LED Lighting
12th Annual Building Codes Education Conference
March 27 - 30 2017
Bozeman, MT
Jaya Mukhopadhyay, Co-Director, Integrated Design Lab
Montana State University, Bozeman, MT
Learning Objectives

WHAT WE WILL COVER:

- WHAT ARE LEDS & HOW DO THEY WORK?
- THE COMPONENTS OF LED LIGHTING SYSTEMS
- OPERATIONAL CHARACTERISTICS
- DESIGN APPLICATIONS
What is a Diode?

A DIODE IS A SOLID-STATE DEVICE THAT ACTS LIKE A GATE OR A SWITCH

- ALLOWS ELECTRONS TO FLOW IN ONLY ONE DIRECTION
- OFTEN USED TO CONVERT AC TO DC
- P-N JUNCTION (P: POSITIVE VOLTAGE, N: NEGATIVE VOLTAGE
- ELECTRONS IN THE N-SIDE WILL WANT TO GO TO THE P-SIDE
- HOLES OF THE P-SIDE WILL WANT TO GO TO THE N-SIDE
What is a Light Emitting Diode?

“LIGHT IS GENERATED BY A DIRECT CONVERSION OF ELECTRIC ENERGY INTO PHOTONS WITHIN A SOLID SEMICONDUCTOR DIE”

ADVANCED LIGHTING GUIDELINES

• PHOTONS THAT ESCAPE THE CHIP PRODUCE VISIBLE LIGHT, OTHERS ARE REABSORBED

• THE LIGHT PRODUCED IS HIGHLY DIRECTIONAL & FREQUENCY (COLOR) SPECIFIC

• LEDS HAVE A MAXIMUM DRIVE CURRENT

• LEDS HAVE A MAXIMUM CHIP JUNCTION TEMPERATURE (TJ)
How Does a LED Work?

TO TURN ON AN LED:

• **FORWARD VOLTAGE (VF) APPLIED TO ANODE LEAD** (KNOWN AS “FORWARD BIASING THE LED”)

• **LIGHT OUTPUT INCREASES WITH INCREASED FORWARD CURRENT THROUGH THE LED**

• **THE RATED CURRENT IS A FUNCTION OF CHIP SIZE & DESIGN**

• **FEW COMPANIES MANUFACTURE THE BASIC LED CHIPS**

**LEDS HAVE NO GAS, NO FILAMENT, NO GLASS BULB, NO MOVING PARTS THAT MIGHT FAIL**
What are the Types of LEDs?

MINIATURE LEDS

- INDICATOR LAMPS, SIZES 2 MM TO 8 MM, THROUGH-HOLE OR SURFACE MOUNT

MID-RANGE LEDS

- FEW LUMEN OUTPUT FOR LIGHT PANELS, EXIT SIGNS, CAR TAIL-LIGHTS

HIGH-POWER LEDS

- FOR ARCHITECTURAL LIGHTING

- POWER DENSITIES UP TO 300 W/ CM², MUST HAVE A HEAT SINK

- EXAMPLES: NICHIA 19, LUMILEDS REBEL, OSRAM
What are the Components of a High-Power LED Package?

AN LED PACKAGE CONSISTS OF:

- AN LED CHIP OR “DIE”

- SUBSTRATE: SLUG OF COPPER, CERAMIC OR ALUMINUM MOST COMMON: ACTS AS A THERMAL PATHWAY

- ENCAPSULANT: CLEAR COVERING THAT PROTECTS THE CHIP & BOND WIRES: USUALLY SOFT SILICON GEL OR HARD EPOXY

- LENS (OPTIONAL): TO INCREASE OUTPUT EFFICIENCY OR CHANGE DISTRIBUTION

- LEADS: ELECTRICAL CONNECTIONS, EITHER A LEADED LED PACKAGE TO INSERT IN A CIRCUIT BOARD OR A SURFACE MOUNT WITH SOLDERED CONNECTIONS ONTO PRINTED PADS
Advantages of LEDs

- **Efficacy (Lumens/Watt): Similar to fluorescent**
- **Directional Source: Efficient Optics Possible**
- **CCT & CRI Improvements, Comparable to CFL Lamps**
- **Very Long “Useful” Life**
- **No Mercury or Lead**
- **No Infrared or Ultraviolet**
- **Cold Operation**
- **Resistant to Impact & Vibration**
- **Instant On, Digital Control Possible**

![LED Efficacy Compared to Conventional Lighting Technologies](https://www.energy.gov/eere/ssl/led-basics)
How Do LEDs Produce Color?

- Color is determined by chip composition.
- Each chip produces photons of a unique color.
- Slight variations in chips lead to color variations.
- High brightness red, amber: alln-gap chips.
- High brightness blue, green, cyan: ingan chips.
- Gap in yellow-green region filled by different colors in same device.
- Producing a quality white light has been a challenge.
## Colors of LED Lamps

### LUXEON REBEL COLOR PORTFOLIO

<table>
<thead>
<tr>
<th>Color</th>
<th>Part Number</th>
<th>Wavelength Range (nm)</th>
<th>Min Flux (lumens/ mW)</th>
<th>Typical Flux (lumens/ mW)</th>
<th>Test Forward Current (mA)</th>
<th>Maximum Ratings</th>
<th>Typical Efficacy (lm/W)</th>
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* Low VI parts.
THREE METHODS FOR CREATING WHITE LEDS:

• SINGLE COLOR WHITE LEDS (SINGLE LAMP)

• MULTIPLE-COLOR WHITE LEDS (RGB MIXING OF MULTIPLE LAMPS)

• HYBRID METHOD
BLUE LED PLUS PHOSPHOR:

• SPECTRUM: BLUE SPIKE WITH GREEN, YELLOW, RED PORTIONS

• EARLY LEDS: BLUISH WHITE, UNEVEN COLOR IN THE BEAM

• NEW ADVANCES IN PHOSPHORS: RED ENHANCED

• WARM WHITE LED WITH CCT DOWN TO 2700K

• NEW TECHNOLOGY: GAN ON GAN CHIPS (SORAA COMPANY)

• HIGH LIGHT OUTPUT, HIGH CRI (DEEP RED COLOR RENDERING)

• GOOD ALTERNATIVE TO MR16 HALOGENS

• 2700K OR 3000K, CRI UP TO 95
RGB (RED, GREEN, BLUE) COLOR MIXING:

- LEDs dimmed to different levels to create particular color
- Use where colored light is desirable
- Hybrid White: White LED plus Red LED to lower the CCT
- Tends to be expensive
- Pastels may look unnatural
SLIGHT VARIATIONS IN MANUFACTURING CREATES COLOR VARIATIONS:

- EACH CHIP TESTED FOR VOLTAGE RATING, COLOR, & LUMEN OUTPUT
- SORTED INTO BINS BY RANGE OF PERFORMANCE VALUES
- BINS RESPOND TO MACADAM ELLIPSE: RANGE OF COLOR DIFFERENCES THAT ARE PERCEPTIBLE
- SINGLE COLOR LEDS SORTED BY DOMINANT WAVELENGTH
- PHOSPHOR WHITE LEDS: USES CIE COLOR COORDINATE RANGES
- NEMA STANDARD SSL 3-2011 SETS BINS FOR CHROMATICITY, FORWARD VOLTAGE, LUMINOUS FLUX FOR LEDS USED IN GENERAL LIGHTING
LED Color Binning

MAC ADAMS ELLIPSE

Example of target on CIE chromaticity chart (x, y)

NOTE: A and B are each 1 step from the target, but 2 steps from each other.
C and D are each 2 steps from the target, but 4 steps from each other.

CIE 1931 x, y chromaticity diagram

https://www.ecse.rpi.edu/~schubert/Light-Emitting-Diodes-dot-org/chap17/chap17.htm
Electronic Power Control

POWER SUPPLY: Converts incoming AC voltage to a usually lower DC voltage

LED DRIVER: Regulates & limits the LED current
May be combined with power supply
Similar to a ballast in a fluorescent system

Together these components supply & regulate power to the LED array

CONTROLLER: Switch, dim, or allow color mixing in the system
How Does Heat Affect LEDs?

- Current through the junction creates heat.
- Can damage LED if heat exceeds maximum $T_j$.
- LEDs employ a heat sink near the chip junction.
- Heat must flow easily from heat sink to the environment.
- Light output decreases with increasing junction temperature.
- This heat effect on light output is reversible.
CONVENTIONAL LAMPS RATED LIFE:

- RATED LIFE AT 50% LAMP FAILURE POINT

LED LAMPS USEFUL LIFE:

- BASED ON LUMEN MAINTENANCE & DEPRECIATION
- STANDARD: IES LM-80
- USES LP MAINTENANCE MEASUREMENT WHERE:
  - L IS INITIAL OUTPUT
  - P IS PERCENTAGE MAINTAINED OVER A NUMBER OF HOURS

EXAMPLE: L70 / 60,000 WHERE 70% OF INITIAL OUTPUT (30% LOSS) REACHED IN 60,000 HOURS
Light Output for LEDs


SPECTRAL DISTRIBUTION POWER

Tri-phosphor linear fluorescent

Daylight

Incandescent

93 CRI LED Lamp

Phosphor LED Lamp

Tri-Color LED Lamp
CURRENT LED REPLACEMENT TARGETS:

- INCANDESCENT/HALOGEN SCREW BASE
- FLUORESCENT T12 & T8, 4 FOOT LAMPS

Courtesy of SATCO

Courtesy of Lighting Design Lab
OMNIDIRECTIONAL INCANDESCENT LAMPS:

- TARGET: GENERAL SERVICE INCANDESCENT LAMPS
- SHAPES: A, BT, P, PS, S, & T
- RECENT IMPROVEMENTS IN LIGHT OUTPUT & EFFICACY: SOME NOW SURPASSING CFL PERFORMANCE

DIRECTIONAL INCANDESCENT LAMPS:

- SHAPES: BR, ER, K, MR16, PAR16/20/30/38
- DISTRIBUTION: SPOT, FLOOD, WIDE FLOOD
- DOE “CALIPER” TESTING: LED PAR30 & PAR38 EXCEED HALOGEN IN LIGHT OUTPUT & EFFICACY WITH IMPROVED CBCP

Courtesy of GE

Integrated Design Lab, Bozeman, MT
LED MR16 Replacements

7W 12V Energy Smart™ MR16 Dimmable Lamp

The 7W MR16 range has been developed to replace 35W & 50W equivalent MR16 halogen lamps and offers a high level of technical performance in the form of a halogen shaped LED lamp. Simple to change, it offers an outstanding lumen package that ensures a relatively short payback period.

- Multiple colour temperatures (2700-3000K)
- Reduces ongoing maintenance costs
- Suitable for track and recessed lighting
- Outstanding performance up to 56lm/W efficiency for 7W lamp

Image courtesy of Soraa.

Soraa Vivid 95 CRI Comparative Spectral Signature

Courtesy of GE & SORAA
LINEAR FLUORESCENT REPLACEMENT LAMPS:

• TARGET: 4 FOOT T8 & T12 IN EXISTING TROFFERS

ADVANTAGES:
• ENERGY SAVINGS: 2-18W ABOUT 40% (CHECK LIGHT OUTPUT)
• MAINTENANCE SAVINGS: FEW SPOT REPLACEMENTS OVER LIFE
• NO MERCURY OR LEAD
• COLD STARTING (WHICH MAY IMPROVE LIFE)
• SHOCK & VIBRATION RESISTANT

DISADVANTAGES:
• POOR LIGHT OUTPUT: MAY NEED TO ADD LAMPS TO MAINTAIN LEVELS
• STRONG DIRECTIONALITY: POOR UNIFORMITY
• COST OF BYPASSING BALLAST (OR REDUCED EFFICACY IF USING THE BALLAST)
• SOME FLUORESCENT LAMPS RATED AT 55,000 HOURS SO MAINTENANCE BENEFIT MAY NOT EXIST
3D Symmetrical Batwing Distribution

ArcForm is a highly efficacious, fully luminous fixture with brilliant color rendering and an innovative 3D symmetrical batwing lighting distribution. It delivers pure, white light—free of glare, color shifts, hotspots or striations, with unparalleled uniformity, maximizing visual comfort and energy savings.

A New Dimension In Lighting Performance

Advanced LED optical design and patented MesoOptics technology combine to deliver wider fixture spacing while ensuring optimal light levels, perfect uniformity, and maximum energy savings.

Scan to view ArcForm video or visit arcform3d.com

Courtesy of PHILIPS LEDALITE
LED Applications

Modular light installations of the third kind – with the Philips LivingSculpture 3D module system, users can concentrate fully on the design of their three-dimensional light installations. The technical know-how and controls are both taken care of by the module system.

LivingSculpture 3D module system
Module dimensions: 32.4 x 32.4 cm (12.7 x 12.7 in)
(1/3 of package, seamless combinable)
OLED head dimensions incl. frame: 7.8 x 7.8 cm (3 x 3 in)
Max. rod plug-in positions per module: 16
Max. OLEDs per module: 16 OLEDs
Length of rods: available in intervals of 25 cm (0.99 ft),
25 cm (0.99 ft) – 40 cm (15.75 in)
(Rods according to ordered installation)
Online configurator at: www.lumiblade-experience.com
Rod shapes straight
Finishing module chrome
Weight: ~3.5 kg/module
(incl. full equipment with OLEDs, rods, etc.)

Electrical Specifications
Power in: 100V – 240V AC, 50/60Hz, 60 W
Power out: 24 V DC (SELV)

Content Management
Data input: DMX via ArtNet
Hardware:
- MacBook Pro™, ENTTEC Data Gain Software
- WHITExed LivingSculpture DMX-Controller
- Option: Apple iPad® for live animation

Installation
4 screws/module in base plate to the ceiling

OLED Specs
Outer dimensions: 7.8 x 7.8 cm (3 x 3 in)
Color temperature: ~3000K
Max. luminance per OLED: ~2000cd/m² (nits)

LivingSculpture

4/7/2017
Integrated Design Lab, Bozeman, MT

PHILIPS LUMIBLEADE

Courtesy of PHILIPS LUMIBLEADE
LED Applications

1. Thermal Management
   MB-LED extruded aluminum heat sinks are designed to dissipate heat well below the recommended operating temperature. Ensuring 50,000 hours of operation at 70% lumen depreciation (LED).

2. Power Supply
   The Class 2 LED power supply is adjacent to the LED engine to improve efficiency and ensure optimal performance. The minimum power factor rating for the MB-LED power supply is 0.95. ETV dimming control is offered as a standard in most luminaires.

3. Accessories
   Fixtures and control units are available for all MB luminaires. Available options include remote control modules, color/scene control, and dimming. These features are available for selected luminaires in the product lines.

4. Optics
   Flood and accent reflectors feature precise European design and construction. The compact reflectors are constructed of an optical grade materials for high performance conditions. The MB-LED track luminaries utilize a high performance LED strip. These compact high flux density light sources deliver uniform high-quality illumination without flicker.

5. Luminaires
   The MB-LED track luminaries utilize a high performance LED strip. These compact high flux density light sources deliver uniform high-quality illumination without flicker.

6. Control
   The MB-LED track luminaire utilizes a high performance LED strip. These compact high flux density light sources deliver uniform high-quality illumination without flicker.
LED Applications

All Aboard

An aluminum art structure incorporating a new LED string product turned the heads of visitors to an international transportation exhibition this past September. The installation, designed by Ambion GmbH from Kassel, Germany, succeeded in attracting crowds of visitors to the booth of transportation leader Bombardier, with its imagery of train traffic across the globe. The VC-Dot 1 LED strings from Martin Professional comprise more than 2,000 individually controllable pixel dots. The product can be specified with one, four, or nine LEDs per pixel and can be ordered in either an RGB color-mixing version or cool mid-blue or warm white single-color version.
LED Applications
LED Applications

IMMERSION® LED Refrigerated Display Lighting

IMMERSION® LED Refrigerated Display Lighting from GE has changed the way people see refrigerated displays. Standard fluorescent lighting will flood a display case with broad and diffuse light which can create shadows, light spillage and glare. Unlike fluorescent, dedicated GE LED systems distribute light evenly on the shelves and throughout the case. Cabinets achieve higher overall illumination and therefore become much more eye-catching. At the same time, IMMERSION® allows retailers to dramatically bring down operating costs and energy consumption.

These products comply with GE’s Ecomagination initiative, ensuring that light fittings fulfill high-performance claims without containing any mercury, lead or glass. Long life reduces material waste. Consequently, it makes handling and recycling less of a concern. Lightbars can be easily incorporated into new vertical/horizontal cases or retrofitted into existing ones.

Features >>> Benefits
Unique optic design
Brighter and more uniform lighting across package facings
3000, 3500, 4100 and 5000 K CCT
Multiple colour temperatures to create the perfect look for every refrigerated area
Many vertical and horizontal lightbar sizes
Fit into a variety of chillers and freezers
Low wattage and heat
Dramatic energy savings and less CO₂ emissions
50,000 hour lifetime and ongoing performance
No material waste, significant maintenance costs reduced. Reliable LED bars, absolutely not affected by cold temperature or multiple "turn on/off"
No IR or UV emissions.
Optimal selling environment for food merchandise

LED Display Case Lighting System

The GE LED Display Case Lighting System brings glass cases to life. It creates a high ambient light level uniformly throughout the case, yet still delivers the all important sparkle thanks to unique optics. Combined with the tangible benefits of long life, energy saving and guaranteed reliability, this system is a retail revolution.

Light where you need it
Traditional lighting technologies direct the light only to certain areas of the display case, creating undesirable shadows, light spillage and glare. GE’s LED system offers significant improvements on these conventional systems.

Features >>> Benefits
Unique reflector optics
Mechanise sparkle, with high level of uniform light inside case
Directional LED light sources
Split light reduced, giving high application efficacy
Highly efficient LEDs
Alum up to 80% energy saving compared to low-voltage halogen lamps
5300 K and 4200 K CCT
Perfect colour temperatures to show off valuable merchandise
50,000 hour lifetime
Over 10 years of reliable performance in retail environment

Cost of ownership over useful life of LED system
In this example, a single 25.9 W LED Display Case unit is used instead of 6 halogen 20 W HPLL lamps in a new jewellery display case. The benefits are clear:
- 85% saving in energy consumption and CO₂ emissions
- 11 year life of the LED system eliminates lamp replacement costs
- 64% reduction in total cost of ownership over LED useful lifetime
- 2.4 year payback

Assumptions
- Energy cost of $0.1 per kWh, 2.56 kg CO₂ emitted per kWh fluorescent
- Fixtures returned to retailer at end of warranty life
- 64% maintenance factor across the system life. Maintenance factor may vary

Courtesy of GE
Resources

**Laboratories:**
- Lighting Design Lab, Seattle
  www.lightingdesignlab.com
- Lighting Research Center
  www.lrc.rpi.edu

**Government:**
- Energy Star
  www.energystar.gov
- Energy Efficiency & Renewable Energy
  www.eere.energy.gov/buildings

**Magazine:**
- Architectural Solid State Lighting
  www.architecturalssl.com
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