

LED Technology

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<http://www.lrc.rpi.edu/programs/solidState/index.asp>

Lighting History

Over the past 100 years, **incandescent** and **gas discharge** technologies have provided many light sources for a variety of lighting applications.



Evolving new technology

Light Emitting Diode
(LED)



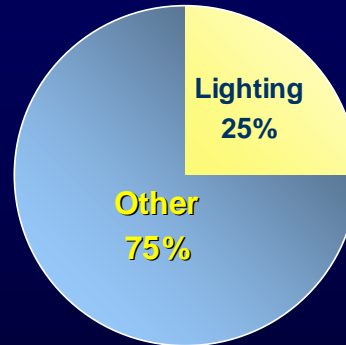
Solid-State Lighting

What are the benefits of using LEDs?

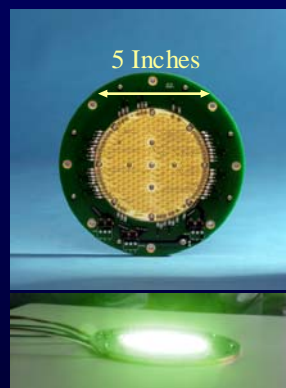
- Potential for energy savings
- Potential for lower replacement cost
- Rugged and durable
- Unique lighting solutions
- Dynamic control of intensity and color
- Small size
- Potential for low ultraviolet (UV) and infrared (IR) radiation

Why solid-state lighting?

- ❑ Lighting accounts for about 25% of the total electric energy use in U.S.
- ❑ Demand for energy keeps increasing
 - Solid-state lighting holds the promise for significant energy savings



R&D prototypes



Lamina Ceramics

Very High Flux

- ❑ Lamina Ceramics
 - 13,000 lm (17 lm/W) R,G,B white LED system
 - 28,000 lm (20 lm/W) PC white LED system

High Efficacy

- ❑ LRC,CREE > 80 lm/W

LED applications – Success Stories

LEDs in these applications have shown to:

- ❑ use 80% less energy than incandescent signals
- ❑ Reduce maintenance costs (because of their longer life compared to incandescent lamps)

Traffic Signals



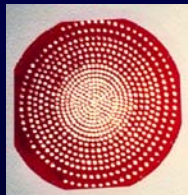
EXIT Signs



Evolution of LED Traffic Signals

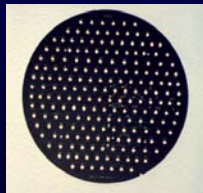
- ❑ Improved product performance and better optics have reduced the number of LEDs per traffic signal

700, 5-mm LEDs



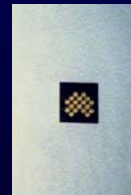
1993

200, 5-mm LEDs



1996

18, high-flux LEDs



1999

Growing use

- Significant interest around the world for using LEDs
 - Architectural
 - Indoor
 - Outdoor
 - Transportation
 - Automobile
 - Aircraft

LED Basics

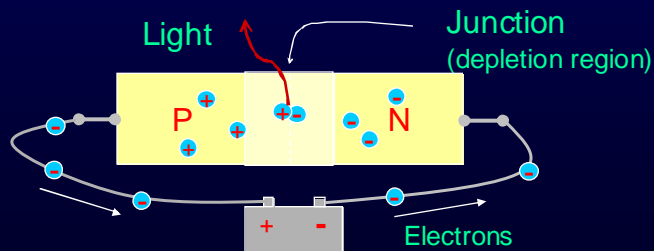
Light Emitting Diode

- ❑ What is a diode?
 - A two-terminal electronic device
 - Permits current to flow in only one direction
 - Used to rectify ac, convert to dc
- ❑ LEDs are semiconductor diodes
 - LEDs have electrical characteristics common to all diodes



Light Emitting Diode - PN Junction

- ❑ **P material:** Has a slight “deficiency” of electrons for molecular bonding when forming a crystal.
- ❑ **N material:** Has excess electrons left over from the crystal bonding process, which can move and carry current.
- ❑ Photon (light) is generated when the positive and negative charges recombine.

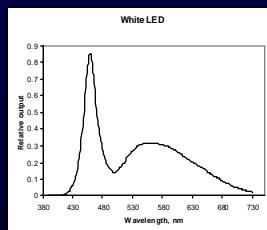
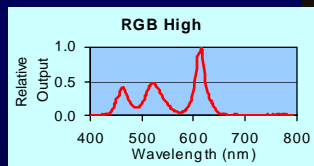


History

Deep red LEDs	GaAs (mid 1970s)
Yellowish-green LEDs	GaP (mid 1970s)
Red LEDs	AlGaAs (mid 1980s)
Yellow to red LEDs	AllnGaP (early 1990s)
Blue to green LEDs	InGaN (mid 1990s)
White LEDs	InGaN + phosphor (mid 1990s)
	RGB white (mid 1990s)

White light with LEDs

Mixing different colored LEDs (red, green, and blue) in the right proportions produces white light.

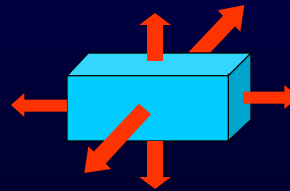
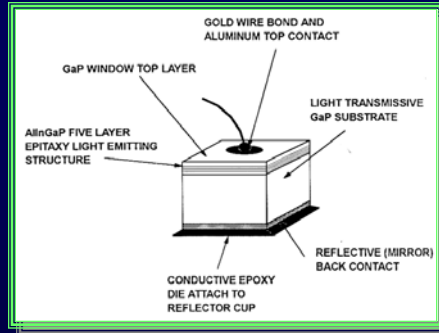


Combining blue LEDs with yellow phosphors produces white light.

LED Die

Indicator-type LED:
Typical die sizes are around 250 microns (0.25mm) square.

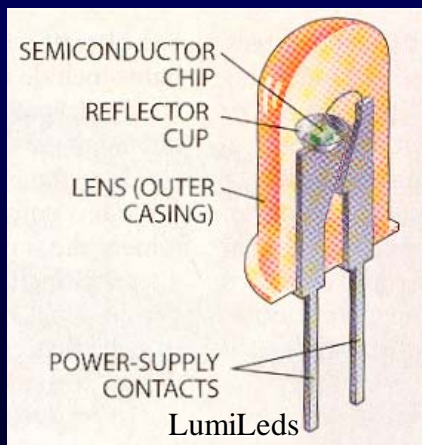
Illuminator-type LED:
Larger die sizes up to 900 microns



Light is emitted through all 6 sides

LED Construction

Indicator-type LED



Reflector cup

- ❑ Improves light collection

Lens (epoxy dome)

- ❑ Improves light extraction
- ❑ Directs the light in a particular direction

Definitions

Internal quantum efficiency (IOE) = $\frac{\text{Internally generated photons}}{\text{Electrons in}}$

External quantum efficiency (EQE) = $\frac{\text{Photons out of the device}}{\text{Electrons in}}$

Extraction efficiency (EE) = $\frac{\text{Photons out of the device}}{\text{Internally generated photons}}$

$$\text{EQE} = \text{IOE} \times \text{EE}$$

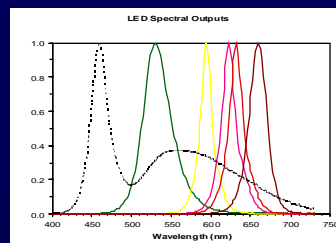
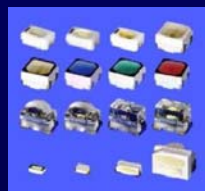
Light Extraction

- ❑ Usually more than 70% of the light generated by a LED is trapped within the device
 - Total Internal reflections (TIR)
 - Fresnel reflection limit light extraction

- ❑ Many different methods have been proposed for improving light extraction
 - Chip shaping
 - Structured surface
 - Photonics bandgap etc.

Commercial Devices

Indicator-type LEDs



LED Packages

- 3 mm
- 5 mm
- SMD

Color	Efficacy (LPW)	Flux per device (Lumens)
Red	29	1.7
Green	36	2.0
Blue	8	0.5
White	15 - 20	2



Commercial High-Flux LED Devices

□ Goals:

- Higher flux per device
- Higher efficiency
- Better color properties for white LEDs
 - Good color rendering
 - Much lower color variation between lamps
 - Stable color over time
- Longer life
- Lower cost

Review manufacturers' data sheets for exact values

Luminous Flux / Efficacy – 2005

High-Power LEDs	Typical Products	
	Flux per device	Efficacy (lm/W)
Red	43	44
Red-Orange	54	55
Amber	36	36
Green	30	25
Blue	14	11

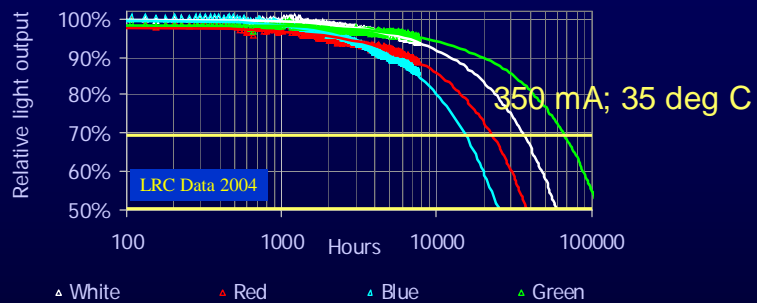
High-Flux White LEDs	Performance	
	Flux per device (lm)	Efficacy (lm/W)
LumiLeds	20 - 120	17 - 30
OSRAM	28 - 120	21
Nichia	32 - 42	24 - 31
CREE (Xlamp)	60	34

More flux per device

- ❑ Different device geometry/materials
- ❑ Larger semiconductor devices
- ❑ Higher drive current together with better heat extraction

LED life

LED Life definition: 30 % light output degradation
High Power LEDs



	Red	Green	Blue	White
L_{70}	22,000	65,000	13,000	35,000
L_{50}	36,000	120,000	22,000	58,000

LED Systems & System Performance

System reliability

- Reduced replacement cost is one of the promises for LEDs
- It is the final system performance that matters to the end user

System reliability

System performance is affected by:

- Packaging configurations
- Drive current
- Operating environment
(ambient temperature, humidity,
etc.)

Why is heat management important?

Higher temperature near the LED junction

Short-term effect

- Lower light output
- Wavelength (color) shift

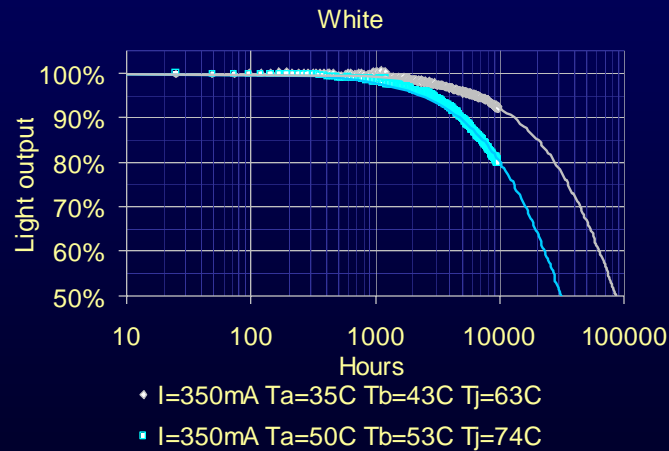
Long-term effect

- Higher degradation rate (shorter life)

Poor heat management could lead to poor system performance.

Heat affects life significantly

An 11 degree C change in junction temperature reduces the life, (L_{70}), from 45,000 hours to 15,000 hours.



Summary

□ Technology Trends

- Rapid advances
 - Higher efficacy and flux per device
 - Improved useful life
 - Better color properties
- Performance varies significantly among different products

LEDs will displace traditional light sources
in certain niche applications in the near
future

For more information
www.lrc.rpi.edu/programs/solidstate

Lighting
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