High CRI/High Efficiency White LED Technology

FRANK SHI, Professor

fgshi2000@yahoo.com

Optoelectronics Packaging & Materials Labs

University of California, Irvine, CA, USA

Outline

I. Introduction
   - WLED for Lighting: Challenges
   - Means for Achieving High Efficiency & High Quality

II. Remote Phosphor (RP) based WLED
   - Concept、 Advantages
   - History、Classification

III. WLED with High Efficiency & Quality with Remote Phosphor

IV. Advanced Method for Achieving High Quality/Efficiency Warm WLED

V. Phosphor Design Capacity: High Quality/Efficiency for All CCTs

VI. RP WLED Commercialization: CapLED

VII. Next G Method for High Quality/Efficiency Neutral & Warm RP-WLED
   - B + Phosphors
   - HV chips

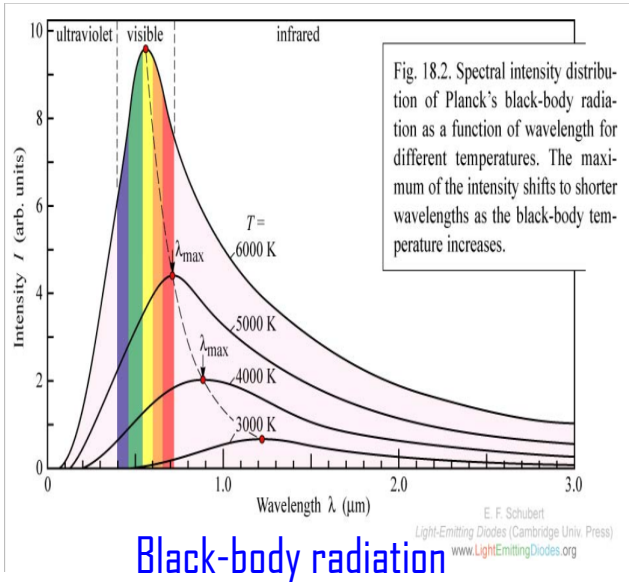
VIII. Challenges & Future Outlook

I. Introduction

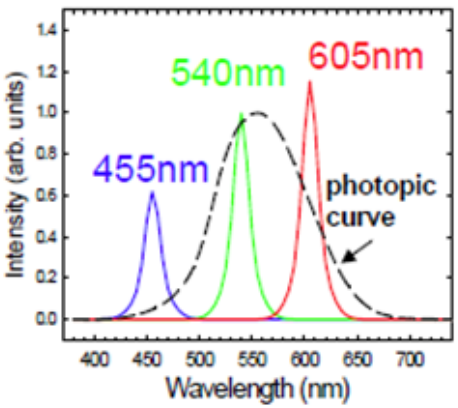
- WLED for Lighting: Challenges
- Means for Achieving High Quality & Efficiency WLED

White Light Qauality & Light Spectrum

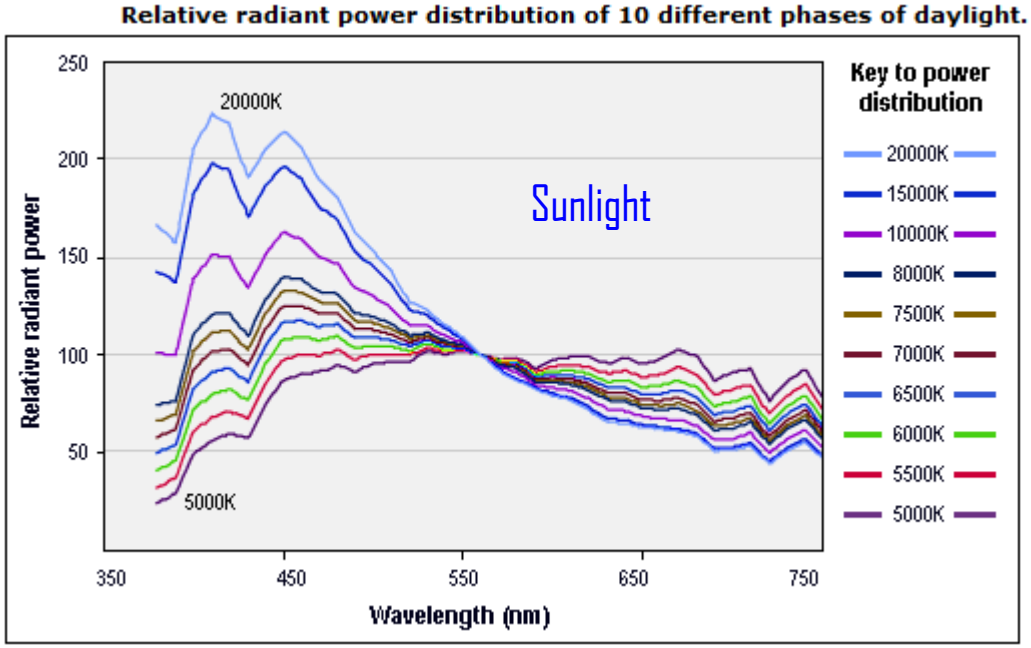
- White light is a visible spectrum of different colors that appears white under human eyes.
  - ✓ Examples of white light: sunlight, incandescent light, common light at home or office, etc.
- White light source is characterized by
  - ✓ Color render index (CRI)
  - ✓ Correlated color temperature (CCT)
  - ✓ Efficacy (lm/W)
  - ✓ Reliability & Lifetime
- Different white light sources have different light spectra & qualities
  - ✓ Continuous (full) spectra: i.e., sunlight or incandescent (black-body radiation) light
  - ✓ Non-continuous spectra: i.e., white LEDs, fluorescent lamp



Black-body radiation



RGB LED



Type I: Multi-Color WLEDs

- Multi-color WLEDs
  - ✓ Has potential high quality
    - high CRI
    - high efficiency
    - Color dynamics: color tunable
  - ✓ Disadvantages
    - Currently only RGB types
    - Efficiency is still low for G- or Y-LEDs
    - Low CRI due to non-continuous and spiky spectrum
      - Color LEDs have narrow band
      - CRI <= 82
    - High cost
    - Complicated driving circuit and driver design

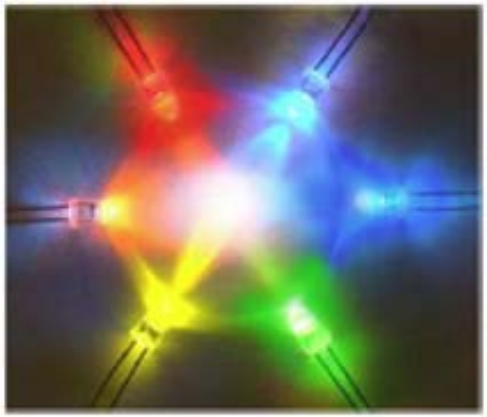
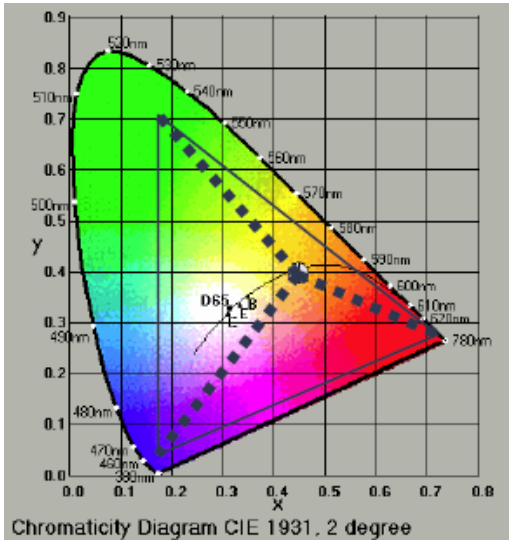
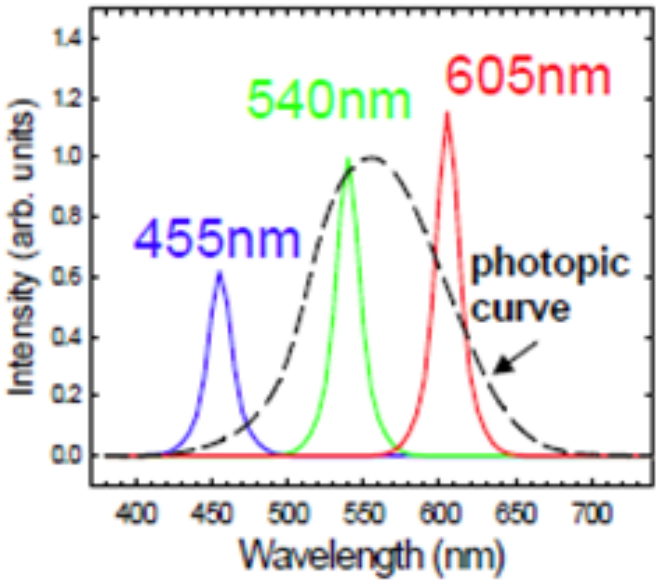


Figure courtesy of E. F. Schubert

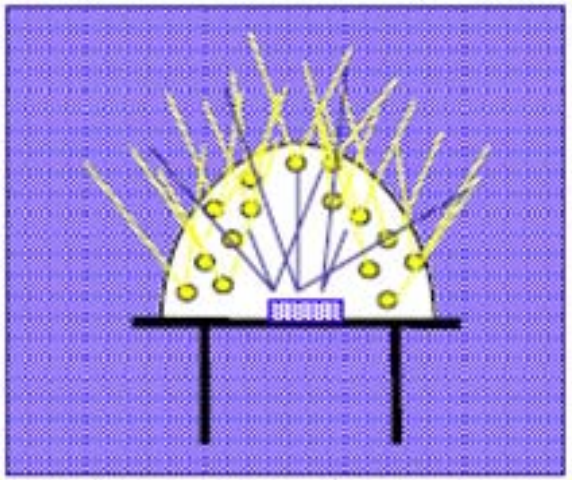


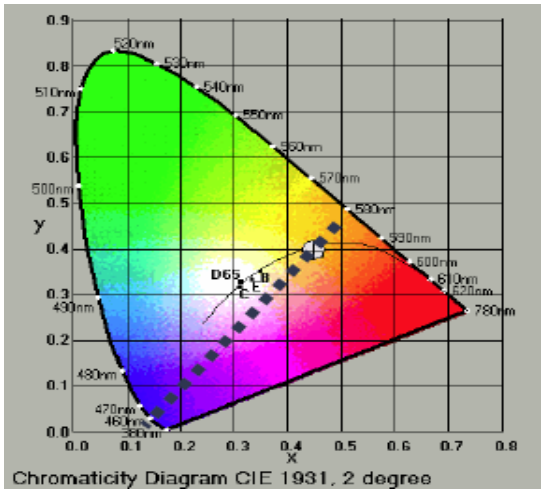
RGB

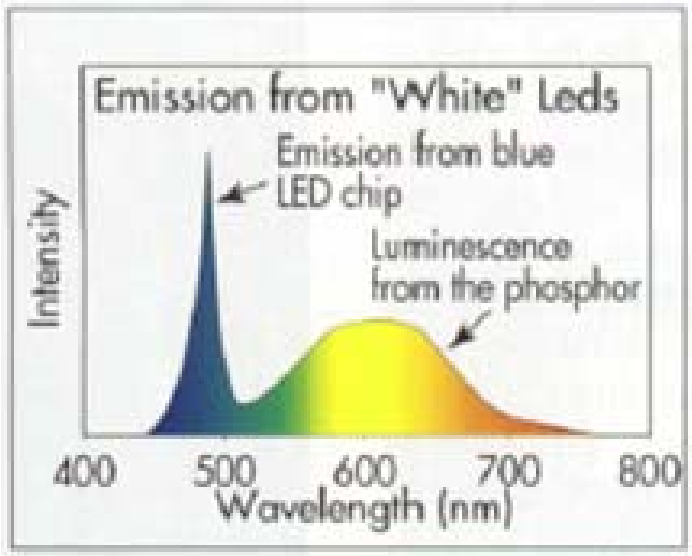


Type I I: Phosphor-Based WLEDs

- Blue chip + Yellow phosphor or UV + BY phosphors
  - ✓ high efficiency
    - ✓ Commercial approach to 160 lm/W
  - ✓ Low CRI
    - ✓ CRI < 72
  - ✓ Not possible for warm white
    - ✓ CCT is limited from neutral to cold or ultra cold
    - ✓ Will be off blackbody curve if move toward warm color or low neutral color region
  - ✓ Lower cost than RGB LEDs

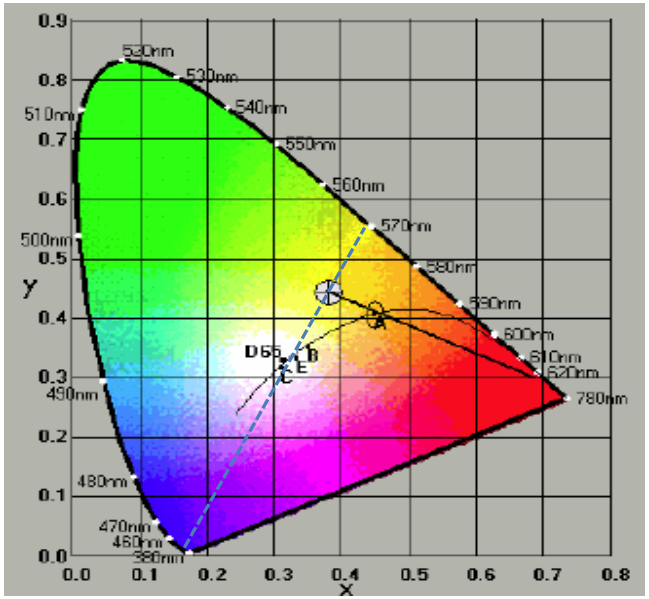


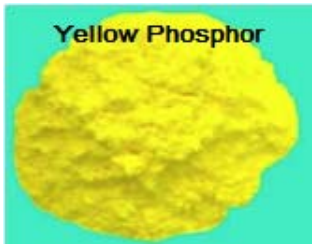


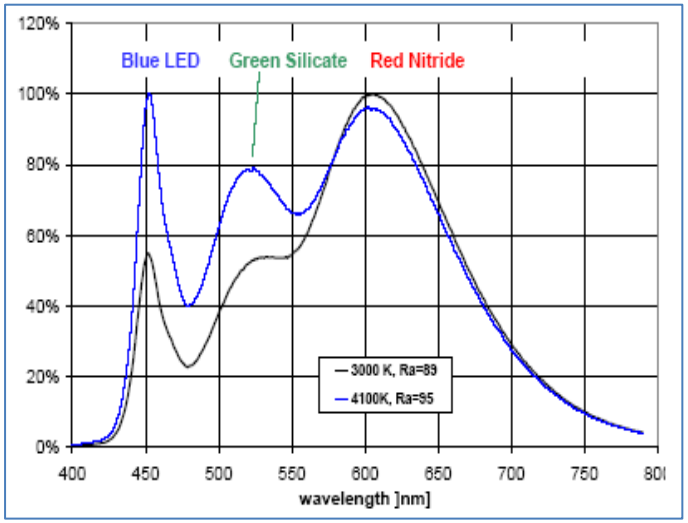


Phosphor-Based WLEDs (con't)

- Blue chip + GR or YR phosphors
  - High CRI is possible
    - Up to 97
  - Efficiency greatly depends on formulation
  - Wide range of CCT
    - From warm white to ultra cold white





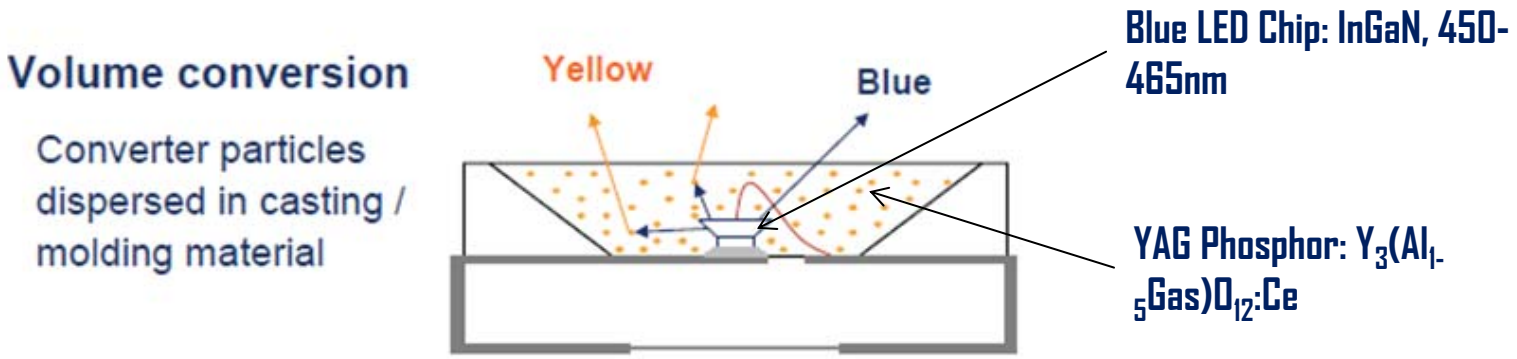


WLEDs for Lighting: Challenges

- ✓IP
- ✓Efficiency
  - Light trapping due to light scattering and trapping by phosphor particles
- ✓Reliability and lifetime
- ✓Color quality challenge
  - Method of improving CRI and Rendering issue
  - Angular CCT uniformity
  - CCT variation among LED packages

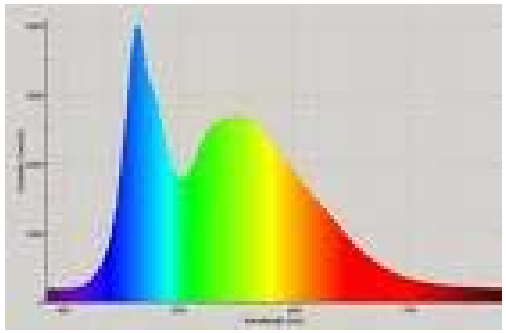
IP Challenges

- Volume Conversion Method



Nichia's IP: Blue LED Chip + YAG Phosphor

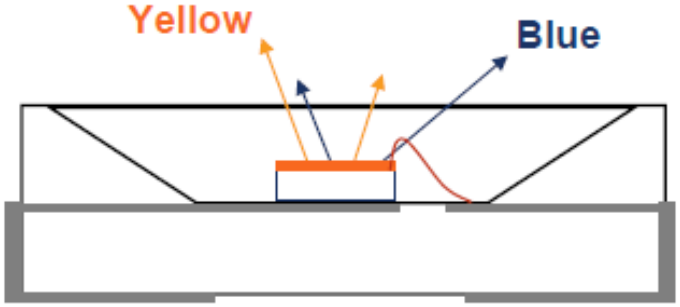
Osram's IP: Blue LED chip + Orthosilicate phosphors;

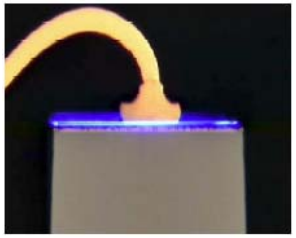


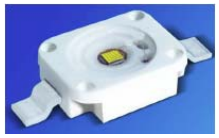
IP Challenges: Chip Coating Method

Most suited for thin-film LED chips from wafer-bonding

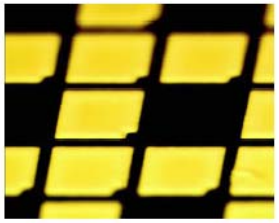
Phosphor layer on surface emitting chip







Osram

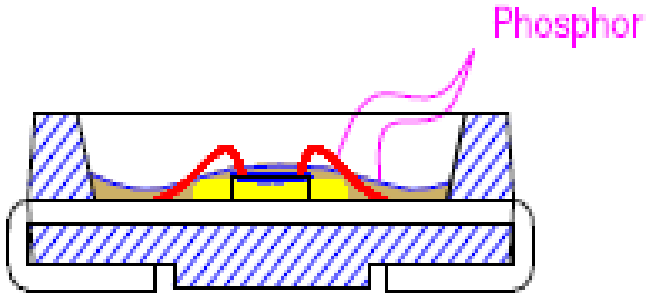


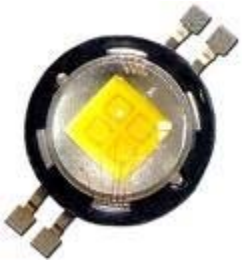
Cree

- Phosphor coated in wafer level
- Phosphor coated chip can be sorted
- Higher yield and color homogeneity than volume conversion method
- Efficiency is lower since light back scattering into chip is higher
- Difficult to adapt to material change

Chip/Leadframe Coating Method

Suited for both flip-chip and thin-film LED chips





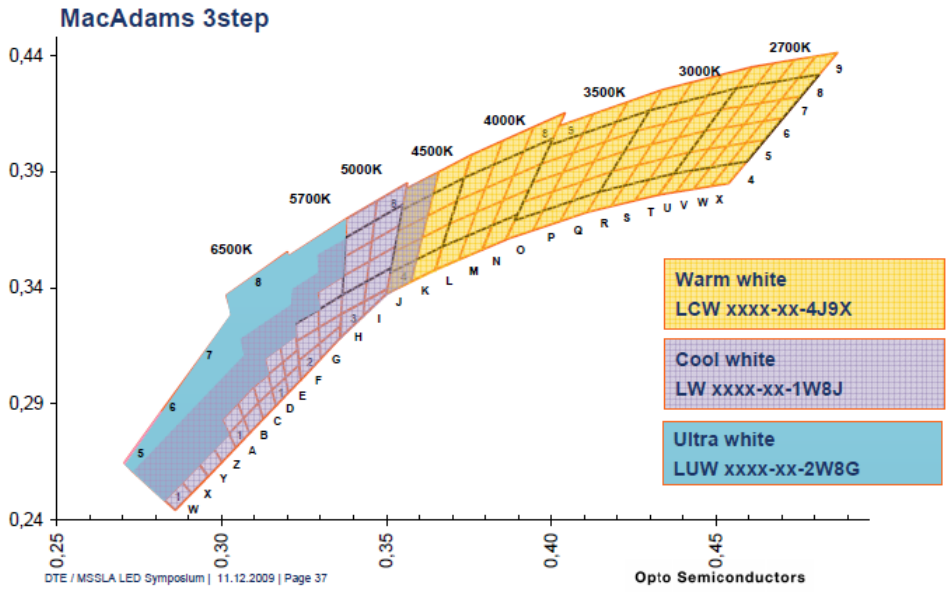
Seoul Semiconductor

Powerlightec

1. Phosphor not only coated on the surface of LED chip, but also coated on the bottom of the leadframe house
2. Less light back scattering and higher efficiency than chip plating/coating method
3. Low color quality and yield

CCT Variation Challenges

- ✓ Same manufacturing process results in different colors
- ✓ Biggest issue in WLED manufacturing
- ✓ High costly sorting machines are needed
- ✓ Resulting in complexity in lighting fixture design



Binning:

1. Sorting of finished LED packages according to CCT
2. The LEDs are placed into bins according to their CCTs
3. The binned LED are then placed into reels for shipment

Thermal Challenges

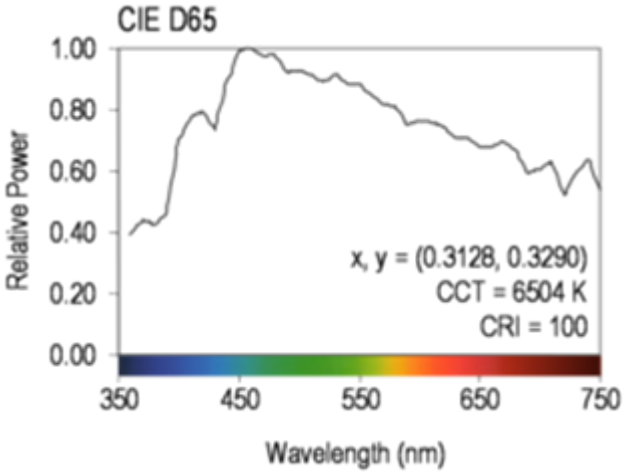
- ✓ The main cause of LED degradation
- ✓ Conventional phosphor-based LEDs have additional thermal load on phosphor materials. This thermal load comes from LED chips and light trapping.

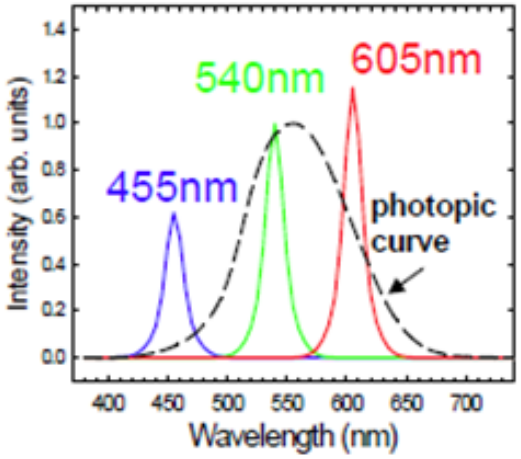
Efficiency Challenge

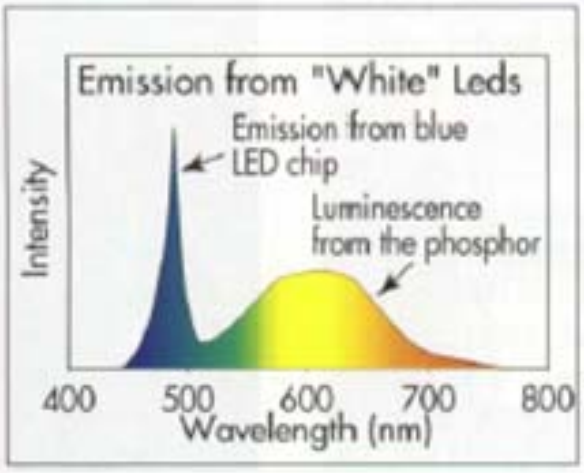
- ✓ Compared to cool white, warm white LED requires higher concentration of phosphors, resulting in stronger scattering and more light loss in package
- ✓ ~40% light output decrease when CRI increases from 65 to 85 and CCT decreases from 5000K to 2700K
- ✓ Packaging method and phosphor recipes are critical to solve this problem

Quality Challenges

- ✓RGB emitter: spiky spectrum, not continuous → not able to truly reflect colors of objects even with high CRI
- ✓Typical phosphor conversion LED emitter:
  - ✓Discontinuity of spectrum still exists: spiky type
  - ✓Poor color rendering can happen, even with high CRI
  - ✓High light loss for high CRI due to high phosphor concentration







- ✓LED light quality is still far from reference light, i.e., sunlight for cold white, and incandescent for warm and neutral white
- ✓"High" quality of LED light is currently on at warm white CCT

Means for Achieving High Efficiency & Quality

- ✓Phosphor formulation
  - ✓Multi-phosphor formulation is required, i.e., RYG phosphors

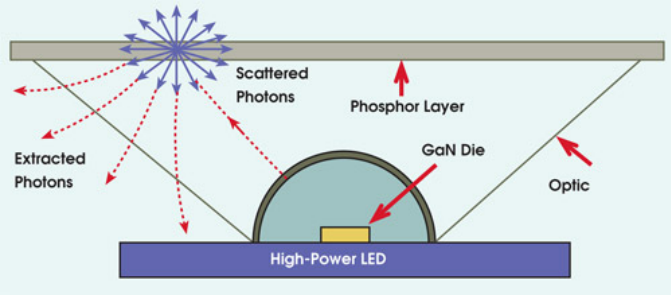
- ✓Package/phosphor placement geometry
  - ✓Need a package with low light trapping
  - ✓Minimize heat load on heat sensitive components/materials, i.e., phosphors & LED chips
    - ✓Heat source needs to be separated
- ✓ Solution: Remote phosphor structure + RY/G phosphors

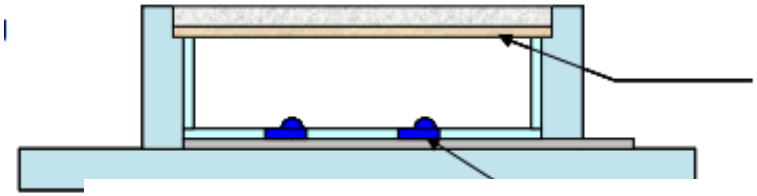
II. Remote Phosphor Based WLEDs

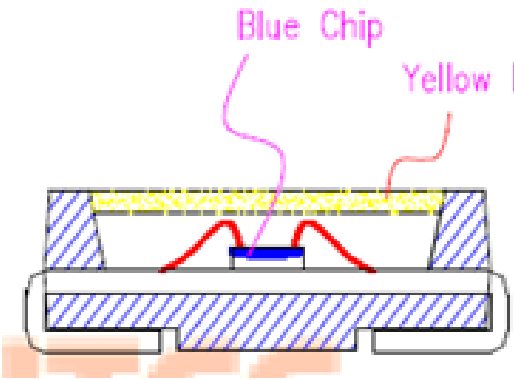
- Concept of RP-WLEDs
- Advantages
- History
- Classification

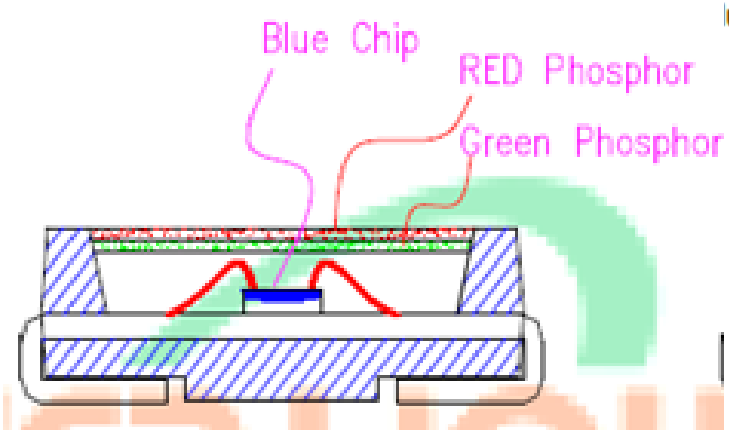
Remote Phosphor Based WLED: Concept

- Phosphor materials are separated from LED chips
- Thermal load is separated
- Reduce light entering/reentering LED chips









Remote Phosphor: Advantages

- ✓ High efficiency
  - ✓ Less scattered & emitted light is absorbed by LED chips
  - ✓ Less light is trapping in the package

Remote Phosphor: Advantages

- ✓Better thermal stability due to heat sources are separated
  - ✓Phosphor is located away from the heat generating LED junction
  - ✓Phosphor efficiency is increased
- ✓More reliable and better lifetime
  - ✓Phosphor lifetime is increased
  - ✓LED chip lifetime is increased

Classification

❖ Lamp level

- Packaging free
- Difficult for directional lighting

Philips

Bruck

Intematix

❖ Integrating Emitter Level

- Packaging is required
- Can easily control light pattern for directional lighting
- Easy to use to make lamp
- Fixed on emitter

Osram

GE

❖ Detachable @ Emitter Level & Lamp level

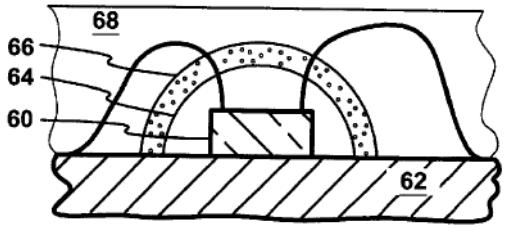
- Packaging free
- Can use conventional reflector to control light pattern
- Easy to use to make lamps: basic units for lamp applications

SGI

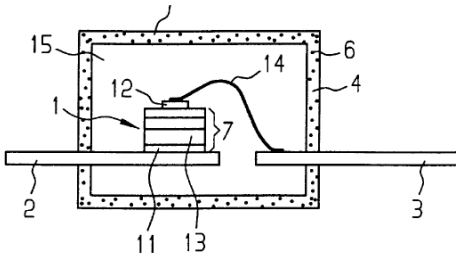
Nepes

Cree

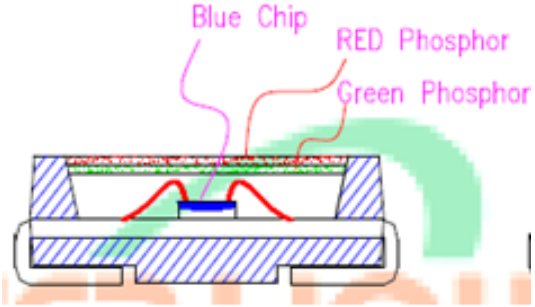
RP-WLED Overview: Integrating Emitter Level



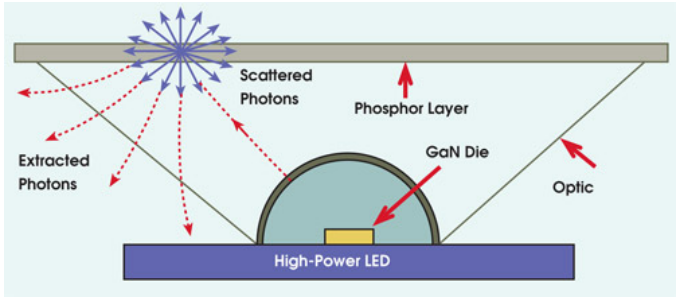
HP



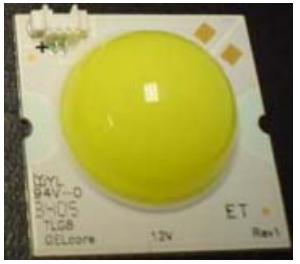
Siemens



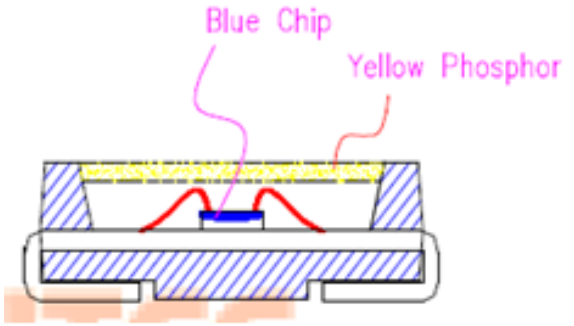
Osram's Multi-layer remote phosphor method



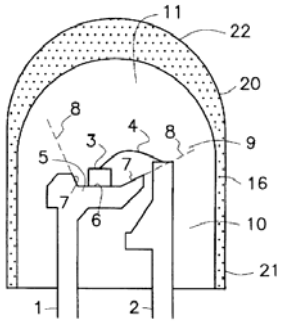
RPI



GE



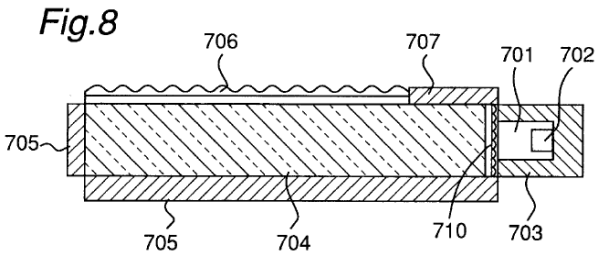
HP, Citizen's single-layer remote phosphor method



Senkan Electronic

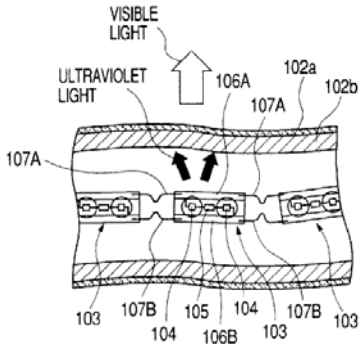
Osram

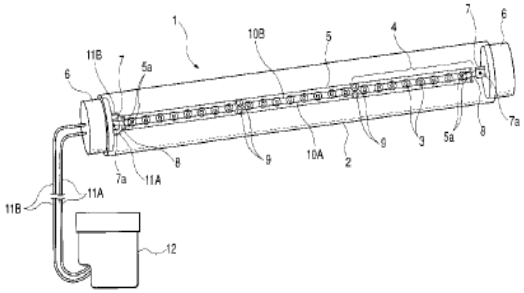
RP-WLED Overview: Lamp Level



Nichia

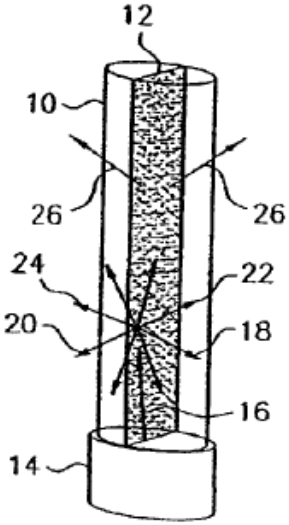
Philips



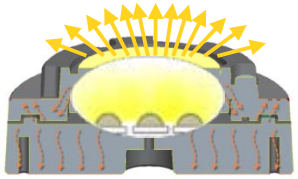


Toyoda Gosei

Cree



RPI



Bruck

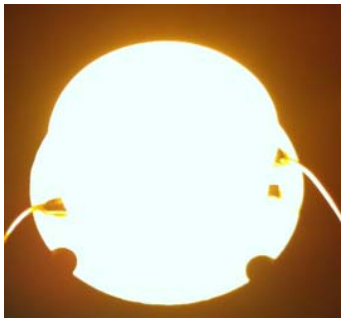
Intematix

RP-WLED Overview: Detachable @ Emitter Level

- Can use conventional reflector to control light pattern
- Easy to use to make lamps: basic units for lamp applications
- Can be used lamp level directly

NepesLED

SGI-G1



Major RP-WLED Technologies: Break Phosphor Barrier of WLEDs

❖Molding methods

Philips

Intematix

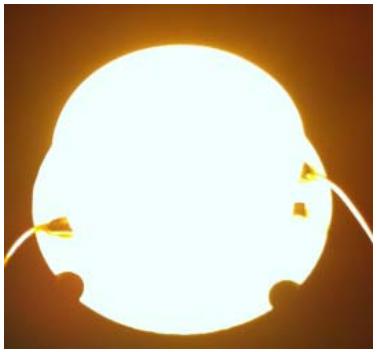
Osram

GE

Cree

❖Dispensing method

NepesLED



SGI-GI

III. WLED with High Efficiency & Quality with Remote Phosphor

- CCT ~ 2700K-3500K
- General Way to Achieve Warm White
  - ✓Adding Red and Green phosphors to Yellow one (CRI>=85)
- High CRI required high phosphor concentration. However, due to less light trapping of RP:
  - ✓ RP-WLED has higher efficiency: up to 30% enhancement for high CRI compared to conventional WLED

Comparison of RP-WLEDs

	SGI-RP	Company-A	Company-B
Types	Emitter/Module/Lamp	Lamp /Module	Lamp /Module
Light distribution	Controllable light distribution; can be as broader as 300-degree Directly used for light bulb, down light, fluorescent replacement Can be used with reflector to shape light output	Normal: similar to conventional flat top package Required scattering film or cover for light spreading Poor light mixing	Broad
Manufacturing	Casting/Dispensing/Molding	Molding	Molding
Adaptability	Easy to adapt to material changes such as phosphor material and LED chip bins Easy to test for new materials Easy to frequently improve quality of SGI-RP	Not easy to adapt to material changes Not easy to test for new materials Not easy to frequently improve quality	Harder to adapt to material changes compared to MCW and Intematix remote Not easy to test for new materials; Not easy to improve quality.
Applications	light bulbs, down light, industrial lighting, fluorescent replacement; etc	Limit to directional lighting	light bulbs, etc
Outlook color	Phosphor color can be faded	Uncomfortable phosphor color	Uncomfortable phosphor color

IV. Advanced Method for Achieving High Quality/Efficiency Warm WLED

- (Blue chip + Yellow phosphor) + Red chip

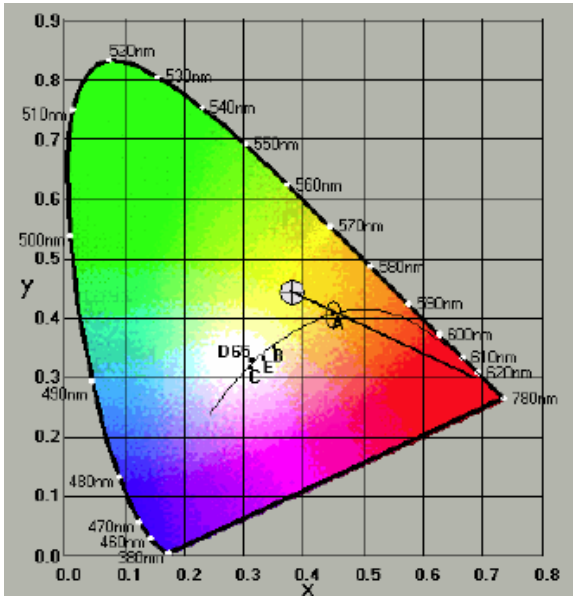
➢ Advantages

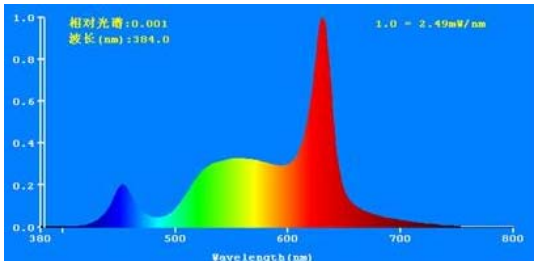
- CRI>=85
- No light output decrease compared to cool white

➢ Disadvantages

- Red chip has a different lifetime from Blue chips, resulting in CCT shifting during life aging period
- Separate control circuit needed for Red chip
- Color mixing could be an issue

White +Red Chip

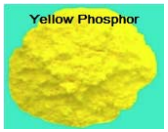


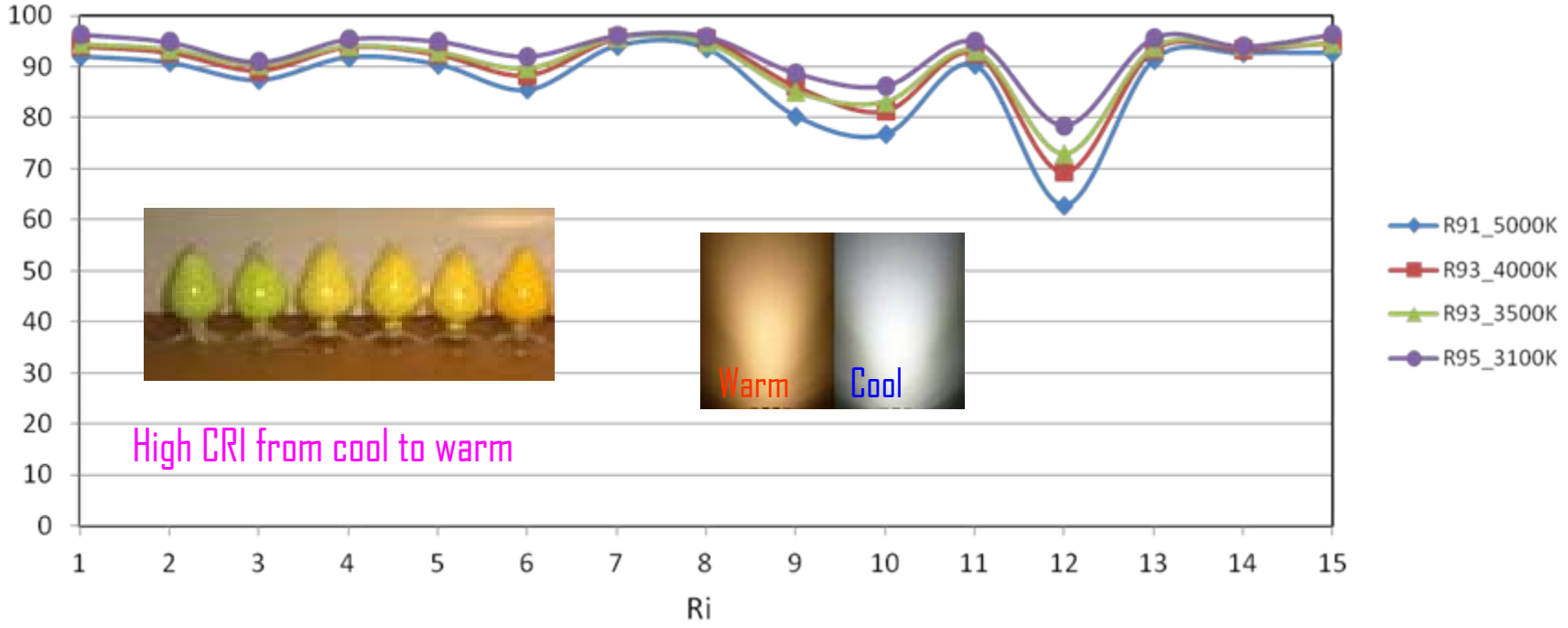


Spectrum

V. Phosphor Design Capability: High Quality/Efficiency for All CCTs

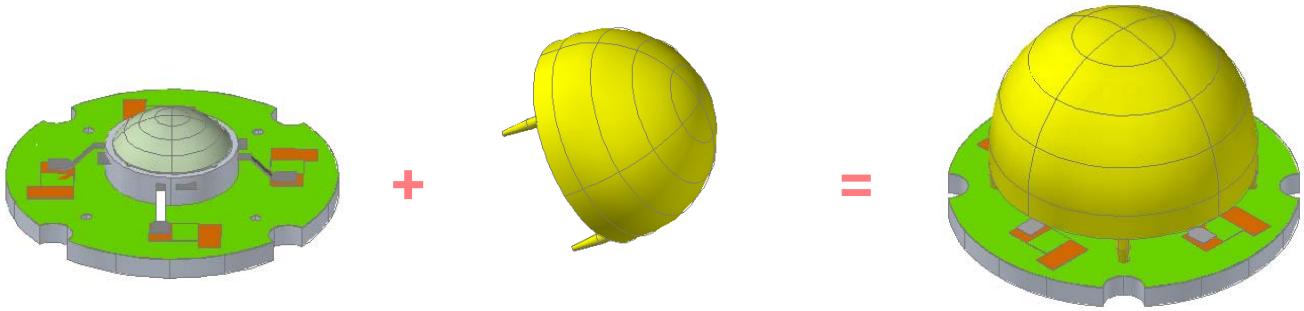
- ✓ Have designed unique phosphor recipes with High-CRI (>=80, >=85, and >=90) and high efficiency covering from cool to warm, which cannot be bought from market
- ✓ These phosphors are ready for customer's testing and mass production





VI. RP-WLED Commercialization: CapLED

- Avoid all patent issues
- Unique design & processing: avoid RP patent issues



Blue Package + Phosphor Cap = White LED

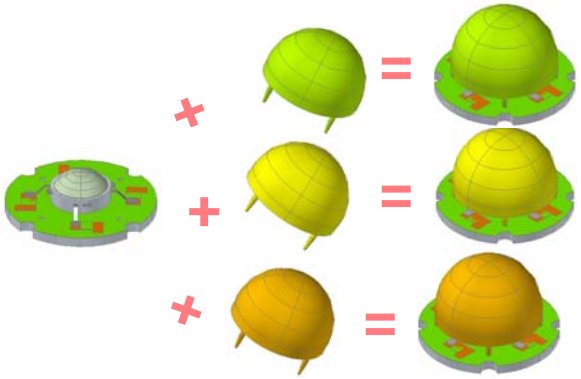
❑ Features & Advantages

- ✓Unique/low-cost fabrication processes
- ✓100% yield in CCT binning to guarantee low-cost packages
- ✓High color homogeneity in angular view
- ✓Almost 360° viewing angle
- ✓No glare & eye comfortable
- ✓High efficiency & High CRI
- ✓Long lifetime

✓100% yield in CCT binning to guarantee low-cost packages

Customers can ask for one specific CCT bin without price increasing, while competitors can double and even triple the price

- With one blue LED bin to create different colors

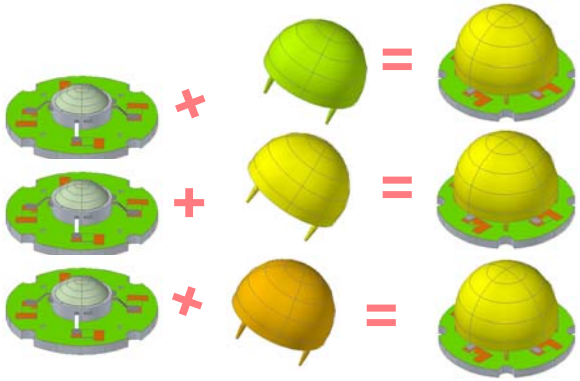


CCT=7500K

CCT=5500K

CCT=3500K

- With different blue LED bins to create the same color

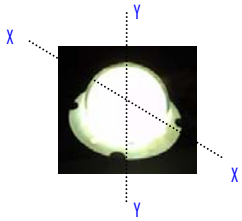


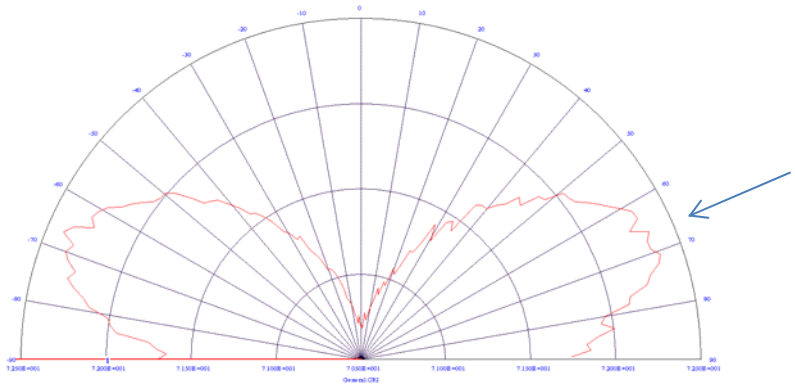
CCT=5500K

CCT=5500K

CCT=5500K

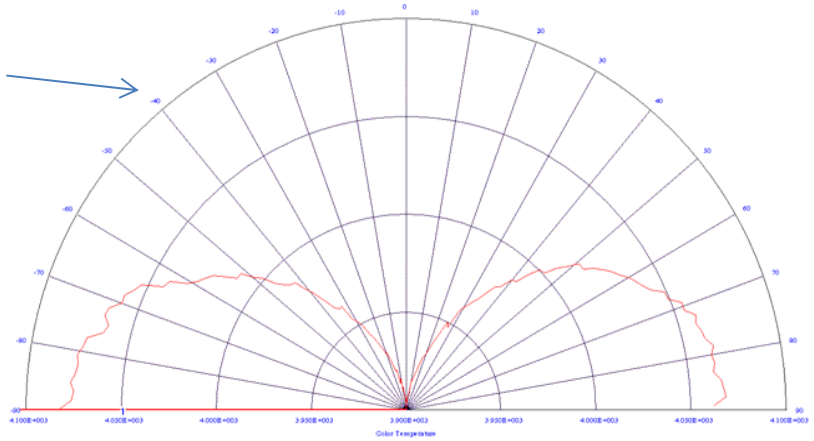
✓High color homogeneity in angular view



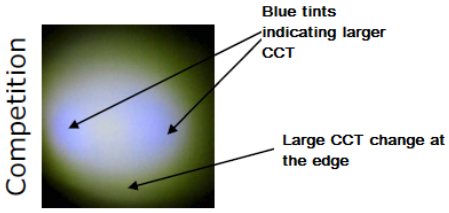


- ✓ The difference value of CRI over the viewing angle is < 2
- ✓ LEDs from competitors can have more than 10 shift over the viewing angle

- ➢ The difference value of CCT over the viewing angle is < 2 for cold white light
- ➢ LEDs from competitors can have more than 3500K shift the viewing angle



Vs



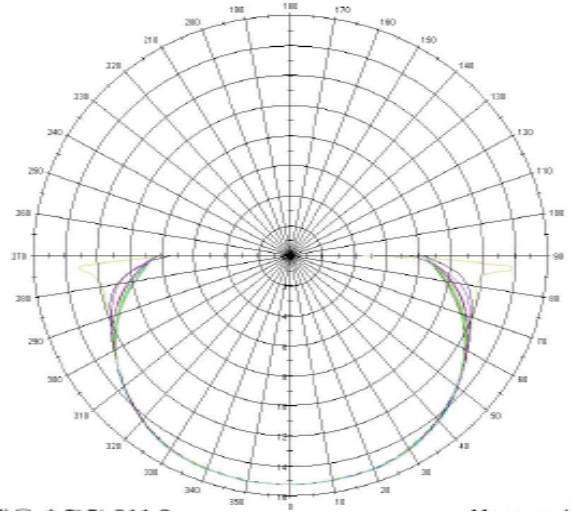
✓Broad viewing angle

- More flexible for optical design

NEPES LED

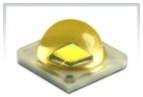
Φ19.6
SMT & CAP structure

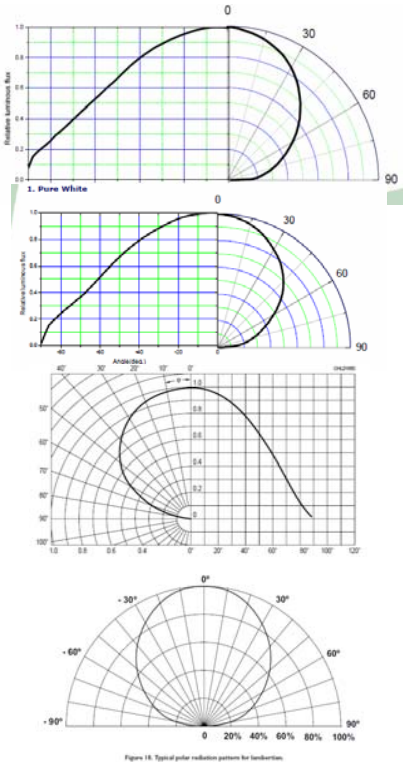
180 degree pattern



Conventional

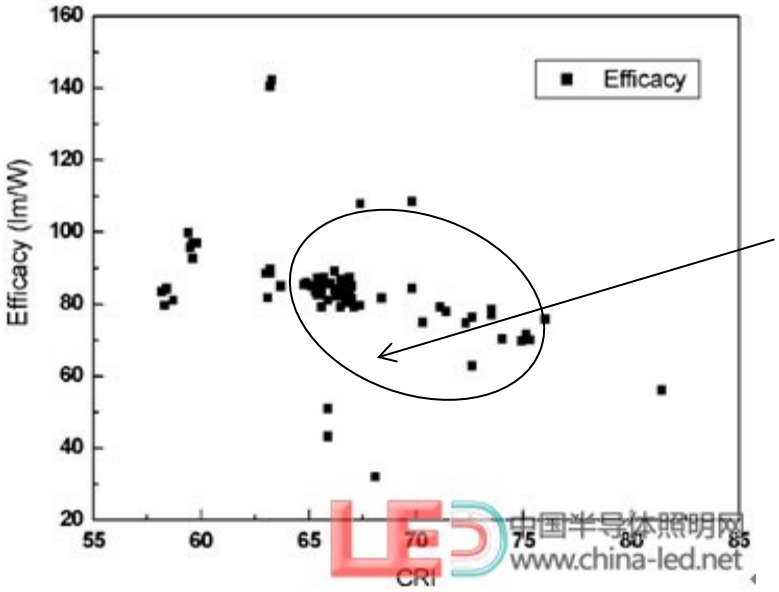
- SMT type
- 120~130 degree angle
  - need Lens to control the angle





✓High efficiency & High CRI

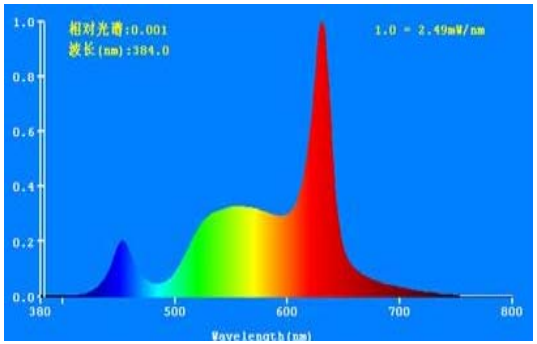
- Special optics to reduce phosphor scattering effect to enhance light extraction. **As a result, only ~10% efficiency loss when changing from cool to warm compared to up to 40% loss for competitors' products**
- Special/low-cost phosphor recipes to achieve high-CRI and high light efficiency. We can easily achieve CRI>85 and CRI>90 for all color ranges with only a little efficiency drop



- Most of commercial products have a CRI ranging from 65-75 only, and their efficiencies drops sharply when CRI increases above 75

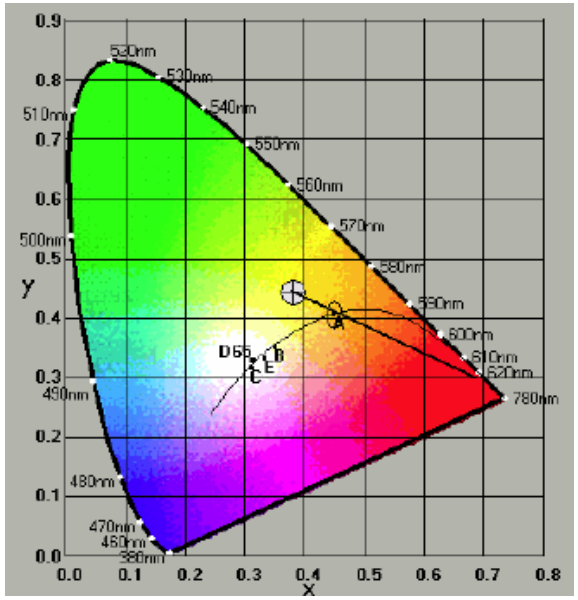
VII. Next G Method for High Quality/Efficiency Warm & Neutral RP-WLED

- HV chips (RB) + GY remote phosphor
  - Advantages
    - CRI>=85
    - No light output decrease compared to cool white
    - CCT Tunable
    - Enable high efficiency driver design
    - Color uniformity can be achieved with RP structure/optics while efficiency is maintained
      - ✓ High CCT angular uniformity
      - ✓ High CRI angular uniformity
      - ✓ High "quality" color rendering
    - Allow chip separation
      - ✓ Can optimize lifetime and color consistency over time by using chip/package arrangement
    - Possible for high CRI and high CCT (cold white)



Spectrum

White +Red Chip



Challenges & Future Outlook

- ✓ Full-spectrum WLED
  - ✓ High efficiency
  - ✓ Low cost

- ✓ "Smart" WLED with "real" tunable CCT, high efficiency and high quality
  - ✓ CCT can be changed from warm to cold
  - ✓ CRI is maintained
  - ✓ High efficiency
  - ✓ Coordinate is maintained on black-body curve

Source: NLPIP (lighting research center)

Thank You