MANUFACTURING FOR COLOR POINT CONSISTENCY

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Meeting the Product User Expectations

- Initial Color Point Accuracy and Consistency ("Born-On" Performance)
- Long-Term Point Accuracy and Consistency
Meeting the Product User Expectations

- Incumbent Light Source Color Point Consistency
  - User Tolerance
  - User Frustration
Managing LED Luminaire Initial Color Point Accuracy

- Binning (Inventory Management)
  - LED Device Mixing
    - BOM Management Mission = No Leftovers!
- Quality Assurance
  - Manufacturing Process Control
  - Testing / Verification
Mixing Different LEDs for Color Consistency

- Can enable excellent color consistency, using the full distribution of LEDs
- Requires a luminaire design with multiple LEDs
- Requires a lighting application with the ability to mix light from different LEDs
- May reduce cost but also increases manufacturing complexity
3000K LED Mixing Tool Example
Meeting **Long-Term** Color Quality Performance Expectations

- Determine the Requirements for the Application the Product Will Serve
  - “Born-On” Color Quality Performance
    - Consistency
    - Color Spatial Uniformity
  - “Long-Term” Color Quality Performance
    - Consistency
    - Stability
    - Color Spatial Uniformity
Meeting Long-Term Color Quality Performance Expectations

- Color Point Stability Information From the Device Manufacturer
  - LM-80 Data
    - Wide Range of Device Stress Levels is Preferred
    - Projection Methods?
- Select the “Appropriate” Highest Operating Stress Threshold(s) for the LED Device
- Identify and Control All Other Contributing System Level Elements
  - Non-LED Component Aging Effects
  - Contamination
- Incorporate Some Level of Active Color Management?
Degradation Sources

1. Silicone Encapsulant Degradation
2. Chip Degradation
3. Phosphor Degradation
4. Lead Frame Degradation
5. Plastic Degradation
Mid Power Plastic LED Package Example (6,000 Hour Data)

• LM-80 / TM21
  – ~43,000 hrs. (36,000hrs. 6X Rule Limit)

• Average Chromaticity Shift Within 7-step MacAdam Ellipse (Meets Energy Star Requirements)

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Mid Power LED Package Example (17,000 Hour Data)

- LM-80 / TM21
  - <20,000 hrs.

- Average Chromaticity Shift of a Nearly 20-step MacAdam Ellipse

- Demonstrates a Need for Lower Stress Condition(s) Data

Credit LEDs Magazine @ 85°C
Ceramic/Silicone Dome Architectures

Degradation Sources

1. Silicone Encapsulant Degradation

2. Chip Degradation

3. Phosphor Degradation
High Power Ceramic LED Package Example (11,000 Hour Data)

- **LM-80 / TM21**
  - \( > 100,000 \) hrs.

- Average Chromaticity Shift Less Than a 3-Step MacAdam Ellipse

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**FIG. 7.** LM-80 test results for high-power ceramic-based LED after 11,592 hours at 105°C.

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Wide Range Color Point Data Example
Secondary Optical System Aging / Degradation

- Typical Lens/Refractor Materials
  - Acrylic (PMMA)
  - Polycarbonate
  - Silicone
  - Glass

- Typical Reflector Materials
  - Anodized Aluminum
  - Paint
  - Plastics / Films
  - Metalized Plastics

All have well known and predictable aging characteristics, based on a variety of environmental exposure conditions
Chemical Incompatibility Mechanism

- Tightly sealed secondary optic (adhesive, tape, etc.)
- Adhesive outgases VOCs, concentrates under optic
- VOC penetrates silicone lens
- Heat, photonic energy turn the VOC brown
- Significant light loss, color-shift mechanism
One Example

Normal LED

Contaminated LED
Chemical Compatibility Experiment

- Standard LED (Control)
- Sealed Secondary Optic
- Secondary Optic Removed @ 336 hrs
Conclusions

• LED devices will continue to get better and less expensive.
  – More Epi With Less Electrical and Thermal Stress?
• Luminaire manufacturers will continue to demand more and longer-term testing and data for LED device color quality performance (in the near term).
• Luminaire manufacturers will continue to demand that highly reliable and standardized methods for color quality performance of LED devices be developed and adopted.
  – Color Quality Projection Methods for Use With LM-80 Data
  – Accelerated Testing Methods
    • Multi-Level Stress Conditions
• Acceptable “Born-On” color consistency is possible today.
Thank You for Your Kind Attention

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