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# A Guided Tour of SSL Area Light Sources – Past, Present and Future


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**May 10, 2012: 8:30–10:00 AM**

PRE-CONFERENCE
LIGHTFAIR Daylighting Institute®
LIGHTFAIR Institute®
Monday, May 7 –
Tuesday, May 8, 2012

TRADE SHOW & CONFERENCE
Wednesday, May 9 –
Friday, May 11, 2012

Las Vegas Convention Center
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In collaboration with The Illuminating Engineering Society

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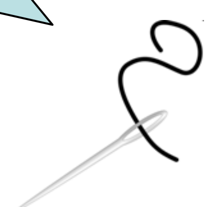
# Learning objectives

1. Fundamental principles of luminescence
2. Technologies for area SSL sources
3. Metrics and how these technologies compare
4. What of applications they enable and how they will impact future luminaire design

<u>Throughout this seminar, we'll use symbols to call out key concepts and common threads.</u>

# Overview

- Why area light source (JF)
  - Introduction
  - Metrics
- SSL area sources and technologies (ML)
  - Basic Physics
  - Detailed examples
  - Summary
- Lighting Application (JF)
- Conclusions

# Why area light source

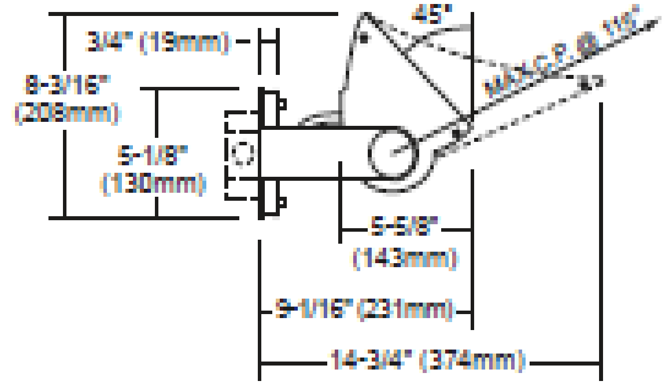
Architecture: Smallwood, Reynolds, Stewart and Associates
Lighting: Terry Bell / CD+M Lighting Design Group, LLC
Photography: Paul Warchol

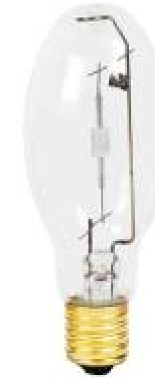
**Architecture: Gensler**
**Lighting: Darrell Hawthorne / Architecture & Light**
**Photography: Nic Lehoux**


Architecture: Centerbrook Architects and Planners
Lighting: ARUP / Atelier Ten
Photography: Robert Benson

Lighting: Jeff Wilson / Phos Lighting
Photography: Ashley Campbell

Project: McCormick Convention Center
Architecture: Thompson, Ventulett, Stainback & Associates, Inc.
Lighting: Fisher Marantz Stone, Inc.
Photography: Steve Stoneburg



**Design Intent:** Illuminate grand space using curved luminous surface to accentuate architecture

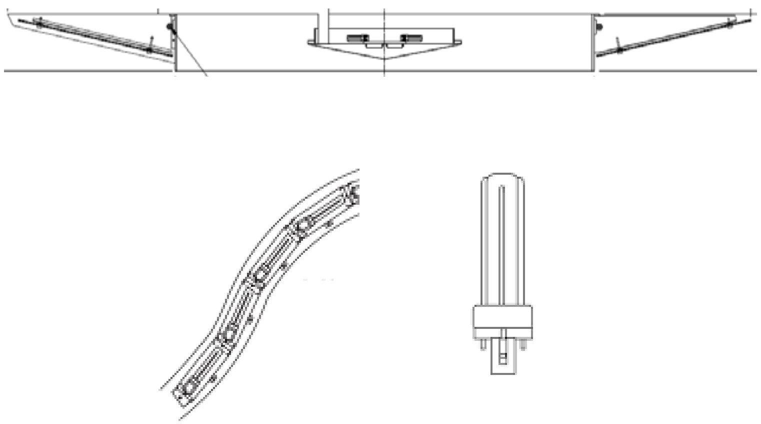
**Luminaire:** Wall-mounted indirect ceramic metal halide

**Lamping:** 2 – 400W ED28

**Luminaire efficacy:** 70 lm/W

**Implementation:** Each luminaire weighs over 60 lbs and requires 2 remote ballasts mounted in ventilated area

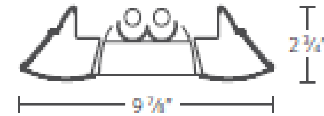
Project: Central Chicago Police Headquarters
Architecture: Lohan Caprile Goettsch Architects
Photography: David Seide



Design Intent: Provide visual hierarchy and orient patrons using large luminous surface and illuminated sculpture, both of which provide general illumination

Luminaire: 18' dia custom pendant and concealed architectural cove lighting
Lamping: 42W Triple Tube CFL – 38 in pendant; 144 in cove
Luminaire efficacy: 70 lm/W
Implementation: 1200 lb custom luminaire in finely detailed and complex installation

Project: Corporate Environments
Lighting: Morgan Gabler, Gabler-Youngsten Architectural Lighting Design
Photography: John Williams



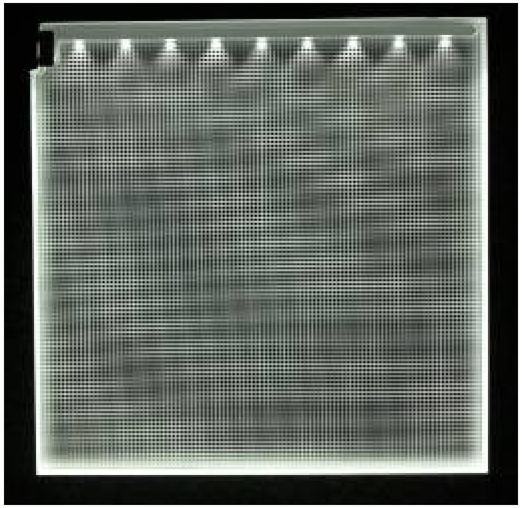
Design Intent: Use floating luminous surface to provide comfortable and diffuse illumination while preserving visual rawness of the building infrastructure
Luminaire: Pendant indirect-direct linear fluorescent
Lamping: 2 – T5HO per 4’
Luminaire efficacy: 76 lm/W
Implementation: Requires installation of floating ceiling clouds and independent seismic bracing of ceiling clouds and luminaires - while visual mass of luminaires is minimal, the practical solution compromises the design intent

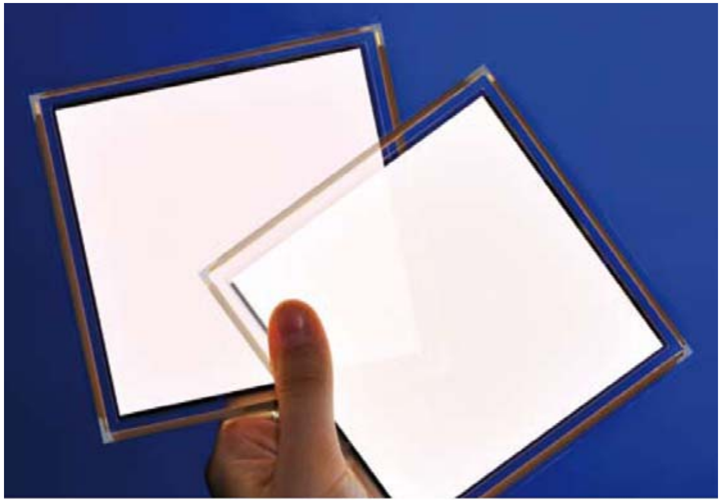
# Why area light source

- We have illustrated a historical perspective of the desire for and implementation of area light sources using “virtual” approaches.
- Later we will explore how actual area light sources may be realized.
- But first let’s define how to evaluate these technologies.

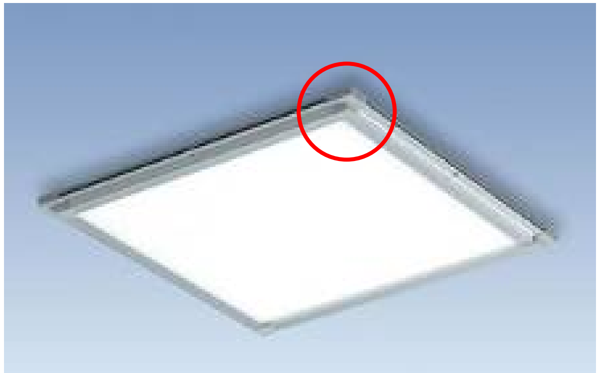
# Metrics

- Efficacy
- Lifetime
- Light quality
  - CRI (Ra and R9), CCT, Duv
  - Color consistency within the panel and as a function of viewing angle
  - Uniformity within the panel and panel-to-panel
  - Appearance/pixelation





# Metrics



- Form Factor
  - Thickness
  - Size
  - Border width
- Cost per area and per kilolumen
- Technology Maturity and Promise
  - Industry participation
  - Manufacturing presence
  - Product/sample availability
  - Long-term projections and theoretical limits
- Other
  - Flexibility
  - Transparency
  - Off-state appearance
  - Robustness
  - Thermal
  - Driver
  - “Green”

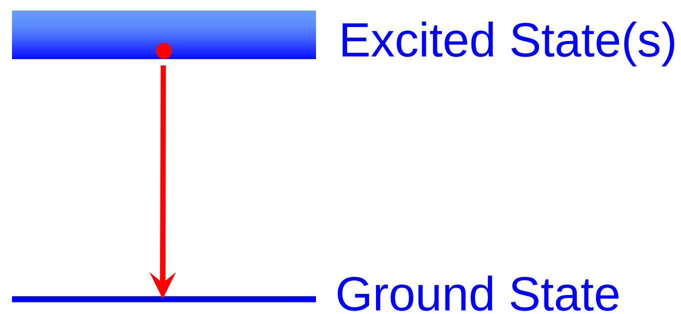
# SSL Area Sources and Technologies

- Basic physics – different kinds of "luminescence"
- SSL area sources and evaluation metrics
  - Thin film EL
  - Edge-lit LED flat panels
  - OLED
  - Micro-plasma
  - Printed Micro LED
  - Quantum Dot LED (QLED)
- Summary comparison

# Luminescence

Basic Physics

Energy Diagram




An excited particle (atom or molecule) can only lose its extra energy in a few ways:

- ❑ Generate heat
- ❑ Transfer the energy to another particle
- ❑ Break apart
- ❑ Emit light: luminescence

NOT low temperature aka Incandescence

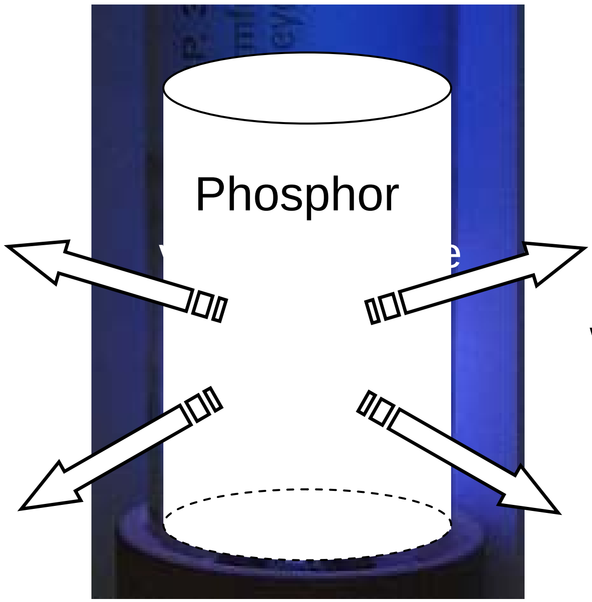
*The low-temperature emission of light (as by a chemical or physiological process)*

*– Merriam-Webster Dictionary*

# Different Kinds of Luminescence

Basic Physics

- Photoluminescence
  - The emitting specie is excited by high energy photons.



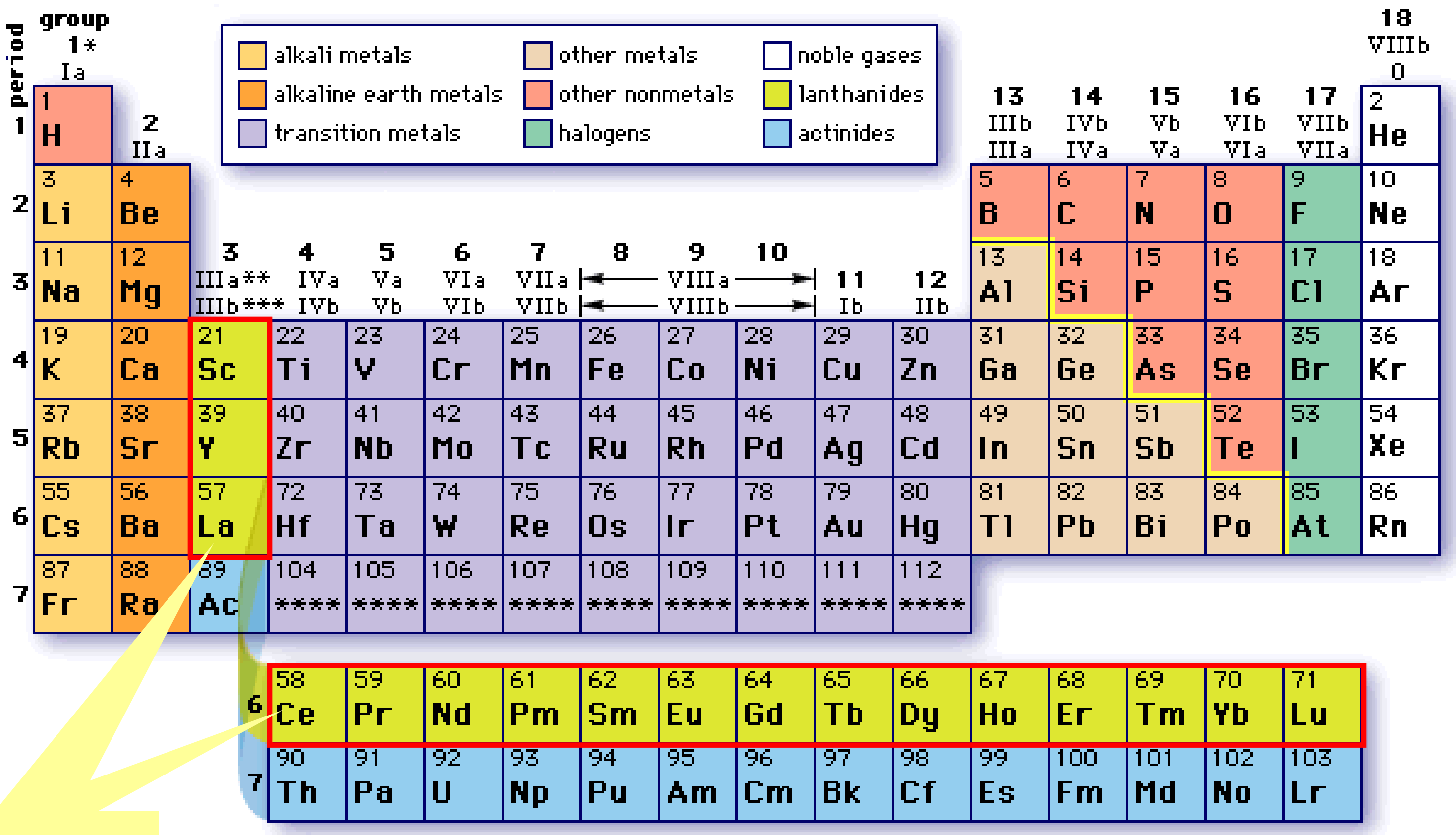

White Light

Uses rare-earth phosphors:

E.g., Tb, Ce:La$PO_4$, Eu:$Y_2O_3$

Fluorescent Lamp

# Rare Earth Elements



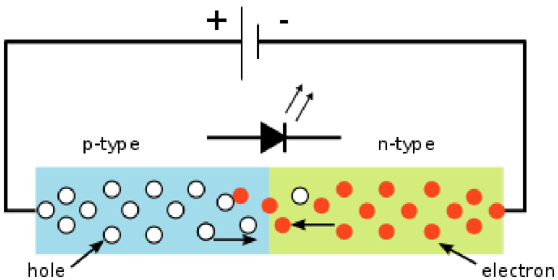

Rare Earth Elements

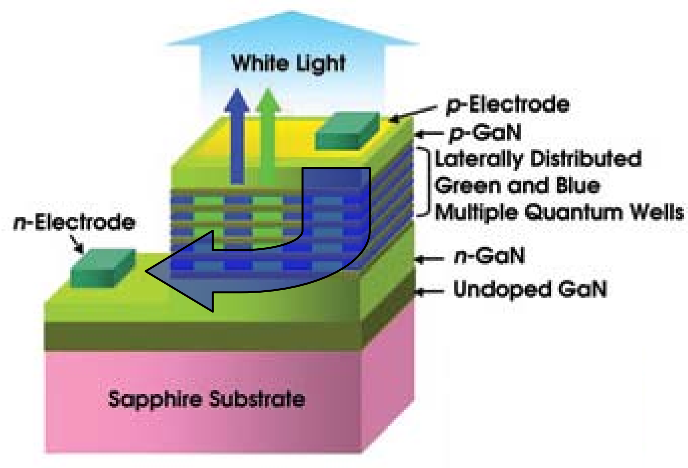
# Different Kinds of Luminescence

Basic Physics

- Photoluminescence
- Electroluminescence
  - The emitting specie is excited as the result of passing an electrical current or applying an electrical field.

Early *pn* junction LED



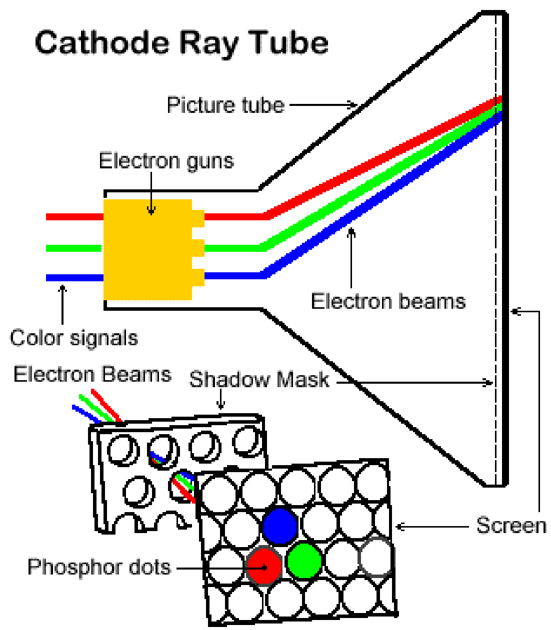

Today's high brightness LED

Phosphor converted LED:
Blue LED + yellow-green phosphor (Ce:$Y_3Al_5O_{12}$)

# Different Kinds of Luminescence

Basic Physics

- Photoluminescence
- Electroluminescence
- Cathodoluminescence
  - The emitting specie is excited by an electron beam.




RGB phosphors:

$Y_2O_2S:Eu+Fe_2O_3$

$ZnS:Cu,Al$

$ZnS:Ag+Co\text{-on-}Al_2O_3$

# Different Kinds of Luminescence

Basic Physics

- ❑ Photoluminescence
- ❑ Electroluminescence
- ❑ Cathodoluminescence
- ❑ Chemiluminescence
  - ❖ Emission of light with limited heat, as the result of a chemical reaction.

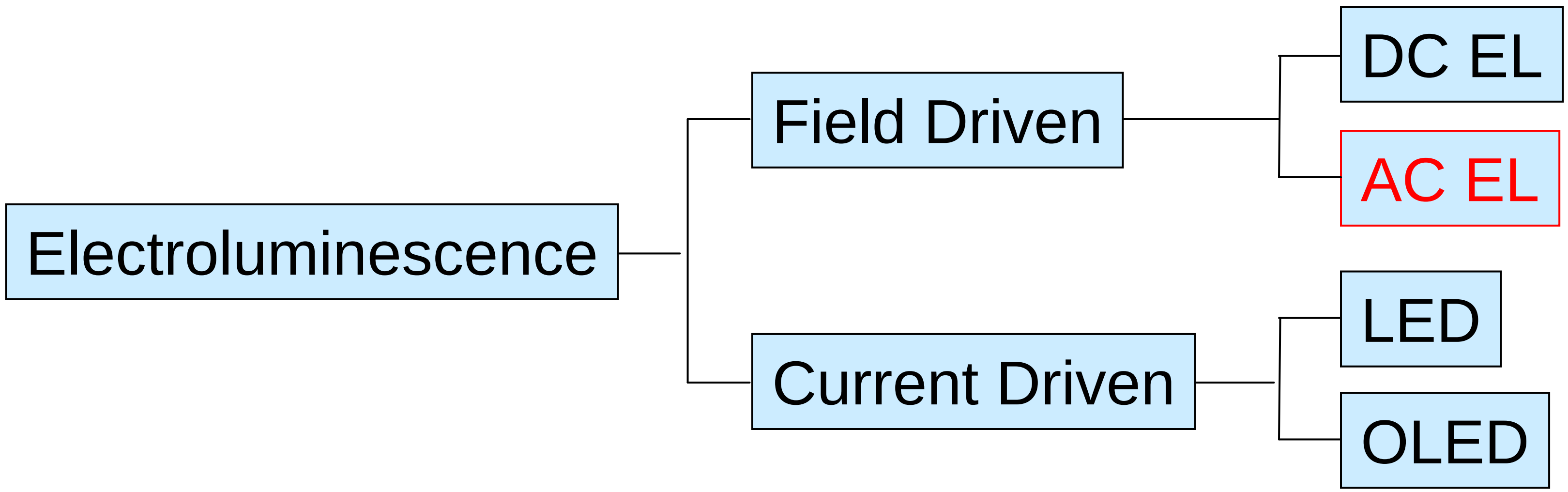
NOT limited heat
aka Combustion

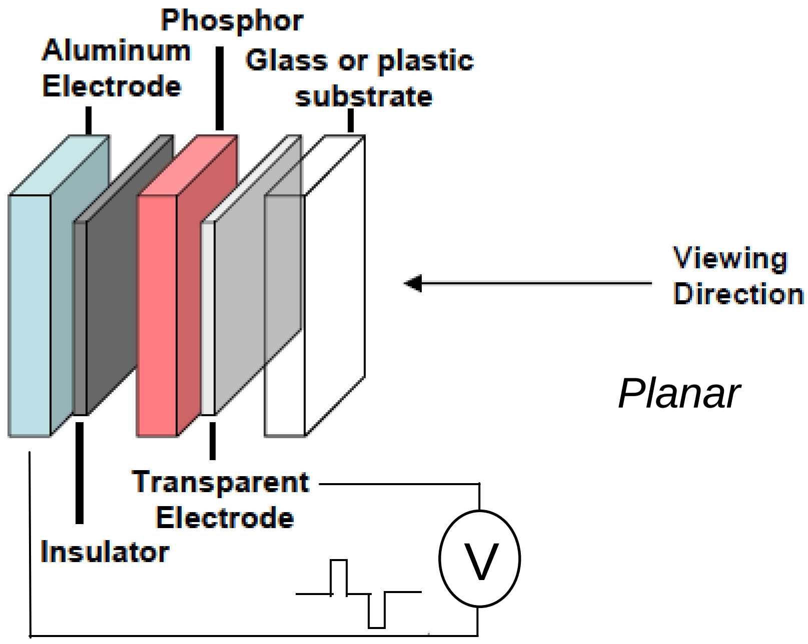
# Different Kinds of Luminescence

- Photoluminescence
- Electroluminescence
- Cathodoluminescence
- Chemiluminescence
- Other mechanisms
  - Radioluminescence: excitation by radiation (alpha, beta)
  - Sonoluminescence: excitation by sound (collapsing a bubble)
  - Bioluminescence: excitation by cellular activities
  - Triboluminescence: excitation by breaking bonds in a material

In the era of electric lighting, the dominant mechanisms are photo- and electro-luminescence.

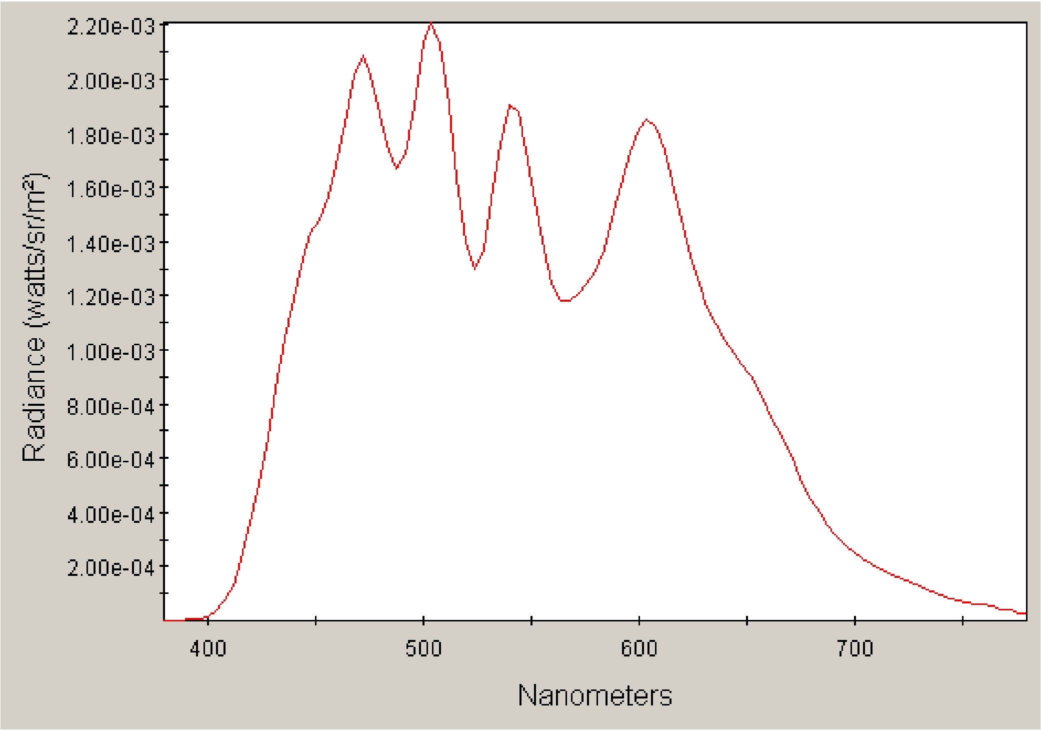
# Electroluminescent Panel




- Essentially a parallel plate capacitor with a layer of phosphor in the middle
- AC voltage results in a sheet of charge “sloshing” back and forth exciting the phosphor layer which emits light.

# Electroluminescent Panel – Properties

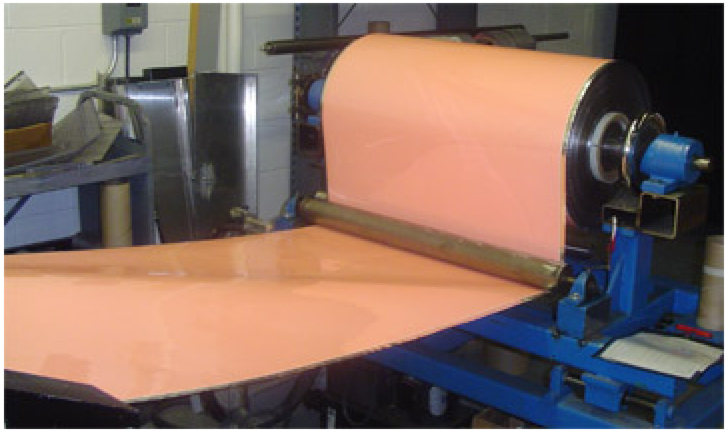



Luminance 110 cd/m$^2$
CCT 5813K
CIE (0.325, 0.353)
Duv 0.009
CRI Ra 91, R9 62

- Emission is from a typical SrS:Ce/ZnS:Mn phosphor. Duv is higher than optimal. Color rendering is very good.
- Luminance is dependent on the frequency of AC voltage.
- $L_{70}$ on the order of 1000 hrs. Luminance decay is exponential and a function of luminance.

# Electroluminescent Panel – Pros and Cons

- Pros
  - Large area, flexible
  - Inexpensive
  - Mechanically robust



*E-Lite*

- Cons
  - Low luminance/lifetime
  - Poor color quality for general lighting

*E-Lite*

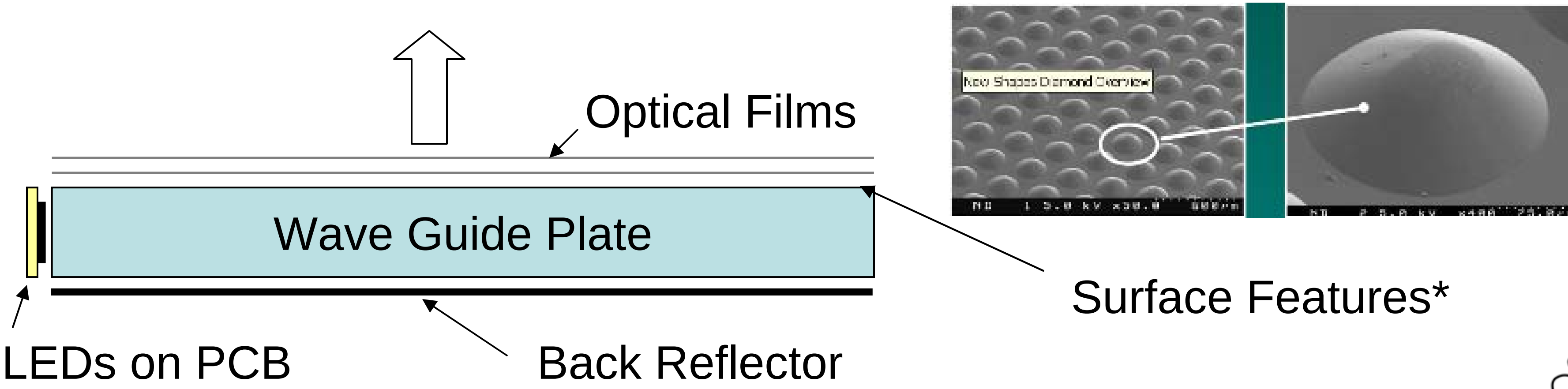
# Electroluminescent Panel – Application & Future

- Current Applications
  - Nightlight, egress lighting
  - Architainment
- Other EL applications
  - LCD backlight
  - TFEL displays
- Future for general lighting
  - Limited


*E-Lite*


*Planar*

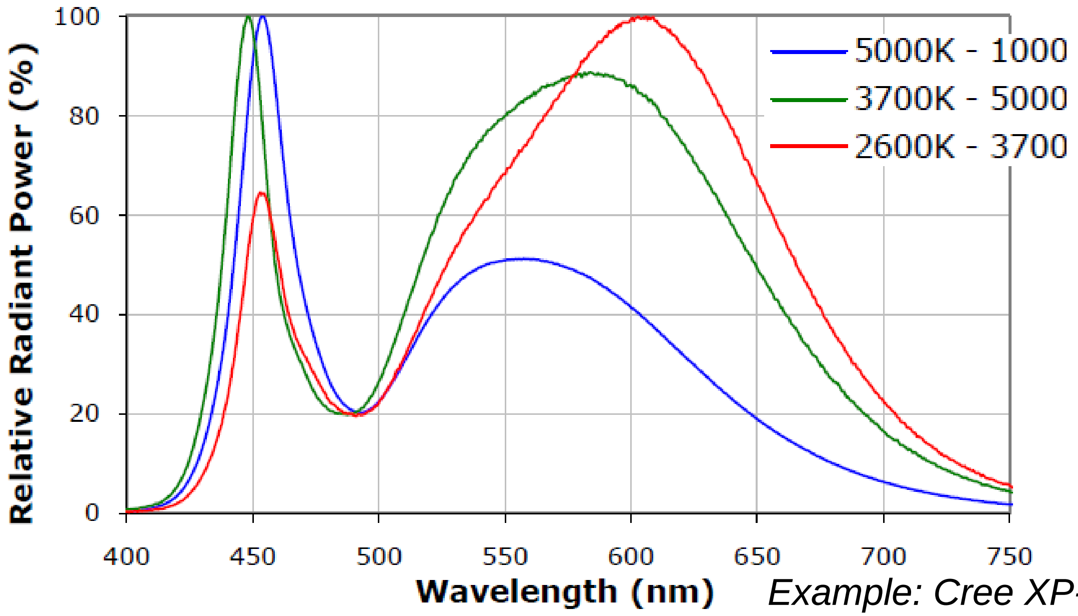
# Edge-Lit LED Flat Panel




- Originated from LED backlight technology in LCD displays.
- Emission from LEDs at panel edge is coupled into the waveguide, propagates and is scattered by surface features (v-groove, microlens).
- Coupling efficiency (panel output/LED output) varies widely from 55-95%.
- Waveguide thickness varies from many millimeters to 250 microns.

**K. Drain, Rambus, DOE SSL R&D Workshop, Feb 2011*

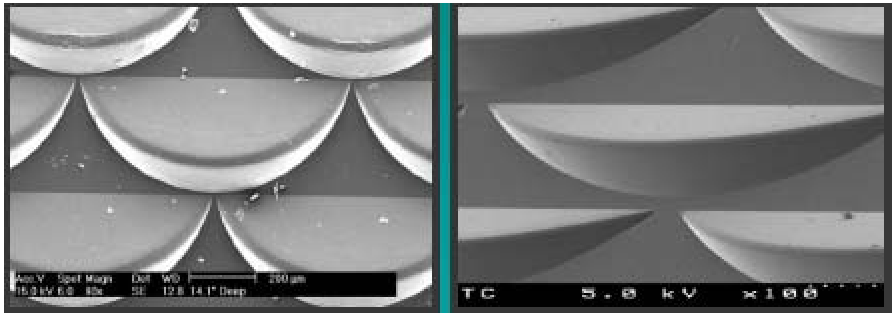
# Edge-Lit LED Flat Panel– Properties



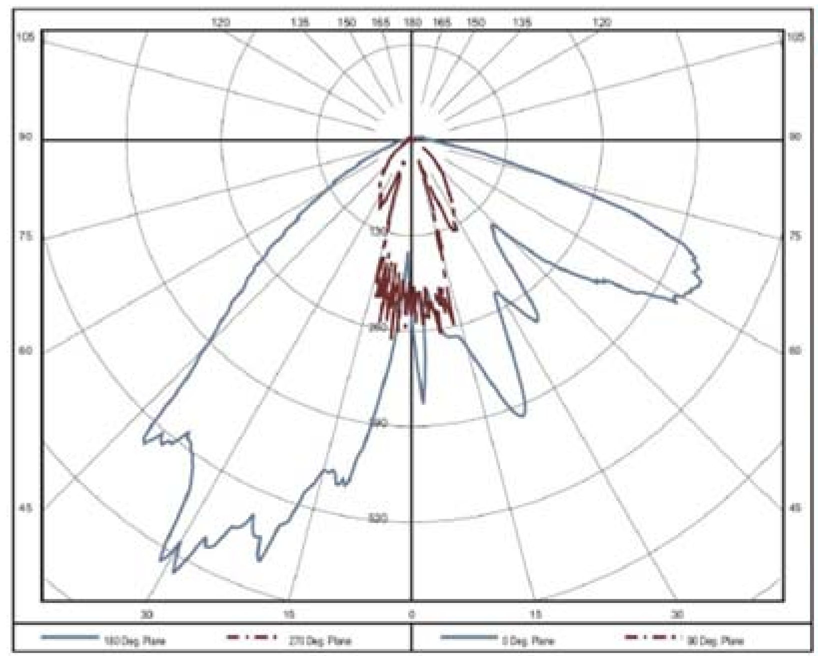

*Example: Cree XP-G*

- Emission spectrum is by-and-large the same as the LEDs used.
  - It is possible to use both cool and warm white LEDs and have a CCT tunable source (e.g. LG Innotek), or to use RGB LEDs and perform color mixing within the waveguide.
  - Since tens or even hundreds LEDs may be used, tight binning of individual LEDs is not as critical to panel-to-panel color matching.

# Edge-Lit LED Flat Panel– Emission Angle Control




Asymmetric microlens and resulting photometric distributions*



- One advantage of the microlens approach is the possibility to steer emission by change profiles of the microlens.
- Alone or in combination with additional optical films it’s possible to realize high angle cut-off for glare control and bat-wing distribution for indirect, volumetric lighting.

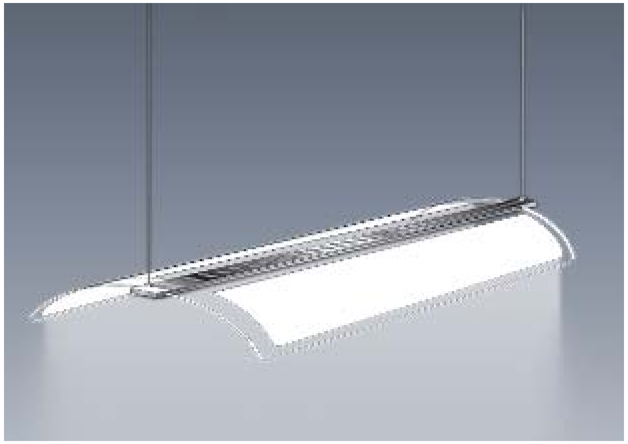
**K. Drain, Rambus, DOE SSL R&D Workshop, Feb 2011*

# Edge-Lit LED Flat Panel– Design Possibilities

*Kite, Peerless*

*GE*

*Rambus*

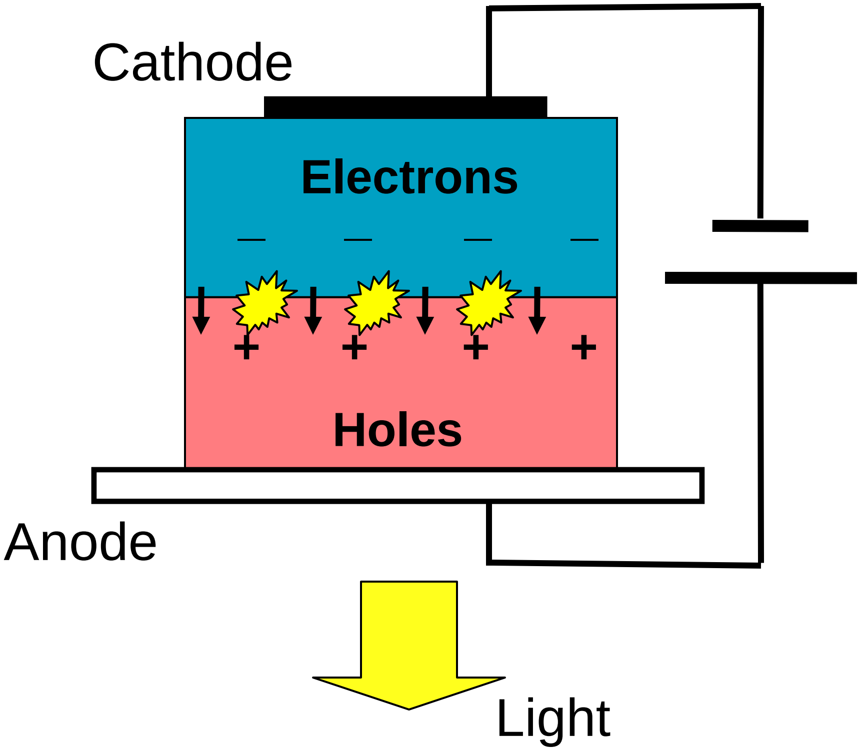


*Rambus*

# Edge-Lit LED Flat Panel – Pros and Cons

- Pros
  - Harness the rapid development of LEDs in both performance and cost.
  - Versatility in photometric distribution control
  - Possibility for curved surfaces
- Cons
  - Coupling efficiency around 60% for the most available architecture; need many “tricks” for the best coupling efficiency.
  - Border width, WGP thickness vs. performance trade-off
  - Flexible WGP performance uncertain
  - Possible to do truly arbitrary shapes?
- Future
  - Certainly will be a major area source technology

# Organic Light Emitting Diode (OLED)

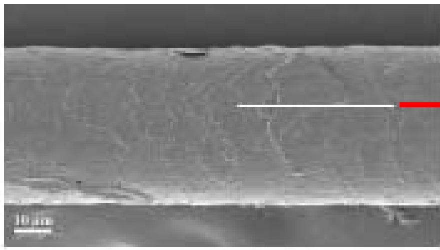



LG 55” OLED TV

Samsung 55” OLED TV

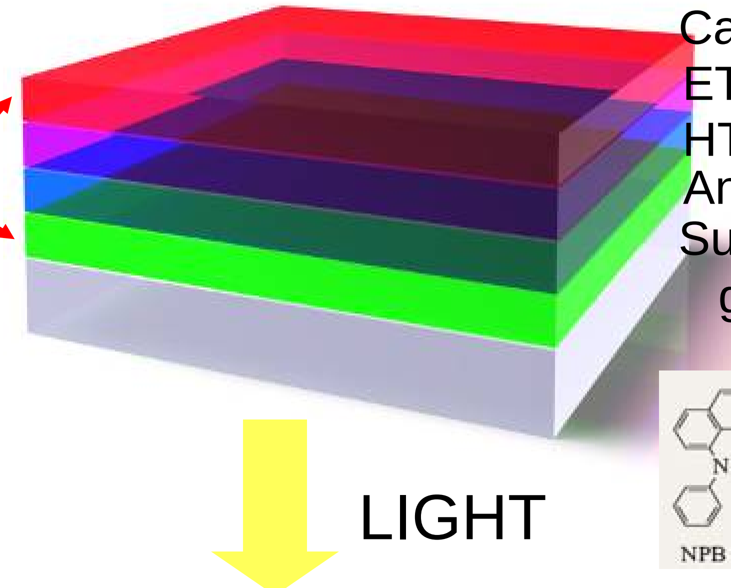
- OLEDs are planar two-terminal devices. Upon application of a current, electrons and holes recombine inside the device to emit light (electroluminescence).

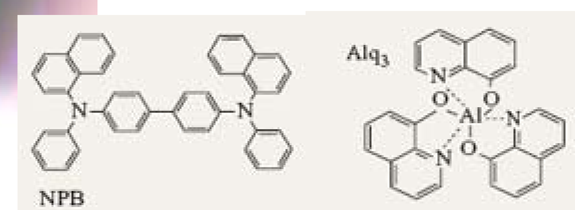
# Organic Light Emitting Diode (OLED)



Comparison to a human hair

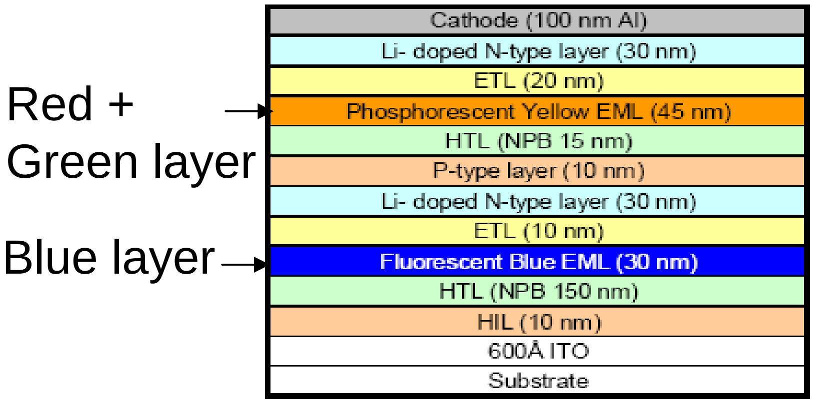
*Source: Osram*



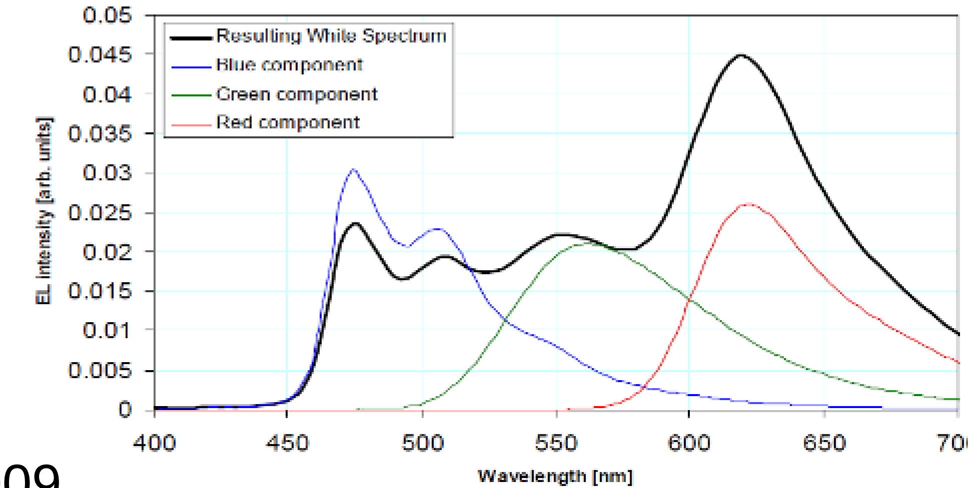




- ❑ The are called "organic" because the key functional layers are made of complex carbon containing molecules.
- ❑ The active layers are less than 1 micron thick.
- ❑ They are inherently large area devices and can be made flexible.

# OLED – Properties




White OLED, Kodak, ca. 2009




*Universal Display*

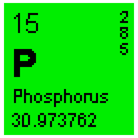
- Typical white OLEDs today have emission from red, green and blue molecules in the same device rather than blue + phosphor in LEDs.
- Emission spectra from organic molecules are broad. High CRI, Ra, R9 > 90 possible.
- *Phosphorescent* OLEDs enable higher efficacy. State-of-art is 60 lm/W, $L_{70}$ = 15K hrs @ 3000 cd/m$^2$ (LG Chem).

# A Little Clarification

- Phosphorescent, Phosphorescence
  - Originally refers to a type of photoluminescence where the material does not immediately re-emit light, as opposed to fluorecence.
  - Emission comes from a spin-forbidden (triplet) state.
  - OLEDs do not contain any phosphor.

- Phosphor
  - Emits light when irradiated by high-energy electromagnetic radiation or particle radiation
  - Includes both phosphorescent and fluorescent materials.
  - Often transition metal or rare earth metal compounds

- Phosphorus
  - The chemical element named for its light emitting behavior, emits light from *chemiluminescence*, not phosphorescence.
  - Phosphorus is *not* used as a phosphor in lighting and displays.




# OLED vs LED – Luminaire Efficacy Projections

| | 2012 | | | 2015 | | | | 2020 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **LED** | **Edge-lit LED** | **OLED** | **LED** | **Edge-lit LED** | **OLED** | **OLED high light extraction** | **LED** | **Edge-lit LED** | **OLED** | **OLED high light extraction** |
| **Package/ Panel lm/W** | **141** | **141** | **60-80** | **202** | **202** | **125** | **152** | **266** | **266** | **168** | **204** |
| **Driver Efficiency** | **86%** | **86%** | **86%** | **89%** | **89%** | **89%** | **89%** | **92%** | **92%** | **92%** | **92%** |
| **Thermal Efficiency** | **86%** | **86%** | **100%** | **88%** | **88%** | **100%** | **100%** | **90%** | **90%** | **100%** | **100%** |
| **Optical Efficiency** | **86%** | **79%** | **100%** | **89%** | **83%** | **100%** | **100%** | **92%** | **87%** | **100%** | **100%** |
| **Luminaire lm/W** | **90** | **82** | **52-69** | **141** | **131** | **111** | **135** | **202** | **192** | **155** | **188** |

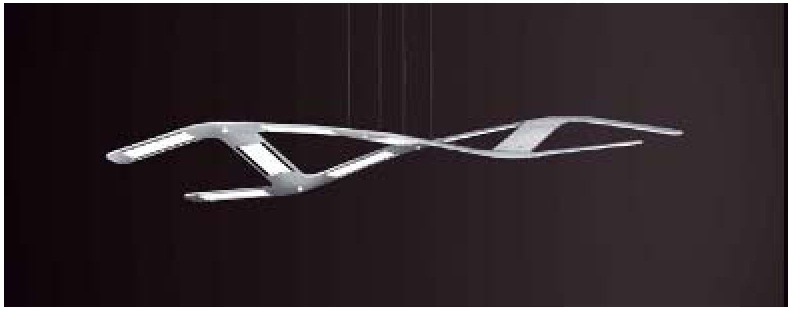
- Based on DOE and ABL projections.
- Current density of 35 A/cm$^2$ assumed for LEDs. Higher current density results in lower efficacy before 2020. LED package listed for 25°C.
- *Today*, edge-lit panels typically don't use the highest efficacy LEDs.

*Lu et al., DOE SSL R&D Workshop, Jan 2012*

# OLED Luminaires – New Design Possibilities

*Kindred, Winona Lighting*

*Blackbody*



*Airbesc, Osram*

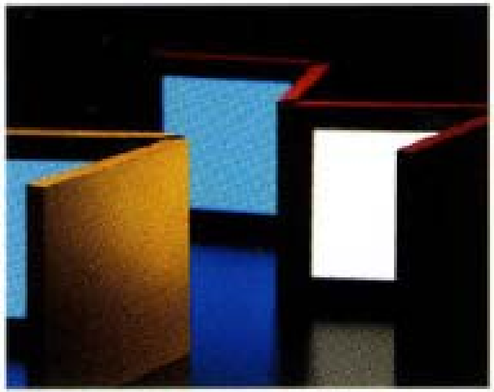
*O'Leaf, Philips*

*Victory, Liternity*

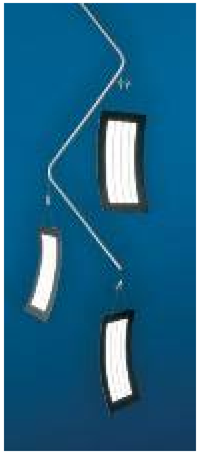
# Other Unique Aspects of OLEDs

Clean edge, thin
*Panasonic*

Full color tuning in a flat panel package
*Mitsubishi Chemical/Verbatim*



Flexible
*GE, Konica Minolta*



Transparent
*Novaled*

Arbitrary shapes
*Philips*

# OLEDs – Pros and Cons

- Pros
  - Outstanding quality of light
  - Thin form factor (<2 mm), thin border width (<5 mm)
  - Low temperature operation (<10°C above ambient)
  - Transparent, flexible OLEDs, arbitrary shapes possible
  - Long-term efficacy projected to match edge-lit LED
  - Potential for printing process
- Cons
  - Cost (needs volume)
  - Lifetime (3x increase desired; will improve naturally with efficacy)
- Future
  - OLEDs will be another major area light source technology besides edge-lit LED

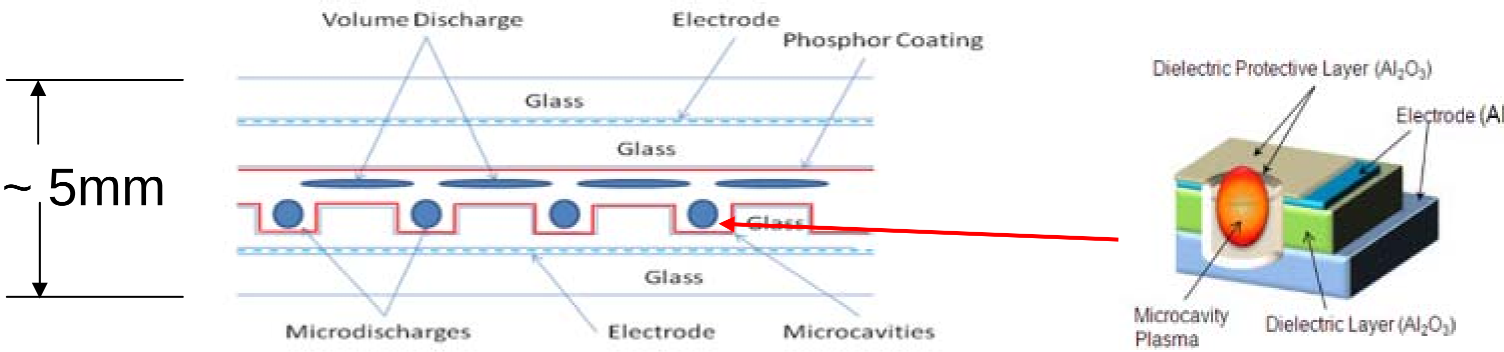
# Comparison of Area Source Technologies – Past and Present

| | Efficacy | Lifetime | Light Quality | Form Factor | Cost | Tech Promise | Other |
|---|---|---|---|---|---|---|---|
| **EL Panel** | ★★★★ | ★★ | ★★ | ★★★★ | ★★★★ | ★ | ★★ |
| **Edge-Lit LED** | ★★★★ | ★★★★ | ★★★ | ★★★ | ★★★ | ★★★★ | ★★★ |
| **OLED** | ★★★ | ★★★ | ★★★★ | ★★★★ | ★★ | ★★★★ | ★★★★ |

★Poor ★★Fair ★★★Good ★★★★Excellent

# Microplasma Lighting

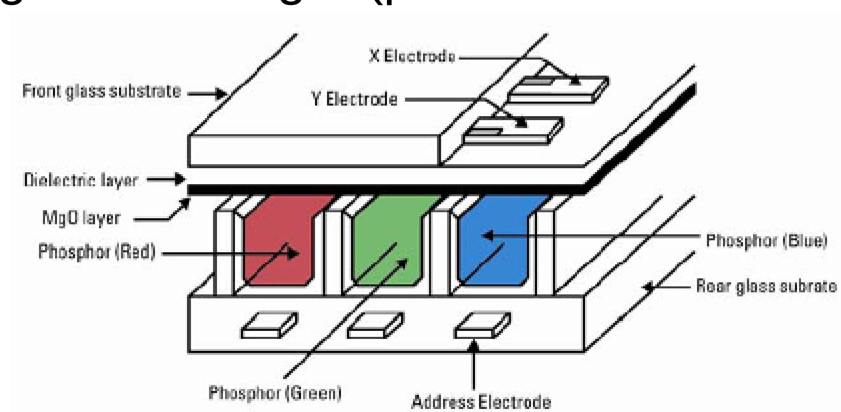
- Plasma is a state of matter similar to gas in which a certain portion of the particles are ionized.




*Microplasma planar panel by Eden Park Illumination*

- Electrons collide with plasma inside the cavity ➔ UV light ➔ strikes the phosphor coating ➔ white light (photoluminescence)

Cf. plasma display panel (PDP)



# Microplasma Lighting – Characteristics

- Max luminance: 8000 cd/$m^2$
- CRI: 80-85
- Lifetime: $L_{70}$ 50K hrs
- Efficacy: 30-40 lm/W currently, expected to increase to 60 lm/W, theoretical limit > 100 lm/W
- Leverages existing manufacturing know-how
- Estimated purchase cost for 12”x12” panel: $100-200

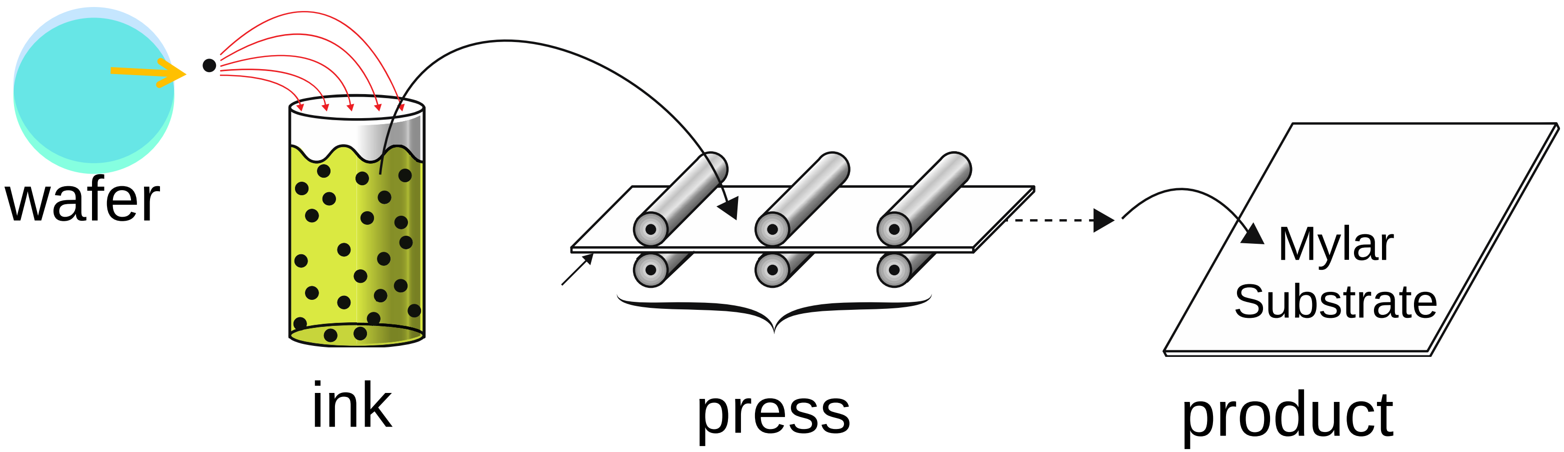
*Source: Eden Park Illumination*

# Printed Micro LEDs

- Problem to be solved: How to make a large-area, flexible light source without making an OLED?

- Solution: start with a wafer of inorganic LEDs, break into tiny individual LEDs, then disperse onto a sheet and make electrical connections.
- Two teams using the same general approach
  - NthDegree Technologies: “Printed Solid State Lighting”
  - Prof. Ralph Nuzzo’s group, University of Illinois: “Printing Solid Inks”

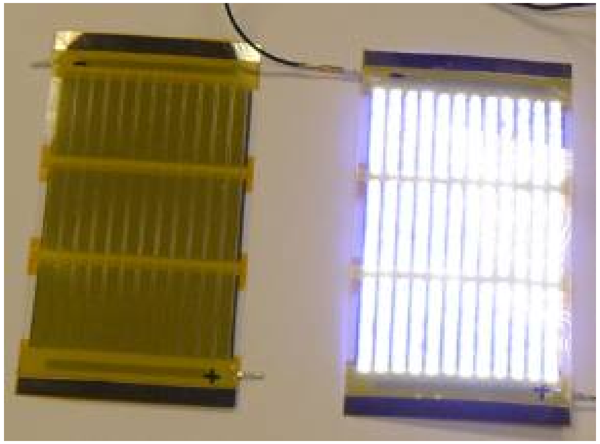
# Printed Micro LEDs – 1st Approach




*Source: NthDegree Technologies*

- LEDs the size of an ink particle (27 micrometers) forms a suspension.
- This “ink” is coated onto a plastic substrate.
  - Think of the LEDs as a large number of loaded dice thrown on to a surface – enough will land the right way.
- Fast and low-cost, although not necessarily the highest performance

# Printed Micro LEDs – 1st Approach



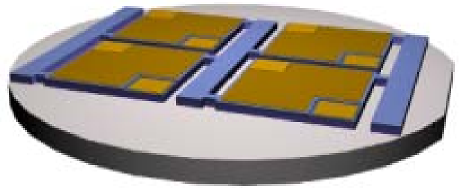
2’ x 4’ Replacement
1.75” thick with power supply

Edison Replacement

*NthDegree Technologies*

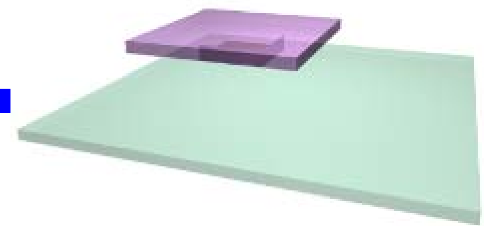
# Printed Micro LEDs – 2$^{nd}$ Approach

**LEDs on wafer**

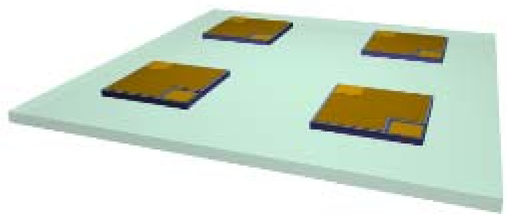


**Ohmic Contact and Trench Formation & KOH Undercut**

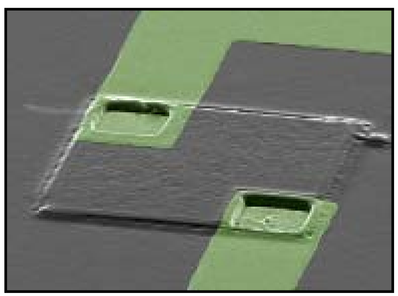

**Lift off with PDMS stamp**



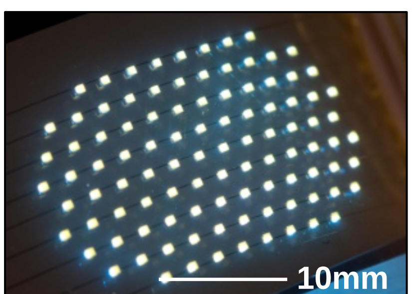
**Print to secondary substrate**



**"Step & Repeat" "Areal Expansion"**



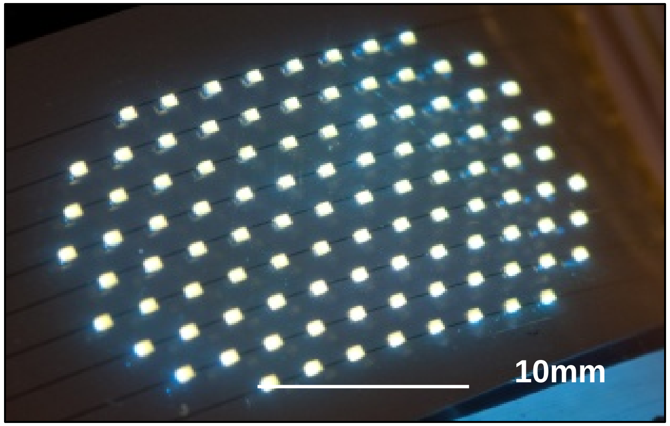
**Metal connections**



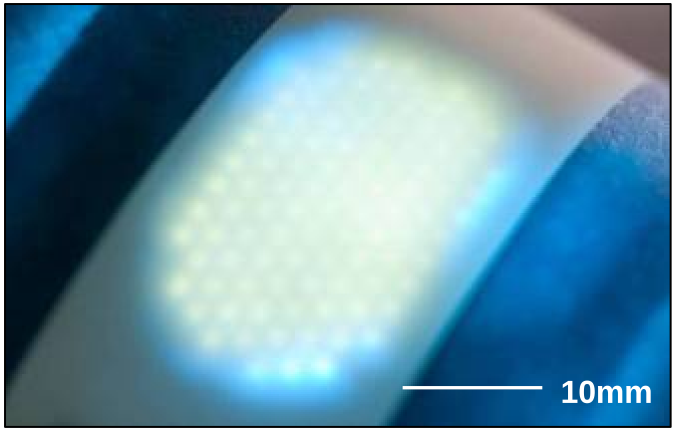

*Source: Prof. Nuzzo, Univ. of Illinois*

- Same performance as wafer based LEDs
- Process intensive

# Printed Micro LEDs – $2^{nd}$ Approach



Lit micro LED array



Lit micro LED array w/ diffuser


On transparent and flexible substrate

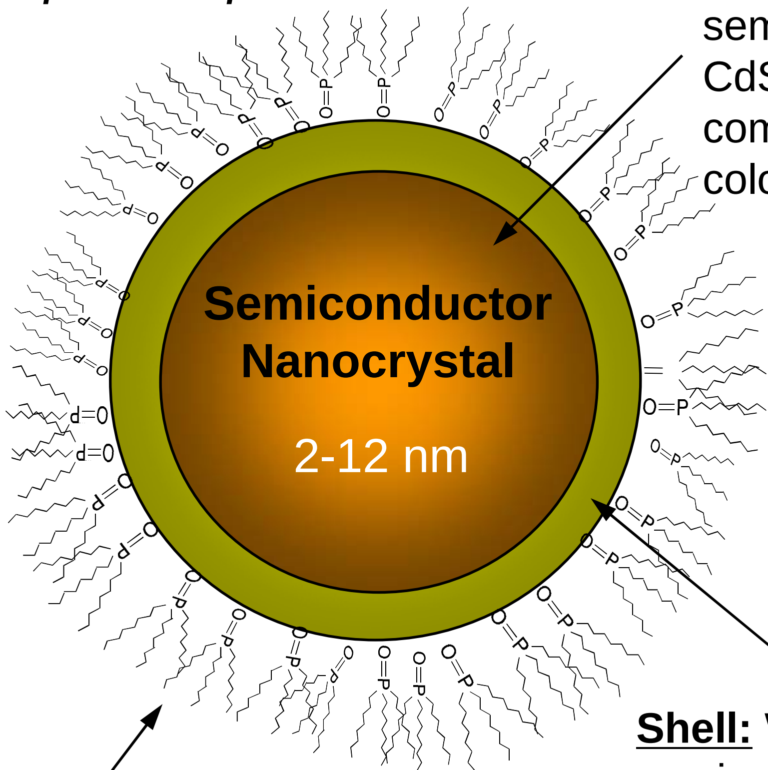
Overlay a dollar bill

*Source: Prof. Nuzzo, Univ. of Illinois*

# Quantum Dot LED (QLED)

***Quantum dots are functionalized nano particles.*** *Three parts of QDs are engineered to optimize performance:*

**<u>Core:</u>** Binary or ternary semiconductors,e.g., CdSe, InP; size and composition determines color




Color determined by

- ❑ In LED: crystal composition, e.g. In concentration in InGaN
- ❑ In OLED: type of molecule

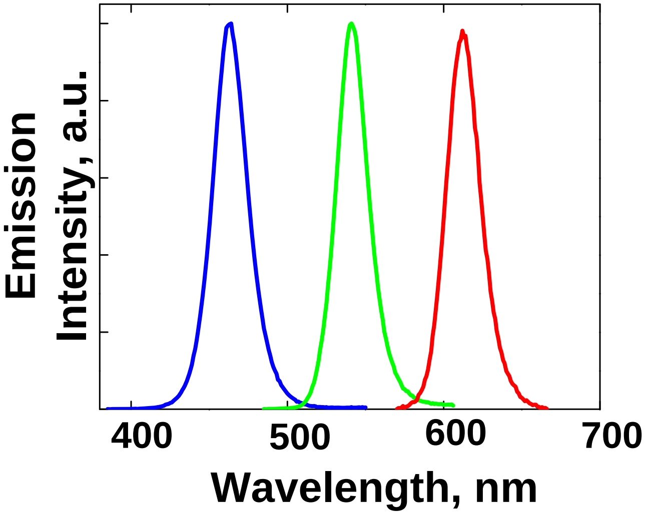
**<u>Shell:</u>** Wider bandgap semiconductor; enhances efficiency and stability

**<u>Caps or Ligands</u>**: Typically aliphatic organics; passivates & functionalizes surface; allows solution process

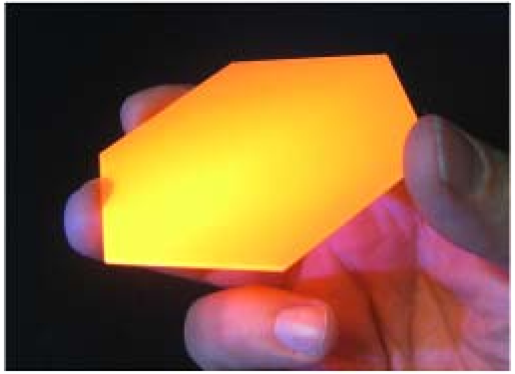
*Source: QDVision*

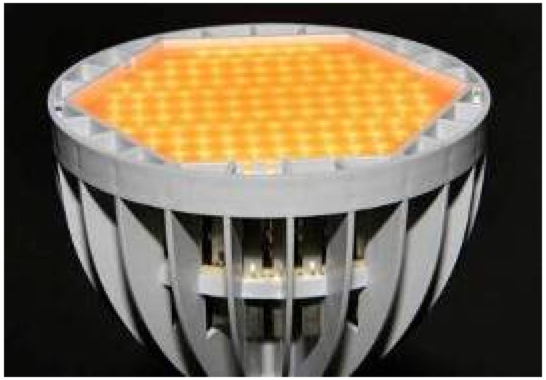
# Quantum Dots as Phosphor

Photoluminscence of QDs
in solution




Narrow band emission tunable
throughout the visible range

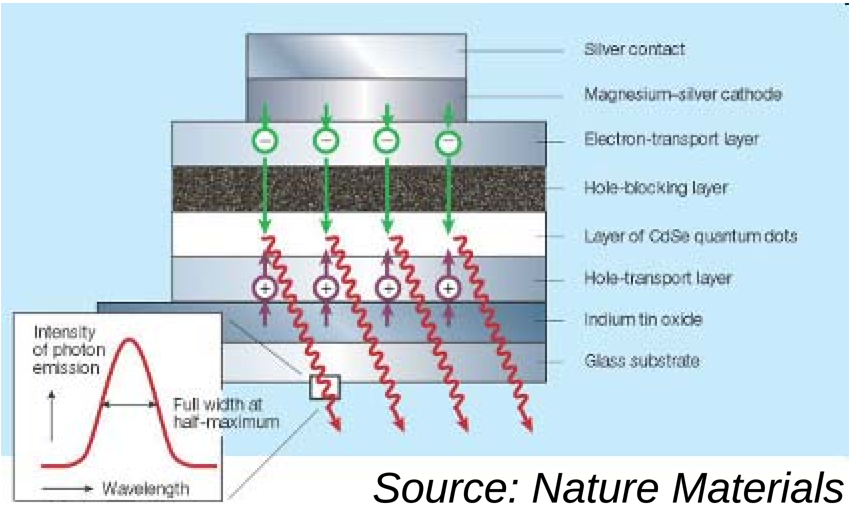




*Nexxus Lighting PAR lamp with QD optic for red shift and CRI enhancement*

*Source: QDVision*

# QD Light Emitting Diodes (QLEDs)




*Source: Nature Materials*

- The basic QLED structure is very similar to that of an OLED.
- QLEDs can be thought of as solution processed OLEDs with QDs as emitters.
- Red QLED performance approaches the best red OLEDs.

White flexible QLED

RGB QLEDs

*Source: QDVision*

# Comparison of Area Source Technologies – Future

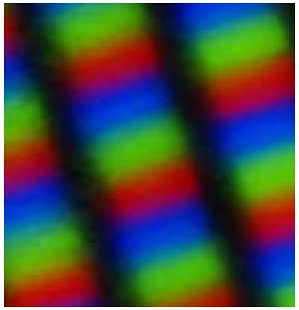
| | Efficacy | Lifetime | Light Quality | Form Factor | Cost | Tech Promise | Other |
|---|---|---|---|---|---|---|---|
| **µ plasma** | ★★★ | ★★★★ | ★★★ | ★★ | ★★★★ | ★★ | ★ |
| **µ Printed LED1** | ★★ | ★★★ | ★★ | ★★★★ | ★★★ | ★★ | ★★ |
| **µ Printed LED2** | ★★★★ | ★★★★ | ★★★ | ★★★★ | ★ | ★★★★ | ★★★ |
| **QLED** | ★★★ | ★ | ★★★★ | ★★★★ | ★★ | ★★★★ | ★★★★ |

★Poor ★★Fair ★★★Good ★★★★Excellent

# Lighting and Display

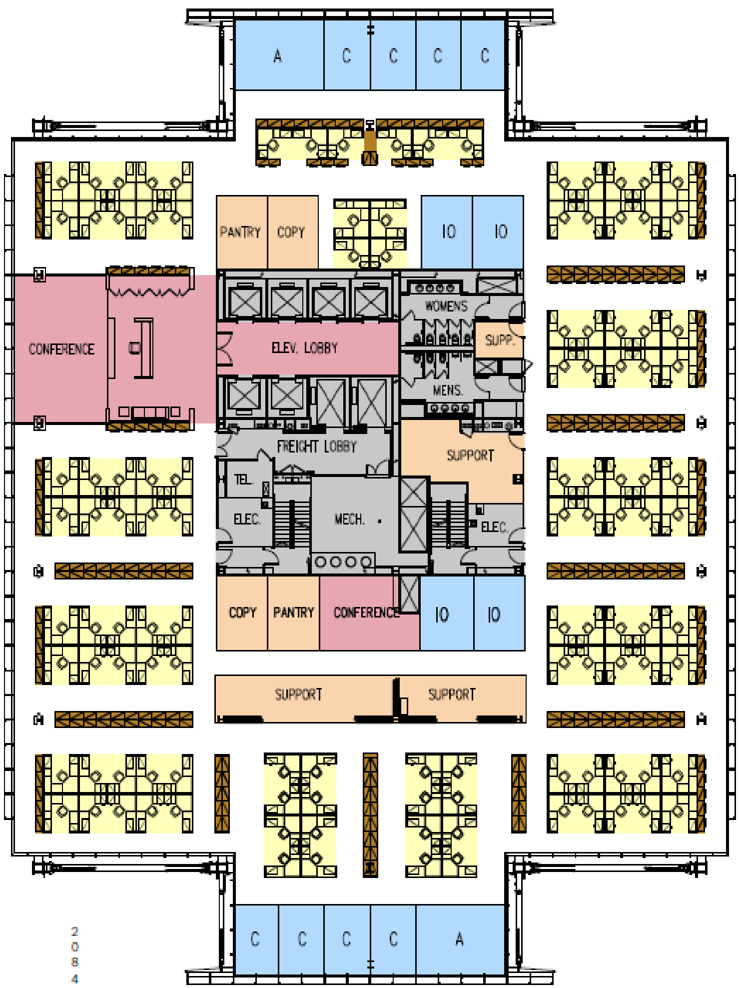
- Many light sources and display devices operate on the same physical principles.

- Displays commands a higher price ($\$/in^2$) and tend to be the preferred vehicle for new technologies.
  - Displays need RGB pixelation addressing.
  - Displays need saturated RGB; general lighting needs color points along the Planckian locus, with good color rendering.
  - One or two technologies tend to dominate displays. Many different lighting technologies tend to co-exist.

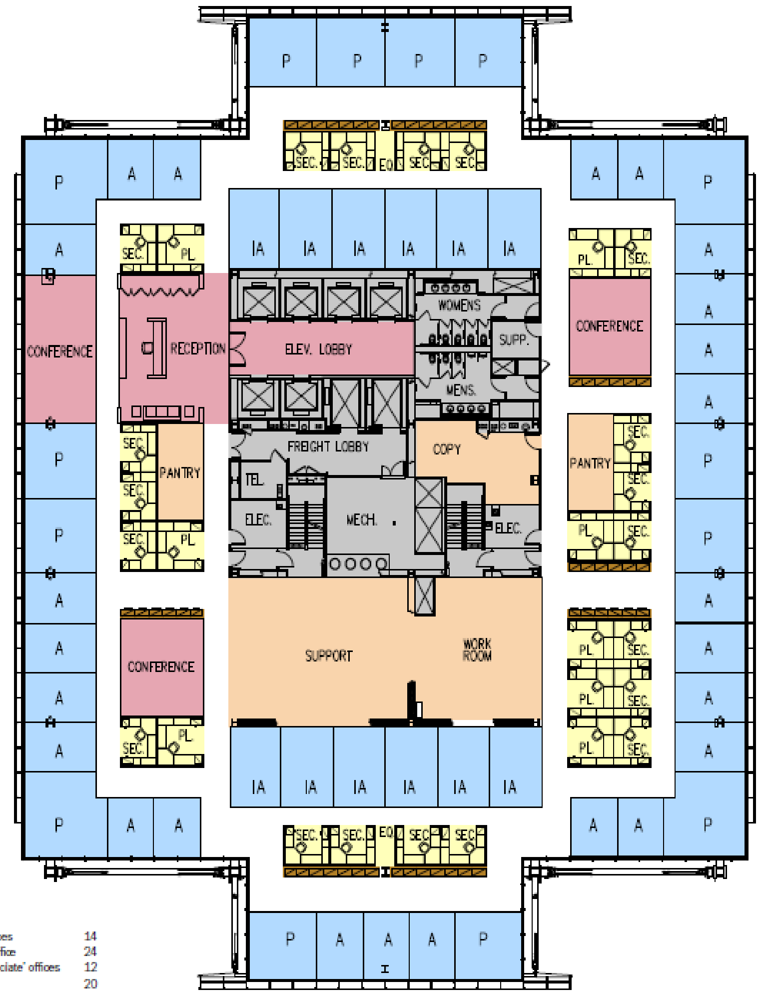


- As competition in displays drives down margins, many display makers are looking to SSL as an area of expansion – *lighting is no longer in the shadow of displays!*

# Lighting Application




| | |
|---|---|
| 'A' offices | 2 |
| 'B' offices | 0 |
| 'C' offices | 8 |
| Interior | 4 |
| Workstation | 116 |
| Conference | 2 |




| | |
|---|---|
| 'Partner' offices | 14 |
| 'Associate' office | 24 |
| 'Interior Associate' offices | 12 |
| Secretary | 20 |
| Paralegal | 8 |
| Conference | 3 |

# Using Area Light Sources

*Rapt Studio*

*LG Chem*

# How Much Do I Need?

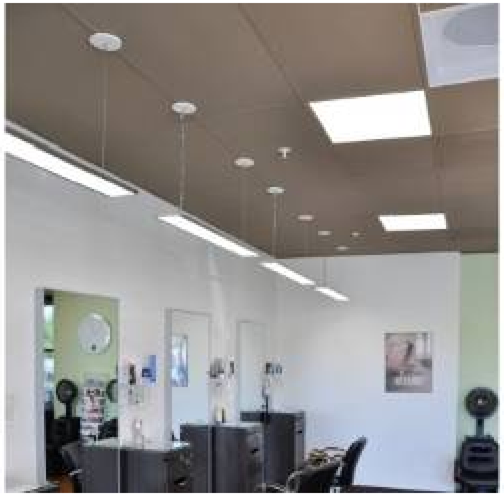
| | | |
|---|---|---|
| Baseline – Traditional Systems | 2x4 fluorescent lensed troffer | 10% |
| | 2x4 fluorescent parabolic troffer | 10% |
| | 2x4 fluorescent advanced troffer | 10% |
| | Linear fluorescent indirect / direct | 4% |
| Advanced Alternatives | 2x4 LED advanced troffer | 10% |
| | Fluorescent low ambient / task | 4-10% |
| Area - Low | @ 1500 cd/m$^2$ | 14% |
| Area - Med | @3000 cd/m$^2$ | 7% |
| Area - High | @ 5000 cd/m$^2$ | 4% |

Ceiling Coverage = % of ceiling area obstructed by luminaire
There is no need to cover the whole ceiling

# Familiar Form Factors

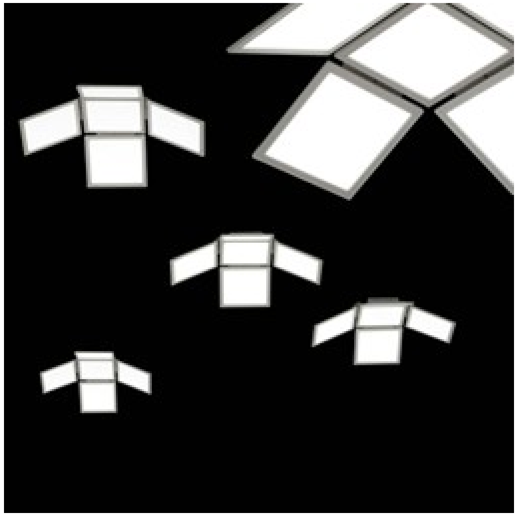
*GE and Lunera*

# Familiar Form Factors




*Lunera*

# New Form Factors



**This design demonstrates the unique character possible with area light sources.**

**The light is noble, pure, simple, honest.**

**LIGHT itself becomes the luminaire.**

**Luminaires connect with us emotionally by their design intent and beauty.**

Panels: 60 lm/W panels, CRI>80, CCT 3500K, $L_0$=3000 cd/m$^2$, L70 15,000 hrs @ 3000 cd/m$^2$

Luminaire: 5 panel module, 370 lm total, 7.3 W, 51 lm/W including driver and optical losses

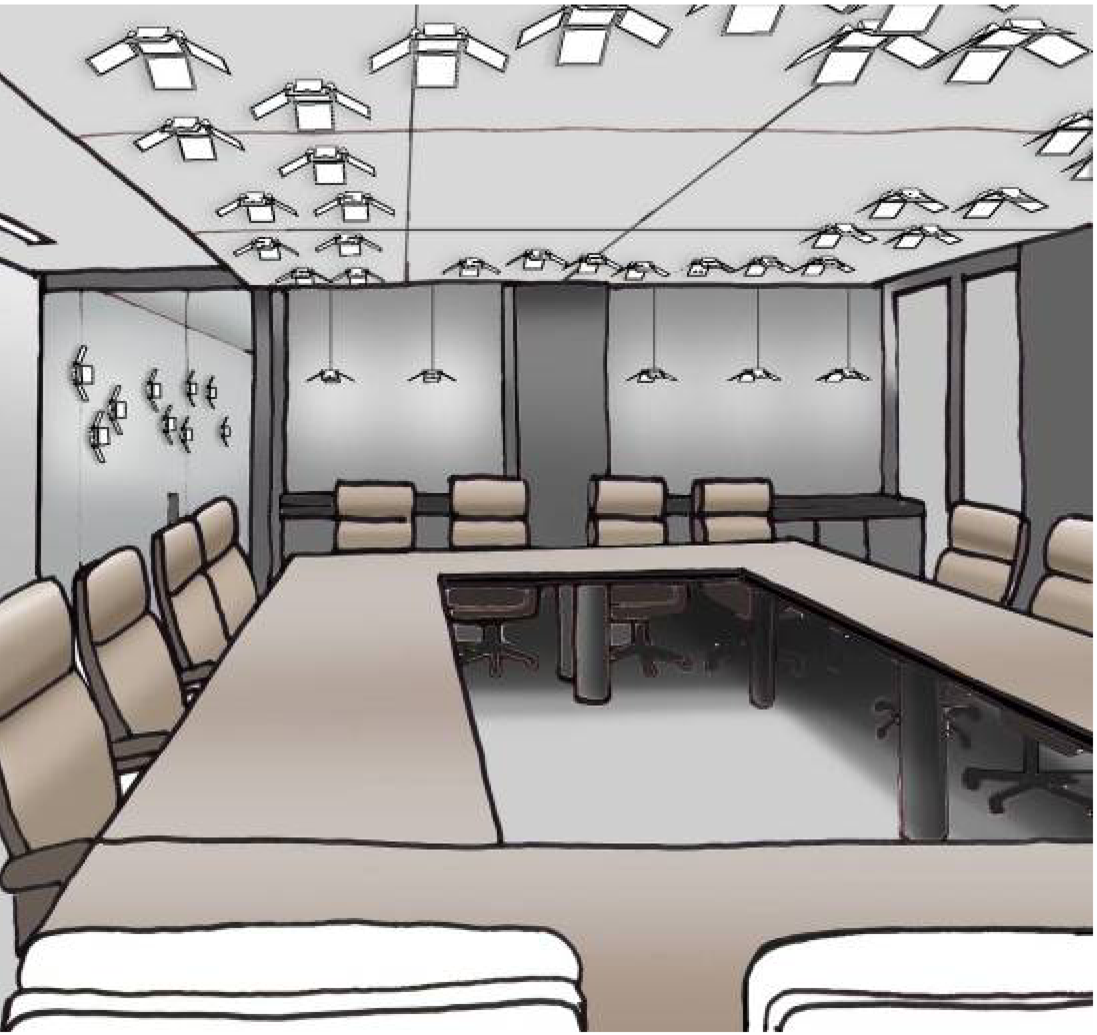
Panels: 60 lm/W panels, CRI>80, CCT 3500K, $L_0$=3000 cd/m$^2$, L70 15,000 hrs @ 3000 cd/m$^2$

Luminaire: 45 panels, 3382 lm total, 66 W total, 51 lm/W including driver loss

*Acuity Brands*

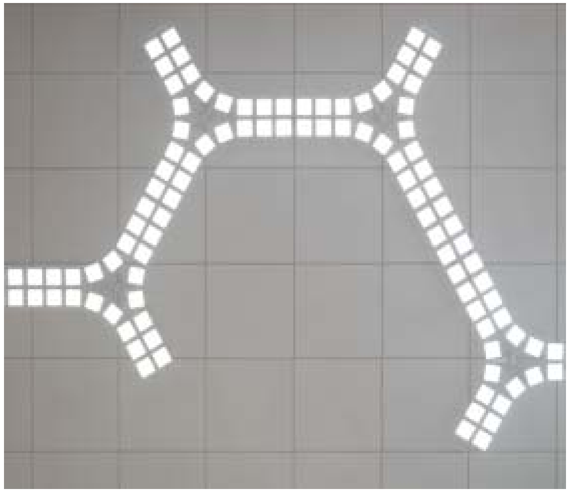
**Photography: John Sutton 2011**

# New Form Factors



*Acuity Brands*

# New Form Factors



**This design evokes the connectivity and beautiful branching of a growing neuron.**

**Organic patterns form and flow gracefully through a space in unique and fluid motifs for close-to-ceiling applications.**

Panels: 60 lm/W panels, CRI>80, CCT 3500K, $L_0$=3000 cd/m$^2$, L70 15,000 hrs @ 3000 cd/m$^2$

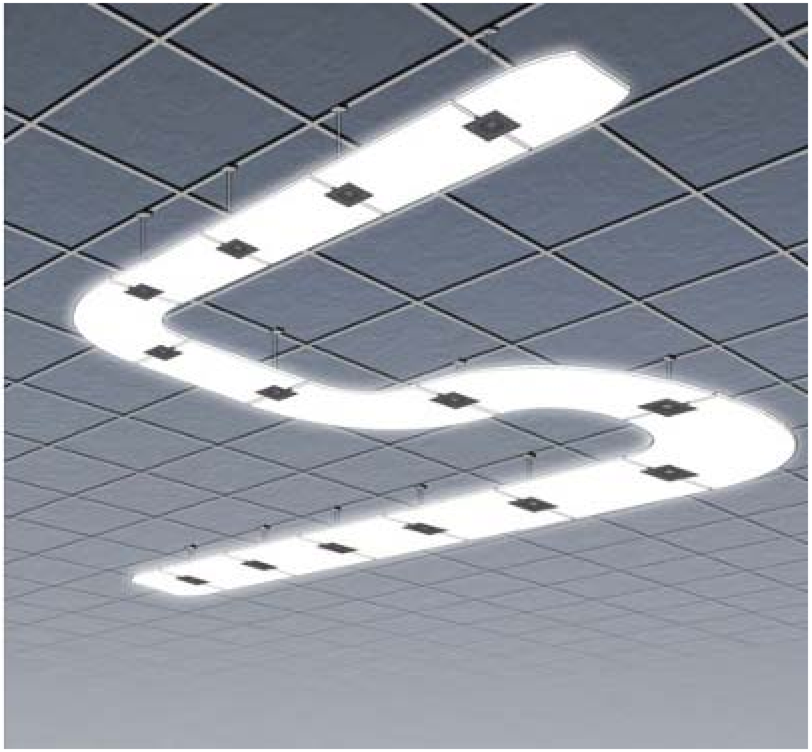
Tri Section: 24 panels, 1810 lm total, 35 W, 52 lm/W

Straight Section: 8 panels, 603 lm total, 12 W, 52 lm/W

*Acuity Brands*

**Photography: John Sutton 2011**

# New Form Factors



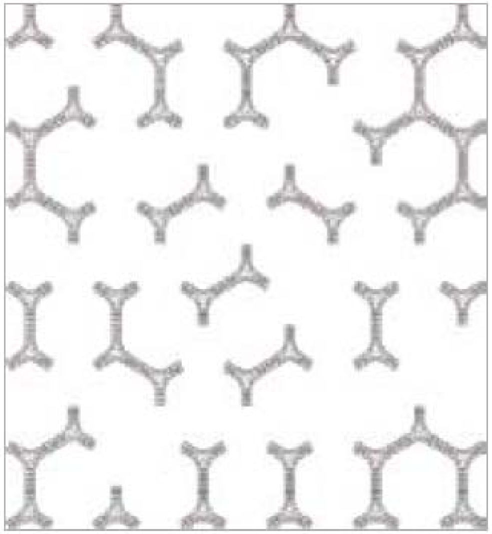
*Rambus*

*Acuity Brands*

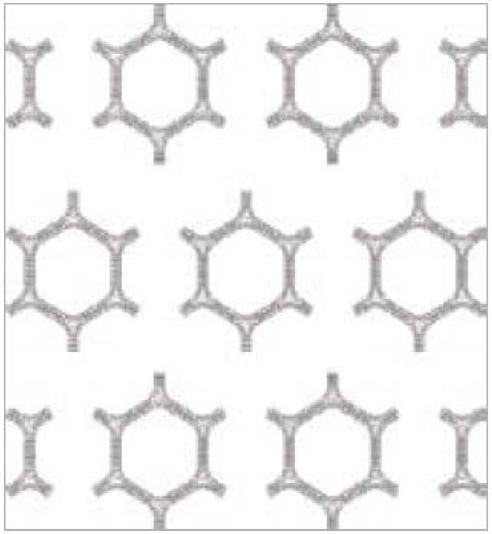
**Photography: John Sutton 2011**

# New Metrics for Design

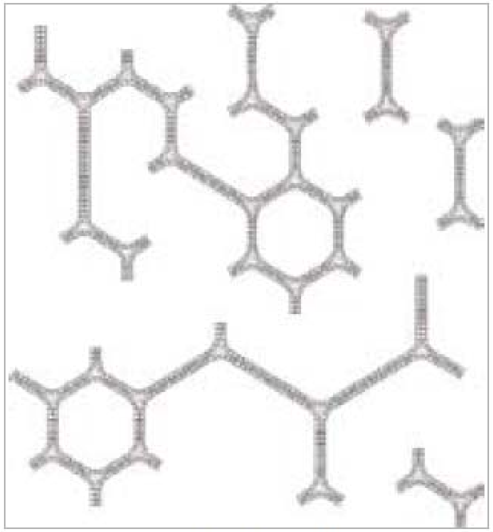
- Density of panels (3000 cd/m² example)
- Application efficiency



48 TRI sections
Ambient avg: 50 fc
Max / Min: 2.1:1
LPD: *1.05 W/ft² **0.79 W/ft²
# of 4" sq. panels: 0.72/ft²



50 TRI sections
Ambient avg: 53 fc
Max / Min: 2.6:1
LPD: *1.10 W/ft² **0.83 W/ft²
# of 4" sq. panels: 0.75/ft²



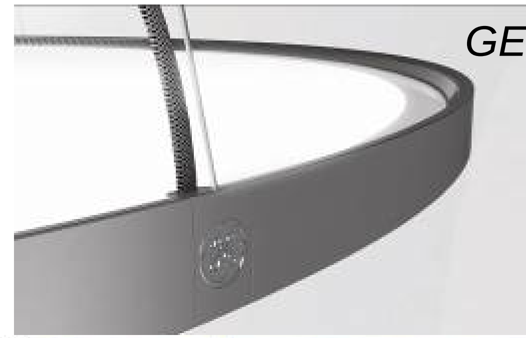
32 TRI + 22 STRAIGHT sections
Ambient avg: 43 fc
Max / Min: 4.9:1
LPD: *0.86 W/ft² **0.65 W/ft²
# of 4" sq. panels: 0.59/ft²

*60 lm/W
**80 lm/W

# New Form Factors

**~ 46 fc @ workstations**

**0.76 W/ft$^2$ @ 60 lm/W**
**0.57 W/sf @ 80 lm/W**
**0.45 W/sf @ 100 lm/W**



# Newer Concepts

# Newer Concepts

**A snapshot of a ballerina**
**can be breathtaking, but witnessing her dance from beginning to end can touch our soul.**

*Acuity Brands*

# Newer Concepts

# Newer Concepts

*Acuity Brands*


This is just the beginning.

# Conclusions

- Area light sources offer designers many opportunities for practicing the craft of architectural lighting.
- Old and new lighting technologies make flat panel sources practical to implement.
- A combination of medium luminance and small size panels offer the best design flexibility and application efficiency.

# Please complete the course evaluation forms.

# THANK YOU!