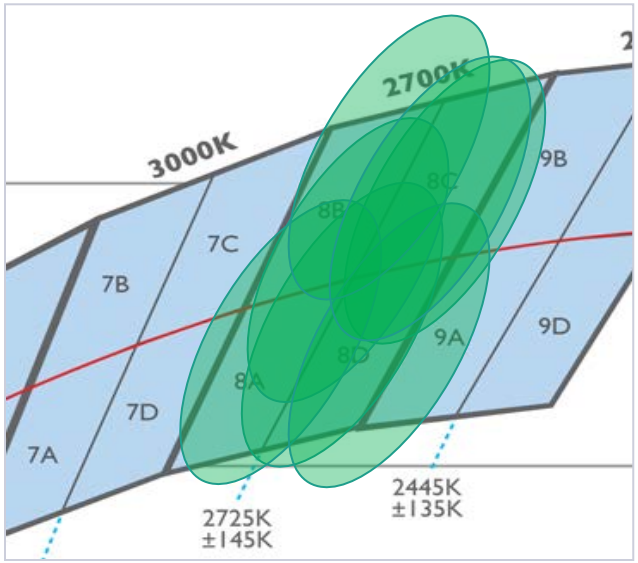


Molded Phosphor (500 units)
u' σ = 4 pt
v' σ =10 pt

Conformal Phosphor (2500 units)
u' σ = 1 pt
v' σ = 2pt

But we deal with this ...

- Pump λ distribution
- Phosphor color point distribution
  - Vendors: typical Δxy = ±0.005
- Tester issues:
  - Color point resolution (Δxy = ±0.0015)
  - Calibration (Δxy = ±???)



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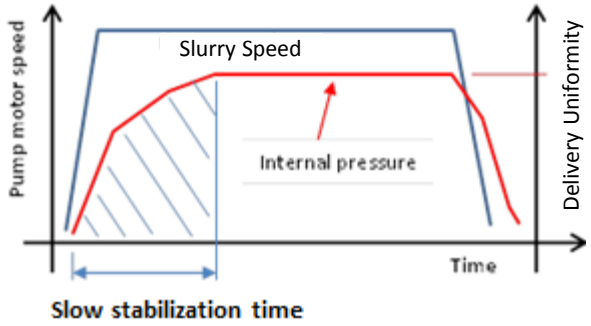
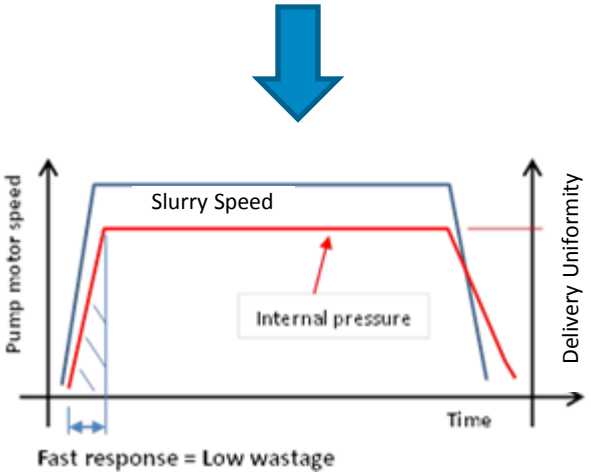
LED Converter Cost

- Phosphors are expensive materials
  - Cost measured in k$/kg
  - Significant portion of packaged LED cost
- Phosphor powder batch-to-batch variations are major cost adder
  - Variations of particle size distribution
  - Color point variation (composition)
  - New batches must be ‘qualified’
    - Trial and error mixing approach to develop transfer functions
    - Much material wasted finding ‘sweet spot’
- High-mix product environment leads to material inefficiency
  - Desire mixing/application systems that can quickly dial-in and stabilize a given color point





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LED Converter Reliability

- A ‘brighter’ LED also brings:
  - Higher photon flux
  - Dissipation of higher thermal loads by phosphor + matrix
- Most common LED phosphor materials are quite reliable
  - QDs are an exception, but reliability improving
- Silicone matrix materials are being pushed to their limits
  - VOC-induced transient browning
  - Thermally-induced permanent browning
  - Silicone cracking
  - LM-80 compliance

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Conclusions

- High-mix CCT/CRI environment creates a scalability problem
  - Must maintain many color converter recipes across product platforms
- Many color converter application methods
  - Often where manufacturers differentiate from each other
- Color converter solutions are a significant portion of the packaged LED cost
  - Phosphor material variations lead to much wastage of expensive materials
- Converter matrix materials are the reliability weak link
  - Could push LEDs harder if silicones could keep up...
  - Cracking & browning over 10k+ hours, thermal cycling


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The Brighter LED