

COLOR DEGRADATION & NON-UNIFORMITY IN LED LIGHTING SYSTEMS



COLOR SHIFT OVER TIME

- Energy star only requires $Du'v' < .007$ over 6000 hours
- Recent LD&A article “LED Color Stability Is Still a Question”

<http://www.ies.org/lda/HotTopics/LED/20.cfm>

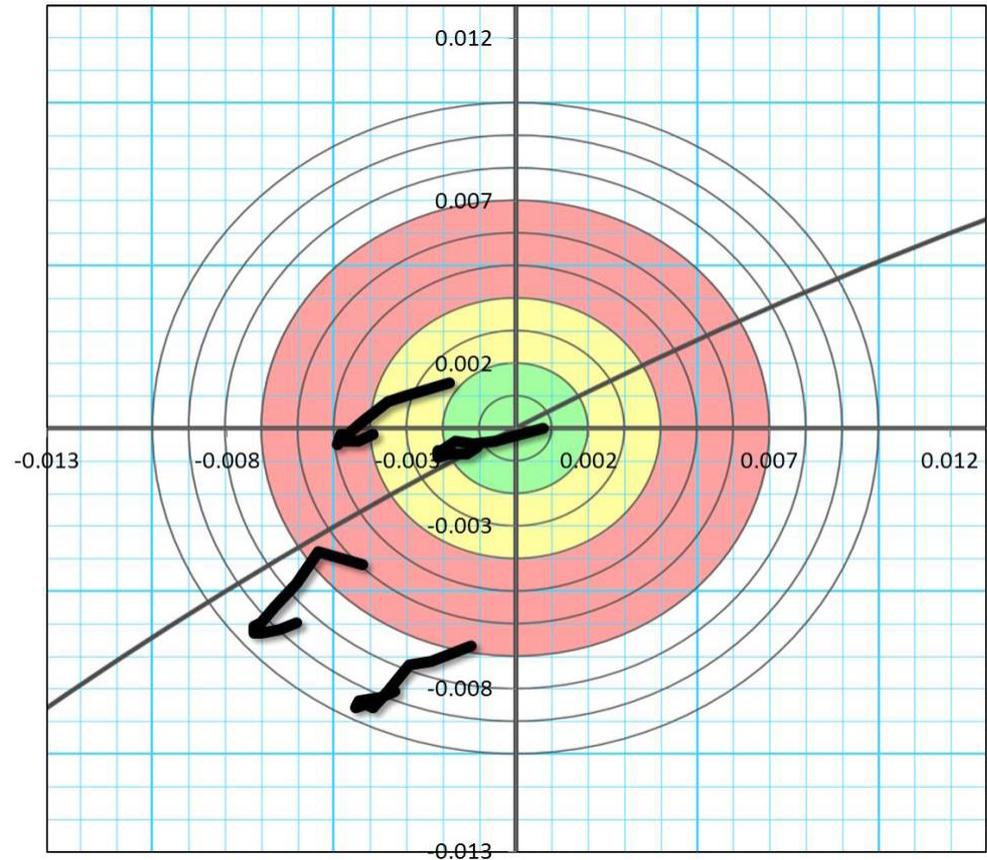
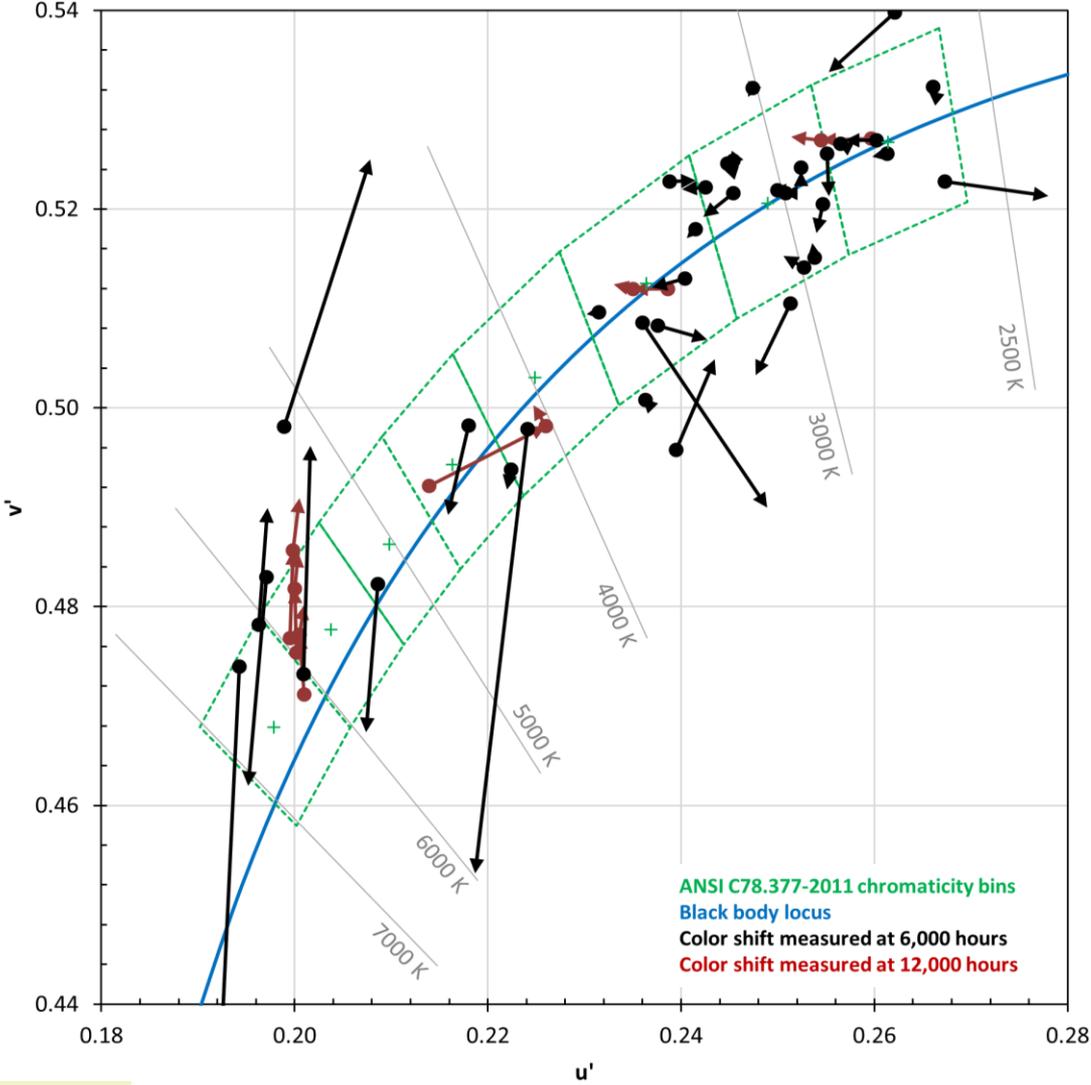


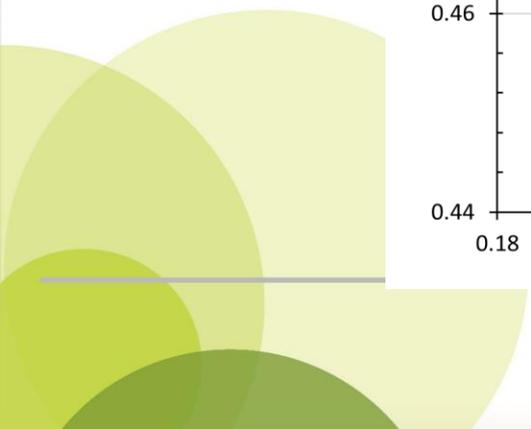
IMAGE USED FROM PLDC 2011 PRESENTATION “GETTING COLOR RIGHT – IMPROVED VISUAL MATCHING OF LED LIGHT SOURCES”

DOE GATEWAY REPORT

COLOR MAINTENANCE OF LEDs IN LABORATORY AND FIELD APPLICATIONS



ANSI C78.377-2011 chromaticity bins
Black body locus
Color shift measured at 6,000 hours
Color shift measured at 12,000 hours



OR MAYBE MORE THAN ONE

- LED color over angle is routinely inconsistent (batch to batch) and does not achieve the same uniformity as incumbent technology.



COLOR OVER ANGLE

- Traditional domed LEDs suffer from color over angle variation due to phosphor path length differences and edge effects.
- Mid-power devices are often worse.

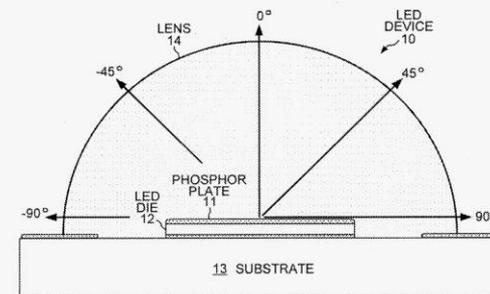
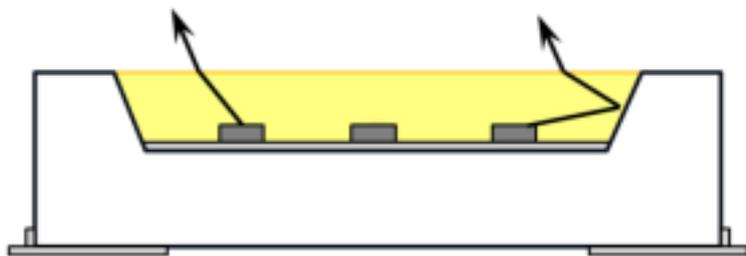


FIG. 1
(PRIOR ART)

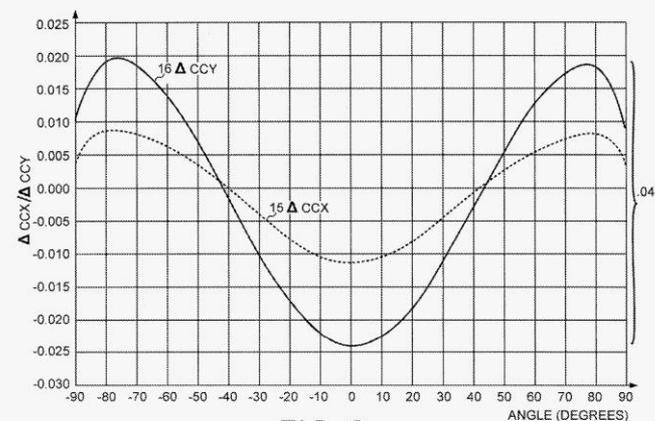


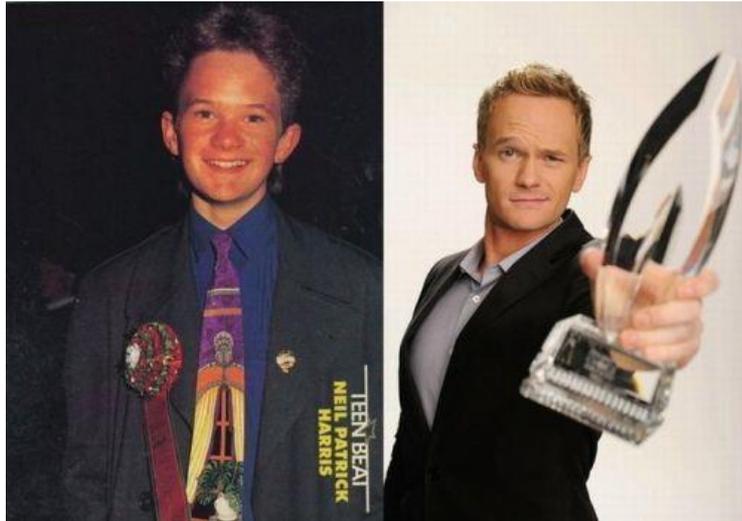
FIG. 2
(PRIOR ART)

IMAGE USED FROM BRIDGELUX PATENT APPLICATION
US20130292709 A1

WHY?



DO YOU REMEMBER THE 90s?



AMERICAN CAR COMPANIES BUILT...



DETROIT ALSO BUILT...



WHAT WAS SUCCESSFUL? WHY?

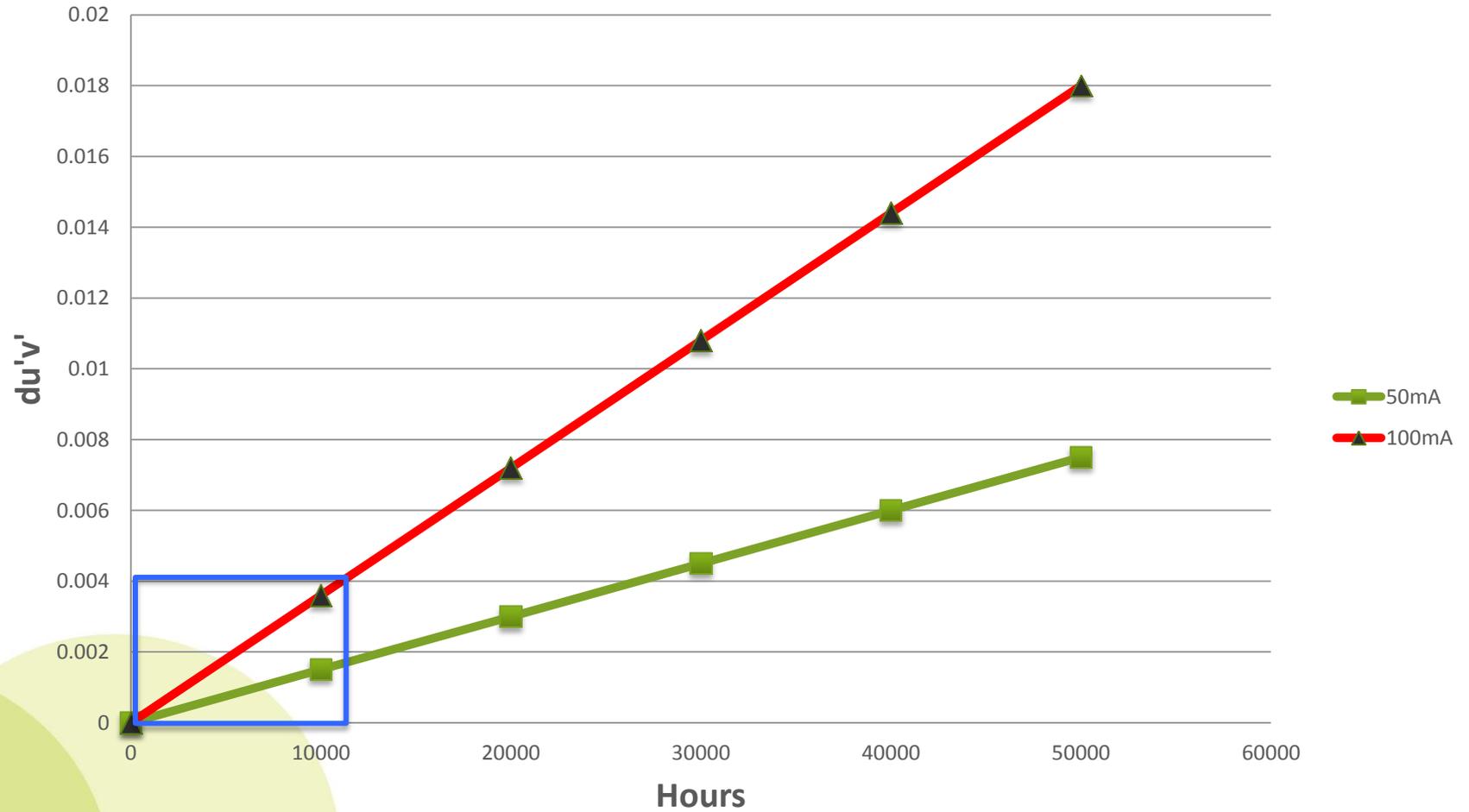
- SUVs provided huge margins to car companies, and lots of people bought them.
- Compact fuel-efficient cars provided low margins, and fewer people bought them.
- End result – until the Great Recession, American car companies continued to sink major effort into launching larger and more luxurious SUVs.
- WE paid them to do it.

SUVs VS. LEDs

- Where is the focus of LED development today?
 - Lumens per Watt
 - Lumens per \$
 - Lumens per device
- So what? What is the disadvantage of accepting current color maintenance and uniformity?

COLOR MAINTENANCE

Color Shift vs. Time (Brand X mid-power package)



EXAMPLE #1

- Using the LED from the previous chart
- Low Cost Downlight, 2700K
 - 85% Electrical Efficiency
 - 85% Optical Efficiency
 - 20 “mid-power” packages for ~600 lumens, 100 mA drive current
 - System Efficacy: ~86 LPW
 - LM80 L70: 168K hours
 - Du’v’ at 50K hours: **.018**

EXAMPLE #1 (REVISED)

- Adding LEDs to reduce drive current, heat, and color shift
- Low Cost Downlight, 2700K
 - 85% Electrical Efficiency
 - 85% Optical Efficiency
 - 40 “mid-power” packages for ~650 lumens, 50 mA drive current
 - System Efficacy: ~93 LPW
 - LM80 L70: 239K hours
 - Du’v’ at 50K hours: .0075
 - Side note:
 - Package thermal resistance of 20C/W.
 - Reduction of 0.15W/package reduces the junction temperature by 3C.

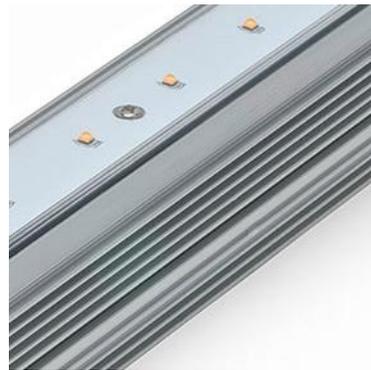
EXAMPLE #1 CONCLUSIONS

- Adding LEDs to compensate for poor color maintenance performance.
 - Doubles component count
 - Increases the hypothetical COGS by 20%
 - Improves performance, but not materially
- Would a “premium”, color-stable device be more cost effective?

EXAMPLE #2

Linear Cove Lighting

- 10 high power devices/foot = 820 lm/ft @ 4000K (less than 10 watts)
- Direct view of LEDs shows significant variation of color from nadir to 90 degrees
- Significant color non-uniformity unacceptable to customers
- **Solution:**
 - Addition of a diffuser film over the LEDs to color mix the output



EXAMPLE #2 CONCLUSION

- Adding diffuser film to compensate for poor COA performance.
 - Decreases efficacy by 10%
 - Additional cost equivalent to a 15% increase in LED cost
 - Lumen output reduced by 10% (740 lm/ft) @ 4000K
 - Additional component to assemble = additional manufacturing cost
- Would a “premium” device with better COA have been more cost effective?

COLOR MAINTENANCE AND UNIFORMITY

- Is it impossible to make more color stable, color uniform LEDs? NO.
- But it is NOT free.



CONCLUSION

- WE, the LED fixture manufacturers, are paying LED companies to focus on LPW and LP\$.
- Increasingly, improved efficacy and even LED cost reductions are not governing factors in improved fixture cost.
- Known areas of potential improvement exist in LED components that can drive improved manufacturability, lower fixture costs, better user experiences.

