Improvement of energy efficiency and lifetime of Cathodoluminescence (CL) phosphors coated with nanoscale ZnO films using Atomic Layer Deposition (ALD)

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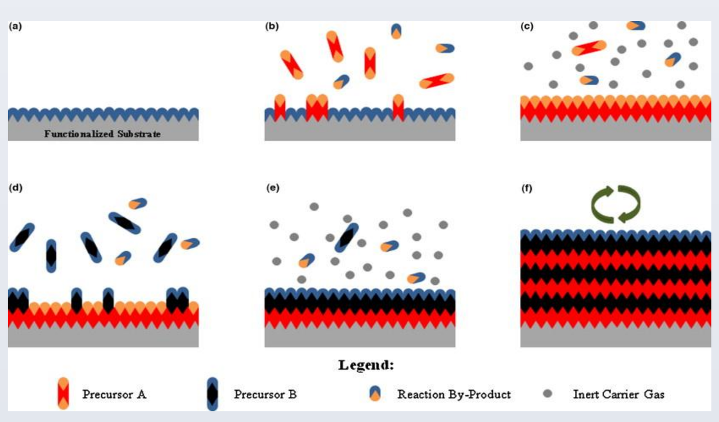
Objective

- Demonstrate that Coated Trichromatic (RGB) Phosphors with ZnO Using ALD methods improve efficiency, lifetime, good spectrum, thermal and electrical conductivity of commercial phosphors and white-mixture of phospor for Field Emission display and lighting sources

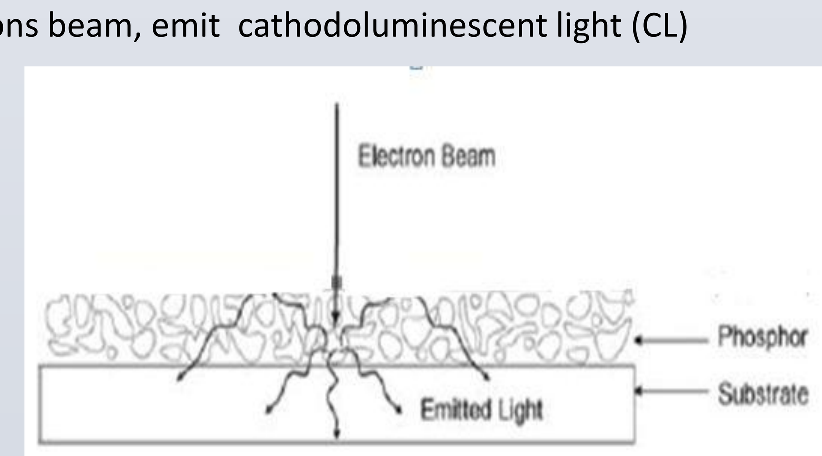
Atomic Layer Deposition



ALD provides unique features such as precise thickness control of ZnO thin films with atomic resolution, high uniformity and absolute conformity. ALD is capable of coating complex surface morphologies, capable to penetrate minute voids minute voids to passivate the surface of the particle [Minoru]

CL Phosphor

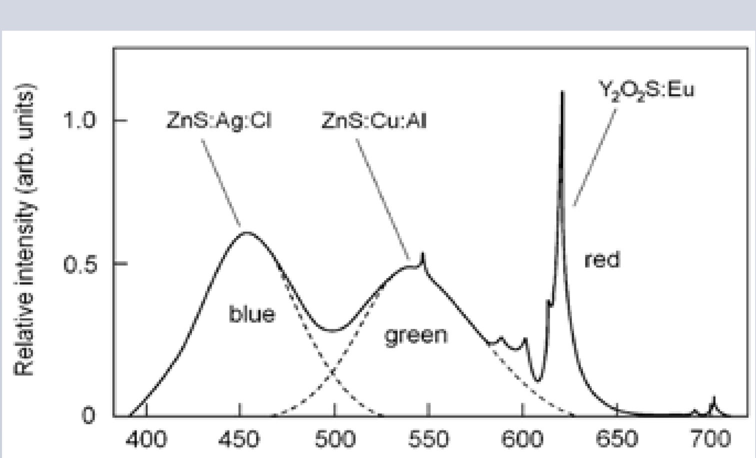
Arrangement of particles (nm-µm), under irradiation or stimulation from electrons beam, emit cathodoluminescent light (CL)



Cross-sectional drawing of a powder phosphor

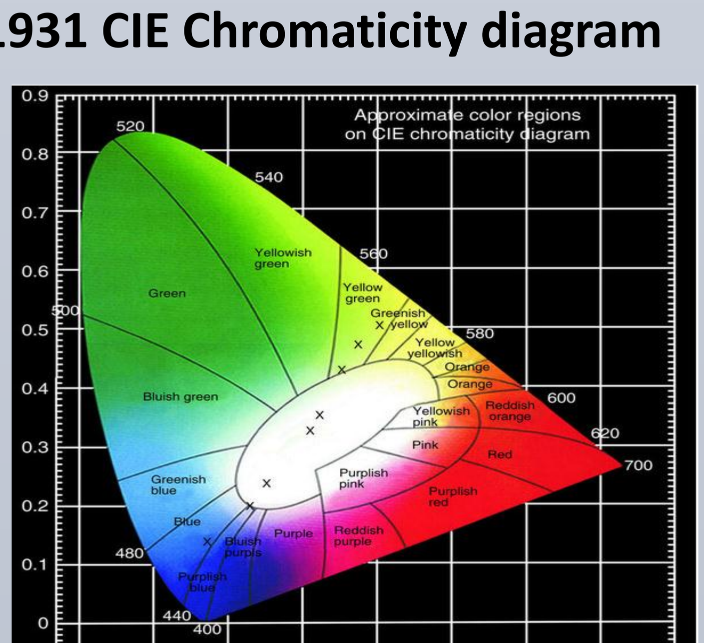
Phosphor spectrum & chromatic visions

Contrary to popular belief, "color" is not really an intrinsic property of the things we see around us. Rather, it is the sensation resulting from a given spectral distribution of light, detected by the three color-sensors in the eye and interpreted by the brain.

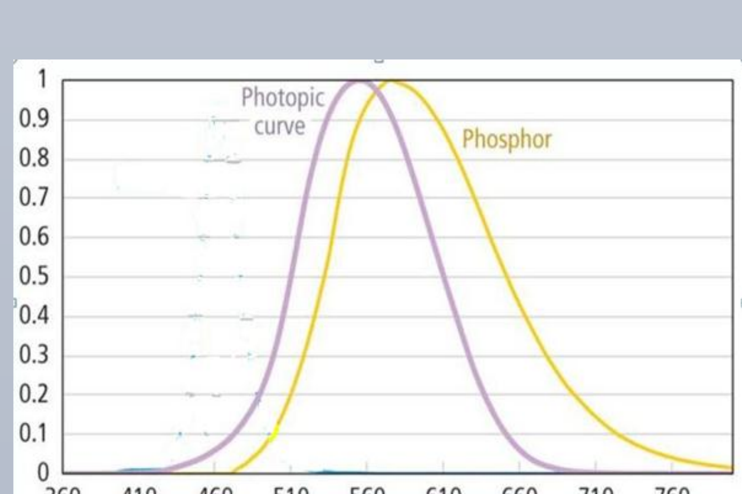


Luminescence spectrum and intensity peak of CL consisting of ZnS:Cu:Al(green) (450nm) ZnS:Ag:Cl(blue)(550 nm) and Y2O3S:Eu(red) (611 nm)

1931 CIE Chromaticity diagram



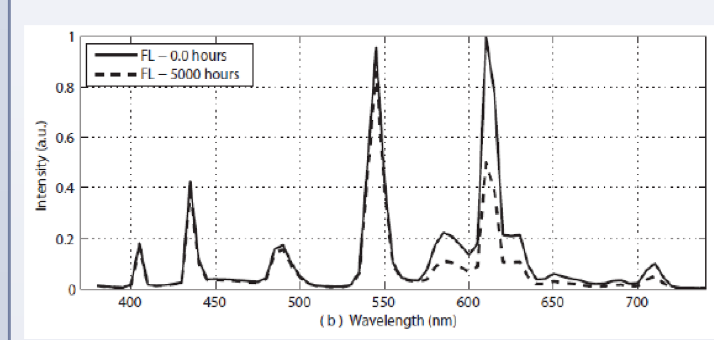
The chromaticity diagram plots the entire gamut of human-perceivable colours by their *xy* coordinates defined earlier.



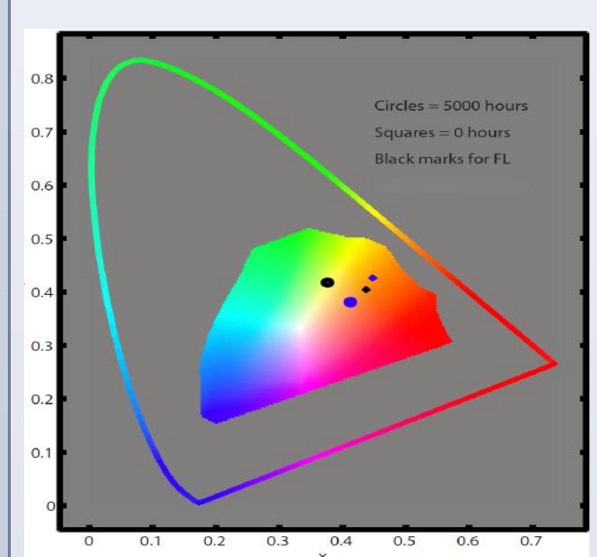
Eye sensitivity is what drives the use of efficacy measured in lumens per watt as the primary figure of merit rather than efficiency. The emission spectrum of the phosphor lines up well with the eye spectral response curve, V(λ).

LIMITATION OF CONVENTIONAL METHODS

Phosphor degradation



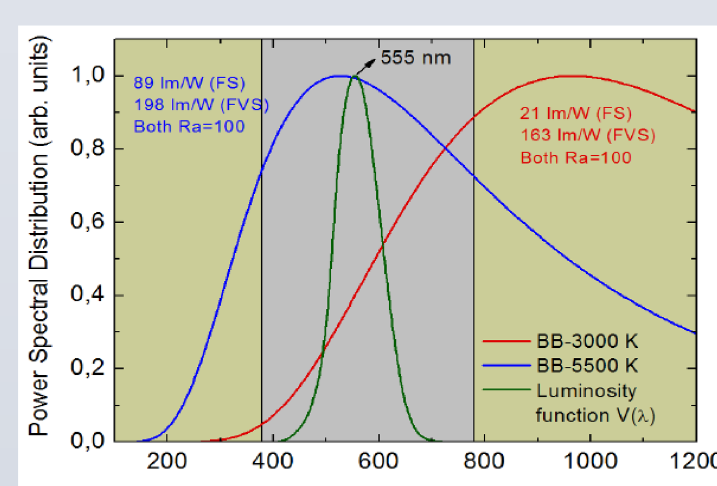
The spectrum content shift



•The chromatic Shift in color space

Plankian Spectral Standards

Incandescent "Soft- light" (3500K) very inefficient : most of wavelength in IR spectrum
Natural-light daylight (5500K): best acuity & minimal eye fatigue



Poor Phosphor Efficacy)

Unavoidable Loss mechanisms

1. Energy conversion from an electron flood to light emission
2. Degradation of phosphor efficacy due to heat
3. Loss of efficacy due to over-charging on the phosphor materials
4. Capture of the electron source current by non-luminescent materials
5. Non-luminescent electronic processes in the phosphors
6. Loss due to non-optimal screening techniques

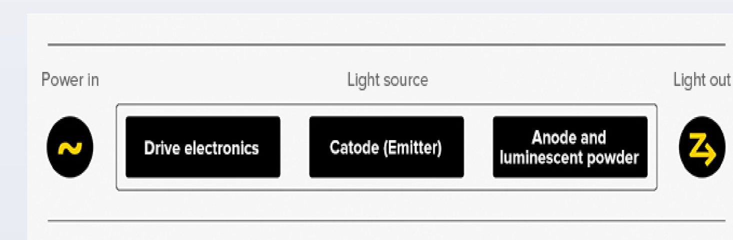
Color	Wavelength λ-nm	Host/LC	Efficiency η max [Lm/W]
Red	611	$Y^2O^3:Eu^{3+}$	59
Red	626	$Y^2O^2S:Eu^{3+}$	89
Green	530	ZnS:Cu,Al	157
Blue	450	ZnS:Cl,Ag	43
White-Mixture		R:G:B=0.7:0.22:0.08	108.3

Limitation of conventional phosphor coating

- Surface defects-Trapping centers
- Poor electrical charge dissipation
- Poor thermal dissipation due to phosphor excess stored heat (phonons)
- Use of non-luminescence binders for adherence
- Poor electrical conductivity
- Results:
  - ✓ diminished efficacy
  - ✓ diminished lifetime
  - ✓ Poor Color quality
- ZnO coating layer too thick and defective causing electron charge-up of phosphor & Poor Heat dissipation
- Phosphors aging (coulomb aging) due to high power density
- Contamination of phosphors:
  - ✓ O_2 forms recombination center (Ag-O) in ZnS particles which gives rise to additional luminescence band on the long-wavelength side of the main blue band of Ag-Cl pair recombination centers.

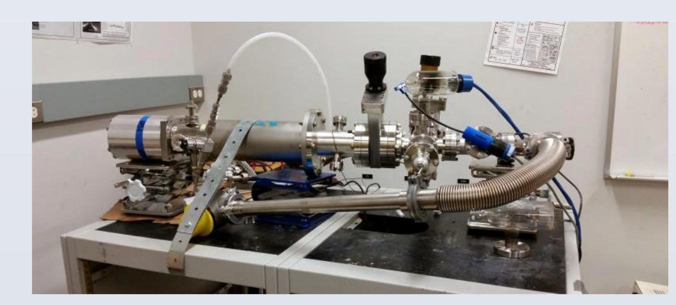
Experiments

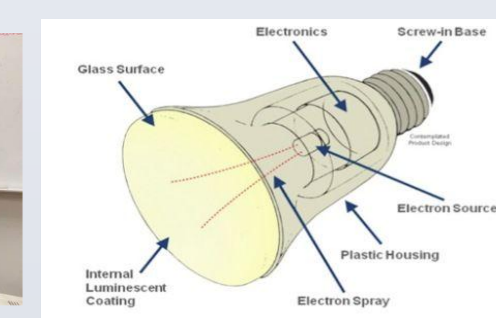
BASIC PRINCIPLES:
Our research is based on two physical phenomena: FEL and CL phosphors coated with ZnO using ALD. Light is created by generating electron beam from electron gun in the center of the lamp. Electrons emitted from the cathode, strike the layers of luminescent CL phosphor screen deposited on the surface of the lamp, creating light as described in figures [1]below.

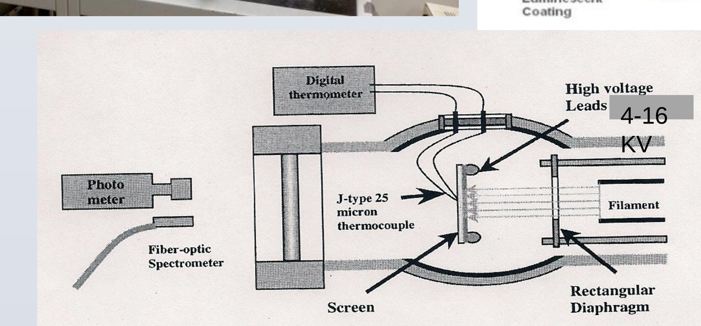


VACUUM SYSTEM & TEST SET UP

Light bulbs have vacuum inside them. This vacuum system is like a big light bulb. which allows swapping out and testing phosphor screen samples with ease, so we can try many different samples to get just the right white color, brightness, lifetime, efficiency..





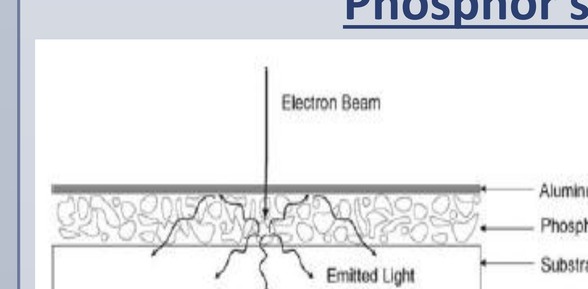


DATA: Characterization & Measurements

Characterize and compare ZnO coated vs. uncoated phosphors at accelerating voltage of 10,14,16kV
Measurements:

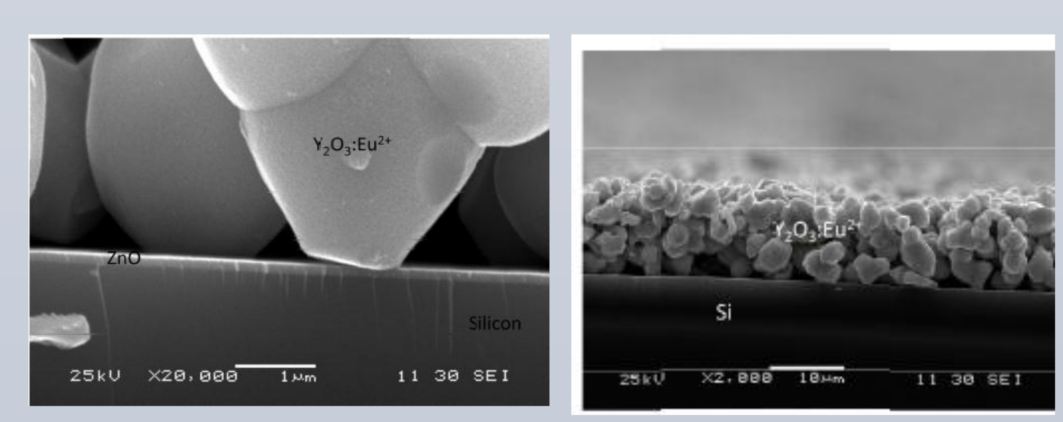
- conductance for electrical conductivity
- Efficacy vs. power density for energy efficiency
- Intensity vs. voltage anode for luminescence

Phosphor screen deposition

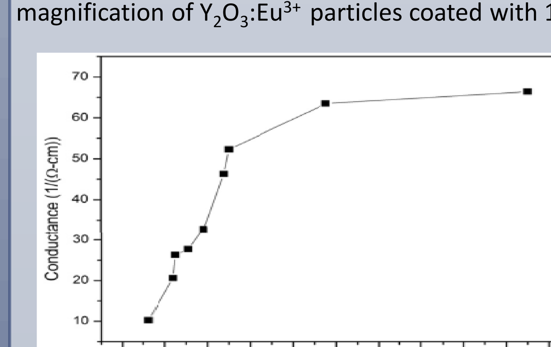


Cross-sectional drawing of a powder phosphor scree [Talbot]

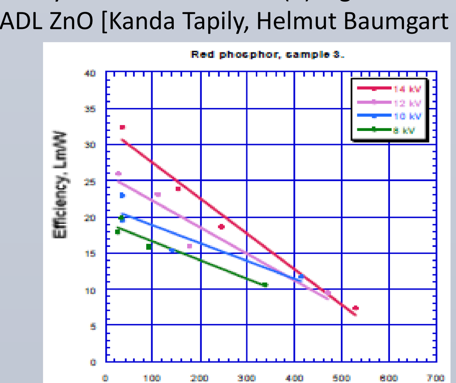
Phosphor is deposited on a glass substrate using liquid gravity settling. Small amount of binder is added to adhere phosphor to glass. After drying, lacquer is applied on top of phosphor which assists with deposition of Al film. Lacquer is removed/baked in a furnace. The samples are tested for spectral content and luminance



SEM image of (a) loosely packed $Y_2O_3:Eu^{3+}$ particles deposited by sedimentation and (b) higher magnification of $Y_2O_3:Eu^{3+}$ particles coated with 100nm of ADL ZnO [Kanda Tapily, Helmut Baumgart



. Conductance of ALD ZnO vs ALD cycle. ZnO Conductivity increases as the coating thickness is increased



Typical efficacy vs Power Density Plot of Y2O3:Eu red phosphor

SUMMARY

Advantages of Coating with nanoscale ZnO ALD improve efficacy and lifetime.

- Use of of luminescence material as binders thus causing luminescence process within ZnO itself
- ZnO (thermal conductor) dissipate heat from phosphors.
- Mitigation of phosphor degradation by reducing aging
- ZnO good electrical conductivity .,
- nano-scale ZnO coating passivates the surface states of the phosphor by filling minute voids of phosphor screen.