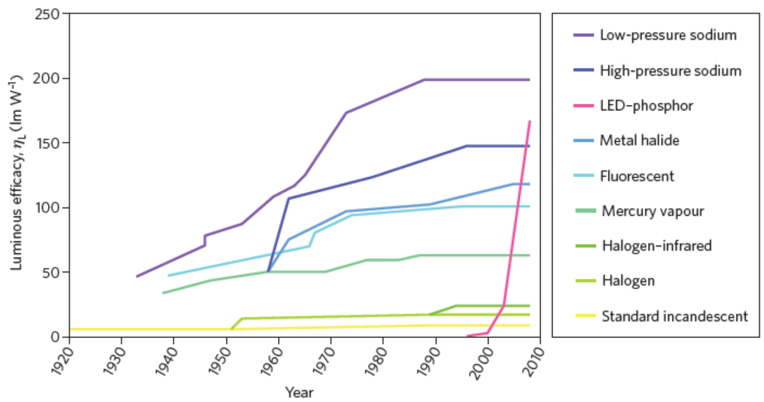
Phosphor Converted LEDs for Solid State Lighting: Materials Challenges and Advances

by Richard Zou
MSE 395
5.28.2009

Introduction to Lighting

- Electric lighting consumes 22% of electricity in United States
- General lighting technology has stayed fairly static
- Incandescent bulb
  - 2-4% efficiency from electricity to visible light
  - Must be replaced after 1000hrs of use

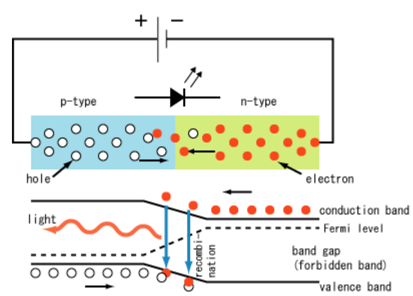
Enter Solid State Lighting

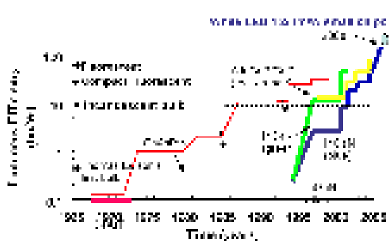


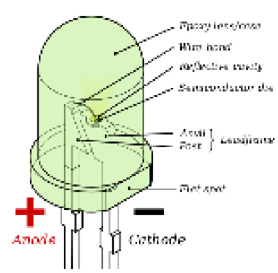
R&D level – 152lm/W Operating Lifetime of 100,000hrs

History of the LED

- Created in 1920s in Russia
- Basic p-n Junction with a voltage Bias
- Blue LED created in 1972(IGaN)

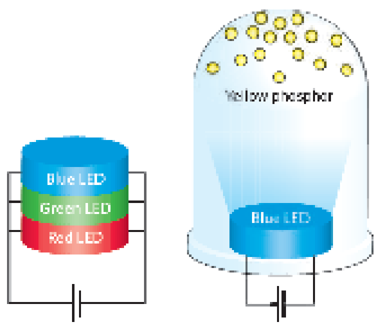


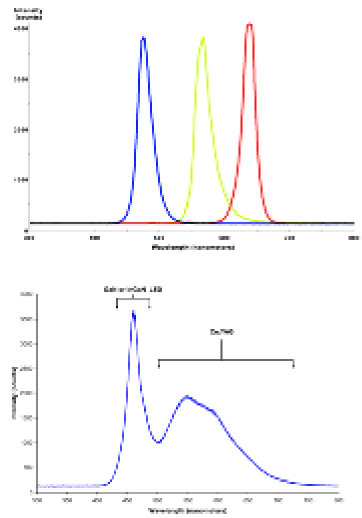




2 Methods to White Light LEDs

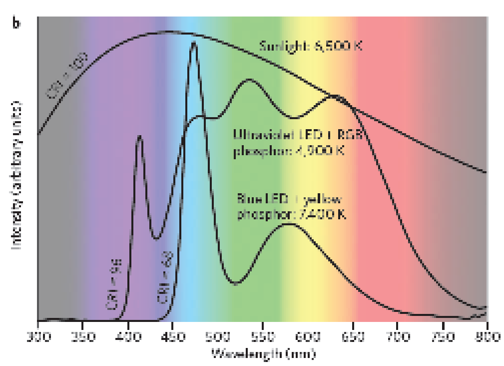
- RGB-LEDs
- pcLEDs





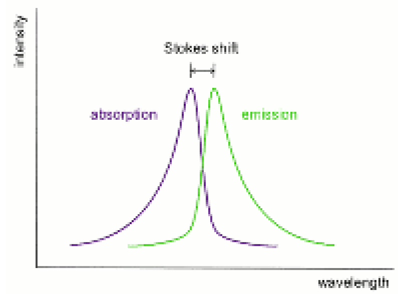
Key Performance Parameters

- Cost
- Stability
- Efficiency
- Color Character
  - CRI
  - Color temperature



Phosphors

- Activator – Ce^{3+} or Eu^{+2}
  - Short luminescence Delay
  - High required excitation density to saturate
- Host Lattice - sulfides, nitrides, silicates and garnets(YAG:Ce)
- Stokes Shift



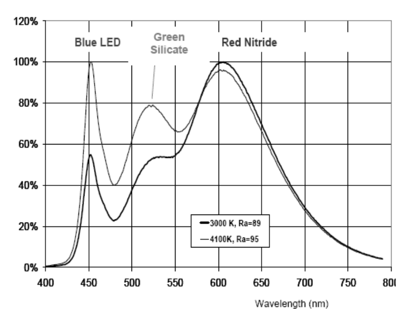
Creating Different Color Temperatures

	Efficiency			CRI
	25 °C	75 °C	125 °C	
Yellow Garnet	100%	96%	88%	70-80
Yellow Orthosilicate	96%	91%	70%	ca. 65

5000-6500K (Daylight White)

	Efficiency	CRI
(Garnet + Red Nitride) I	100%	80
(Garnet + Red Nitride) II	112%	75
(Garnet + Red Nitride) III	123%	70
TAG	116%	76
Orthosilicate 1	105%	63
Orthosilicate 2	128%	56

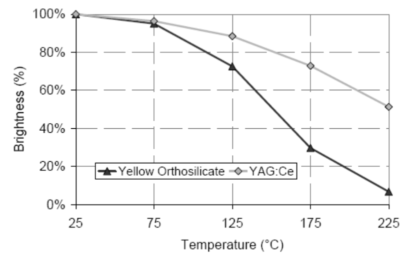
4000K color(Cool White)

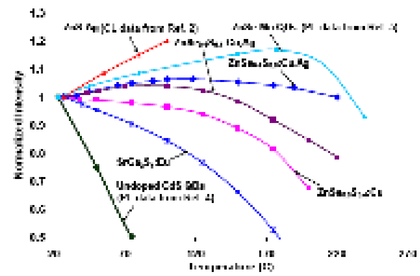


2700-3500K(Warm White)

Thermal Stability

- Need for higher operating temperature
- “Quenching” effect
- Ag/Cu doping “anti-quenching” controlled by conc
- Delamination

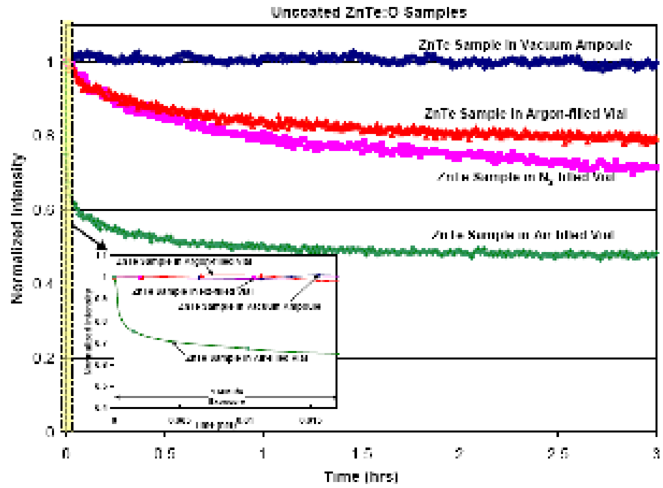




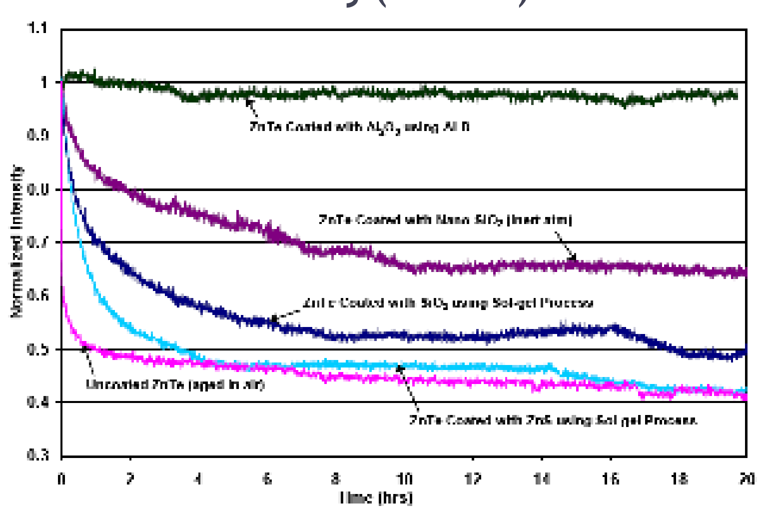
Chemical Stability

- Sulfoselenide Phosphors react with moisture, silver in contact leads
- Diffusion into silicone
- Issues with barriers(sol-gel or nanosilica)
  - Short lifetime
  - Nonconformal

Chemical Stability(cont.)



Chemical Stability(cont.)

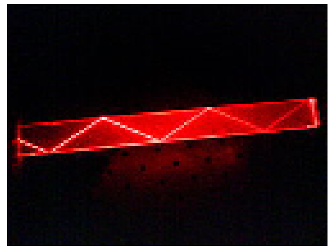


Refractive Index

- Speed within a Medium
- Total Internal Refraction
  - Higher to Lower Index

$$\theta_c = \arcsin\left(\frac{n_2}{n_1}\right)$$

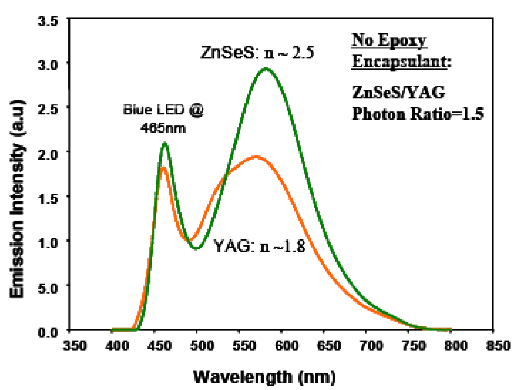
- Lowers light extracted by reflecting back into the chip or module



Laser in PMMA

Refractive Index of Phosphor layer

- IGaN/GaN index – 2.7
- ZnSeS increases extraction by 50%
- Include Polymer(1.4) 10% increase

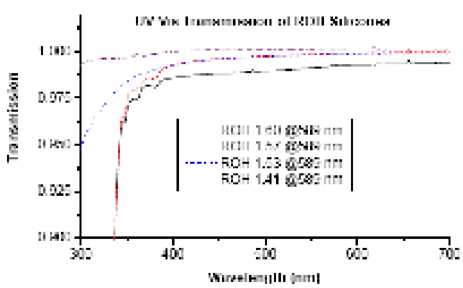


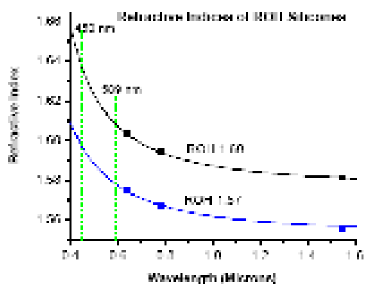
Refractive Index of Encapsulation

- Necessary Parameters
  - Operating temperatures of 120-200°C along with light fluxes of at least 100mW/mm²
  - High optical transmission(>90%)
  - Inert(to LED module components)
  - Low cost and Ease of manufacture

Silicone Encapsulation

- Epoxy – "yellowing", 1.4 index
- Silicone - 1.53 to 1.60 index, one-pot system





Conclusion

- Performance parameters
  - Lower cost, higher efficiency, higher intensity, higher CRI, and variable color temperature.
  - Limited by stability and active material
- Solutions
  - Research into more phosphor materials
  - “Anti-quenching”
  - Chemical Barriers
  - Refractive Index