

PHILIPS

sense and simplicity

LED Innovations in Next Generation Lighting

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January 6, 2012

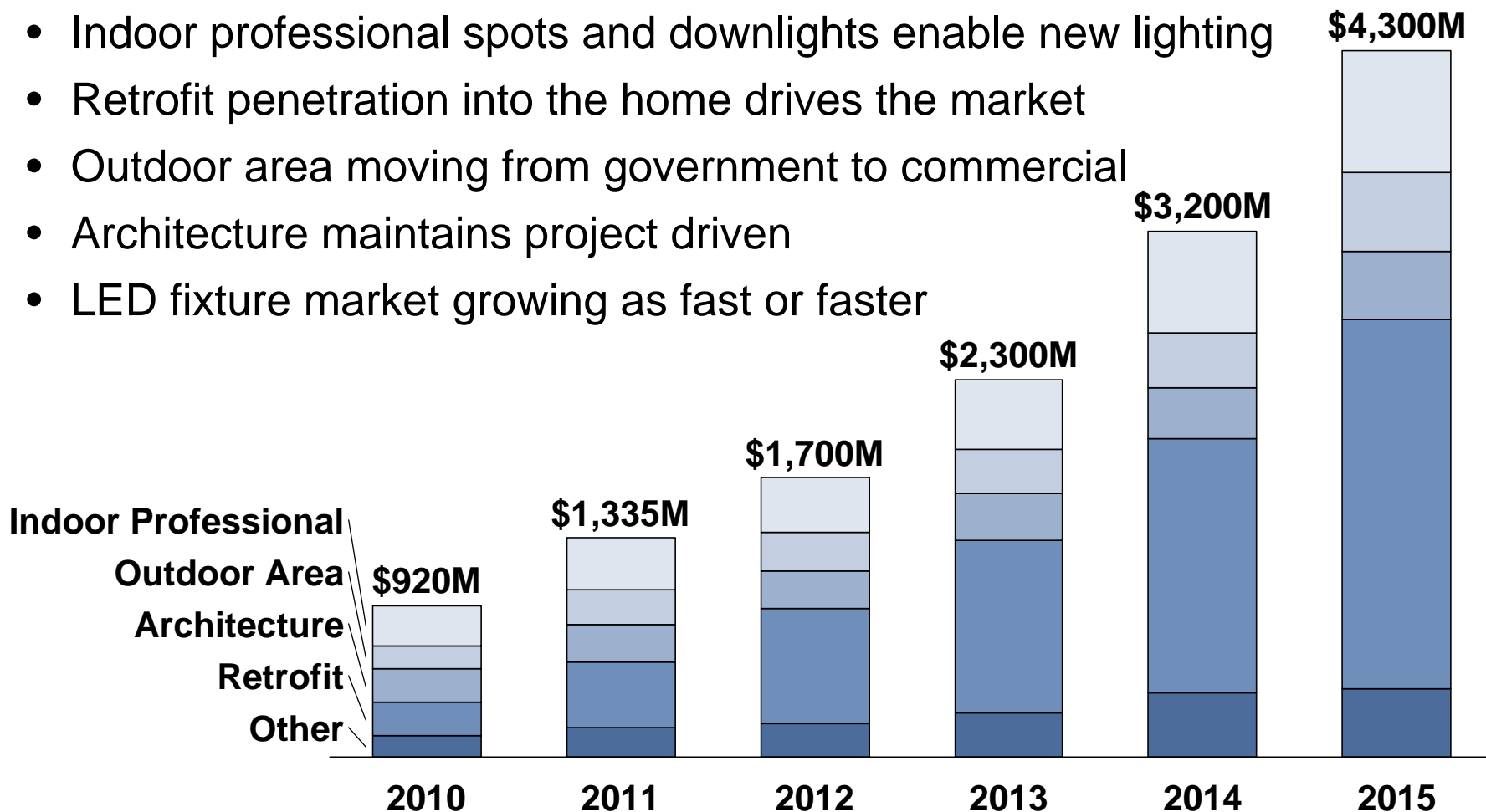
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Outline

- Market Overview
- Technology Projections
- Performance / Cost Innovation Approaches
- Summary

Market is Poised for Rapid Growth

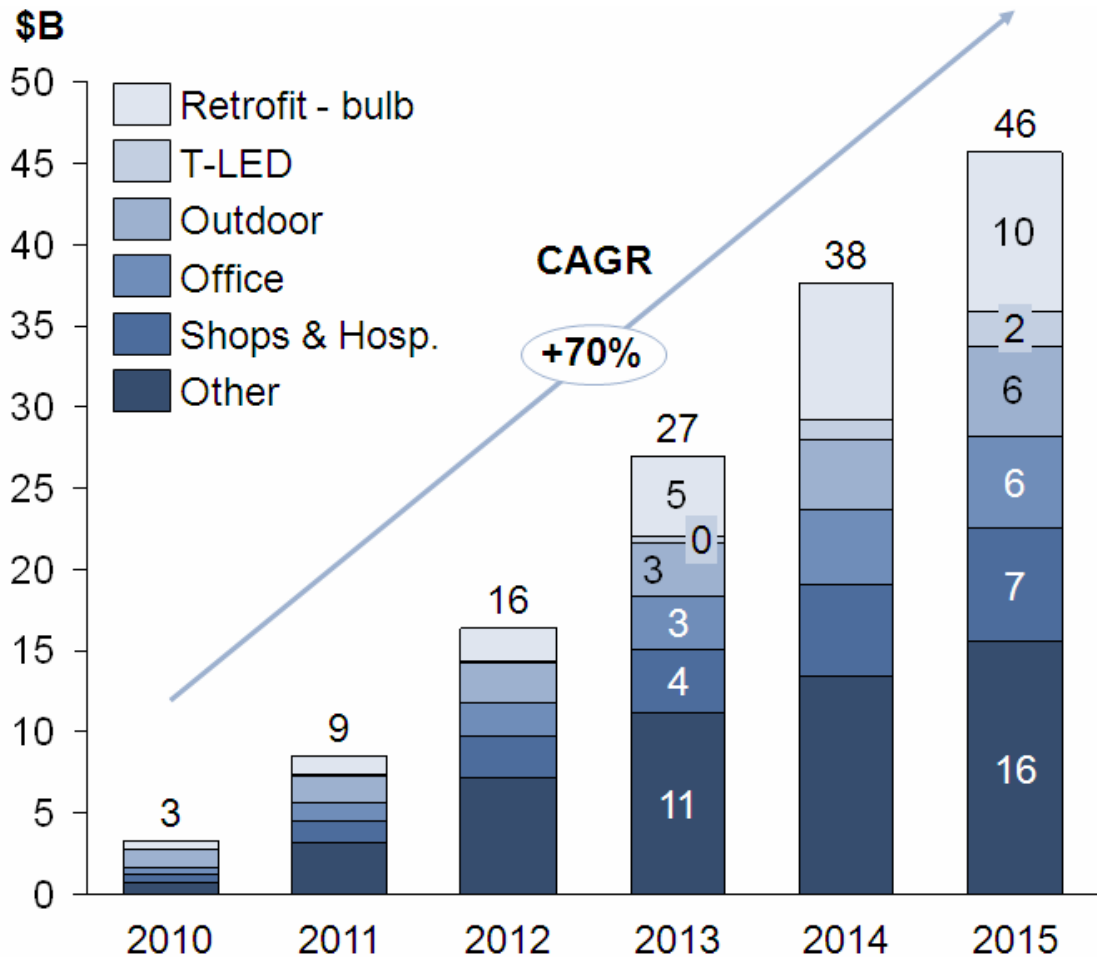
- Indoor professional spots and downlights enable new lighting
- Retrofit penetration into the home drives the market
- Outdoor area moving from government to commercial
- Architecture maintains project driven
- LED fixture market growing as fast or faster



Other: Entertainment, Home, Personal, Safety, Channel, Machine Vision
 Source: Strategies Unlimited 2010, IMS January 2011, Philips Lumileds Mngt Estimates

Global Trends

The LED luminaire and lamp market is accelerating



Source: Strategies Unlimited January 2011 LED Luminaires, Philips management estimates

*Other: Includes Home, industry, Entertainment, Landscape, Healthcare, Architectural

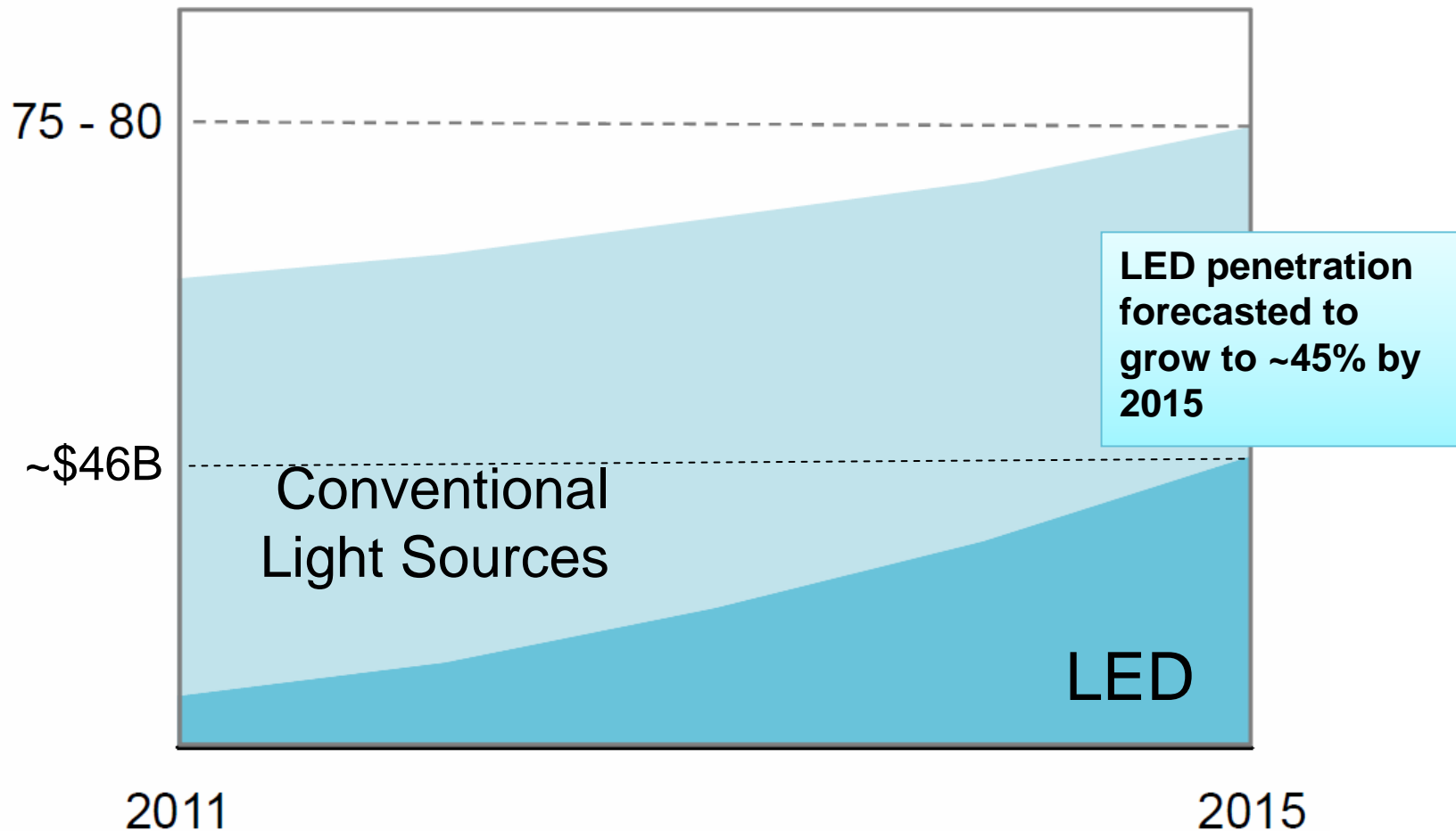
Market drivers:

- Retrofit – bulb: Banning the bulb and lm/\$ increase
- Office: LED troffer TCO improvement and task Quality of Light exceeding conventional lighting
- Outdoor area: System payback reducing from 5-7 years to 2-4 years
- Shops & Hospitality: Spot and downlights providing better quality of light
- T-LED: Reliability and efficacy with illumination grade LEDs

Global Trends

LED adoption forecast (latest Philips Lighting estimates from Financial Week, London – Sept. 15, 2011)

EUR billion



Key Parameters that Drive LED Adoption

User Experience



- System efficacy
 - System selling price
 - System reliability
 - Total cost of ownership
 - Pay back
 - Carbon footprint reduction
 - Utility incentives
-
- Color consistency
 - Color uniformity
 - Color over angle
 - CCT and CRI

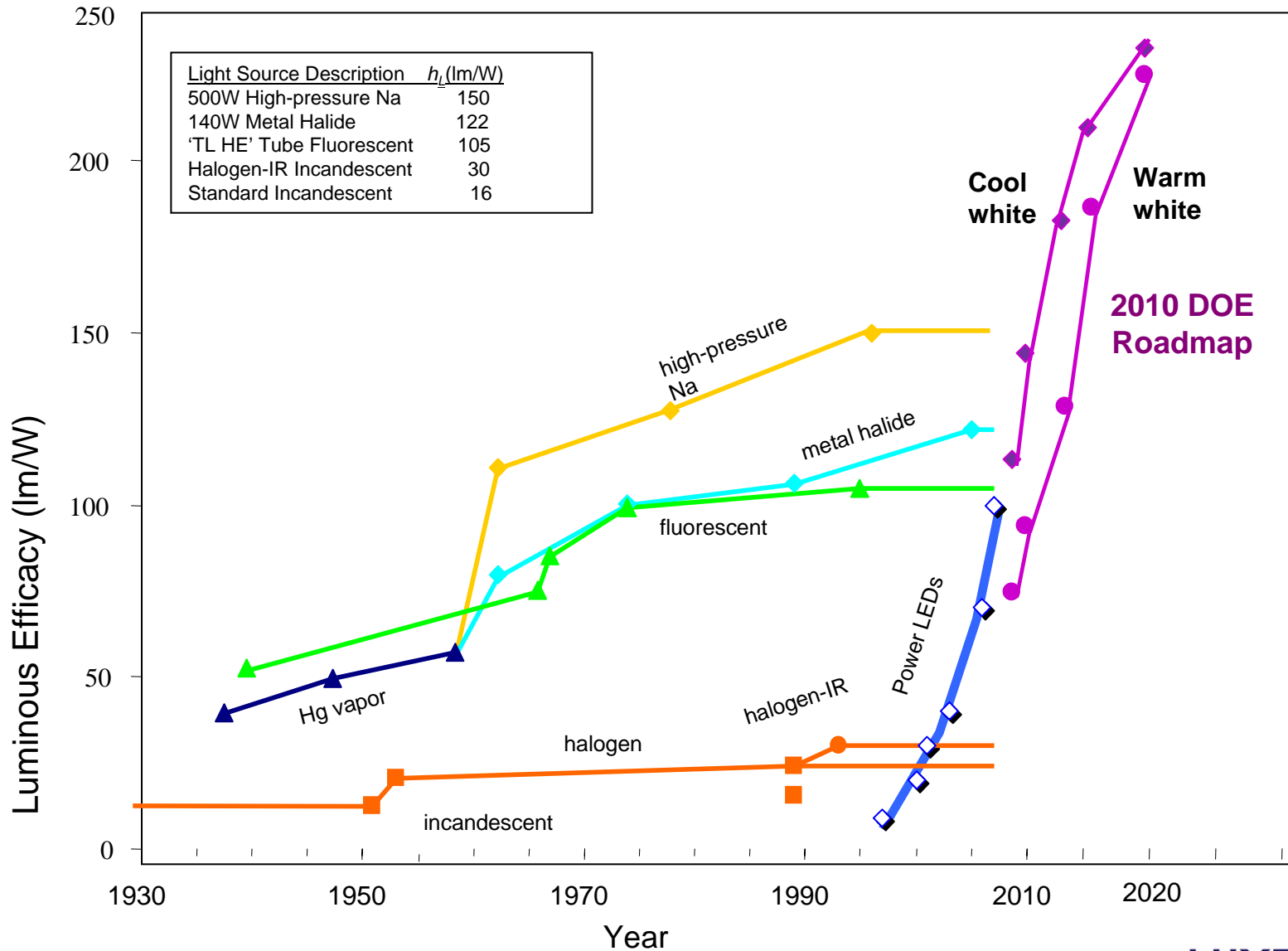
- Luminous Efficacy
("lumens per watt")
- AND**
- Cost
("lumens per dollar")



-
- "Quality of Light"

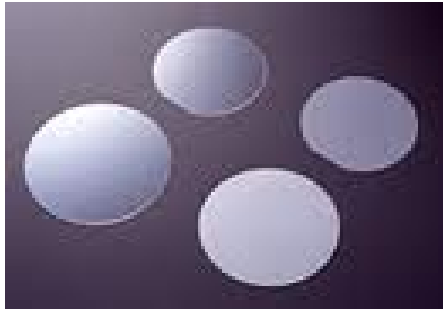
LED Performance Criteria

Evolution of LED Efficiency

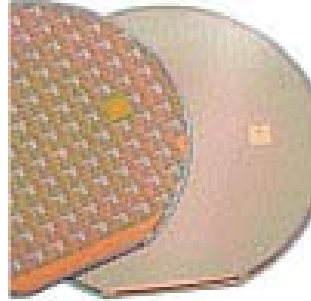


Performance of an LED is determined by the interaction of all of its components

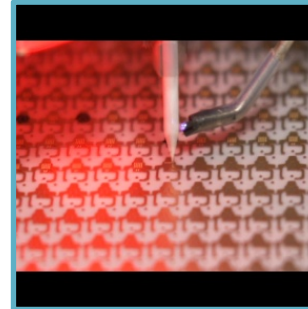
Epitaxy



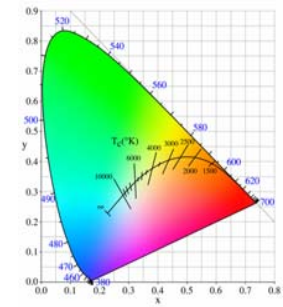
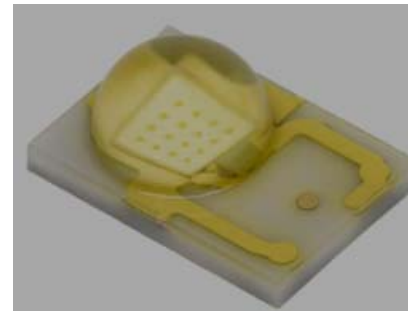
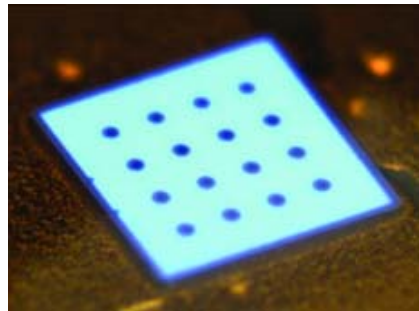
Wafer/Die
Fab



Packaging



Phosphor
(Color Conversion)



DOE Lumen cost & Efficacy Projection

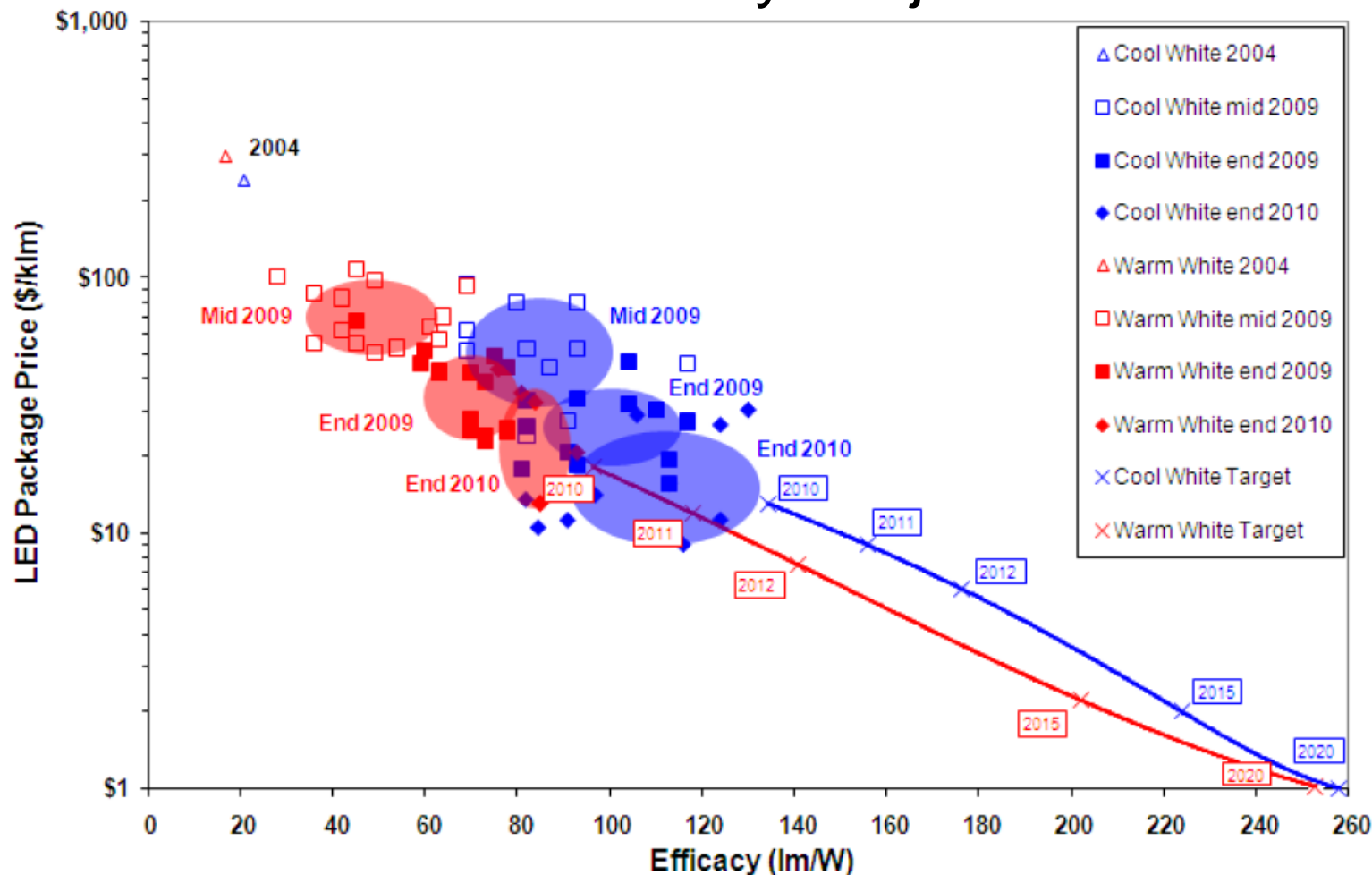


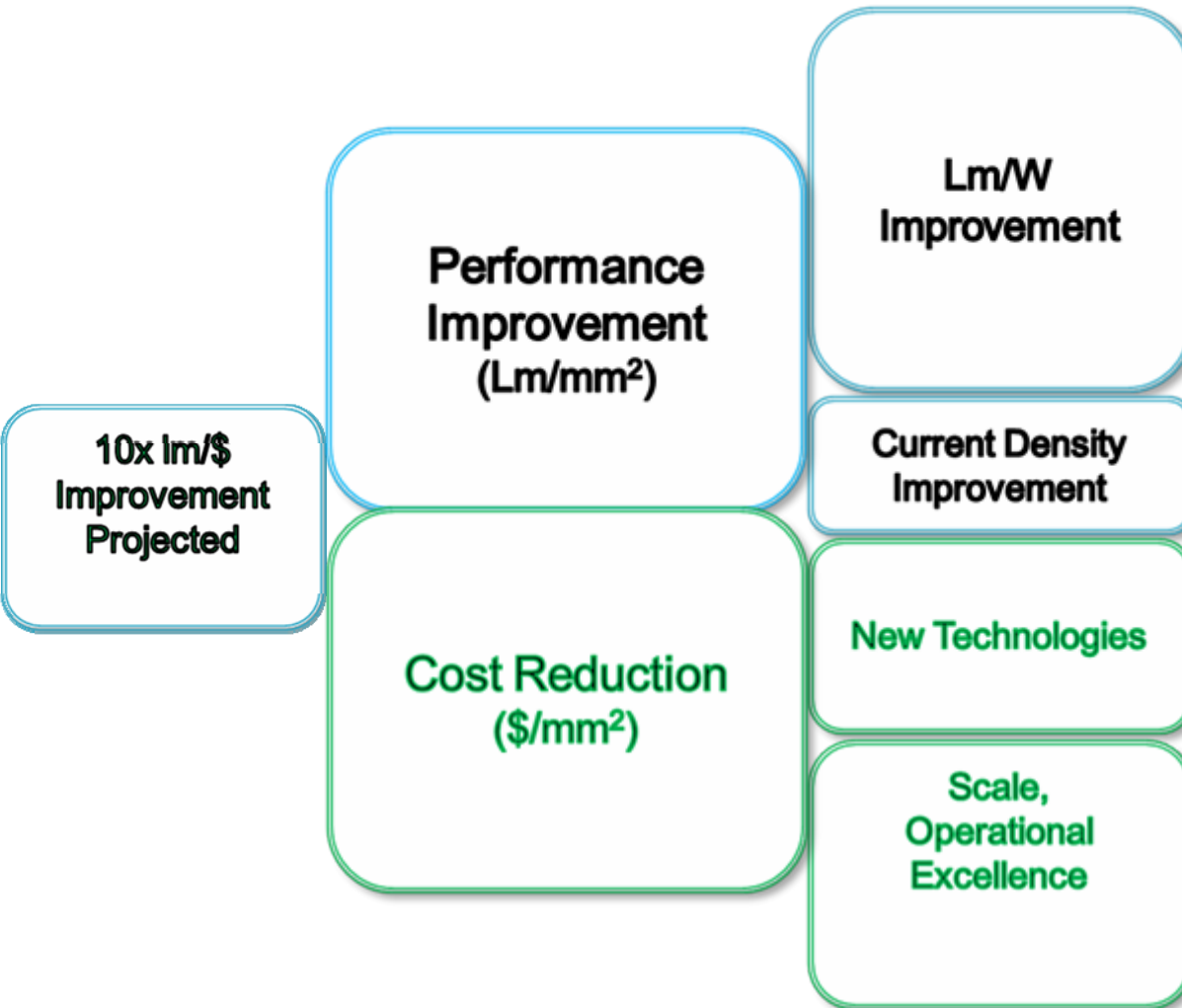
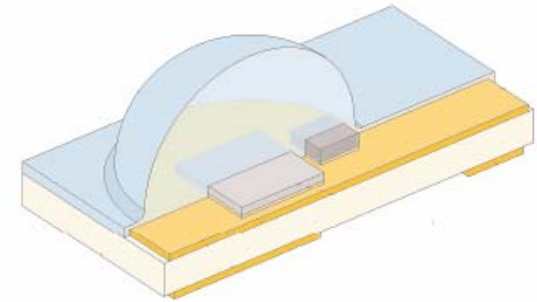
Figure 3.6: Price-Efficacy tradeoff for LED Packages at 35 A/cm²

Note:

1. Cool white packages assume CCT=4746-7040K and CRI=70-80; warm white packages assume CCT=2580-3710K and CRI=80-90.

Source: DOE Multi Year Program Plan May 2011

Efficacy and Cost Drivers



- EPI Efficiency
- Extraction Efficiency
- Phosphor Conversion

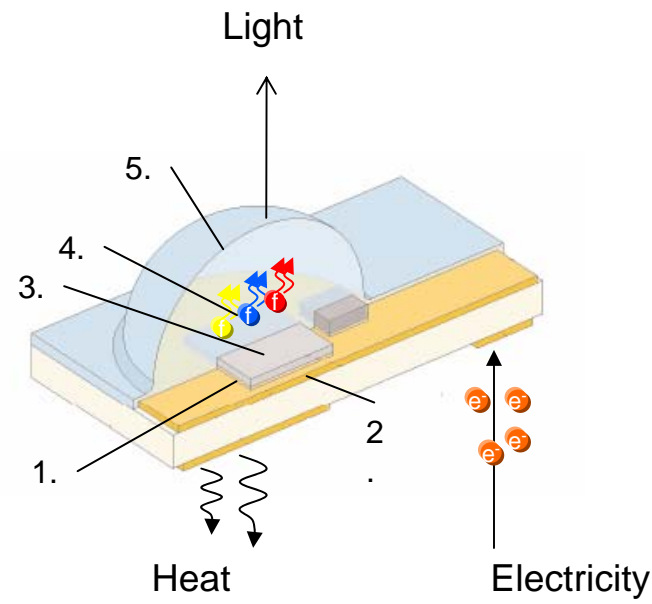
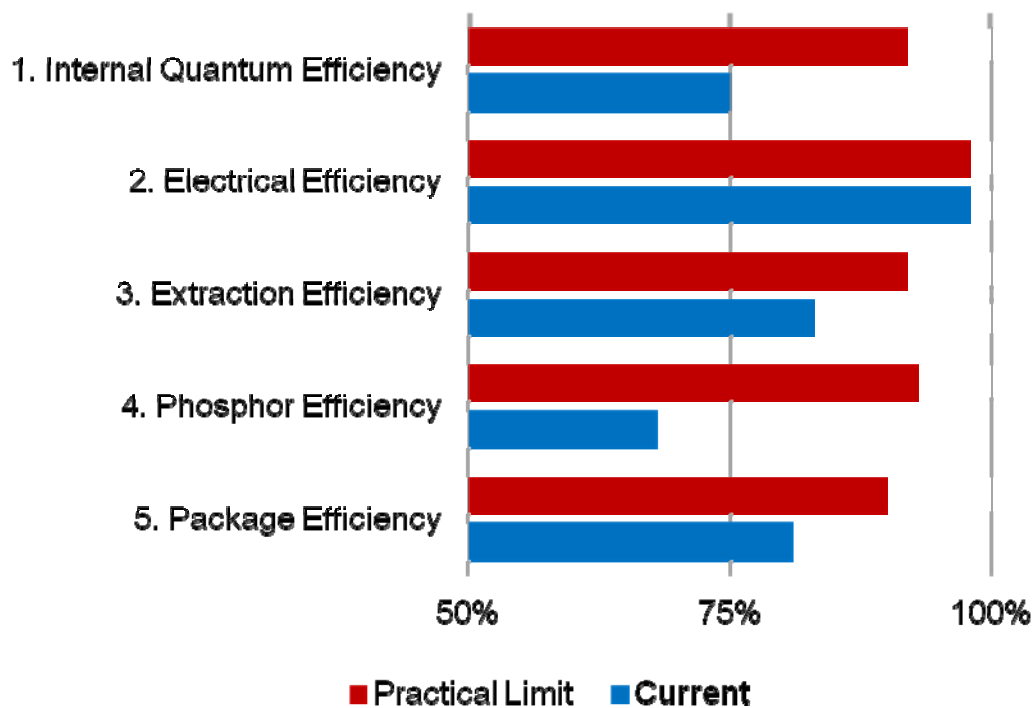
- Drive Current (A)/mm²

- Package Design

- Design for Cost and Manufacturing
- Yield / Utilization
- Equipment Efficiency

Improve Efficiency

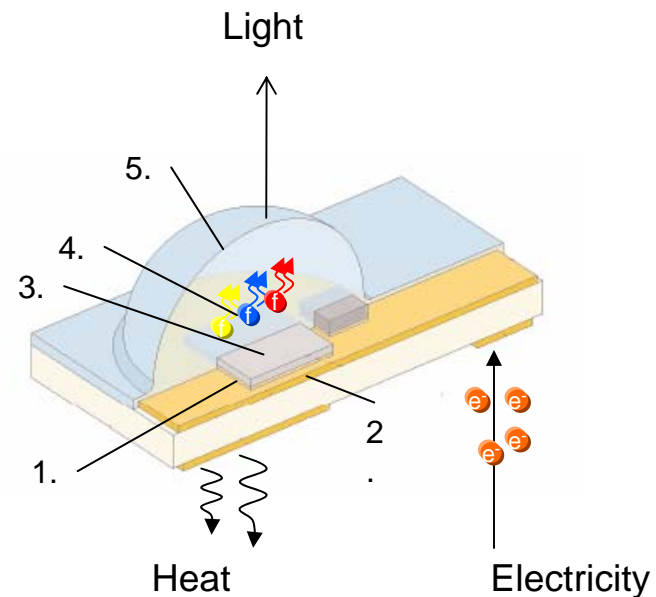
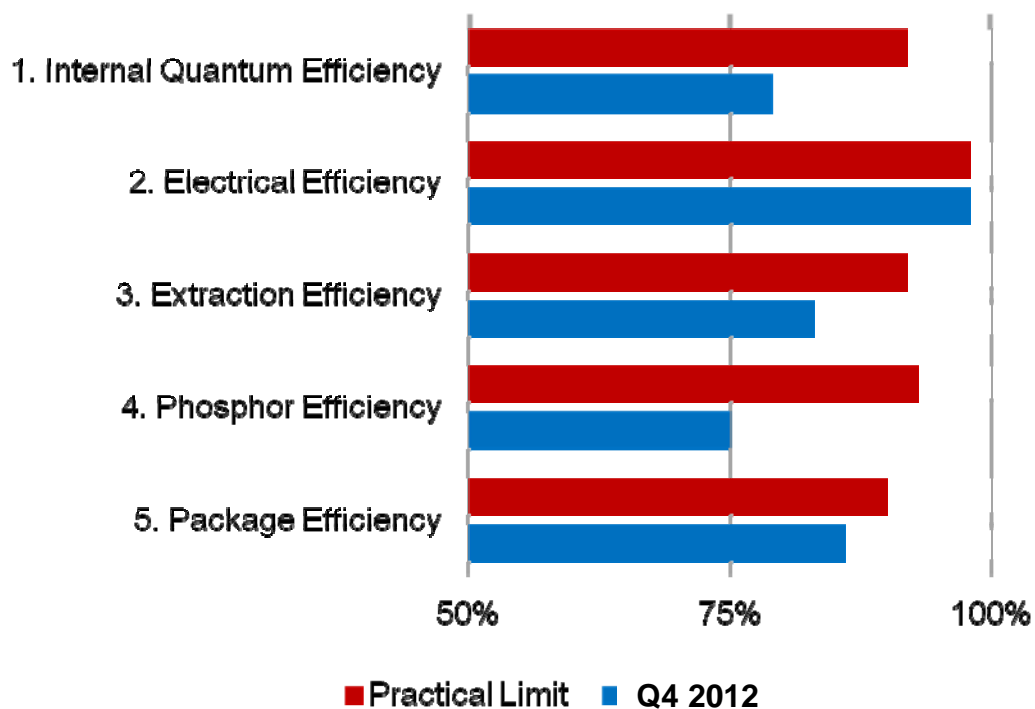
LUXEON Rebel, CCT = 3000K, CRI = 80
 $I_f = 350 \text{ mA}$, $T_j = 85^\circ\text{C}$, $\eta_{LE} = 96 \text{ lm/W}$



Practical Limit that can be achieved: 220 lm/W

Improve Efficiency

LUXEON Rebel, CCT = 3000K, CRI = 80
 $I_f = 350 \text{ mA}$, $T_j = 85^\circ\text{C}$, $\eta_{LE} = 125 \text{ lm/W}$

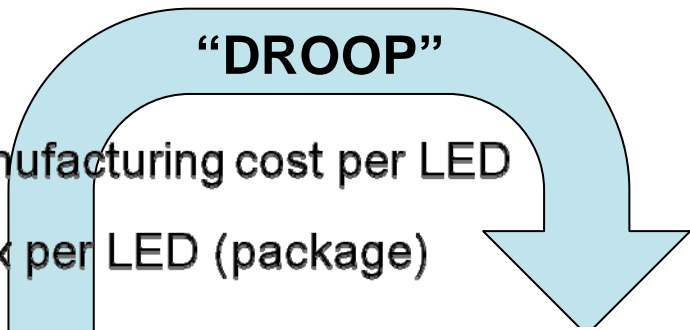


Practical Limit that can be achieved: 220 lm/W

How about at higher drive currents ?

- Increase of flux/\$ (lm/\$)

- Two parallel paths:
 - ① Reduce manufacturing cost per LED
 - ② Increase flux per LED (package)



Laboratory results, chip size = 1x1 mm², CW		350 mA
Internal quantum efficiency	IQE (%)	75
Extraction efficiency	EXE (%)	90
Forward voltage	V _f (V)	
External quantum efficiency	EQE (%)	
Power conversion efficiency	PCE (%)	
Phosphor conversion	CE (lm/W _{opt})	
Luminous efficacy	η _L (lm/W)	
Luminous flux	Φ _L (lm)	

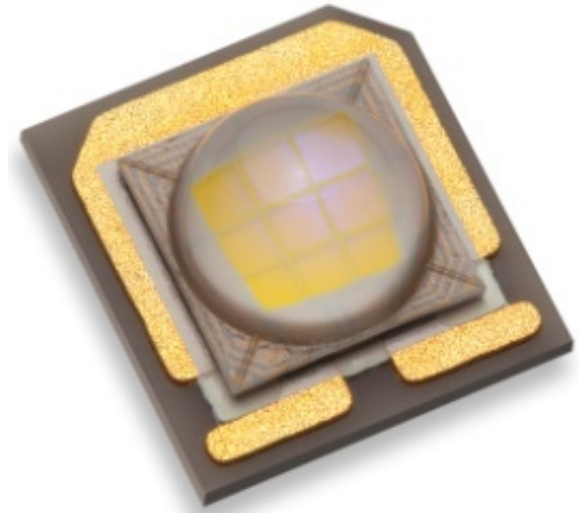
Experimental measurement
 Y. C. Shen et al., Appl. Phys. Lett. **91**, 141101 (2007)
 A. Laubsch et al., IWN 2008
 Device modeling
 K.A. Bulashevich et al., IWN 2008
 First-principles theory
 K. Delany et al., Appl. Phys. Lett. **94**, 191109 (2009)

Pump wavelength: 445 nm

- Likely mechanism: Auger recombination
- Other possible mechanisms: Carrier leakage/localization

Packaging/Device Trends

- Larger Chips for Higher Lumens/watt and improvement
- Chip on Board (COB) arrays of many sizes aimed at a variety of applications
- Freedom From Binning for quality of light, ease of use and reduced system cost.

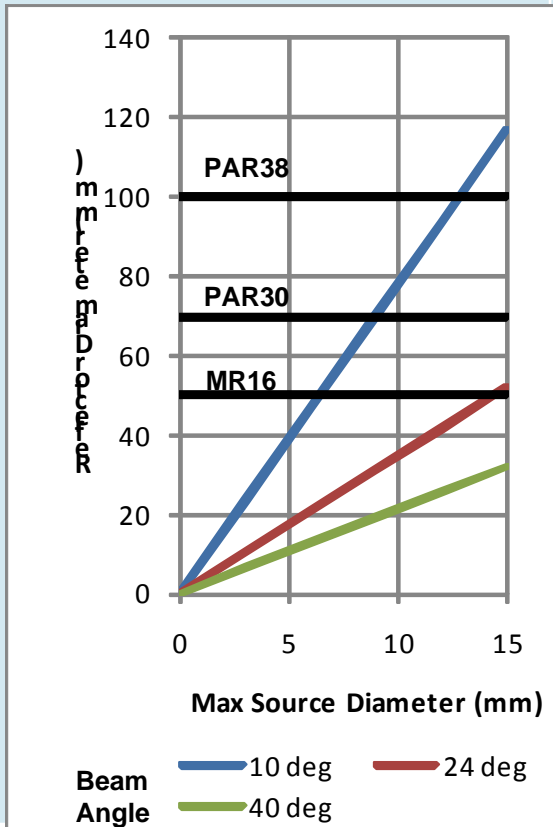


LUXEON S— High Lumen Array for Spotlights

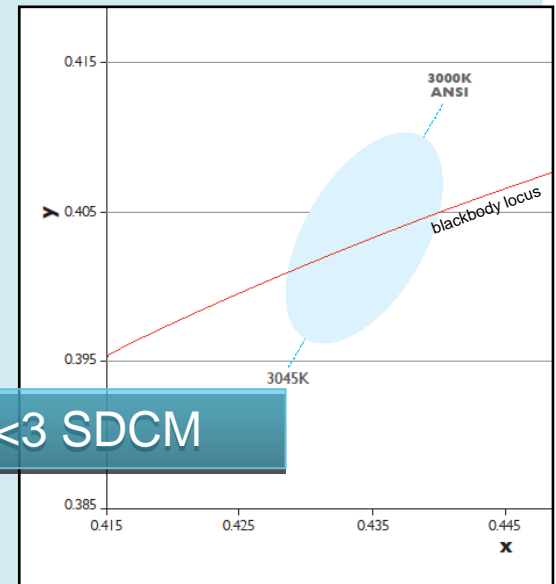
Highest Flux Density
Smallest optical source enables most compact reflectors based on etendue limit for tight

Enables tight, sharp beams
delivering high Punch
High center beam intensity, beam uniformity and crisp single shadow

With Perfect Color
Consistency in quality of light of the product, from product to product and over time



Remember it is not only lm



Hot Targeted Binning to within a single 3 SDCM ensuring no visible color difference in the application

Illumination Grade Criteria

- Operating Condition Performance
 - *Data for real world operating conditions - T_j 85°C*
- Quality of Light Metrics
 - *CRI/R9 @ CCT*
 - *Color over temperature*
 - *Color over angle*
 - *Beam uniformity*
 - *Color over time*
 - *Unit-to-Unit consistency*
- Color Bin Sizes Defined by the Application
- Publicly Available LM80 Reports
- Product Reliability Data



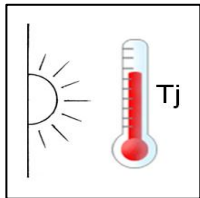
LUXEON Leader in Quality of Light

The 5 leading elements



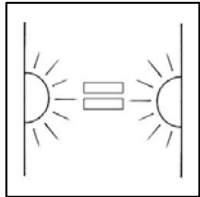
Color Rendering

>CRI 80 (consider also R9)



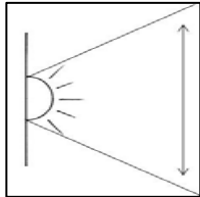
Color in application

Tested at 85°C Tj



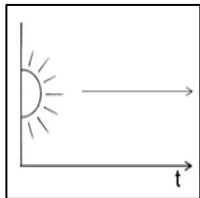
Color consistency between led/lms

<3 SDCM



Color consistency in beam

< 10 points on u'v' scale

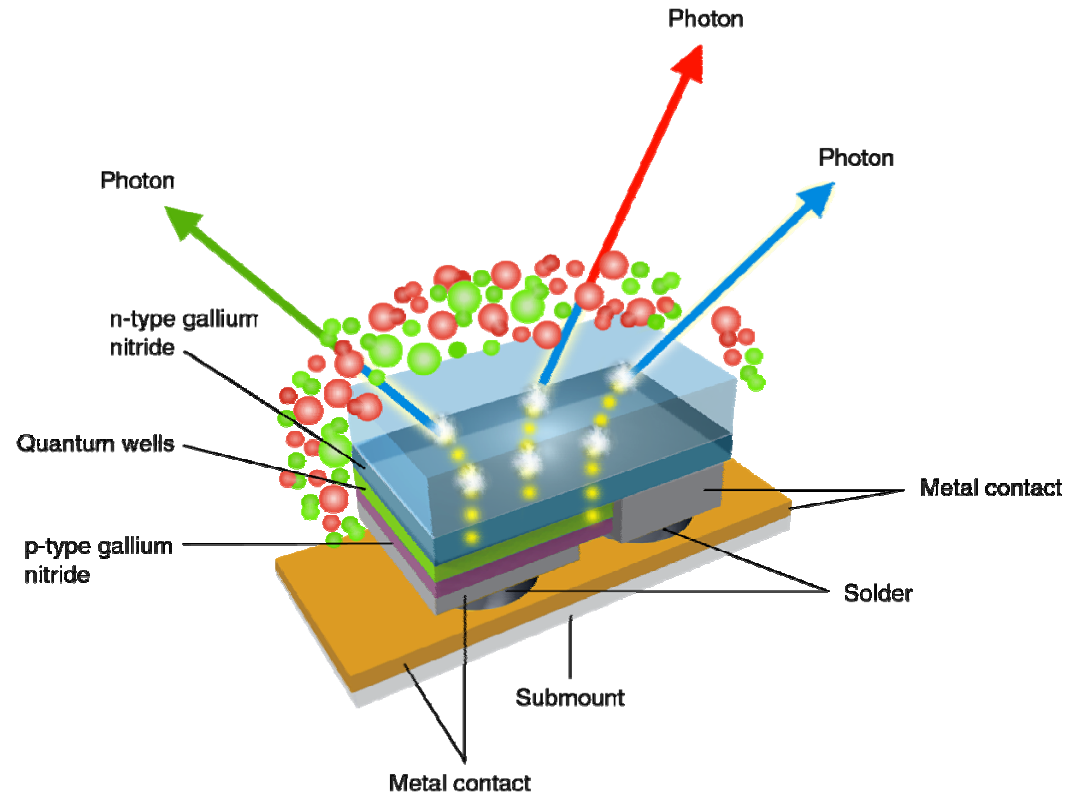
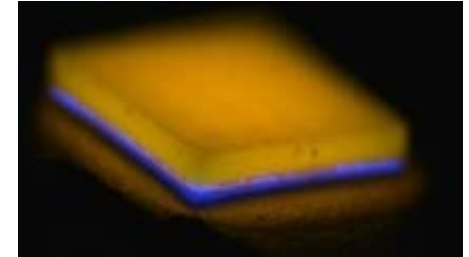


Color consistency over time

<5 SDCM

Phosphor Integration in pcLED

- LEDs emit blue wavelength
- Different Phosphor materials used to convert blue pump into red and yellow/green
- Uniform color requires:
 - stable conversion over temperature
 - Uniform phosphor density and thickness

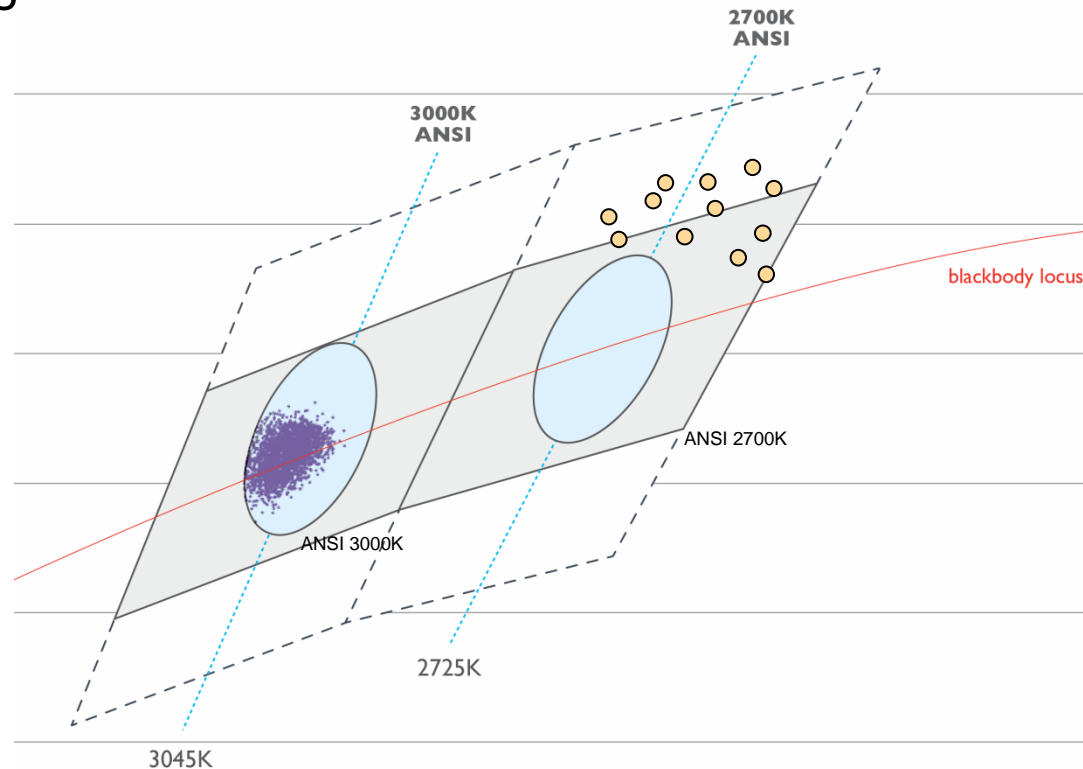


Hot Testing and Color Binning

Simplify solution design – Enable Freedom From Binning

Testing and binning at operating conditions

- Eliminate light output calculations from 25C to 85C
- Eliminate efficacy calculations at operating conditions
- Eliminate need to work from de-rating data
- Reduce time to develop system
- Reduce finished design testing



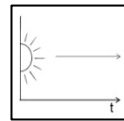
LUXEON

Freedom

LUXEON A



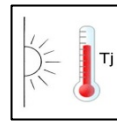
- Tested and specified at 85°C
- 3McA total color distribution, no more white point binning
- Adding CCT and CRI variations
- Unsurpassed long term light output and white point stability
- Highly competitive in lm/W, lm/\$
- Superior color consistency over angle



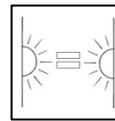
LM80
TM21



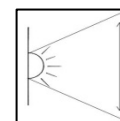
>80
>90



85°C
tested



3McA



0.01d'v'

Technology Innovation
Award recipient at
LIGHTFAIR 2011



Summary



- LED-based general illumination solutions are available and are being used by early adopters worldwide
- The market requires higher efficacy, lower cost and higher quality of light
- Quality of light and efficacy improvements and Lumen/Dollar cost reductions will be achieved through innovations in technology product development and manufacturing
- By 2020 it is projected that Lumens/Watt will have increased more than 10x to over 1000 Lumens/Dollar, and 90% of lighting will be LED based

