

# Color Stability of LEDs Understanding the Basics

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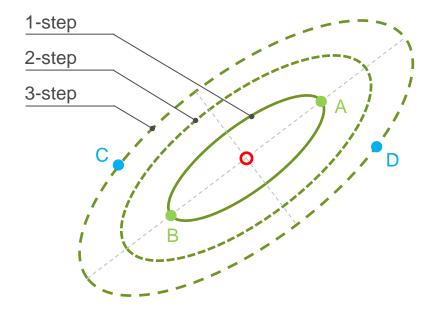
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# Why and where is color stability important?

- Color Shift/Color Stability: Comparison of spectral power distributions over time
  - Many types of lamps emit light differently depending on the operating condition (ambient air temperature, for example). Sometimes these changes are recoverable.
  - For some lamps or luminaires, the materials or construction may change over time, resulting in changes to the spectral output.
  - Color shift is generally independent of lumen depreciation, although they can be related.
- Color Consistency: Comparison of initial spectral power distributions for a group of matching lamps or luminaires
  - Color consistency over time is also different from color stability.



# What metrics are used to describe color shift/color stability?

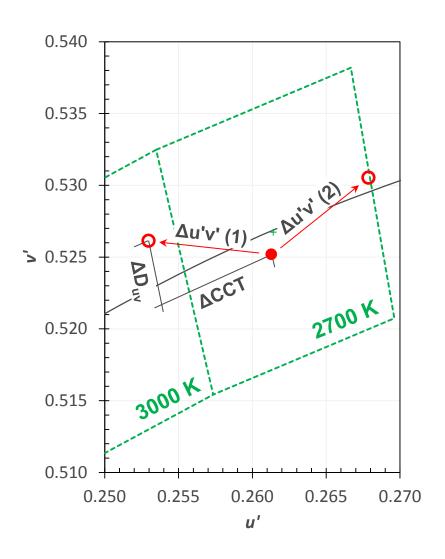


#### **MacAdam Ellipses**

- Experimentally-derived indicators of human color vision tolerances at various chromaticities
- Based on the observations of one highly-trained observer in a very specific scenario/apparatus; results cannot be translated to every installation
- Sometimes referred to as SDCM (standard deviation of color matching)
- Can be reported in multiples (e.g., 3step ellipse)
- Do not convey the direction of shift/difference



# What metrics are used to describe color shift/color stability?



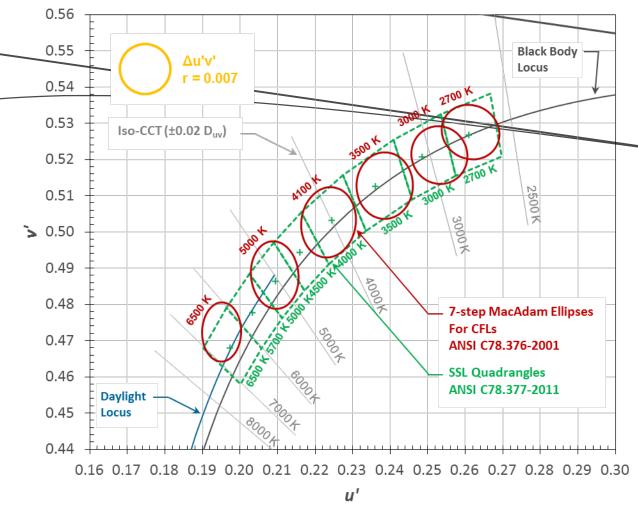
#### Δu'v'

- Δu'v' is the Euclidian distance between two sets of chromaticity coordinates in the CIE 1976 UCS chromaticity diagram.
- As with MacAdam Ellipses, Δu'v' does not convey the direction of a shift
- Δu'v' does not convey whether or not a difference is noticeable



# What metrics are used to describe color shift/color stability?

#### **Δu'v'** and MacAdam Ellipses



- MacAdam ellipses are approximately circles in the 1976 (u', v') chromaticity diagram
- A 1-step ellipse is approximately equal to a Δu'v' of 0.001
- ANSI definitions of white light allow for fairly large tolerances (~14-step difference from edge to edge)



#### When does color shift become noticeable?

# The million dollar question... It depends.

Viewer
Field of View
Surface Characteristics
Proximity
Time

In MacAdam's experimental setup, a just noticeable difference was determined to be three times the standard deviation of color matching (or a 3-step ellipse) for a given observer. However, a 1-step ellipse is often called a *MacAdam unit of color difference*.



### Are there established tolerances for color shift?

• **ENERGY STAR:** Lamp change in chromaticity from 0-hour measurement, at any measurement point during the first 6,000 hours of lamp operation, shall be within a total distance of 0.007 on the CIE 1976 u'v' diagram. Nine or more units shall meet the requirement (10 are required for testing).

http://www.energystar.gov/ia/partners/product\_specs/program\_reqs/ENERGY\_STAR\_Lamps\_V1\_Final\_Specification.pdf?5c9d-0f85

• LRC Assist: 2-Step or 4-Step ellipse for LED binning depending on the application.

http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/colordiscriminationstudy.pdf

 Lacking better standards, tolerances must be established on a case-by-case basis.



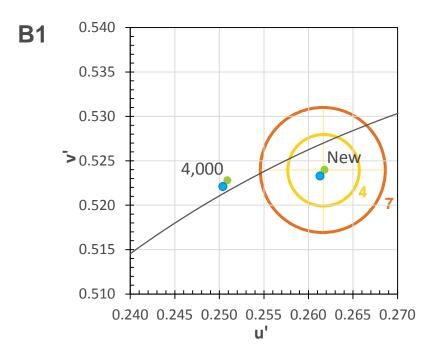
## What Standards Apply to the Measurement of Color Shift?

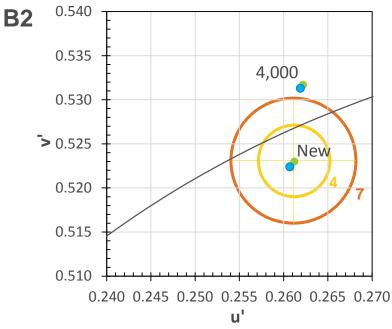
- IES LM-80 (Approved Method: Measuring Lumen Maintenance of LED Light Sources)
  - Applies to LED packages
  - Chromaticity of individual packages measured at least every 1000 hours
    - LEDs are subjected to a predefined set of temperatures and drive currents
    - The chromaticity is then measured at a fixed ambient temp (25° Celsius)
  - The chromaticity shift across the total test duration (6,000 hours min) is included in the LM-80 report
- Extrapolation to complete products?
  - In situ temperature measurement (ISTMT)
    - Less appropriate for lamps (often designed a limits of components/price)
    - More appropriate for luminaires (often more robust)
  - Careful consideration of entire SYSTEM (optics, solder mask, etc.)



# Is color shift a problem for LEDs?

It depends on the exact product and use....

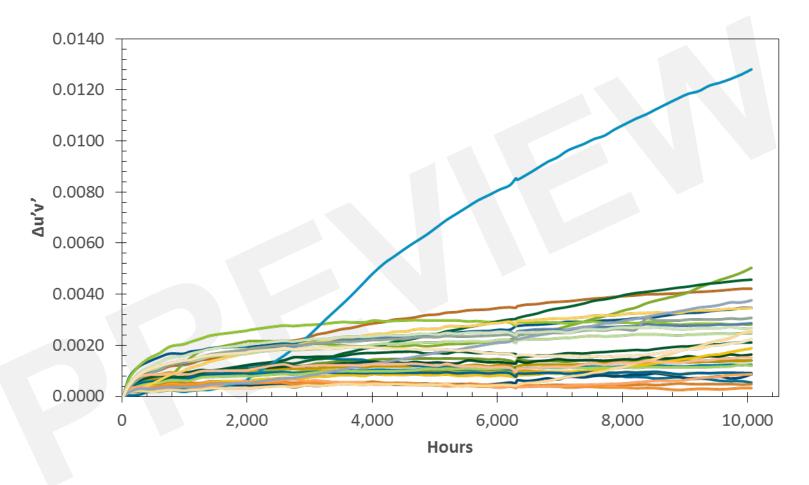




- Bare Lamp
- Bare Lamp with Secondary Optics Removed

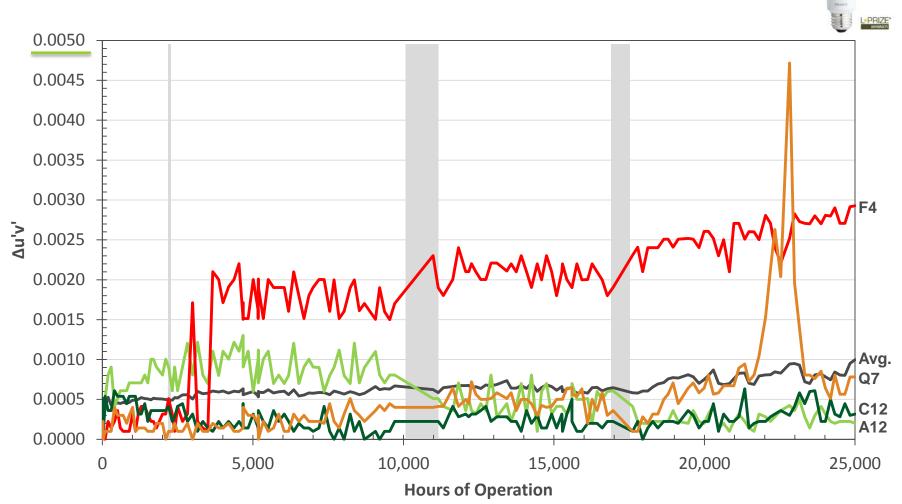
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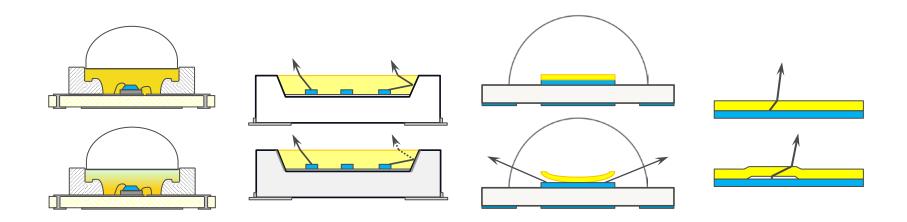
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## What causes color shift in LEDs?

#### LED Packages

- Materials and manufacturing methods used in LED package production are known to contribute to color point stability over time.
- LED color performance is strongly affected by operating temperature (drive current)



## What causes color shift in LEDs?

#### Luminaire Construction

- As with LED packages, the materials and methods used to assemble luminaires can affect the color shift of the product
- Temperature is an important factor
- Lens, diffuser, solder mask, reflectors
- Remote phosphor products are not immune



# What causes color shift in LEDs?

#### Application

- The environment in which the luminaire is operated can adversely affect the color point stability
- Temperature, again!
- Sulfur and other contaminants can degrade materials



# How do LEDs compare to other source types?

- Some LEDs are better, some LEDs are worse
- Color stability is not uniform across other technologies, either.
  - Fluorescent lamps can have long warm-up times and fluctuations during operation
  - Metal halide lamps are notorious for poor color stability
    - Ceramic metal halide offers some improvement



#### Are warranties that cover color shift available?

- Device level warranties are often available
  - Short term (1 to 3 year)
  - Performance relative to component spec
  - Workmanship
- Many common end-product warranties are based only on lumen maintenance
  - $L_{70}$  at 25,000 hours,  $L_{70}$  for 5 years (for example)
- Some warranties offer broader coverage
  - Lumen maintenance and color stability
    - Relative to balance of installation
    - Based on owners perception



#### Are warranties that cover color shift available?

- It's not always so straightforward...
  - Often, the chip manufacturer is different from the lamp or luminaire manufacturer
  - What is allowable?
    - Warranty relative to starting point
    - Warranty relative to other lamps with the same hours of use
  - How many hours/years should be covered?
    - Standardized projections from measured data are not available
    - 6,000 hours is a minimum, but likely not enough
  - What are the procedures for documenting color shift exceeding tolerance?
- Color Consistency Over Time is more easily documented/covered by warranty
  - Allows that color shift may occur, but covers that all products will shift together and stay within a specified tolerance
  - What happens in a mixed installation?
- Warranties may be developed on a case-by-case basis



# How should end users and/or specifiers monitor color over time?

- Establish importance of color shift and review manufacturer data
- Is a color shift warranty an option?
- What action can be taken if color shift is detected?
  - Correction?
  - Replacement?
- Establish a baseline
  - LM-79 photometry, handheld meter, or product data
    - Accuracy likely restricted by budget constraints
  - Store extra samples of new products?
- Create a plan for continued monitoring
  - Visual analysis
  - Handheld metering
  - LM-79 photometry
  - What is the repeatability of measurements?



#### **Discussion**

- How can I determine if an LED product will have color stability issues?
- How can I determine what type of LED package is in an LED lamp or luminaire?
- If color shift has already occurred, are there any remedies other than replacing the product?
- What can I do to minimize the risk of color shift?
- Can existing luminaires be modified to reduce heat build-up?
- Are certain types of products more prone to color shift?

