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sense and simplicity

High-Power Warm-White Hybrid LED Package for Illumination

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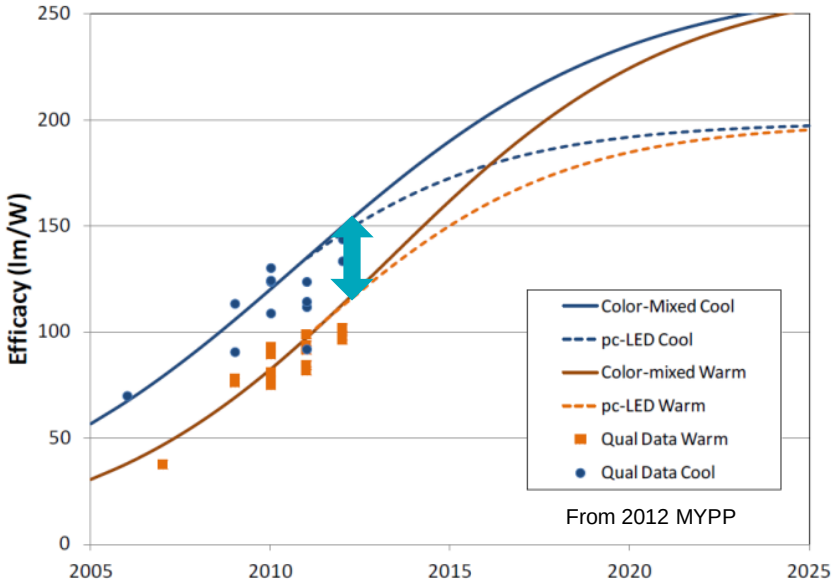
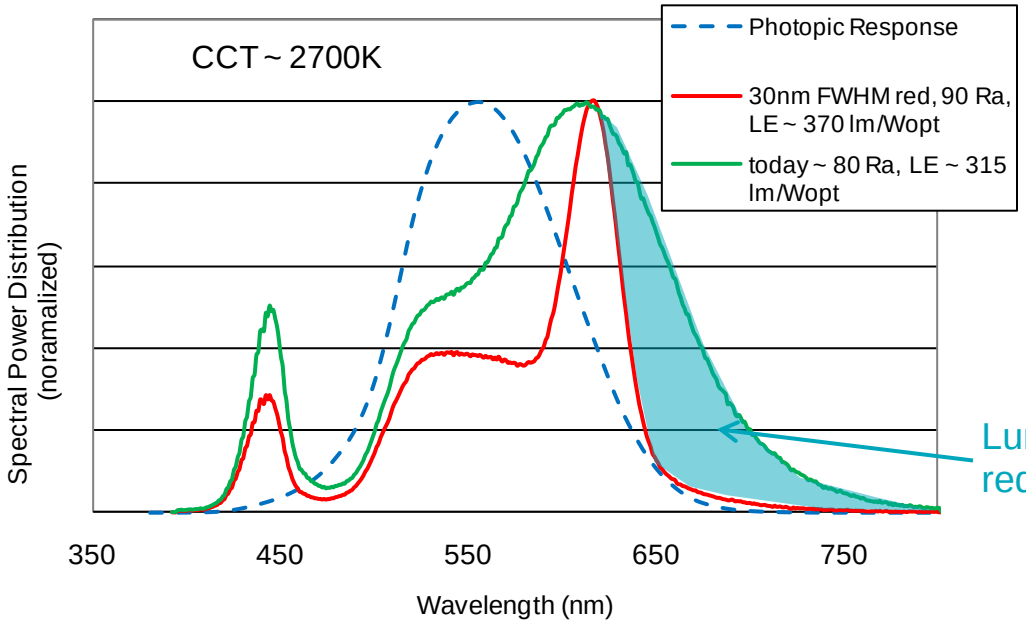
The warm-white lm/W gap

Warm-white lm/W performance lags behind cool-white by ~30%





Cause: broad spectral emission of current red phosphors

Lumen loss of current red phosphors

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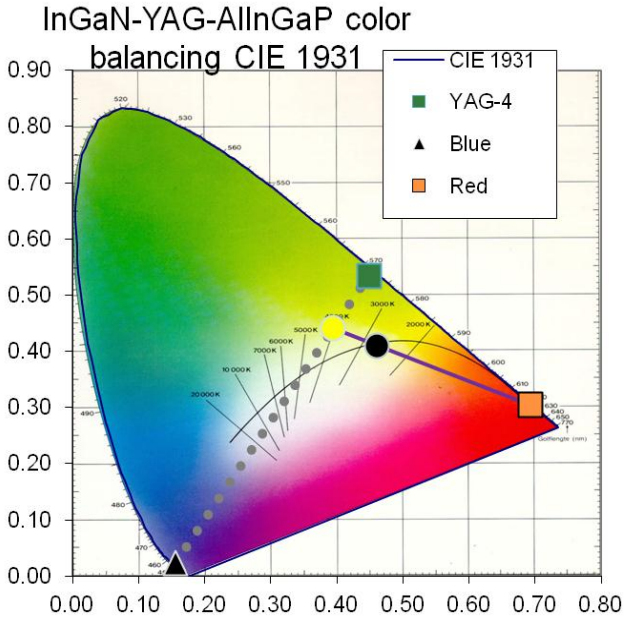
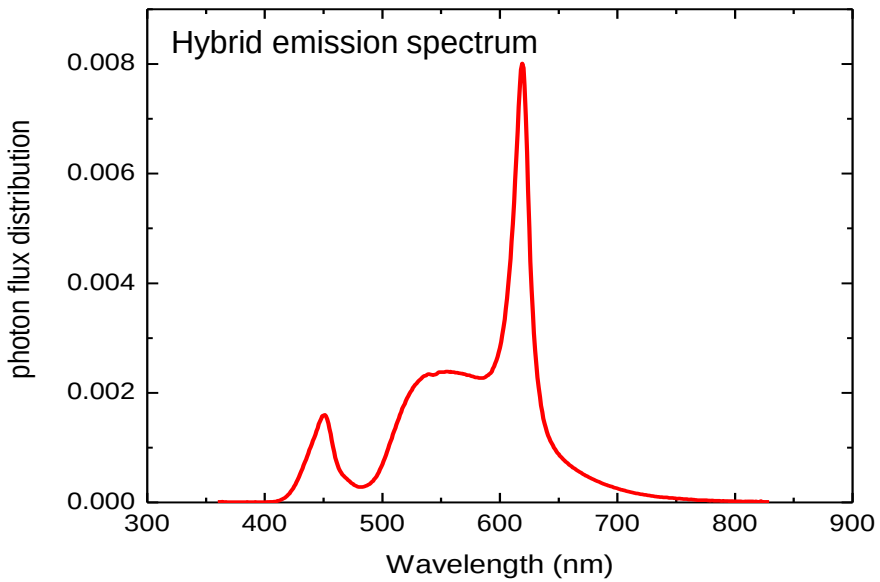
Hybrid LEDs

Approach

Combine phosphor-converted off-white LEDs and direct red LEDs in one package





Benefits

- Stokes loss associated with pc-red avoided by using direct red
- Strong emission in red with minimal emission wasted in infrared

→ **high efficacy** and **high CRI**

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Project objective

Objective: develop a warm-white hybrid LED package for general illumination

- High efficacy: 140 lm/W and 700 lm at T_j = 85 °C
- Warm white: CCT 2700-3500 K
- High CRI: CRI>85

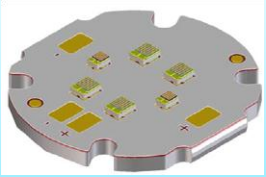
Efficacy of white pc-LEDs today (85 °C, 350 mA)

Color temperature	CRI	Efficacy
Cool white (~5000 K)	80	120-135 lm/W
Warm white (~3000 K)	80	100-115 lm/W
Warm white (~3000 K)	90	85-95 lm/W

Project goal:

140 lm/W

- Integrated electronics for hybrid light engine



Design a package that allows the off-white and red LEDs to be driven according to their respective requirements

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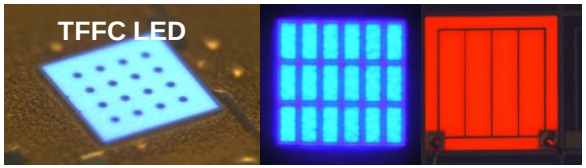
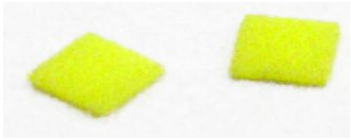
Key areas of hybrid warm-white LED development

Device (chip) design



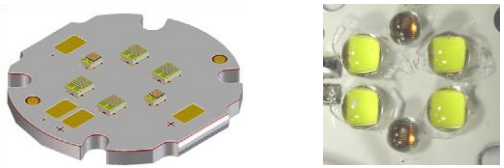
InGaN pump die and thin film AlInGaP red die development

Phosphors



Phosphor integration technique with high conversion efficiency and accurate color control

Package



High-power LED package design and optimization; encapsulation lens development

System Integration

Develop light engine for stable performance under varying operating conditions

Reliability

Understand the operation boundary conditions and identify associated failure modes

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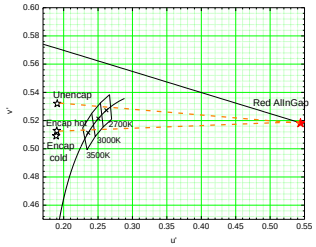
Technical progress since 2012

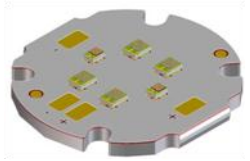
Computational model

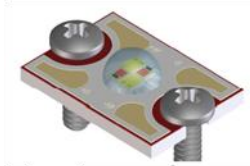
- Generate color point specification for off-white and red LEDs
- Color point and efficacy prediction for the hybrid package



Package development

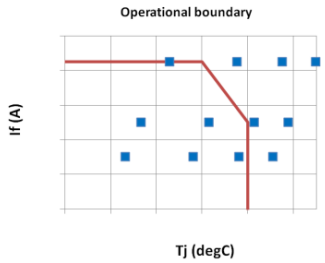
- Two types of packages developed:
  - Multi-lens array package for non-directional lighting
  - Single-lens array package for directional lighting
- Latest build demonstrated 131 lm/W at 85 °C with CRI 90, R9 88, CCT 2955K and total LOP of 760lm





Reliability study

- Completed preliminary reliability study on prototype packages
- Operation boundary conditions identified



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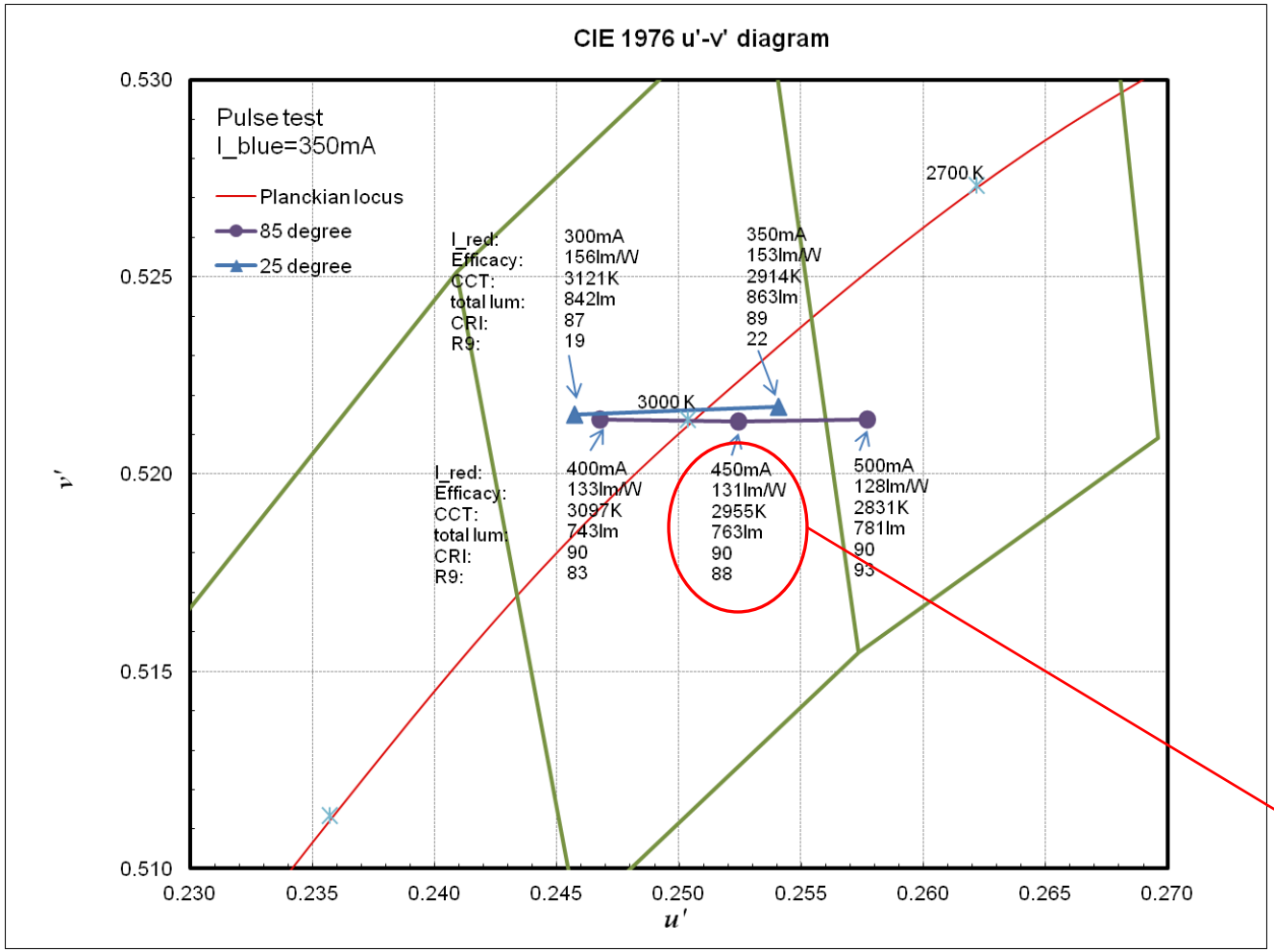
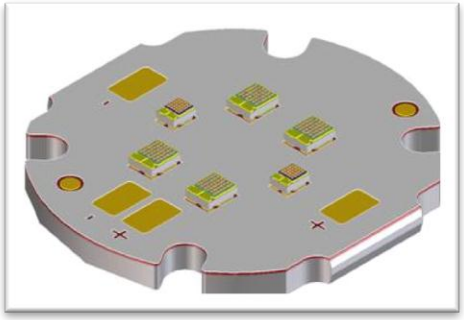
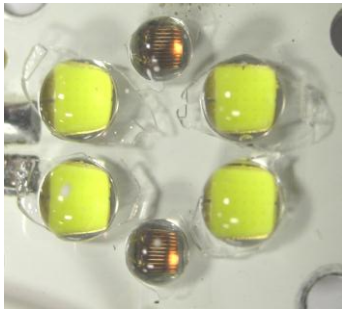
Multi-lens warm-white LED package performance







Efficacy: 131lm/W
CCT: 2955K
Total LOP: 763 lm
CRI: 90
R9: 88

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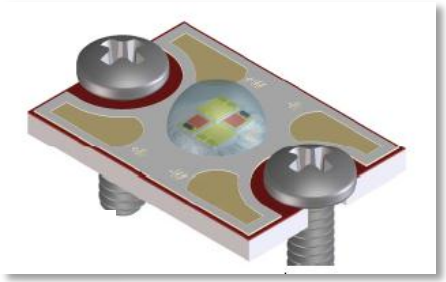
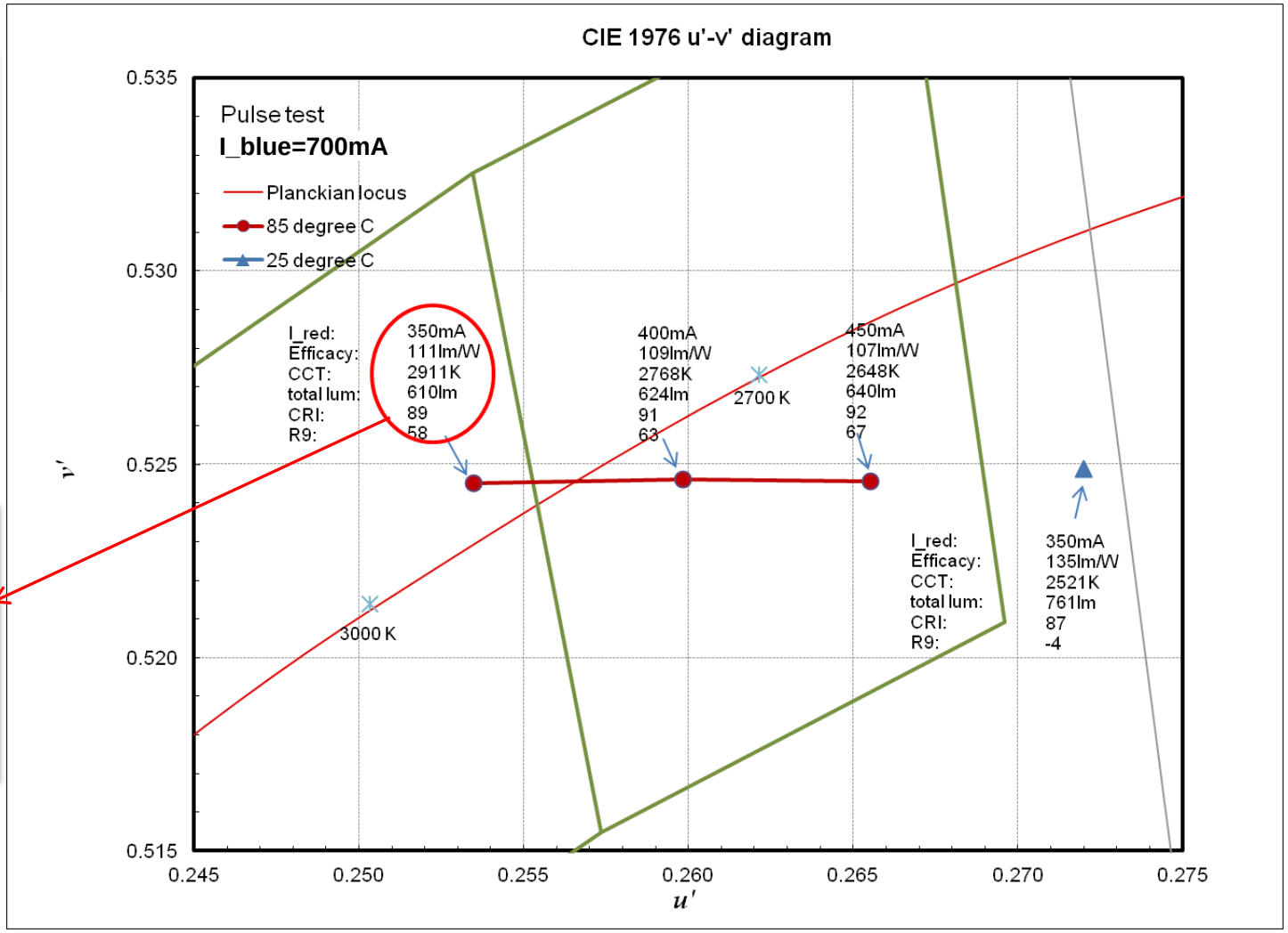
Single-lens warm-white LED package performance



Efficacy:	111lm/W
CCT:	2911K
Total LOP:	610 lm
CRI:	89
R9:	58



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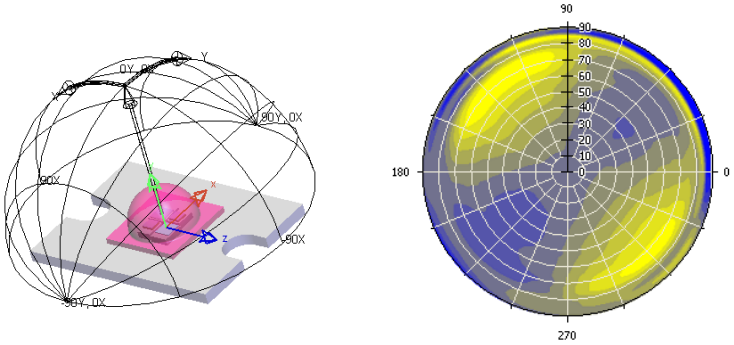
Challenges

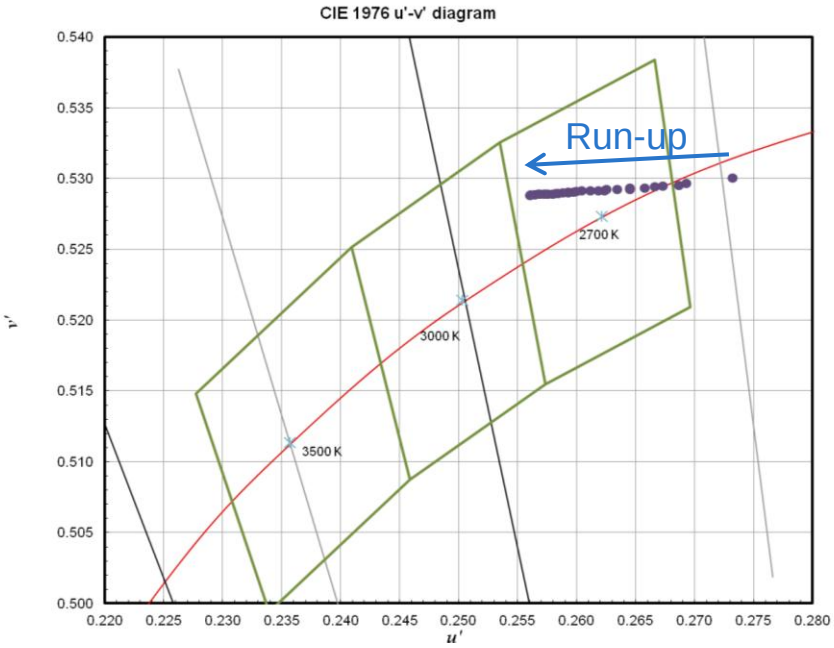
Color over angle (COA)

- COA shows non-uniformity for the single-lens WW packages
- Need to develop effective primary or secondary color mixing optics for spot light applications



Color point (CP) stabilization

- At constant drive current, CP drifts ~ 1 ANSI bin from cold start to stabilization due to different H/C factors
- Need hybrid driver functionality with integrated feedback to adjust drive conditions to operating environment
- Goal: <3 SDCM during run-up and dimming



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Towards a high-quality high-efficiency hybrid light engine

Further efficacy improvement

- Implement epi, device, phosphor and package improvements
- Goal: 140 lm/W (at 85 °C) by September 2013

Integrated hybrid light engine development

- Evaluate various scenarios for hybrid driver integration
- Build on hybrid experience from L-Prize winning bulb
- Goal: develop a hybrid light engine package that enables stable performance over run-up and dimming

Productization

- Define target applications for hybrid package

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Hybrid benefits apply to a wide range of applications

Non-directional

Directional

Small retrofit

- Easily implemented in non-directional lighting due to inherent color mixing
- Primary or secondary color mixing optics needed for directional lighting
- High efficacy provides opportunity for smaller / low-cost heat sink

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Conclusions

Hybrid technology closes the “warm-white gap” providing high efficacy at high CRI

This project aims to make these hybrid benefits available in a single LED package

Project accomplishments so far:

- Realized key technology improvements leading to 131 lm/W efficacy
- Developed hybrid packages for directional and non-directional lighting, and performed characterization and preliminary reliability testing

Outlook:

- Further improve efficacy towards 140 lm/W
- Develop integrated hybrid light engine package that enables stable performance over run-up and dimming
- Define target applications for hybrid package productization


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