AABC Commissioning Group

AIA Provider Number 50111116

OLEDs – The Other Solid-State Lighting Technology

Course Number: CXENERGY1602

Dr. John (Jack) W. Curran
LED Transformations

April 12, 2016

Credit(s) earned on completion of this course will be reported to AIA CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This course is registered with AIA CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Copyright Materials

Acknowledgements/Credits

Support for the development and presentation of this educational seminar was provided by the US Department of Energy and NETL Morgantown

Course Description

LEDs dominate the conversation in lighting. However, Organic Light Emitting Diodes (OLEDs) offer new and exciting capabilities where the light becomes the luminaire. Dr. Curran provides an introduction to the technology, including a comparison with LEDs, highlighting the advantages and disadvantages of OLEDs and what the future holds for this unique technology.

Learning Objectives

At the end of the this course, participants will be able to:

1. Learn how OLEDs function and the fundamental differences between OLED and LED technology

2. Performance comparisons between LEDs and OLED will be presented allowing attendees to plan where OLEDs could be an appropriate choice for future projects

3. Understand how OLED's unique properties can change the design of facilities in terms of lighting

4. Understand the appeal of the technology to architects and lighting designers through a discussion of the aesthetic characteristics of OLEDs

Outline

- Introduction – What are OLEDs
- Unique Features – What makes OLEDs different from other light sources?
- Comparison – Advantages and disadvantages of OLED and LED technologies
- Applications – Examples of OLED design

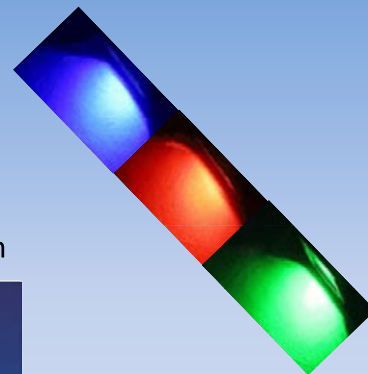
Source: GE

Introduction

An Experiment – What color is the ball?

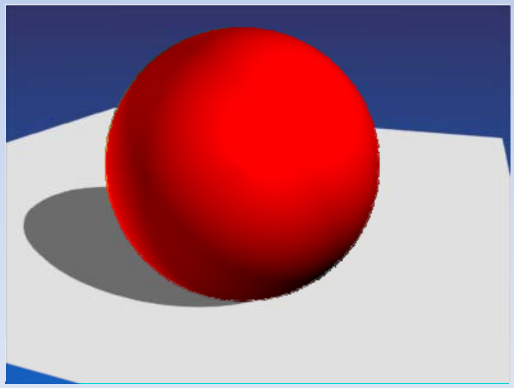
Introduction

An Experiment – What color is the ball?



Without light objects have **NO Color**

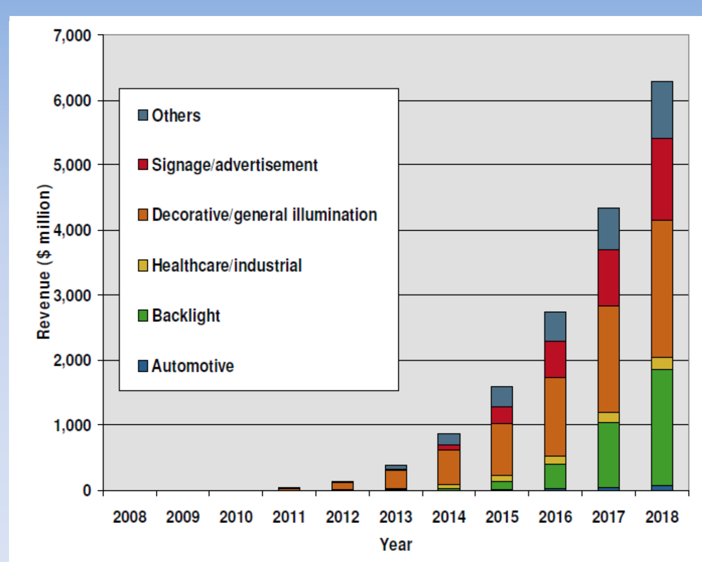
Red object – Absorbs blue & green



Introduction

The Future – Expanded use as costs come down

The expanding market for OLED technology is predicted to be over $2B for decorative and general illumination lighting by 2018

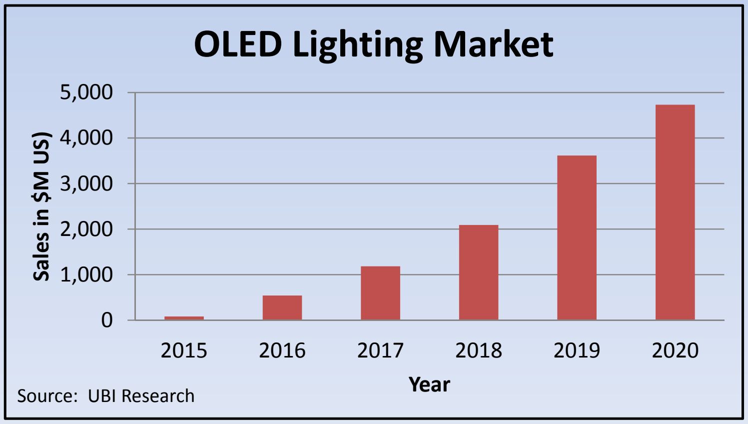


Source: DisplaySearch OLED lighting report: 2009 and beyond

Introduction

OLED Market Forecasts – Widely varying projections

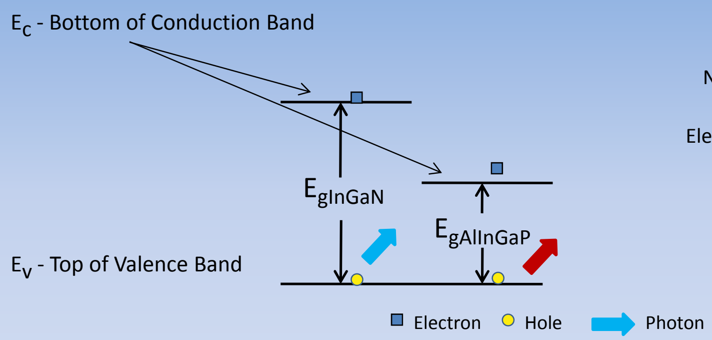
- Lux Research – $58M by 2020
- NanoMarkets – $1.4B by 2019
- UBI Research – $4.7B by 2020

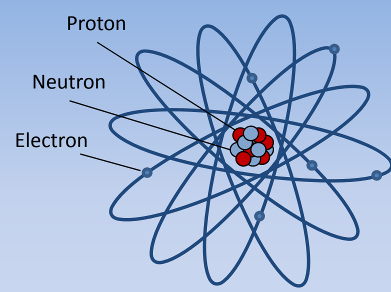


Introduction

How do SSL devices produce light?

Bandgaps – Different gaps, different colors





Smaller bandgap ➔ Lower energy ➔ Longer wavelength photon ➔ **Red**

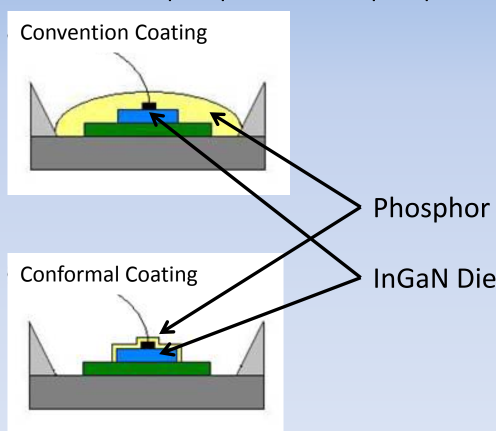
Larger bandgap ➔ Higher energy ➔ Shorter wavelength photon ➔ **Blue**

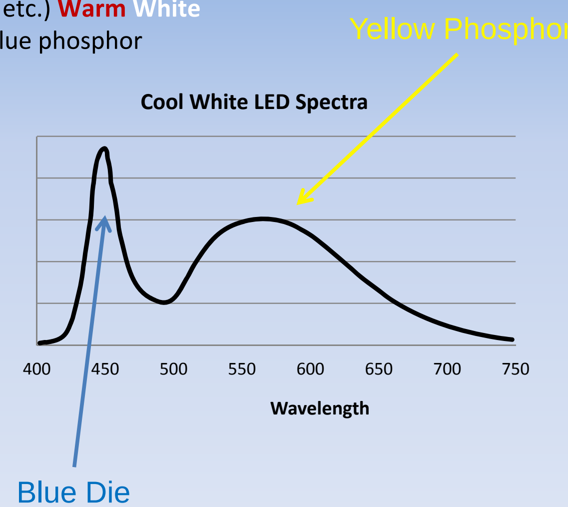
Introduction

How Does an LED Create White Light?

Downconverting Phosphor

- Blue LED + YAG **Cool White**
- Blue LED + YAG + Other phosphor (red, green, etc.) **Warm White**
- UV LED + Red phosphor + Green phosphor + Blue phosphor



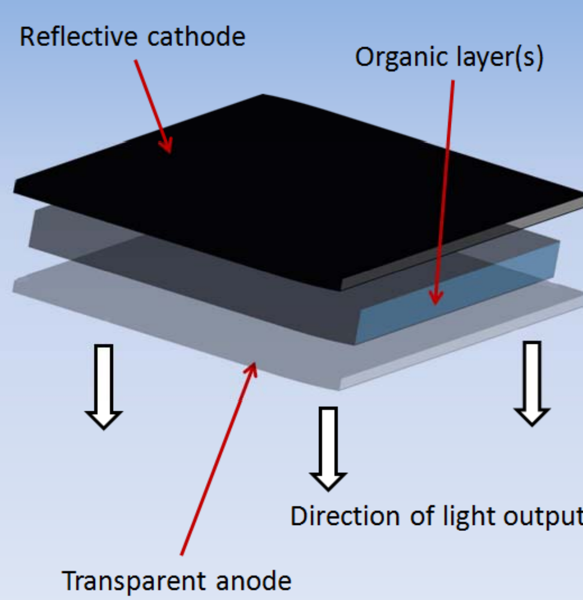


Introduction

What is an OLED?

A "layer cake" with a thickness less than that of a human hair

- An OLED or organic light-emitting diode is a semiconductor device which consists of an electroluminescent organic layer(s) sandwiched between two electrodes, at least one of which is transparent.
- The device is fabricated by sequentially depositing organic layers on a conducting substrate followed by another conducting electrode.
- A common device structure comprises a glass substrate coated with indium tin oxide (ITO) as transparent anode and a thin, opaque metal film as cathode.
- Typical separation between layers is 100 nm or less



What is an OLED?

The major elements of an OLED device consist of the following:

- Substrate – the support material that forms the base of the OLED; it can be of glass, metal or plastic;
- Backplane – the circuitry that provides the power that drives the OLED panel (simple for lighting, complex for displays);
- Organic layers – the actual OLED materials; phosphorescent and fluorescent materials that convert electrical energy into visible light energy;
- Encapsulation – the protective layers that prevent moisture and oxygen from contaminating the organic (light producing) layers of the OLED.

A Close-up View of an OLED

Diagram of a ***Bottom*** Emitting, ***Stacked*** OLED

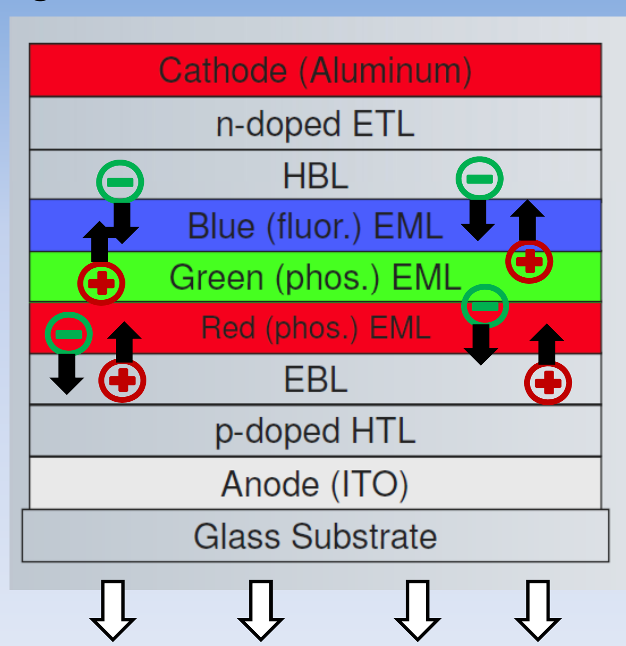
Electron **T**ransport **L**ayer

Hole **B**locking **L**ayer

Emission **L**ayers {

Electron **B**locking **L**ayer

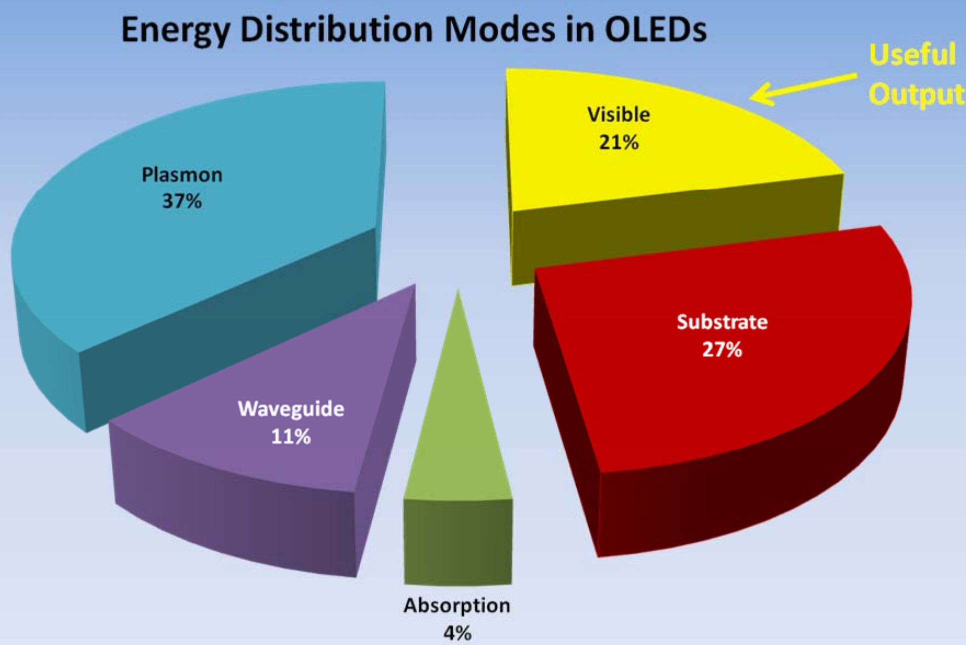
Hole **T**ransport **L**ayer



ITO - Indium Tin Oxide layer forms a transparent electrode

Comparison

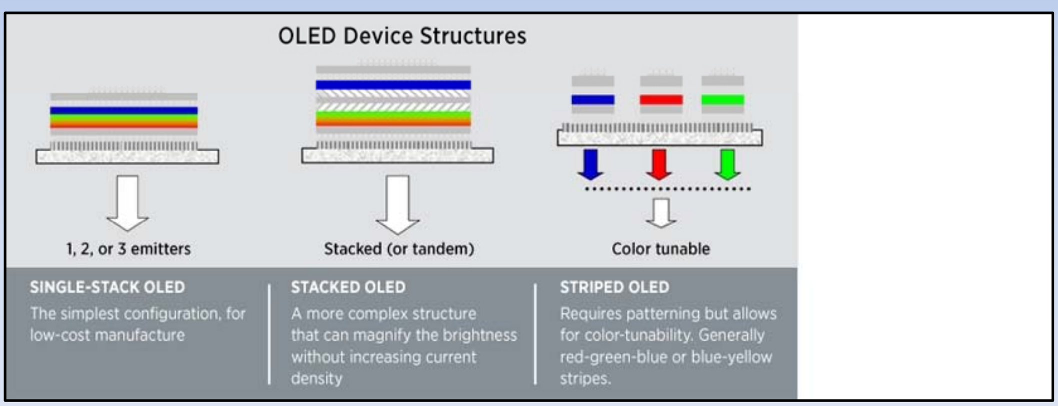
OLED Efficacy – Where the losses are



Introduction

OLED Configurations – Different structures for different applications

OLEDs can be configured as larger-area, more diffuse light sources, which may be more practical for general ambient lighting because the soft light can be viewed directly, with less need for shades, diffusers, lenses, louvers, or parabolic shells. The diffuse light from OLEDs allows them to be used very close to the task surface without creating glare for the user, which means that less total light can be used in order to achieve desired illuminance levels.



Source: *OLED Basics*; US Department of Energy

INTRODUCTION

Some OLED Terms

- Small molecule OLEDs (SM-OLEDs)
  - Molecule weight less than 1,000 g/mole
  - Majority of today's devices, high performance, generally deposited by vapor phase deposition
- Large molecule OLEDs (P-OLEDs or Polymer OLEDs)
  - Are solution processable (i.e. ink-jet printing and spin coating fabrication which could drastically reduce manufacturing cost)
  - Still at the development stage
- Fluorescent materials
  - \+ Last longer than phosphorescent materials
  - – Less efficient with a maximum internal quantum efficiency of 25%
- Phosphorescent materials (PHOLED)
  - \+ More efficient with a internal quantum efficiency of up to 100%
  - – Lifetime shorter than fluorescent materials so most companies use hybrid
  - – Typically requires doping with rare earth heavy metals (usually iridium)

INTRODUCTION

Some OLED Terms – What does "gen" mean

"Gen" refers to the generation of manufacturing line which is based on size of glass panel which the line is capable of producing. Each generation is capable of producing larger and larger panels of glass. This brings down the cost of the substrate on which the OLED is manufactured.

Presently Gen 8 →

Maximum number of panels per glass sheet

Generation	Dimensions (mm)	Panel size (diagonal inches) 3	10	15	32	40	42	46	52	55
1 (AUO)	300 x 400	43	3	1						
1 (SEC)	270 x 360	34	3	1						
2	370 x 470	62	5	2						
3	550 x 650	128	11	5	1					
3.5	620 x 720	160	14	6	1					
4	730 x 920	240	21	9	2	1	1	1		
5	1,100 x 1,250	493	44	19	4	2	2	2	1	1
6	1,500 x 1,850	995	89	39	8	5	5	4	3	2
7	1,870 x 2,200	1,476	132	59	12	8	7	6	4	4
7.5	1,950 x 2,250	1,574	141	62	13	8	8	6	5	4
8	2,160 x 2,460	1,906	171	76	16	10	9	8	6	5
8.5	2,200 x 2,500	1,973	177	78	17	11	10	8	6	5
9	2,400 x 2,800	2,411	217	96	21	13	12	10	8	7
10 (Sharp)	2,850 x 3,050	3,118	280	124	27	17	15	13	10	9
11	3,000 x 3,320	3,573	321	142	31	20	18	15	11	10

Source: CLSA Asia-Pacific Markets

Outline

- Introduction – What are OLEDs
- **Unique Features – What makes OLEDs different from other light sources?**
- Comparison – Advantages and disadvantages of OLED and LED technologies
- Applications – Examples of OLED design

Source: GE

Unique Features

History of OLED Development – Displays and some lighting

- 1950: Electroluminance in organic materials is observed for the first time
- 1987: The world's **first OLED device** is developed at Eastman Kodak
- 1998: Kodak and Sanyo show the world's first AMOLED display
- 2009: LG buys Kodak OLED unit
- 2010: Sony stops XEL-1 OLED TV production
- 2010: DuPont develops new OLED printing technology, can print a 50" panel in less than two minutes
- 2011: Samsung announces they will invest $4.8 billion in OLED production in 2011
- 2011: Verbatim starts shipping color-tunable OLED lighting panels (VELVE)
- 2011: Panasonic develops the world's most efficient white OLED (128 lm/W)
- 2012: The world's first transparent OLED lighting panel now shipping from COMEDD
- 2013: NEC developed the world's most efficient OLED lighting device (156 lm/W)
- 2014: LG shows 77" bendable OLED TV prototypes

First visible LED developed 22 years earlier

Source: The OLED Handbook; Ron Mertins; 2014

Unique Features

Advantages of OLEDs

- Flat Form Factor
  - Emits light over entire surface; also allows for easy heat dissipation
- Flexibility
  - As encapsulation techniques improve, ability to use flexible substrates such as metal foils or plastic

Source: DuPont Displays

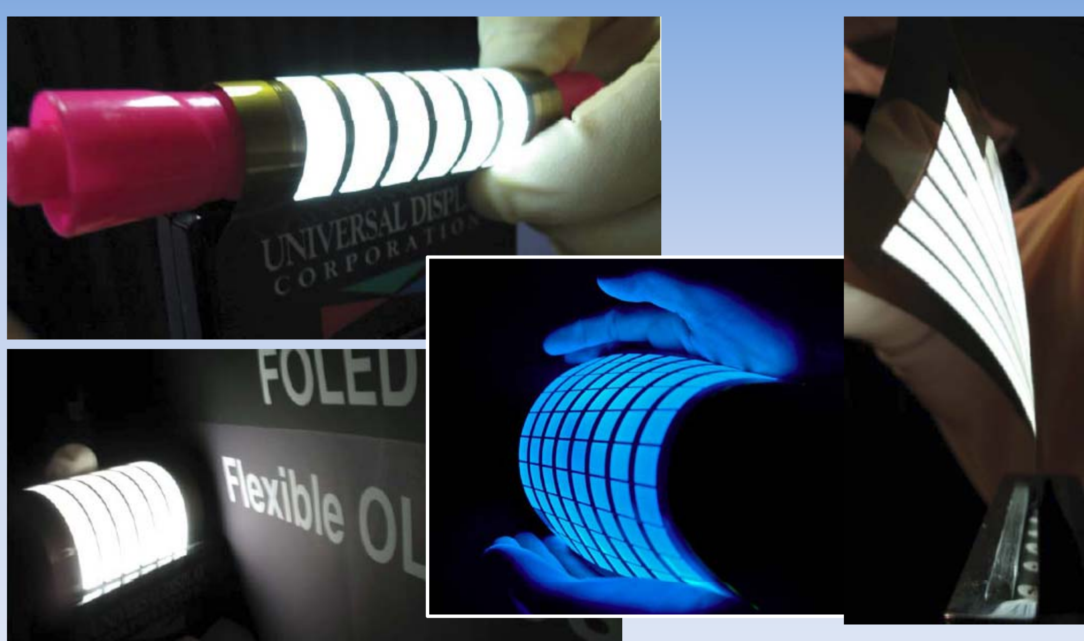
- Color Tunability
  - Spectra depends on the emitter material; generally wider and more flat than that of inorganic LEDs
- Efficiency
  - Target for 2020 is 190 lumens/W
  - Very low luminaire efficiency losses

Source: Novaled

- Transparency
  - Transparent OLEDs can be made which emit light from both sides when on, and are see-through in their off state (using transparent electrodes & substrate materials)

Unique Features

Flexibility

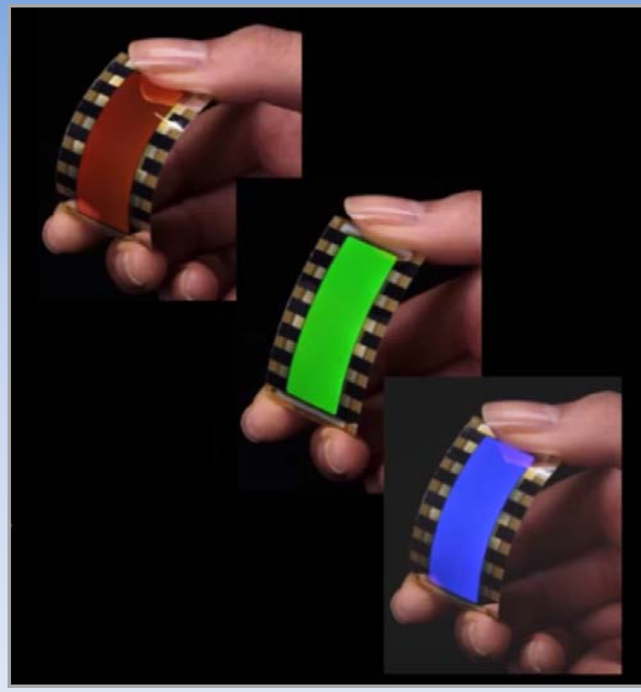


Source: Michael Hack, Universal Display Corporation

Unique Features

Color Tunability – Broad spectra

A combination of flexibility and color tunability



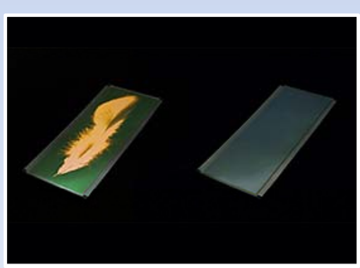
Source: Konica-Minolta

Unique Features

Patterns – Simple displays with high resolution and low power draw

Use of OLEDs with patterns

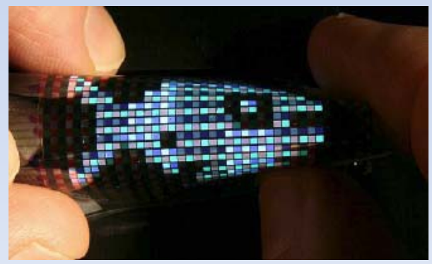
- High resolution (down to the thickness of a human hair) with fine detail
- Half-tones display possible
- Only the illuminated areas consume power, thus saving energy when used as displays
- Image disappears when OLED is turned off



Unique Features

Transparency – Disappears when not in use

Source: Universal Display Corporation



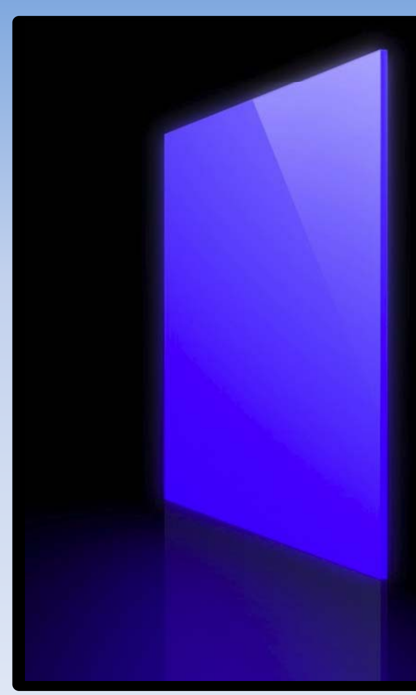
Source: Yuan-Sheng Tyan, Kodak

Unique Features

Color Tunability – Broad spectra

- Wide range of phosphors and flurescent materials allows broader spectra than available with LED technology

- Layer geometry allows uniform mixing of colors without pixialization or color shadows that often occur when mixing LED colors

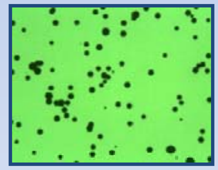


Unique Features

The Major Issues – Performance, cost and lifetime

- Trapping of light inside OLED layers
- Phosphorescent blue material does not match performance of red and green
  - Use of hybrid fluorescent blue and phosphorescent red and green
- Unlikely development of low cost, low resistance, transparent sheet conductors
  - Use of wire grids may eliminate this issue
- Encapsulation to avoid moisture contamination
- Low volume production means high cost
  - Cost reductions driven by display manufacturing which typically does not require the high light output, long lifetimes and high efficacy required for lighting
  - Initial luminaire may require tiling approach

OLED defects caused by moisture[1]



[1]Source: Yuan-Sheng Tyan, Kodak

Unique Features

The Major Issues – Performance, cost and lifetime

Issue	Problem	Solution
Efficacy	Some lab devices can compete with conventional technologies, early products have low efficacy	Work needed to develop efficient, long-lasting blue emitter; next generation products reaching levels that compete with conventional lighting sources
Lifetime	Short lifetimes for blue materials; susceptibility to moisture intrusion	Work needed on high current density, more stable materials, better and low cost encapsulation
Light Output	Current OLED packages produce "dim" light	Work needed to improve light extraction, high current density
Cost	Too high; lower cost device and luminaire materials are needed	Infrastructure investment needed to develop commercial OLED products
Testing Standards	No standards presently available for testing OLED products	Need for reliable test methods standards to establish consistency and reduce uncertainty

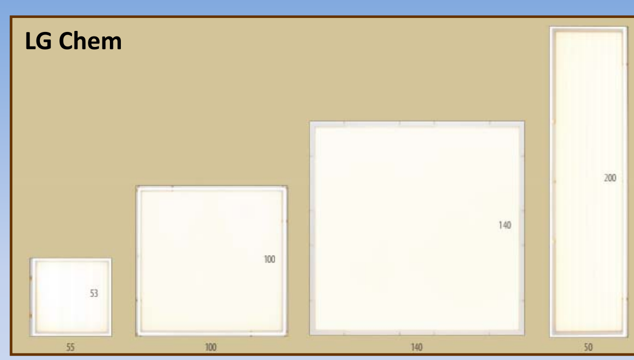
Outline

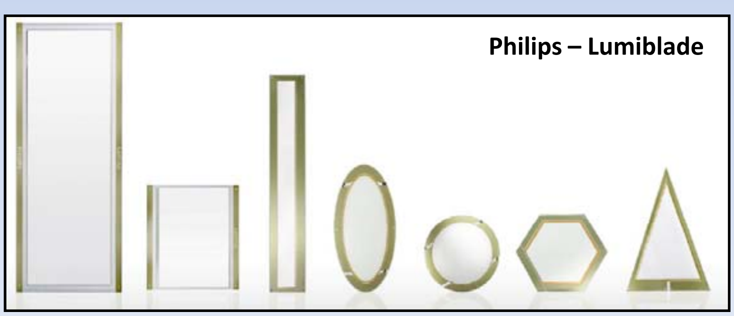
- Introduction – What are OLEDs
- Unique Features – What makes OLEDs different from other light sources?
- **Comparison – Advantages and disadvantages of OLED and LED technologies**
- Applications – Examples of OLED design

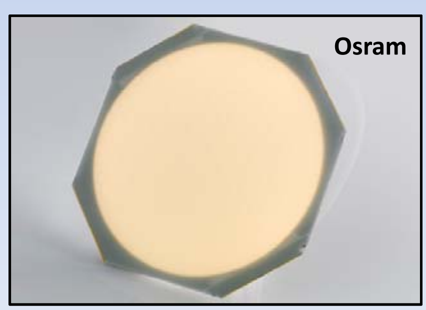
Source: GE

Comparison

OLED Different Shapes & Sizes – Up to 320 mm^2 in a single panel





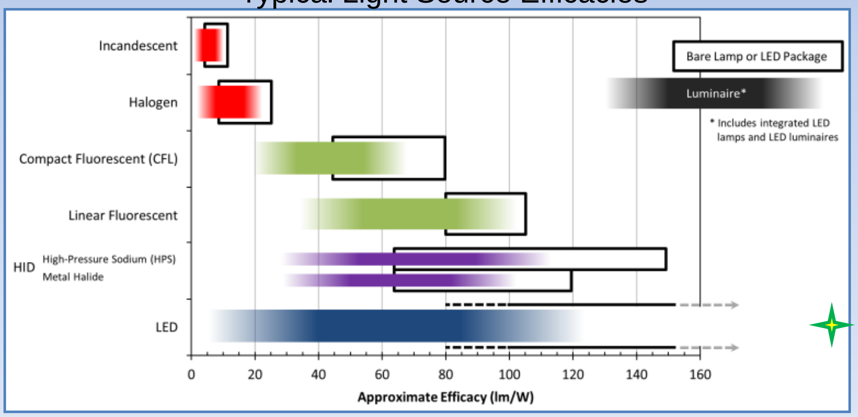


Comparison

Efficacy – What it is and why it is important

Efficacy is a measure of the performance of a device. For lighting efficacy is measured in lumens per watt. The higher the efficacy, the greater the energy savings.

Typical Light Source Efficacies



At least one LED mfg now offers an LED with efficacy of 200 lm/W (at 25^{O}C and 350 mA)

Source: DOE publication *Energy Efficacy of LEDs (March 2013)*

Comparison

LED Luminaire Efficacy – Where the losses come from

Output of the LEDs is only the starting point

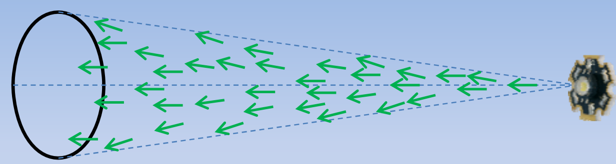
LED efficacy (@ 25^{O}C & 350 mA)		= 200 lumens/watt
Temperature Loss (@85^{O}C)	87.9%	= 175.8 lumens/watt
Drive Current Loss (1050 mA)	87.6%	= 154.0 lumens/watt
Driver Loss	87.5%	= 138.6 lumens/watt
Secondary Optics Loss	90%	= 127.5 lumens/watt
Fixture Loss	95%	= 121.1 lumens/watt

A fixture using 200 lm/W LEDs yields a luminaire efficacy of about 121 lm/W

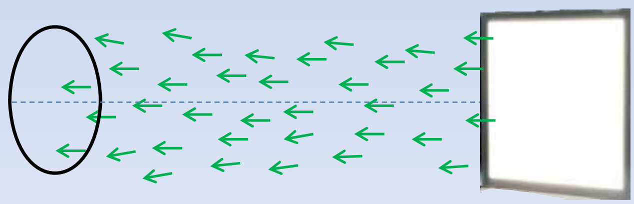
Comparison

Glare Reduction – OLEDs offer a "softer" light output

The LED's point-source characteristic concentrates the light at the source which creates an intense beam which can cause glare when viewed directly.



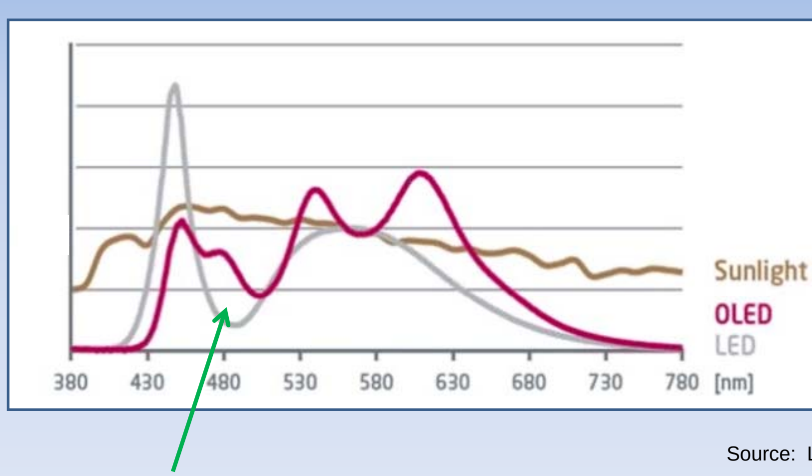
The OLED's uniform light distribution spreads the light over the entire area of the panel creating a soft, glowing light source when viewed directly.



Comparison

Spectral Power Comparison – Less severe dip in the green

OLED spectral power distribution can be designed to more closely match natural sunlight that the corresponding LED spectrum



Source: LG Chem

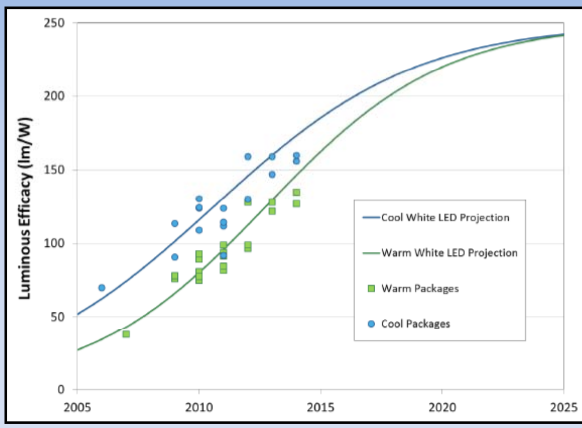
LED Green Gap

Comparison

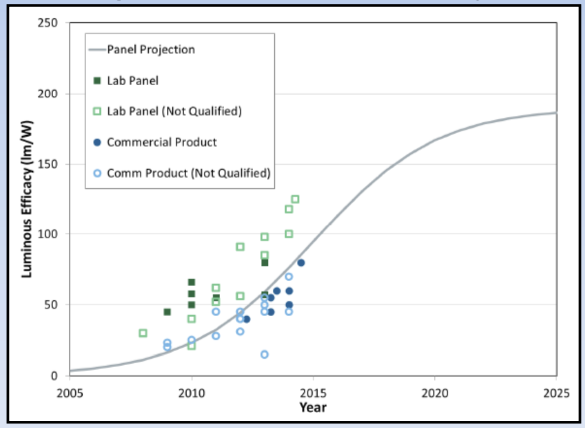
Efficacy – Targets for OLED devices

Comparison of OLED and LED Target Projections

LED Package Efficacy Projections (Commercial Products)



White Light OLED Panel Performance Projections

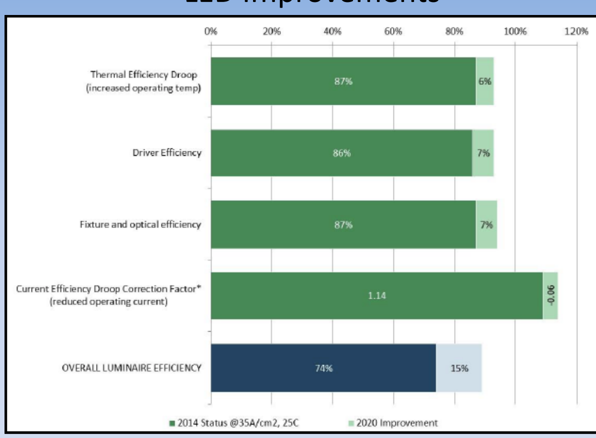


DOE's Solid-State Lighting R&D Plan, May 2015

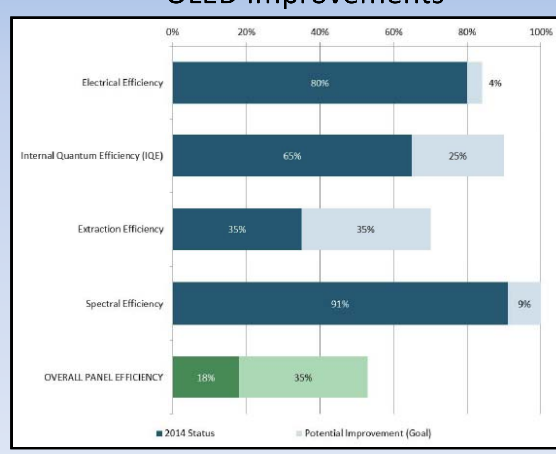
Comparison

LED/OLED Comparison – Where improvement will come from

LED Improvements



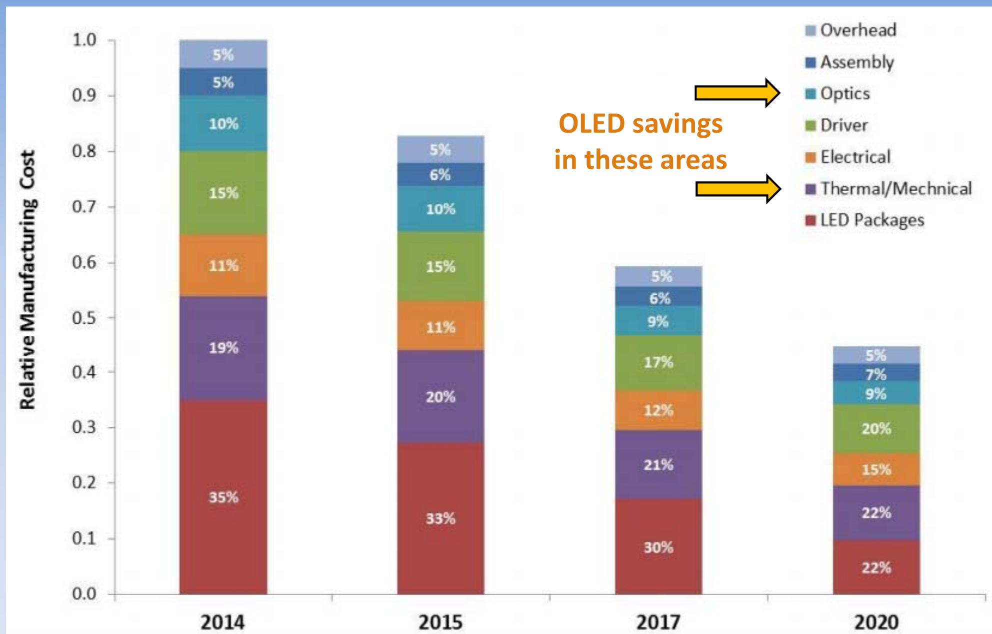
OLED Improvements



DOE's Solid-State Lighting R&D Plan, May 2015

Comparison

One Cost Advantage of OLEDs – Optics and thermal



Source: *Manufacturing Roadmap Solid-State Lighting Research and Development* ; US Department of Energy, August 2014

Comparison

OLED Efficacy – DOE goals vs. present performance

OLED Luminaire Efficiency Projections

Metric	2014	2017	2020	Goal
Panel Efficacy[1] (lm/W)	60	125	160	190
Optical Efficiency of Luminaire	100%	100%	90%	90%
Efficiency of Driver	85%	85%	90%	95%
Total Efficiency from Device to Luminaire	85%	85%	81%	86%
Resulting Luminaire Efficacy[1] (lm/W)	51	106	130	162

[1] Efficacy projections assume CRI >80, CCT 3000^{O}K

Components of OLED Panel Efficiency

Metric	LG Chem NGSA30[1]	Philips FL300[2]	Panasonic[3]	CDT/Sumitomo[4]
LER	328	330	300	335
Electrical Efficiency	80%	64%	83%	70%
Internal Quantum Efficiency	65%	62%	87%	72%
Extraction Efficiency	35%	32%	61%	39%
Panel Efficiency	18%	13%	44%	20%
Panel Efficacy (lm/W)	60	42	133	66

LER – Luminous Efficacy of Radiation

DOE's Solid-State Lighting R&D Plan, May 2015

Comparison

OLED Research Projects – Programs funded by the DOE

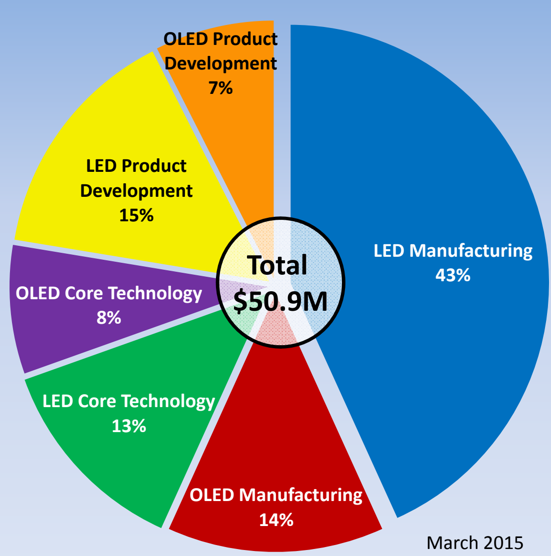
	Research Organization	Project Title
LED	Carnegie Mellon University	Novel Transparent Phosphor Conversion Matrix with High Thermal Conductivity for Next Generation Phosphor-Converted LED-based Solid State Lighting
	Cree, Inc.	Scalable Light Module for Low-Cost, High-Efficiency LED Luminaires
	Cree, Inc.	Low-Cost LED Luminaire for General Illumination
	Eaton Corporation	Print-Based Manufacturing of Integrated, Low-Cost, High- Performance SSL Luminaires
	Innotec, Corp*	Integrating Energy efficient SSL with Advanced Sensors, Controls and Connectivity
	KLA-Tencor Corporation	High-Throughput, High-Precision Hot Testing Tool for HBLED Testing
	Lumisyn*	Nanocrystal-based phosphors with enhanced lifetime stability
	MoJo Labs Inc	Task-to-Wall Solid State Lighting Sensing and Control
	Momentive Performance Materials Quartz, Inc.	Next-Generation LED Package Architectures Enabled by Thermally Conductive Transparent Encapsulants
	Philips Lumileds	Development and Industrialization of InGaN/GaN LEDs on Patterned Sapphire Substrates for Low-Cost Emitter Architecture
	Philips Lumileds Lighting, LLC	High-Voltage LED Light Engine with Integrated Driver
	Philips Research North America	Innovative Patient Room Lighting System with Integrated Spectrally Adaptive Control
	PhosphorTech Corporation*	Plasmonic-enhanced High Light Extraction Phosphor Sheets for Solid State Lighting
	Research Triangle Institute	System Reliability Model for SSL Luminaires
	Soraa	Light-Emitting Diodes on Semipolar Bulk GaN Substrate with IQE >80% at150 A/cm2 and 100°C
	Triton Systems*	Improved Light Extraction from GaN LEDs
	VoltServer, Inc*	Low-Cost, High Efficiency Integration of SSL and Building Controls using aPET Power Distribution System
OLED	Arizona State University	High-Efficiency and Stable White OLED Using a Single Emitter
	MicroContinuum, Inc.*	Roll-to-Roll Production of Low-Cost Integrated OLED Substrate with Improved Transparent Conductor & Enhanced Light Outcoupling
	OLEDWorks, LLC	OLED Lighting Panel with Directional Light Output and High Efficiency
	OLEDWorks, LLC	High-Performance OLED Panel and Luminaire
	OLEDWorks, LLC	Innovative, High-Performance Deposition Technology for Low-Cost Manufacturing of OLED Lighting
	Pixelligent Technologies LLC*	Advanced Light Extraction Material for OLED Lighting
	Pixelligent Technologies, LLC	Advanced Light Extraction Structure for OLED Lighting
	PPG Industries	Manufacturing Process for OLED Integrated Substrate
	Princeton University	ITO-free White OLEDs on Flexible Substrates with Enhanced Light Outcoupling
	University of California-Los Angeles	The Approach to Low-Cost High-Efficiency OLED Lighting

DOE's Solid-State Lighting R&D Plan, May 2015

Comparison

DOE Research Grants – All aspects of solid-state lighting

DOE SSL R&D Active Portfolio



March 2015

The DOE supports SSL R&D in partnership with industry, small business, and academia. Presently there is $50.9 in funding for the current solid-state lighting portfolio.

Approximately 29% of this funding is focused on OLED technology issues

Outline

- Introduction – What are OLEDs
- Unique Features – What makes OLEDs different from other light sources?
- Comparison – Advantages and disadvantages of OLED and LED technologies
- Applications – Examples of OLED design

Source: GE

Comparison

Cost – Printable OLED Lighting

- GE and DuPont announced a pilot program a few years ago to integrate GE's pre-pilot roll-to-roll manufacturing infrastructure with:
  - High performance, solution processable materials
  - Advanced device architectures
  - Advanced encapsulation using ultra-high multilayer barrier films (alternate ceramic/plastic layers)
- Goal: Eliminate differences in OLED performance between laboratory-scale batch process and pre-pilot production
- Not much progress in the last few years

GE roll-to-roll OLED line demonstration, 2007

Cost – Printable OLED Lighting

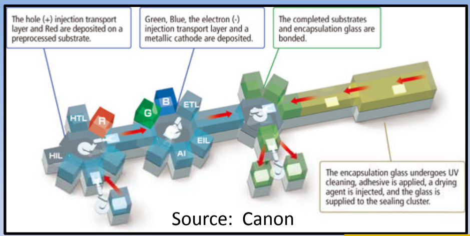
Not all programs are successful

- Project announced for upstate NY
  - Project partners: DOE, Universal Display Corporation, Moser Baer Technologies, NY's Smart System Technology & Commercialization Center (STC)
- Joint effort to design and set up nation's first pilot production facility for OLED lighting panels
- Facility was to provide prototype panels to U.S. luminaire manufacturers to incorporate into products
- Funding fell through and the project did not progress

Located in Canandaigua, NY, the STC will house two pilot phosphorescent OLED manufacturing lines.

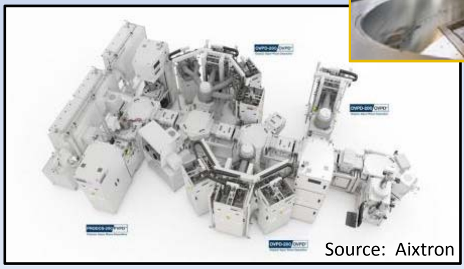
Comparing Approaches – Vacuum deposition versus ink jet

Two approaches to OLED manufacturing



Source: Canon

Vacuum deposition


Source: Aixtron

Ink jet printing


Source: Kateeva

Comparison

Cost – More recent manufacturing sites

LG is planning to construct a new production line for OLED lighting by 2017. They will commit $185M toward this new fabrication line, which will increase its production capacity and will lower prices dramatically.

LG also plans to build a new manufacturing plant in Paju Korea scheduled to go on line by 2018. They plan to invest $8.7B in the facility which will include **Gen 9** glass fabrication capability. which should reduce their cost of display panels by up to 90%

They also announced that they will build a new **6-Gen** (1500x1850 mm) flexible OLED fab at their Gumi production facility. The plant will cost $900M and will have a monthly capacity of 7,500 (1.5 million 5.5" panels) Production is scheduled to begin in the first half of 2017.

Comparison

Cost – More recent manufacturing sites

Konica Minolta in 2014 completed a $100M fabrication facility with capacity to produce 1,000,000 flexible panels per month using a plastic substrate with a roll to roll process

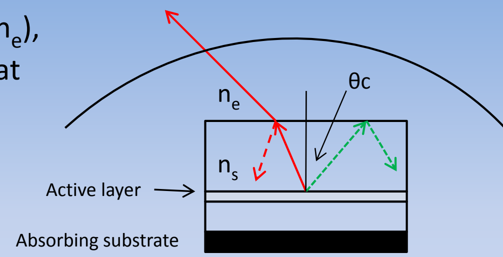
Largest OLED panels presently available are made by LG and measure 320mm x 320mm (12.6" x 12.6") and cost over $600.

Apple is rumored to be planning to convert to OLED displays in their iPhone 8 scheduled for introduction in 2018 which could dramatically increase the demand for OLED panels

Comparison

Light extraction – How LED manufacturers handle the issue

Due to the high Index of Refraction of the semiconductor (n_s) as compared to the epoxy dome material (n_e), by Snell's law, photons exiting the active layer at angles greater than the escape cone angle θ_c will be reflected back into the semiconductor and will not exit the device.



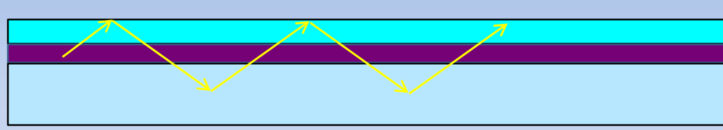
Some device manufacturers cut the sides of the chips to provide better exit angles and extract more light while others rough the surfaces of the chips to create optical interfaces which can improve the overall light extraction. A third approach is to use what are known as photonic crystals to reduce certain propagation modes (reflected) and increase others (exiting).

Source: Lumileds

Comparison

Light Extraction – Methods that OLED manufacturers use

Light extraction is a problem with OLEDs as well as LEDs. In the case of OLEDs, the light gets trapped in the thin organic layers due to the high difference in refractive indices.

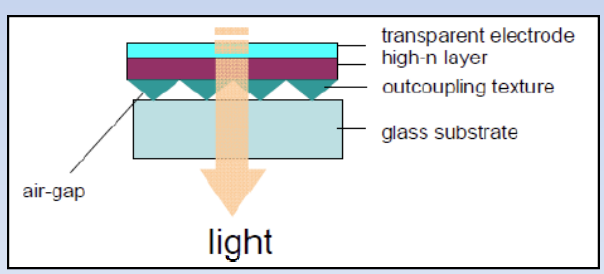


Waveguide entrapment

Improved light extraction method

More light

More complex production $$$

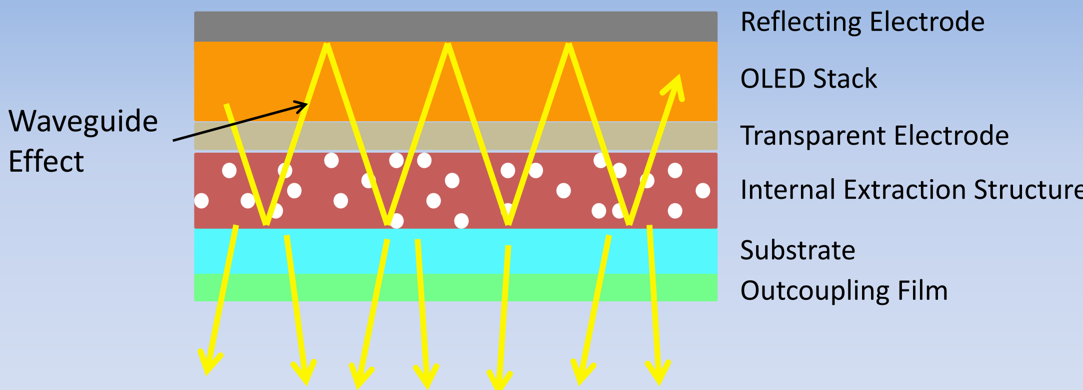


Source: Kazuyuki Yamae, et al., Panasonic Corporation

Comparison

Light Extraction – Methods that OLED manufacturers use

A second approach to improve light extraction from OLED devices

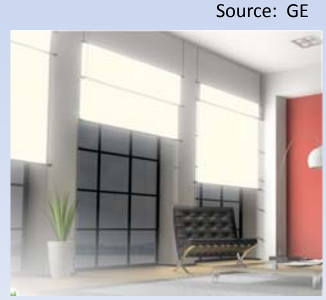


A layer of scatterers (transparent objects with a slightly different index of refraction from the surrounding material) redirect light out of the device

Outline

- Introduction – What are OLEDs
- Unique Features – What makes OLEDs different from other light sources?
- Comparison – Advantages and disadvantages of OLED and LED technologies
- **Applications – Examples of OLED design**

Source: GE



Applications

Research – Driven by display needs presently

Majority of commercial investment in OLED technology has been focused on display applications – for example, Samsung has recently averaged about $5B per year.

Source: Samsung

Source: LG Electronics

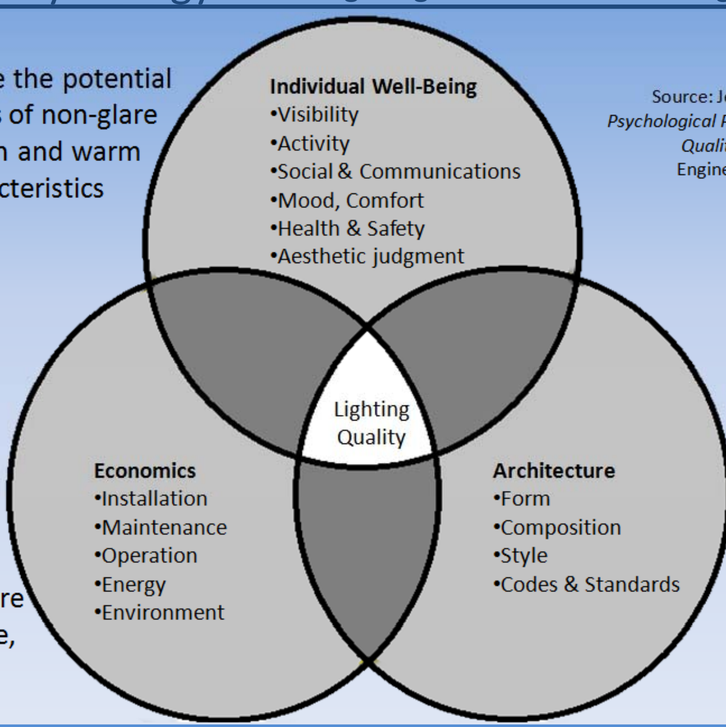
LG plans to produce 600,000 OLED TVs (55", 65" and 77" during 2015

Applications

Human Psychology – How lighting affects our well-being

OLEDs have the potential advantages of non-glare illumination and warm color characteristics

Source: Jennifer A. Veitch Ph.D. (2001) *Psychological Processes Influencing Lighting Quality*, Journal of the Illuminating Engineering Society, 30:1, 124-140,



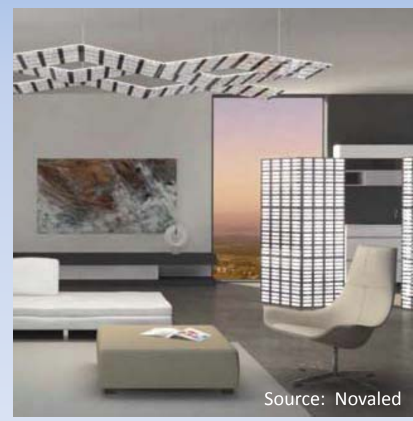
OLEDs do not require heat sinks or large fixtures, they are more expensive, however

OLEDs allow designers new form factors that they have only begun to explore

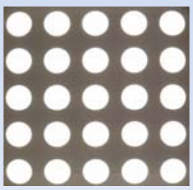
Applications

Niche Products – New form factors but high cost

- Offers Architects/Lighting Designers the ability to eliminate the distinction between light source and luminaire
- Its creates a plane of light with no perceptible volume
- Its form factor is very flexible allowing widely varying form factors and shapes
  - Future flexible substrates will allow infinite variation in shapes
- Provides soft, glare-free illumination without requiring diffusers, baffles, etc.



Source: Novaled

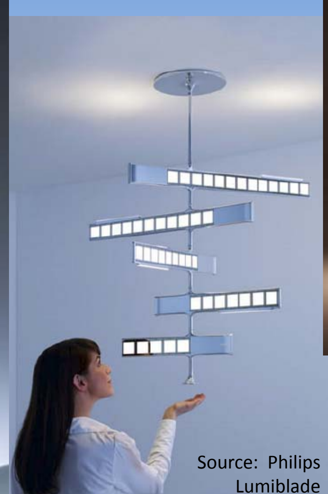


Source: Acuity

Applications

Niche Products – New form factors but high cost

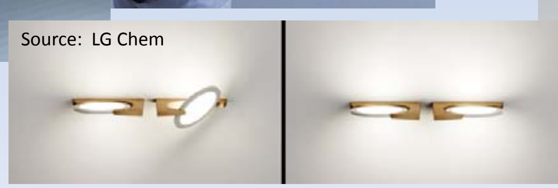
Source: Osram



Source: Philips Lumiblade

Source: Universal Display Corporation

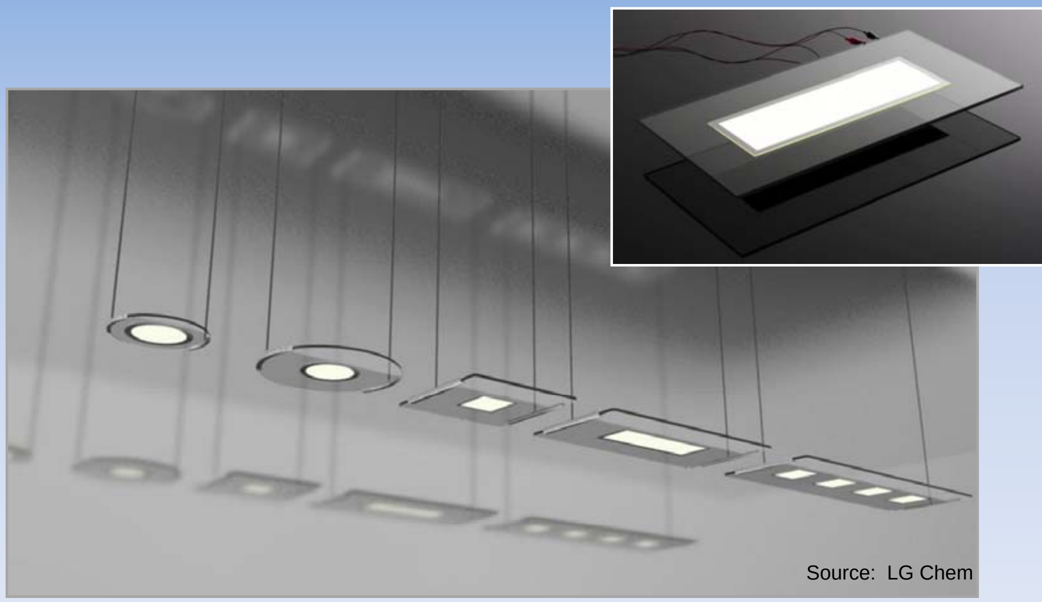
Source: LG Chem



Source: LG Chem

Applications

Unique Characteristics – Allow unusual form factors for luminaires



Source: LG Chem

Applications

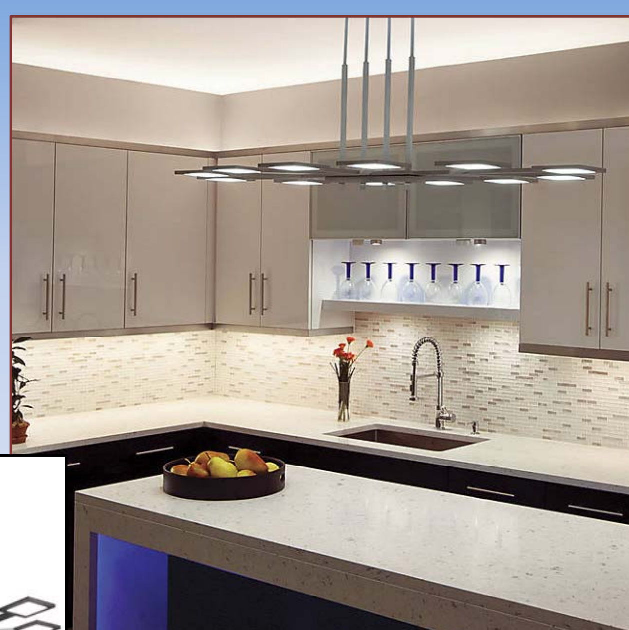
Unique Characteristics – Allow unusual form factors for luminaires

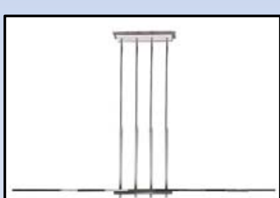
OLED Chandelier

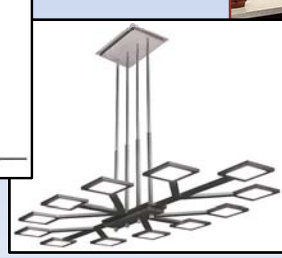
Price: $9,990

Details:

- Finish: Brushed Aluminum
- Material: Aluminum
- Aluminum body
- Brushed Aluminum finish
- Ceiling canopy
- Four stems
- Dimmable with electronic low voltage (ELV) dimmer (not included)
- LED Average Rated Life: 15,000 hours
- LED Color Temperature: 4000K
- CRI: 82
- 2040 lumens
- UL Listed
- Made In China







Source: Modern Forms

Applications

Unique Characteristics – Allow unusual form factors for luminaires

Source: LG Chem

Source: Philips Lumiblade (Riva 1920)

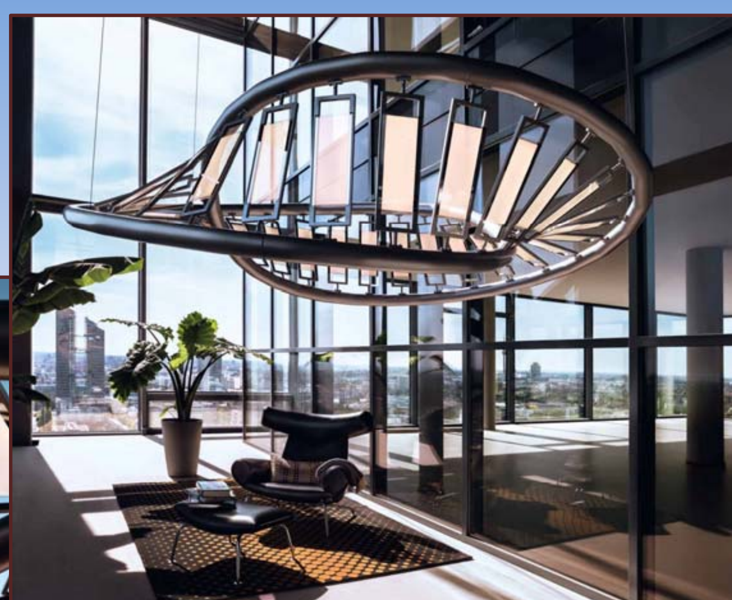
Source: Acuity Lighting

Source: LG Chem

Applications

Transparent OLEDs – An example of new design possibilities

OLED design luminaire "Rollercoaster" by Osram



Applications

Automotive – Exterior lighting

Applications

OLED Ceiling Fixtures – US Embassy (Finland)

US Embassy (Finland)

US Embassy (Finland)

Source: Acuity

Acuity - Trilia

Applications

Unique Characteristics – Allow unusual form factors for luminaires

Source: Blackbody (Astrom FIAMM)

Applications

Waving your hand up and down in front of the sensor as well as forward and backward, changes the light level as well as on/off for the various OLED panels that make up the fixture

From a design competition held in Hong Kong in 2009

Source: Ken Wong

Sensor

Source: Acuity

Applications

OLED Fixtures – A chandelier

This beauty can be yours for only $54,000

Applications

Are OLEDs Only For Multi-Millionaires?

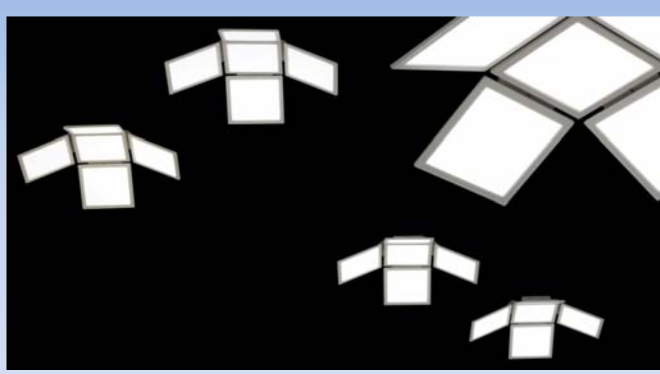
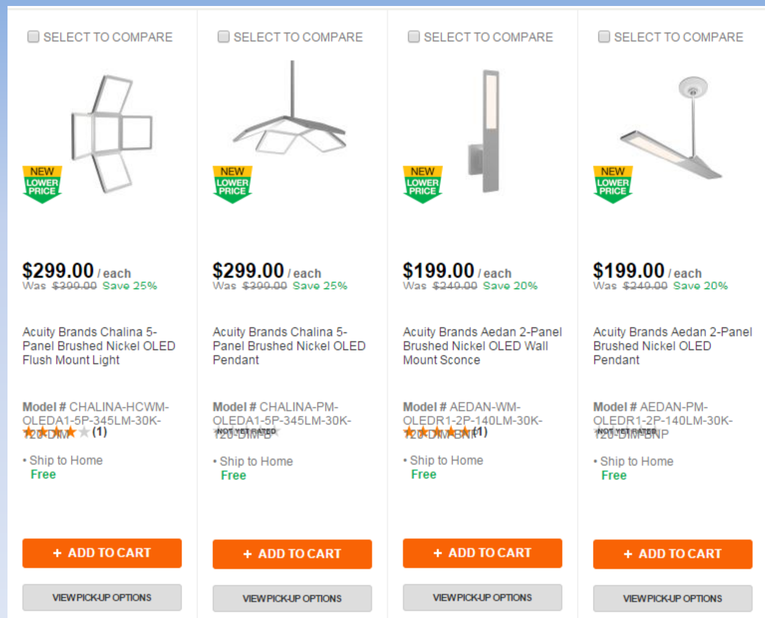


Photo Credit: ©John Sutton Photography 2011

Applications

The Answer is No – OLED fixtures showing up at big-box stores

Available now at a store near you



Final Thoughts

Are OLEDs Ready for Prime Time – It depends

- OLEDs still have quite a ways to go to compete head to head with LED technology for many traditional lighting applications and may, in fact, never get there
- The unique characteristics of OLEDs fit quite nicely with how designers and architects think of lighting; less so for those whose first impulse is to pull out a light meter
- OLEDs can typically provide a broader spectrum than LEDs
- OLEDs naturally produce diffuse light; LEDs have to work at it
- OLED manufacturing cost remains one of the major hurtles to overcome for broader adoption of the technology
- Both OLEDs and LEDs experience cost benefits from their association with the TV/display industry
- OLEDs will have a place in tomorrow lighting landscape

This concludes The American Institute of Architects
Continuing Education Systems Course

Dr. John (Jack) W. Curran
President LED Transformations, LLC
PO Box 224
Stanton, NJ 08885
(908) 437-6007
jcurran@ledtransformations.com

LED Transformations LLC
Your Guide to Solid State Lighting

US Department of Energy
www.ssl.energy.gov

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

acg

CONTINUING EDUCATION AIA