

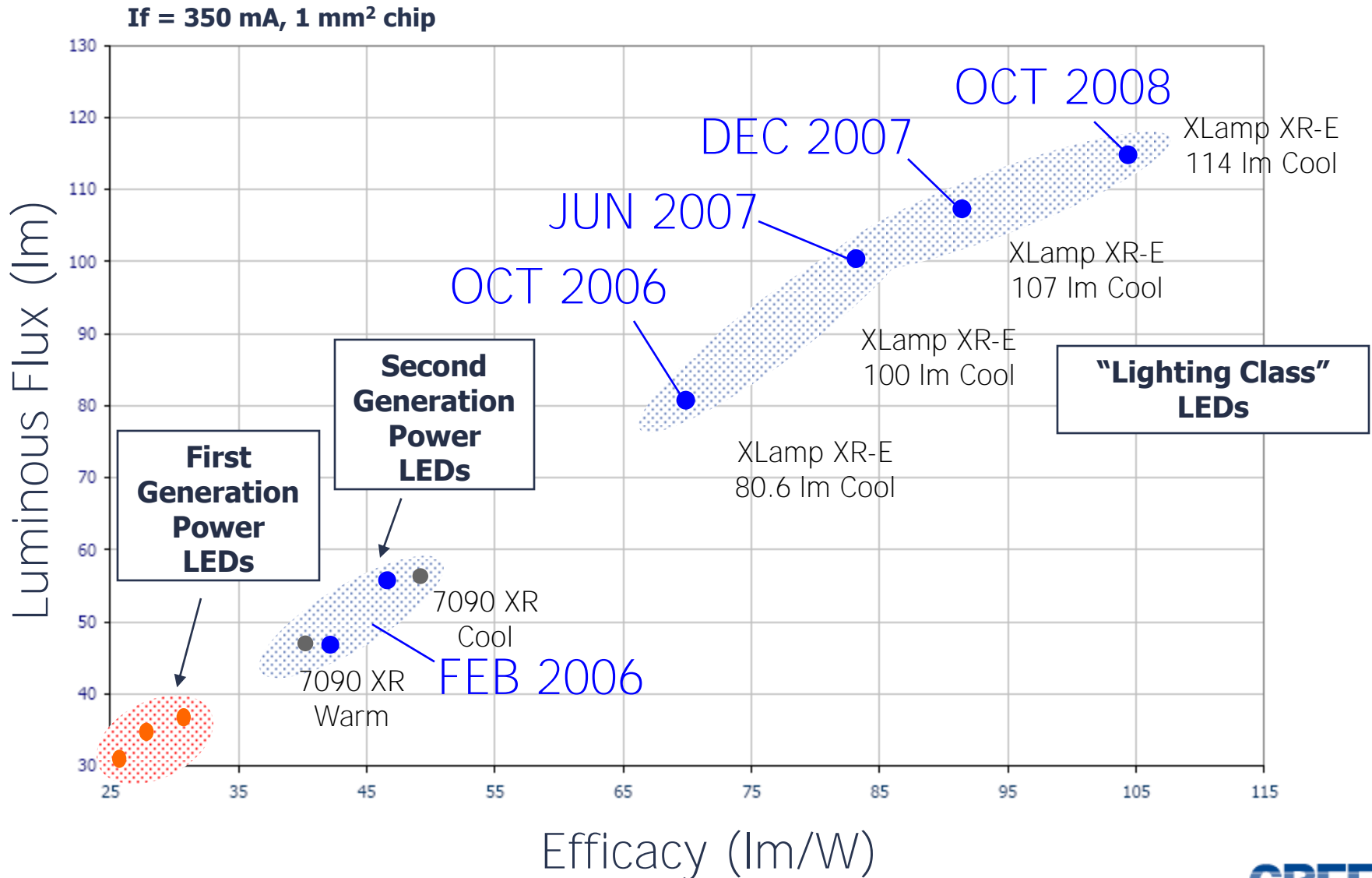


# Demonstrating the Next Wave of LED Chips and Packaging Improvements

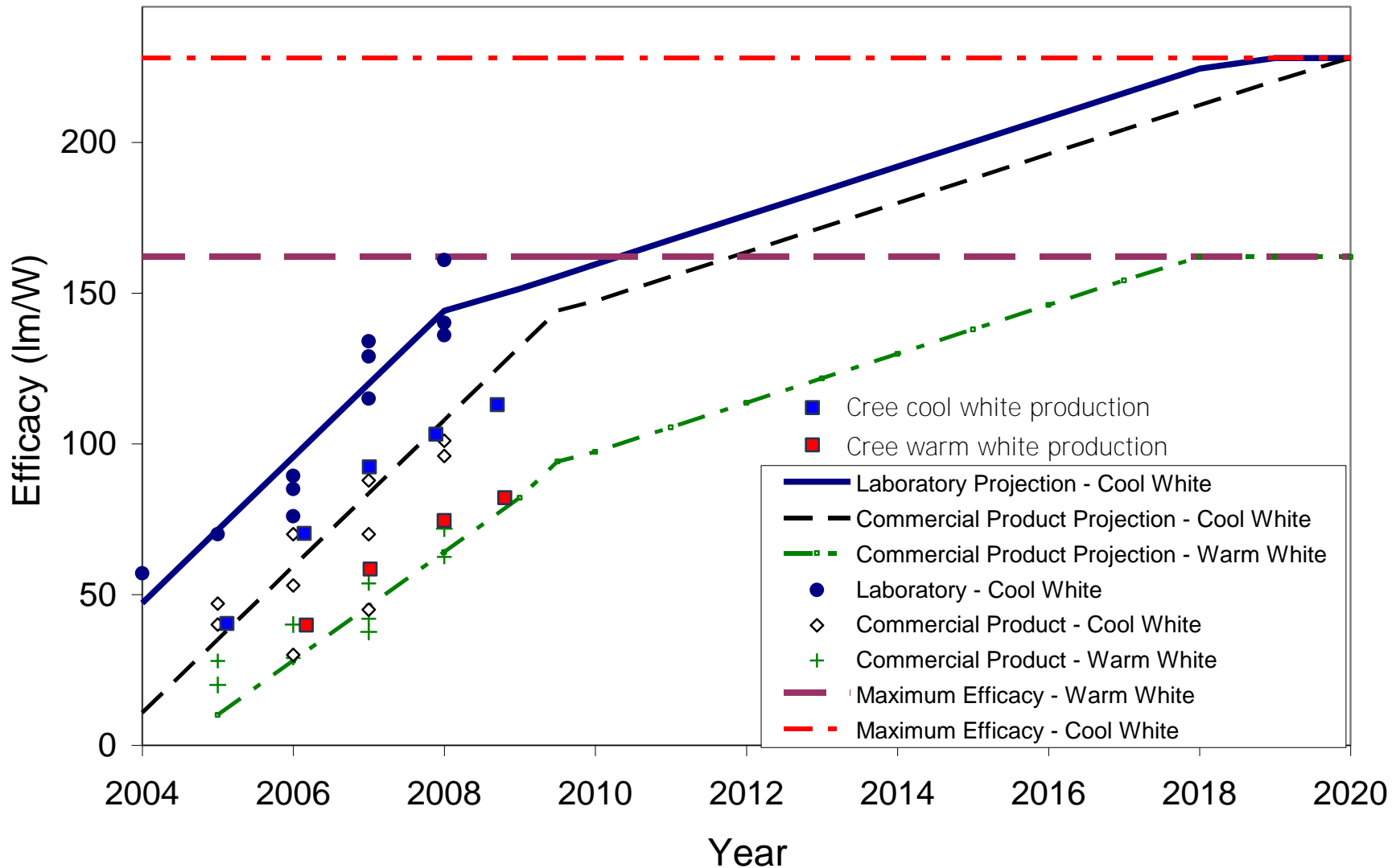
DOE Solid State Lighting Workshop  
San Francisco, February 3-5, 2009



# Cree XLamp® Performance Gains in 2006-2008



# DOE Roadmap



US Department of Energy 2009 Multi-Year Plan for SSL



# XLamp White Portfolio

## *Proven Lighting Class Performance*

Point Source  
Lighting

*4x the light in the  
same package*

XLamp MC-E



XLamp XR-E



XLamp XR-C



- Brightest, most efficient lighting-class LEDs available
- Cost and color point for many mainstream lighting applications



*The same light in  
80% smaller package*

XLamp XP-E



XLamp XP-C



General Lighting



# Cree LED Lighting Solutions Products

- **LR6 Recessed downlight**

- 650 lumens, 12 Watts  $\Rightarrow$  54 LPW
- CCT: 2700 K, 3500 K
- CRI: 92
- Multiple trims, surface mount option



- **LR4 Recessed downlight**

- 540 lumens, 10.5 Watts  $\Rightarrow$  51 LPW
- CCT: 2700 K, 3500 K
- CRI: 94, 91
- Deeper recess than LR6, complete fixture



- **LR24 Recessed luminaire**

- 3200 lumens, 48 Watts (max.)  $\Rightarrow$  67 LPW
- CCT: 3500 K
- CRI: 92
- Fluorescent 2'x2' troffer replacement



# DOE Solid State Lighting Projects

<b>Project</b>	<b>LED Chips and Packaging for 120 LPW SSL Component</b>	<b>Efficient White SSL Component for General Illumination</b>
<b>Objectives</b>	<ul style="list-style-type: none"><li>• Develop a novel 120 LPW SSL lamp module that emits at a color temperature of 4100 K</li><li>• Low cost module suitable for commercial SSL luminaires</li></ul>	<ul style="list-style-type: none"><li>• Develop a novel SSL lamp module emitting at a color temperature of 3000 K with an efficacy of 100 LPW at 25°C and 65 LPW at 125°C.</li><li>• Low cost module suitable for commercial SSL luminaires</li></ul>
<b>Duration</b>	<b>10/2007 – 10/2009</b>	<b>5/2008 – 5/2010</b>
<b>P. I.</b>	<b>James Ibbetson</b>	<b>James Ibbetson</b>

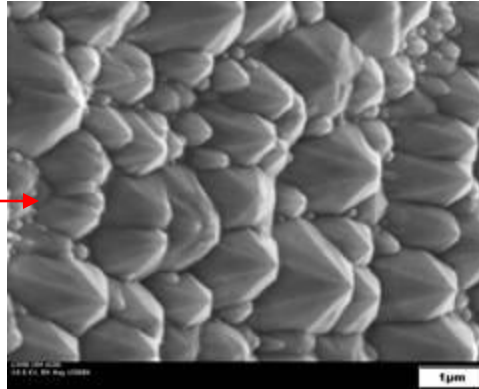
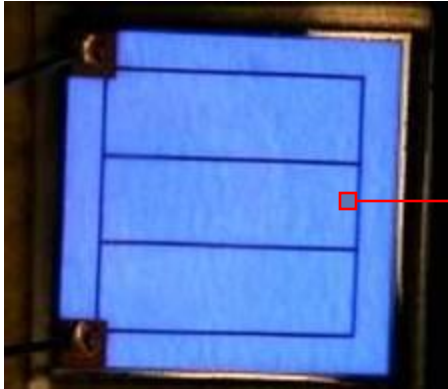
# Projects Team

Team Member	Location	Projects Staffing	Project Roles
<b>Cree Santa Barbara Technology Center</b>	<b>Goleta, CA</b>	<b>Scientists, engineers and technicians (full time staff) at Cree SBTC</b> <b>Specific individuals working on project as needed</b>	<b>Chip fabrication &amp; Design</b> <b>Package design &amp; fabrication</b> <b>Thermal, mechanical and optical design</b> <b>Prototype builds and testing</b>

- **Additional support from Cree, Inc. in Durham, NC**
  - **Cree Lighting (high volume LED lamp builds, LED product applications)**
  - **Cree Opto (GaN/SiC materials, specialty fabrication & characterization tools)**

# 4100K SSL Module – Baseline (9/07) Technology

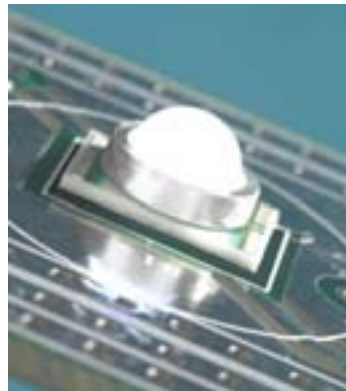
## EZBright™ LED Chip



- State-of-the-art 462 nm chip performance: ~70% light extraction (53% EQE at 350 mA)
- Limited by random surface roughness and finite reflectivity of mirror contact

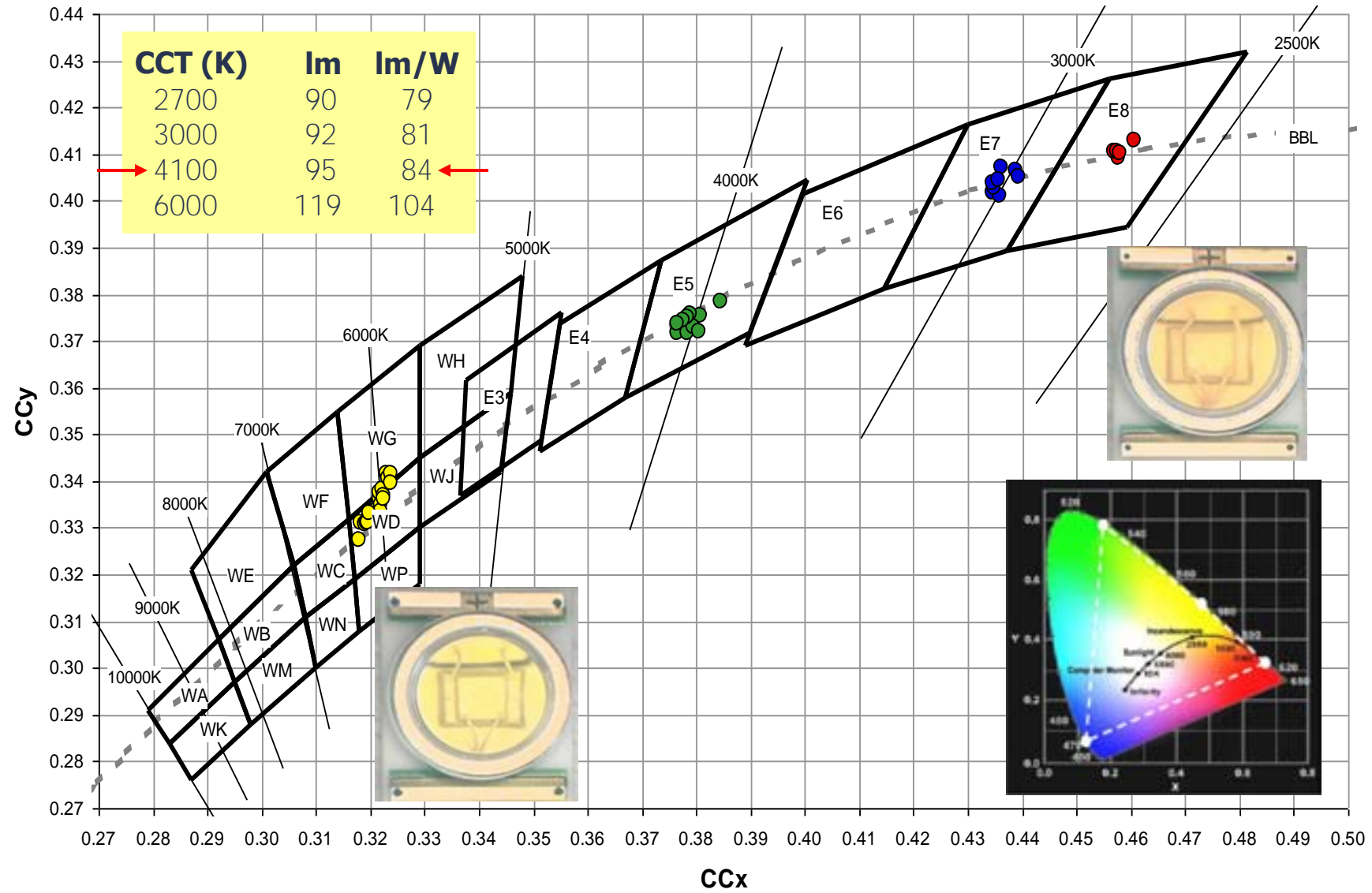
## XLamp™ 7090 XR-E

*\*Cree's brightest product bin @ 350mA (Q4 2007)*



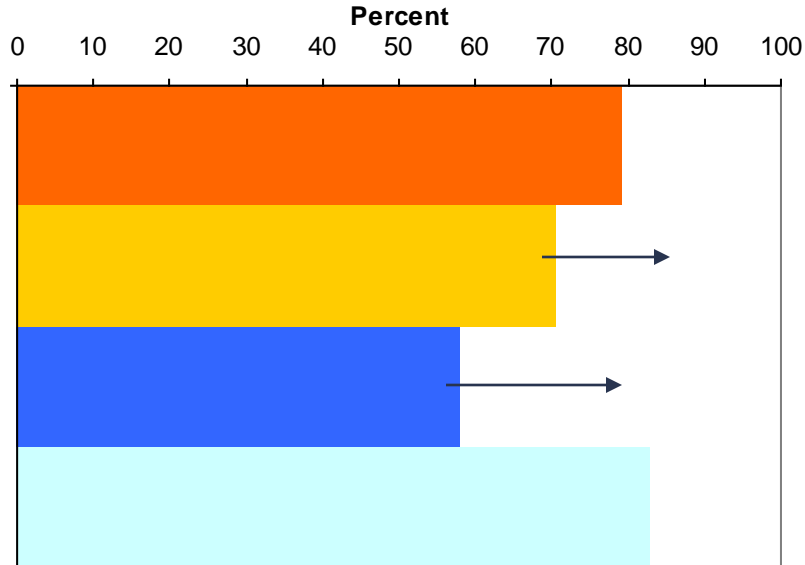
Product	CCT Range (K)	Min. Flux* (Lm)	Efficacy* (Lm/W)
Cool white	5,000 - 10,000	107	93
Neutral white	3,700 - 5,000	81	70
Warm white	2,600 – 3,700	62	54

# Performance Status Q4/07



# Getting to 120 lm/W at 4,100 K

Neutral White Component - Efficiency Breakdown  
Q4 '07 Status: 95 lm @ 84 lm/W



Room Temp., 350 mA

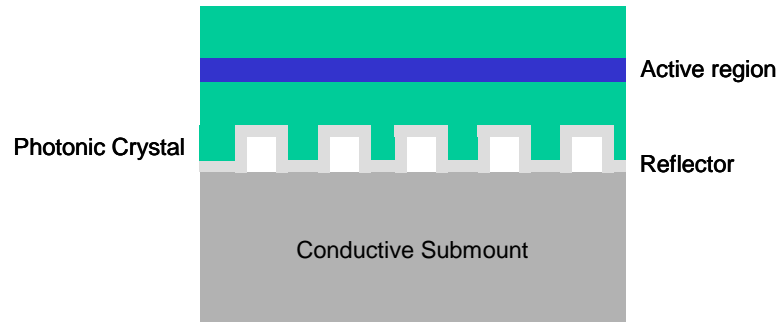
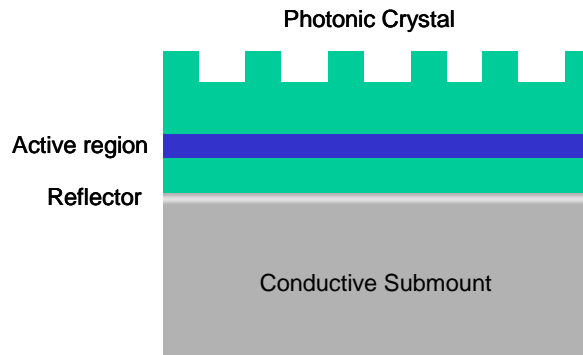
Down-conversion efficiency is ~ 57%

Chip 'wall plug' efficiency is ~ 48%  
(460 nm, 3.25 V)

- **SSL Module project targets areas with current main losses:**
  - Chip light extraction efficiency
  - Down-conversion efficiency excluding Stokes loss
- **Incremental gains anticipated in other areas**
- **Overall, targeting ~40% gain in efficacy at 350 mA**

# Approach for Improved Light Extraction

- **Chip light extraction will be improved by incorporating photonic crystal (PC) element into EZBright chip technology**
  - “PC” is used in a general sense: any periodic or quasi-periodic structure with dimensions comparable to optical wavelengths
  - 1D, 2D or 3D structures possible
  - N-side or p-side element initially under consideration



# Technical Progress: Light Extraction Efficiency

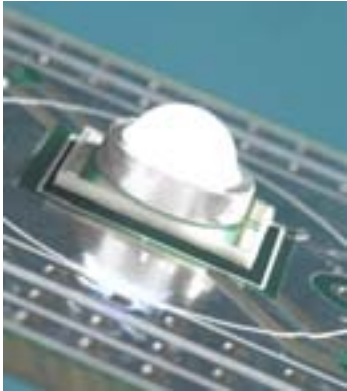
- **Novel PC chip design demonstrated**
- **Scalable process developed on 3" wafers**
- **Strong potential for low cost manufacturing**
- **Optimization of the PC LED fabrication process was performed to increase the efficiency of the initial PC LED devices**
  - **Improvements to the PC-LED design and process led to output power and efficiency comparable to the benchmark EZBright LED**

Fall 2008	Current (mA)	Power Output (mW)	EQE (%)	Dom. WL (nm)	Operating Voltage (V)
Lamp Module*	350	501	52	455	3.6

\* 1 mm<sup>2</sup> chip

# Baseline (9/07) Package Technology

XLamp™ 7090 XR-E (Top Bin @ 350 mA)



Product Bins	CCT Range (K)	Flux (Lumens)	Efficacy (Lm/W)
Cool white	5000-10,000	107	93
Neutral white	3700-5000	81	70
Warm white	2600-3700	62	54

- **State-of-the-art performance at 4100 K: 84 LPW at 350 mA**
- **In-package conversion efficiency ~57%**
  - Stokes loss (19%)
  - Phosphor IQE
  - Re-Absorption loss (chip, package, phosphor scattering)

# Approach for Improved Package Efficiency

- **Reduce existing package optical losses**
  - Reduce impact of absorbing surfaces
  - Improve down-conversion efficiency
    - Up to 81% possible excluding Stokes loss at 4100 K
- **Design lamp module around specifics of new chip design and project goals**
  - Scale up to multi-chip module for high flux
  - Target low cost potential (materials)
  - Possibly novel phosphor/chip integration

# Technical Progress: Package Efficiency

- **Prototype 4-chip lamp modules demonstrated with an efficacy of 102 LPW at 4125 K (350 mA, 1mm<sup>2</sup> chip).**
  - **21% efficacy improvement over single chip package at the start of the project (84 LPW).**
- **Overall conversion efficiency at 4100 K improved to ~65% (compared to ~57% for baseline package)**
- **Reduced absorbing surfaces in package**
- **Performance scales from single chip package to 4-chip modules**

	Current (mA)	Flux (lumens)	Efficacy (LPW)	Chromaticity		CCT (K)	CRI	Input Power (W)
				x	y			
Lamp Module	350	441	102	.3752	.3725	4125	73	4.2

# Technical Challenges & Problems

## Chip:

- **Further improvement in PC quality for better light extraction**
- **Trade off between LED operating voltage and EQE**
- **PC LED reliability has not yet been tested**
  - Accelerated life test
  - Thermal shock

## Package:

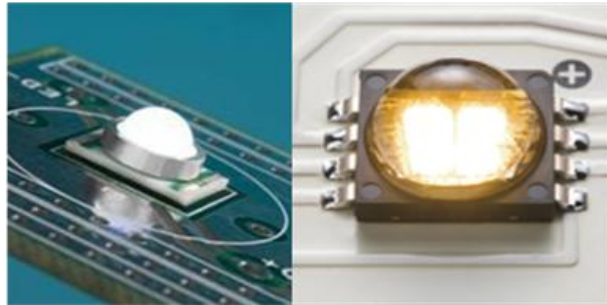
- **Optimize phosphor/chip integration process for new chip design**
- **Reliability under operation of 4-chip prototype lamp module has not yet been tested**

# Commercialization Plan

LED Chips



LED Components



LED Luminaires



- Cree has 3-tiered path to commercialization of proposed technology
- Cree anticipates manufacturing and selling LED module to Cree LLS and OEM manufacturers for integration into lighting systems.

# PC LED Chip Opportunities

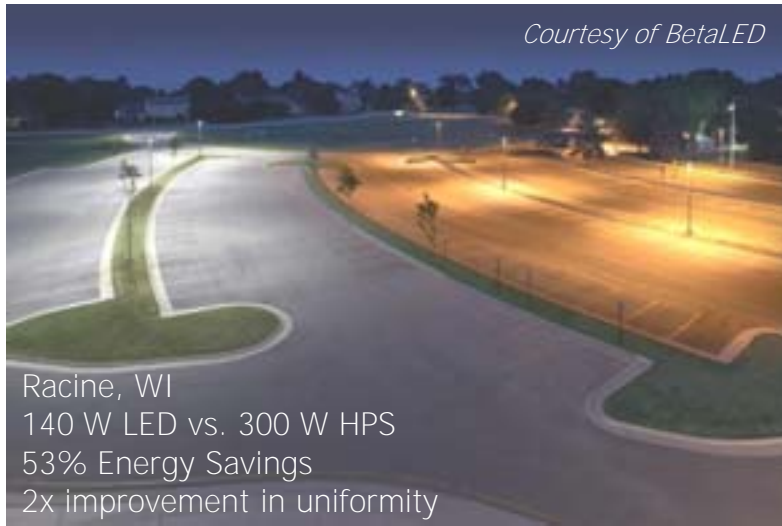
*Bird's Nest*



*Water Cube*



# Neutral White Component Opportunities



*Courtesy of BetaLED*

Racine, WI  
140 W LED vs. 300 W HPS  
53% Energy Savings  
2x improvement in uniformity



*Courtesy of BetaLED*

New Raleigh Convention Center  
49% less energy than HID  
Payback in just over 3 years  
Estimated \$636k savings over 15 years



*Courtesy of BetaLED*

Thortons Gas Station – Edgewood, KY  
62% energy savings  
Better quality of light



Ann Arbor, MI  
53% Energy Savings  
1,300 Downtown Fixtures  
4.4 years payback

*Courtesy of Relume*

# Luminaire Opportunities with New Chip and Package Technology



## Sheraton Hotel Greensboro, NC

- Installed 400 LR6 recessed down lights
- Up to 82% energy savings



80% Energy Savings  
Friendly's Restaurant – Westfield, MA



30% Energy Savings  
Durham, NC

# Summary

- **Photonic crystal LEDs demonstrated**
  - **52% EQE at 350 mA (455 nm, 1mm<sup>2</sup> chip)**
  - **Scalable process developed on 3" wafers**
  - **Achieved comparable efficiency performance to benchmark EZBright LED**
- **Prototype 4-chip lamp modules demonstrated with an efficacy of 102 LPW at 4125 K**
  - **Overall conversion efficiency at 4100 K improved to ~65% (compared to ~57% for baseline package)**
  - **Performance scales from single chip package to 4-chip modules**
- **Met all project milestones to date**



PORTABLE



RESIDENTIAL



OFFICE



RETAIL



ARCHITECTURAL



OUTDOOR

## LED lighting: Energy efficient & planet friendly.

### Cree. Leading the LED lighting revolution.

Join Cree's LED lighting revolution. We invite you to see how our high-performance, high-efficiency LEDs are lighting up the world.

