LED/OLED
Technical Training and Applications
WAC Lighting Company
Today’s Agenda

• LED Technology
  – History of LED
  – Physical properties of components
  – How components interact
  – Power supplies and Drivers
  – Applications
  – Limitations
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  – Physical properties of components
  – How components interact
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  – Applications
  – Limitations
LED History- Early Development

• Discovered accidentally at the beginning of the 20th Century when electricity was applied to the semiconductor Silicon Carbide (SiC) and produced light.

• The first person to experiment and come up with a light-emitting solid-state diode was a British scientist by the name of Captain Henry Joseph Round, while working on dusted core tuning inductors for radio transmission. He was the assistant to Guglielmo Marconi (first transatlantic wireless transmission).

• Russian researcher Oleg Vladimirovich Losev also published a paper approximately at the same time and is often credited as being one of the first discoverers of LED solid state technology.

• Theories were disregarded at the time due to the recent invention of the light bulb
LED History

• The first practical visible-spectrum (red) LED was developed in 1962 by a researcher for the General Electric company, Nick Holonyak Jr., who is officially credited as the “father of the light-emitting diode.”

• Holonyak predicted that his LEDs would replace the incandescent light bulb of Thomas Edison in the February 1963 issue of Reader’s Digest and as LEDs improve in quality and efficiency they are gradually replacing incandescent as the bulb of choice.

• The first LEDs became commercially available in late 1960s, and were red.
  – Used first in laboratory and electronics test equipment, then in a wider range of home appliance, however not powerful enough to illuminate a certain area.
LED History

• 1980's-The development of the GaAlAs (gallium aluminum arsenide) material. The AlGaAs layer confines the electrons to a gallium arsenide region

• LEDs deliver a brightness level ten times bigger than that generated by previous materials.

• The voltage required for operation was lower, resulting in total power savings

• Only available in red (commercially)...Yellow, green and orange LEDs saw only a minor improvement in brightness and efficiency.
LED History

- Late 1980’s

- InGaAlP (Indium Gallium Aluminum Phosphide) visible LEDs, which offered a higher level of versatility as far as the LED's color output was concerned, by adjusting the size of the energy gap.

- Green, yellow, orange and red LEDs all could be produced using the same technology, while the light output degradation level had been significantly improved.

- 1995-Alberto Barbieri from the Cardiff University Laboratory in the United Kingdom investigated the efficiency and reliability of high-brightness LEDs, leading to the appearance of the first white LED.
LED Components

- A **diode** is the simplest sort of semiconductor device. Think of it as a switch telling the electricity in a circuit where to go based on its design.

- **Semiconductor** - is a material with a varying ability to conduct electrical current.

- Semiconductors are made of a poor conductor that has had **impurities** (atoms of another material) added to it. The process of adding impurities is called **doping**.
LED Components

• Aluminum Gallium Arsenide – Red
• Indium Gallium Nitride- Blue
• Aluminum Gallium Phosphide- Green
• Combine all to get white or add a phosphor coating to a blue LED
• Doped material (adding different material types)
• A semiconductor with extra electrons is called N-type material
• A semiconductor with extra holes is called P-type material
How LED Components Interact

- **Photons**, are the most basic units of light.
- Photons are released as a result of moving electrons.
- A greater energy drop releases a higher-energy photon, which is characterized by a higher frequency.
Photons

• Free electrons moving across a diode can fall into empty holes from the P-type layer.
• You can only see the photons when the diode is composed of certain material.
• The atoms in a standard silicon diode, for example, are arranged in such a way that the electron drops a relatively short distance.
• As a result, the photon's frequency is so low that it is invisible to the human eye it is in the infrared portion of the light spectrum. (Infrared LEDs are ideal for applications such as remote controls).
WHY IS THE SKY BLUE?

• The blue color of the sky is due to Rayleigh scattering. As light moves through the atmosphere, most of the longer wavelengths pass straight through. Little of the red, orange and yellow light is affected by the air.

• However, much of the shorter wavelength light is absorbed by the gas molecules. The absorbed blue light is then radiated in different directions. It gets scattered all around the sky. Whichever direction you look, some of this scattered blue light reaches you. Since you see the blue light from everywhere overhead, the sky looks blue.

*source: “Science Made Simple”; www.scencemadesimple.com
WHY IS THE SUNSET RED?

• As the sun begins to set, the light must travel farther through the atmosphere before it gets to you. More of the light is reflected and scattered. As less reaches you directly, the sun appears less bright. The color of the sun itself appears to change, first to orange and then to red. This is because even more of the short wavelength blues and greens are now scattered. Only the longer wavelengths are left in the direct beam that reaches your eyes.

• The sky around the setting sun may take on many colors. The most spectacular shows occur when the air contains many small particles of dust or water. These particles reflect light in all directions. Then, as some of the light heads towards you, different amounts of the shorter wavelength colors are scattered out. You see the longer wavelengths, and the sky appears red, pink or orange.

*source: “Science Made Simple”; www.sciencemadesimple.com
VLEDs and Color

• **Visible light-emitting diodes** (VLEDs), such as the ones that light up numbers in a digital clock

• VLEDs are made of materials characterized by a wider gap between the conduction band and the lower orbitals.

• The size of the gap determines the frequency of the photon -- in other words, it determines the color of the light.
Depletion Zone - No Voltage - No Doping

At the junction, free electrons from the N-type material fill holes from the P-type material. This creates an insulating layer in the middle of the diode called the depletion zone.
How LED Components Interact- Wrong Direction

When the positive end of the circuit is hooked up to the N-type layer and the negative end is hooked up to the P-type layer, free electrons collect on one end of the diode and holes collect on the other. The depletion zone gets bigger.
Current Flow

When the negative end of the circuit is hooked up to the N-type layer and the positive end is hooked up to P-type layer, electrons and holes start moving and the depletion zone disappears.

We are not ADDING Electrons in this process, we are simply adding power and moving them. The interaction between electrons and holes in this setup has an interesting side effect -- it generates light!
Light Emitting Diode Bulb

-In an ordinary diode, the semiconductor material itself ends up absorbing a lot of the light energy.

-LEDs are specially constructed to release a large number of photons outward.

-Additionally, they are housed in a plastic bulb that concentrates the light in a particular direction.

-As you can see in the diagram, most of the light from the diode bounces off the sides of the bulb, traveling on through the rounded end.
Component Model
LED Power Supplies and Drivers

Drivers step down voltage and turn AC to DC and...
CONTROL CURRENT

WHY DRIVERS ARE IMPORTANT

• Driving your LEDs with too much current will permanently disable them.

• If you attach LEDs directly to an unlimited power source, they naturally draw enough current to blow themselves out.
LED Power Supplies and Drivers

LEDs require a constant DC voltage or current to operate optimally.

An LED driver converts 120V (or other voltage) 60 Hz AC power to the low-voltage DC power required by the LEDs and protects them from line-voltage fluctuations. It's analogous to a ballast in a fluorescent or HID lighting system.

- Constant **voltage** types (usually 10V, 12V and 24V)
- Constant **current** types (350mA, 700mA and 1A)
LED Power Supplies and Drivers

CONSTANT VOLTAGE

- Constant Voltage drivers maintain the same voltage despite changes in load
- No limitation on current flowing in
- Higher Amperage will damage LEDs
- May only used for low-power LEDs
LED Power Supplies and Drivers

CONSTANT CURRENT

• Constant current drivers maintain the same current despite changes in voltage
• Permits the use of high-power LEDs that operate at higher wattages without risk of damage
• Not very responsive to dimmers that vary voltage incrementally
LED Dimming

- LEDs are either on or off, and the transition is measured in nanoseconds.
- You control perceived brightness in an LED by turning them on and off rapidly (anything above a hundred hertz) and controlling the duty cycle.
- PWM methods: (Pulse Width Modulation)
  - The simplest is switching on/off the output of a microcontroller.
  - There are also several circuits that implement PWM.
LED Dimming

• Most LED drivers are compatible with commercially available 0-10V control devices and systems
• LEDs can also work with devices governed by the DMX and digital addressable lighting interface (DALI) protocols and, in the future, may include wireless (RF) as a control option.
• Drivers with dimming capability can dim the LED light output over the full range from 100% to 0%.
• 2 wire vs. 3 wire systems
LED Dimming

• A benefit of the PWM method is that it enables dimming with minimal color shift in the LED output.

• Dimming does not result in a loss of efficiency. During dimming, the LEDs are still operated at the same voltage and current as during full light output.
LED Advantages

- LED Advantages
  - No filament that will burn out contributing to longer life.
  - Small plastic bulb makes them a lot more durable.
  - Fit more easily into modern electronic circuits.
  - Efficient, especially compared to the incandescent bulb which requires a lot of heat to produce light on the filament. This heat is wasted energy.
  - The price of semiconductor devices has plummeted over the past decade making LEDs a more cost-effective lighting option for a wide range of situations.
LED Limitations

• Voltage Drop when driver rating exceeded (Pay attention when remote mounting the transformer)
• Be aware of ambient temperatures at the application.
• “Dry location only” drivers must be installed in a weatherproof electrical enclosure if used outdoors.
• “Damp location” drivers should be used in signs or raceways where some moisture is expected
• “Wet location” drivers are typically supplied in a pre-assembled, sealed enclosure for mounting outdoors.
Buying LEDs: what to look for

Did you know that two LEDs of the same rated Color Temperature can look different?

- More than Color Temperature, CRI is important
- Energystar only requires 75 CRI, but 75 CRI may not cover all colors in the visual spectrum of light
History of OLED

• Chin Tang of Kodak discovered OLED electroluminescence in 1979 while working on organic solar cells.
• 1989 Richard Friend, Jeremy Boroughs, and Donal Bradley at Cambridge University discovered polymer-based OLED electroluminescence.
History of OLED

• OLEDs (Organic Light Emitting Diodes) are solid-state devices composed of thin films of organic molecules (carbon based) that create light with the application of electricity.

• OLEDs can provide brighter, crisper displays on electronic devices and use less power than conventional light-emitting diodes (LEDs) or liquid crystal displays (LCDs) used today.
OLED Future

- Hundreds of millions of dollars have been invested in OLED lighting, especially in Europe, the US and Japan
- OLED lighting market to reach $6 B by 2018
OLED

• Why appealing?
  – Excellent viewing angle performance
  – Solid State Lighting (no maintenance required)
  – Rated at 17,000-25,000 to 70% of initial luminance
  – Only need a backplane
  – Compatible with plastic or metal foil substrates
  – Reduced environmental impact & lower recycling costs (no heavy metals)
  – Lower manufacturing costs
OLED Unique Features

• Ultra thin (~1.2mm)
• More color options (color vividness 1000 times better than LCD)
• Transparent
• Flexible
• Efficient: 102 lm/W in lab
OLED Components

• Like an LED, an OLED is a solid-state semiconductor device that is 100 to 500 nanometers thick or about 200 times smaller than a human hair.

• OLEDs can have either two layers or three layers of organic material.
OLED Structure

• A large variety of organic materials printed onto glass or plastic sheets can form ultra-thin organic light-emitting diode (OLED). The organic layers are sandwiched between transparent or reflective conducting layers (electrodes) to apply DC voltage.

![OLED Structure Diagram](image-url)
OLED Components
OLED Components

- An OLED consists of the following parts:
  - **Substrate** (clear plastic, glass, foil) - The substrate supports the OLED.
  - **Anode** (transparent) - The anode removes electrons (adds electron "holes") when a current flows through the device.
  - **Organic layers** - These layers are made of organic molecules or polymers.
    - **Conducting layer** - This layer is made of organic plastic molecules that transport "holes" from the anode. One conducting polymer used in OLEDs is polyaniline.
    - **Emissive layer** - This layer is made of organic plastic molecules (different ones from the conducting layer) that transport electrons from the cathode; this is where light is made. One polymer used in the emissive layer is polyfluorene.
  - **Cathode** (may or may not be transparent depending on the type of OLED) - The cathode injects electrons when a current flows through the device.
OLED Manufacturing

- Vacuum deposition or vacuum thermal evaporation (VTE)
- Organic vapor phase deposition (OVPD)
- Inkjet printing
How OLED Components Interact

• How do OLEDs Emit Light?
• OLEDs emit light in a similar manner to LEDs, through a process called electrophosphorescence
How OLED Components Interact

1. An electrical current flows from the cathode to the anode through the organic layers (an electrical current is a flow of electrons).
2. At the boundary between the emissive and the conductive layers, electrons find electron holes.
3. The OLED emits light.
4. The color of the light depends on the type of organic molecule in the emissive layer.
5. The intensity or brightness of the light depends on the amount of electrical current applied.
Types of OLEDs

- Passive-matrix OLED
- Active-matrix OLED
- Transparent OLED
- Top-emitting OLED
- Foldable OLED
- White OLED
Passive Matrix OLED (PMOLED)

PMOLEDs are easy to make, but they consume more power than other types of OLED, mainly due to the power needed for the external circuitry. PMOLEDs are most efficient for text and icons and are best suited for small screens (2- to 3-inch diagonal) such as those you find in cell phones, PDAs and MP3 players. Even with the external circuitry, passive-matrix OLEDs consume less battery power than the LCDs that currently power these devices.
Active-matrix OLED (AMOLED)

- AMOLEDs consume less power than PMOLEDs because the TFT array requires less power than external circuitry, so they are efficient for large displays. AMOLEDs also have faster refresh rates suitable for video. The best uses for AMOLEDs are computer monitors, large-screen TVs and electronic signs or billboards.
Transparent OLEDs have only transparent components (substrate, cathode and anode) and, when turned off, are up to 85 percent as transparent as their substrate.
• Top-emitting OLEDs have a substrate that is either opaque or reflective. They are best suited to active-matrix design.
Foldable OLED

• Foldable OLEDs have substrates made of very flexible metallic foils or plastics.
• Foldable OLEDs are very lightweight and durable.
• Potentially, foldable OLED displays can be attached to fabrics to create "smart" clothing.
White OLED

• White OLEDs emit white light that is brighter, more uniform and more energy efficient than that emitted by fluorescent lights.
• White OLEDs also have the true-color qualities of incandescent lighting.
• Because OLEDs can be made in large sheets, they can replace fluorescent lights that are currently used in homes and buildings.
OLED Disadvantages

• **Lifetime** - While red and green OLED films have longer lifetimes (46,000 to 230,000 hours), blue organics currently have much shorter lifetimes (up to around 14,000 hours).

• **Manufacturing** - Manufacturing processes are expensive right now.

• **Water/Oxygen** - Water & Oxygen can easily damage OLEDs.
OLED Advantages

• Thinner, lighter and more flexible
• OLEDs are brighter than LEDs.
• OLEDs do not require backlighting like LCDs.
• OLEDs are easier to produce and can be made to larger sizes.
• OLEDs have large fields of view, about 160-170 degrees.
Potential Application

OLED window is transparent during day time

OLED window emits light during night time
WAC OLED prototype

OLED wall sconce

- Color changeable
- 3 inch per OLED panel
- 2mm thick

OLED mini chandelier

- Transparent
- 1 inch per OLED panel
- 0.18W per OLED panel
- Dimmable 100% → 1%