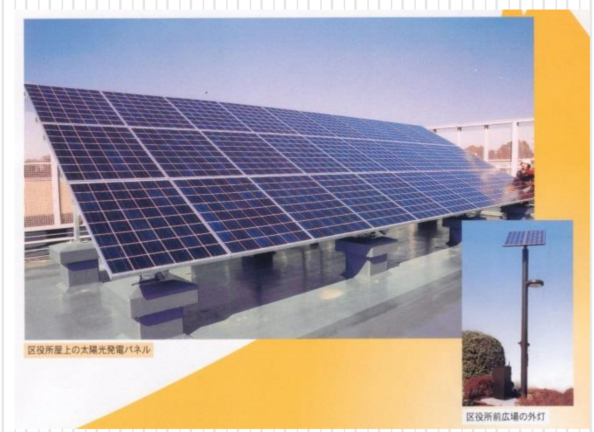
كلية الهندســـــة بشبرا
FACULTY OF ENGINEERING- SHOUBRA

BENHA UNIVERSITY

Optical Communications
ECE423/ELE424/CCE507/ELE480

LEC (03)
Light Emitting Diode



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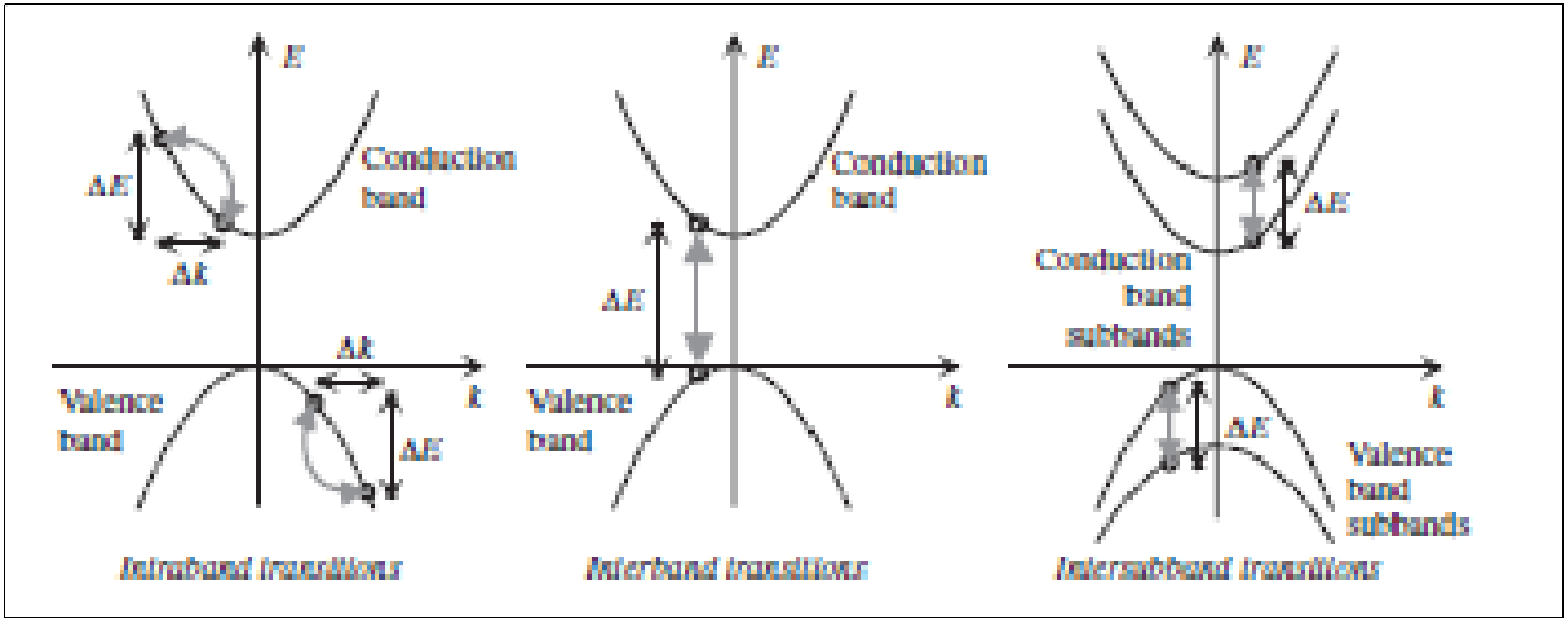
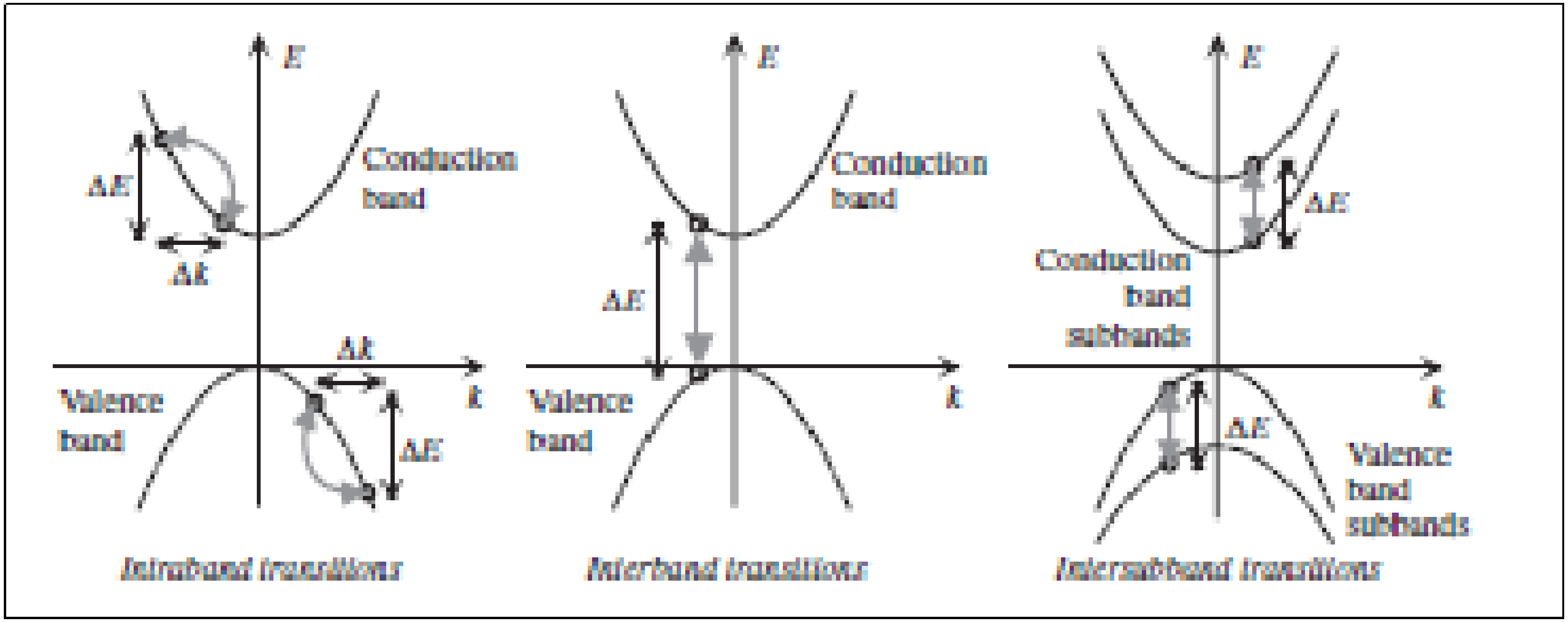
LECTURE OUTLINES

Radiation
Direct & indirect gap semiconductors
LED Characteristics
Parts of LED
Operation of LED
Light Emission
Light Biasing
Light Applications
LED Efficiency
VLC

Radiation

The light absorption process can be described as an incident photon to the semiconductor material having energy (hf) is absorbed by the semiconductor through energy conservation. The photon energy is absorbed by an electron which results in electron transition to a higher state within the energy band diagram. Absorption process can take through three possible scenarios as follows as shown in figure:





Interaband transitions, when the electron's initial and final states are in the same band (e.g conduction band or valence band).

Interband transitions when initial state is valence band and final state is conduction band. $E = qV = h\upsilon = h\frac{c}{\lambda}$ $\lambda(\mu m) = \frac{1.240}{E_g(eV)}$

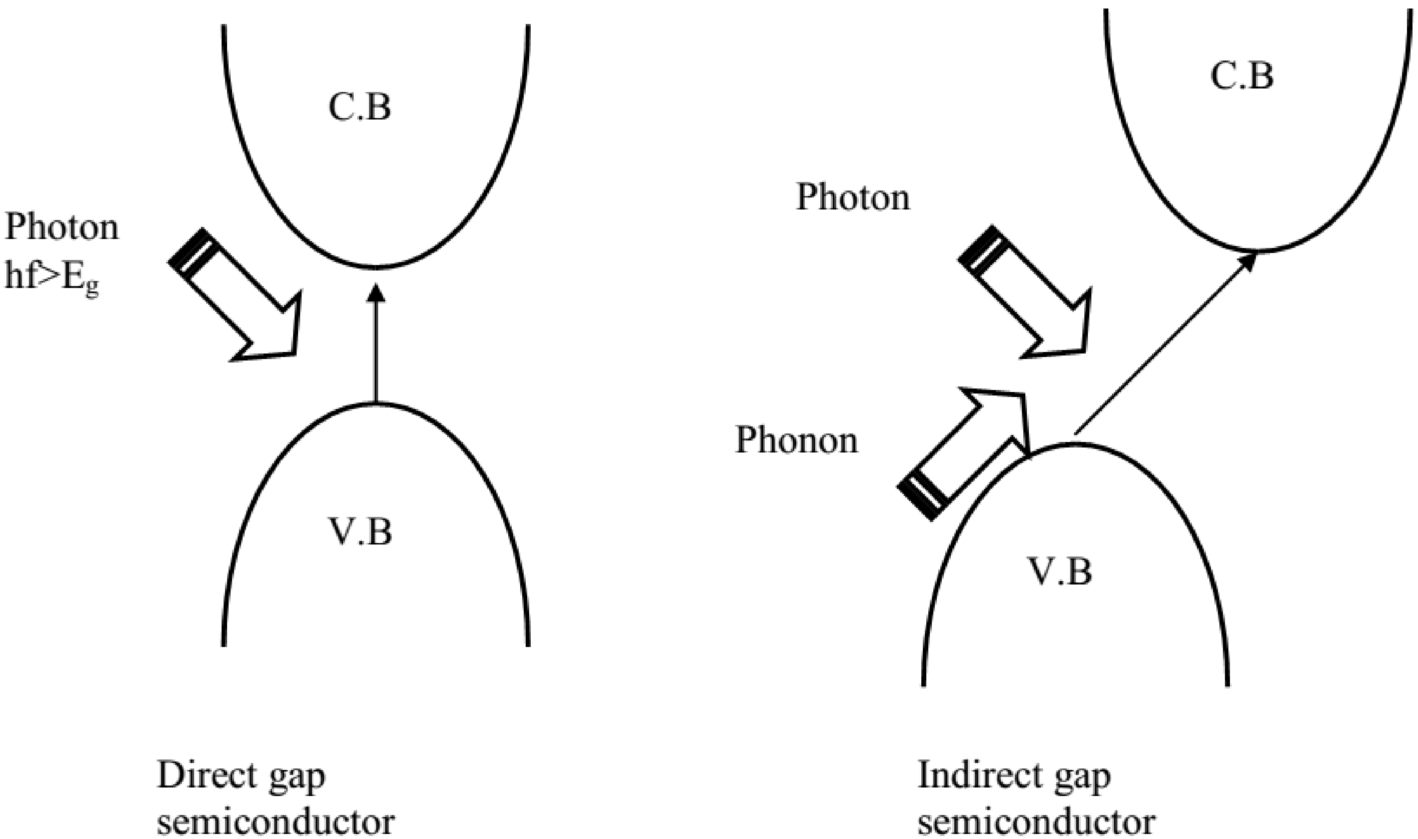
Subband transition. In some cases semiconductors have its band in the form of multiple subbands (many valence bands, many conduction bands), thus cases of intrasubband (when the initial and final state are in the same subband) and intersubband transitions (when initial and final states are in different subbands of the same band) may occur.

Incident radiation can cause a measurable change of some material's characteristics (e.g. resistivity, polarization…etc). This property of some "light sensitive" materials can be used in light detection. Again this effect generally is highly wavelength dependent. Solid state devices generally have its I-V characteristics according to its structure and theory of operation. Incident radiation can cause significant effect on the device characteristics. This phenomenon can be used in many optoelectronic devices Incident radiation which is in the form of light energy can be absorbed and transformed to another form that can be sensed by a material or device through a change in its internal properties or its output I-V characteristics. These effects can used in light sensing transducers where the input optical energy is transformed into output electrical energy.

In most cases these effects are reversible such that it can be used in the reverse process of light emitting devices

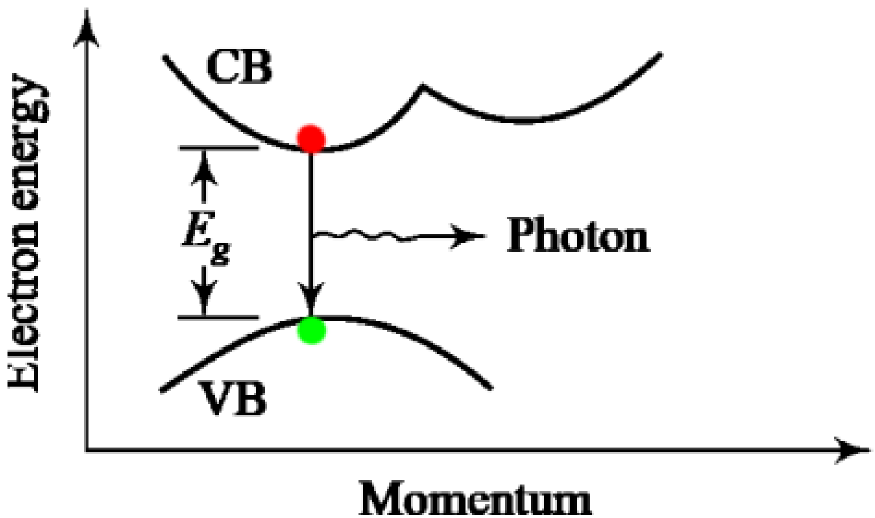
Direct & indirect gap semiconductors

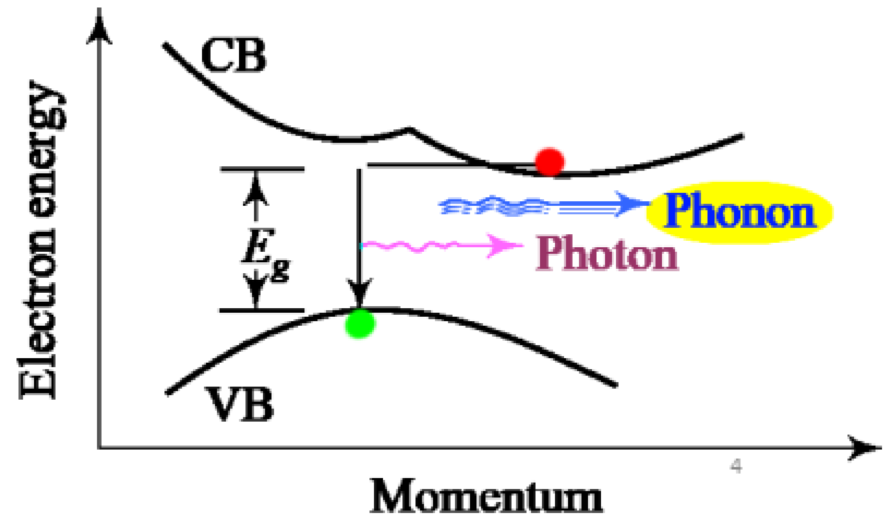
Semiconductors are classified according to vertical alignment of valence and conduction bands into direct and indirect gap semiconductors. Direct gap semiconductors those having both valence band maxima and conduction band minima are aligned on the same vertical axis while in indirect gap semiconductors, both bands are not aligned vertically as shown in figure.



NOT Every EH-pair recombination is Radiative !!

(Direct and Indirect Bandgap materials)





Radiative and Non-Radiative Recombination

- **Absorption** or **Emission of photons** requires a **transition** **from one energy level to another level**.
- The frequency and the wavelength of the emitted or absorbed photon is related to the **difference in energy E**, between the two energetic states:

$$E = E_2 - E_1 = hf = \frac{hc}{\lambda}$$

Photon energy

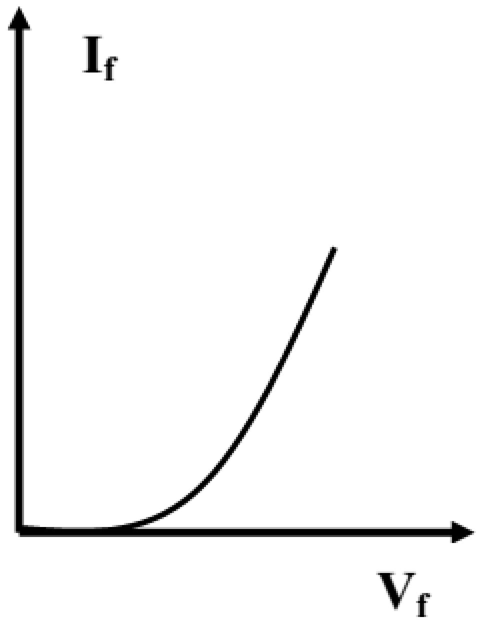
$$\lambda(\mu m) = \frac{1.240}{E_g(eV)}$$

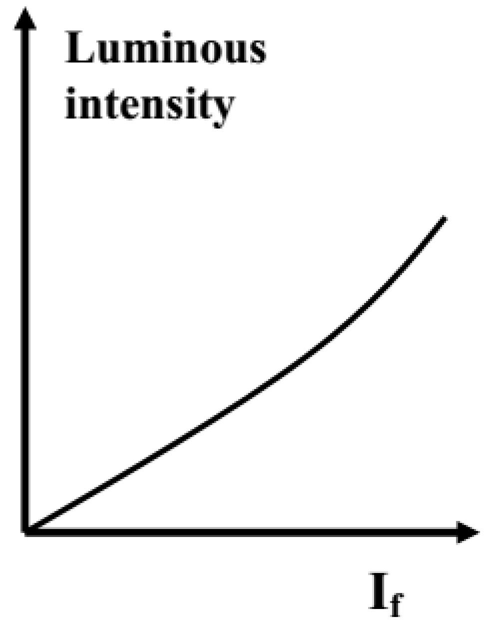
For direct gap semiconductor, a photon having sufficient energy can excite an electron in V.B to jump to C.B directly and the inverse phenomenon (**recombination**) will take place when the electron returns back to the V.B to recombine with a hole.
For indirect gap semiconductor, the electron can absorb a photon if a phonon (a particle model for lattice vibration) participates in the process as shown in figure. A phonon provides the necessary momentum for the electron to move to the C.B. Again for recombination process a phonon is released when electron is to return back to V.B.

When a recombination of holes and electrons generates light, the recombination process is called **radiative recombination**. The process of light emission in this case is called "**spontaneous emission**". If the recombination generates heat (phonon), it is called nonradiative recombination. In this case the emitted light is insignificant. Si and Ge, are indirect gap materials, the greater percentage of energy is given up in the form of heat. In other materials such as GaAs, GaP, the number of photons of light energy emitted is sufficient to create a light source.

LED characteristics

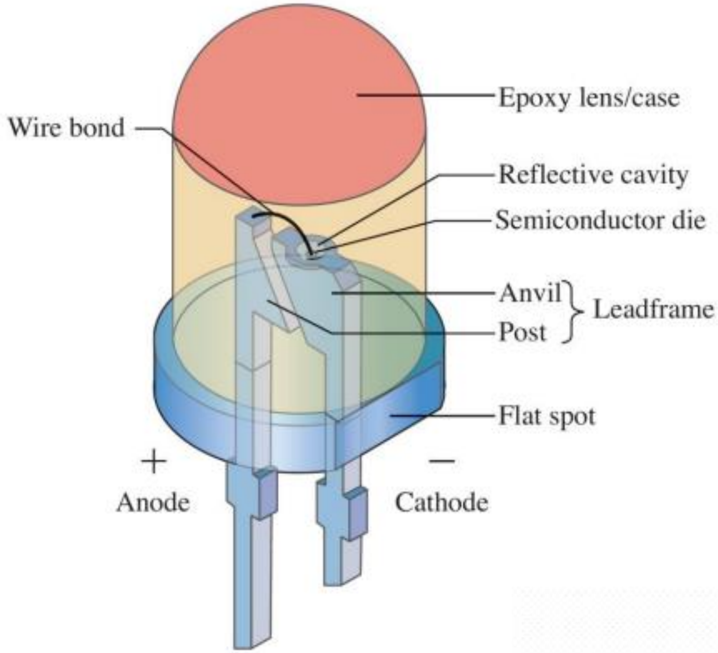
Since the LED is a p-n junction device, it will have forward bias characteristics similar to the diode characteristics. Note that almost linear increase in relative luminous intensity with forward current.

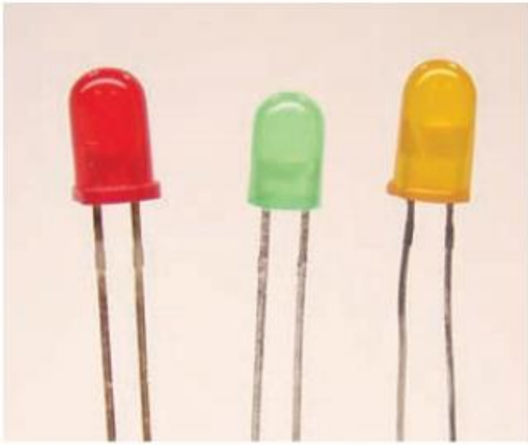


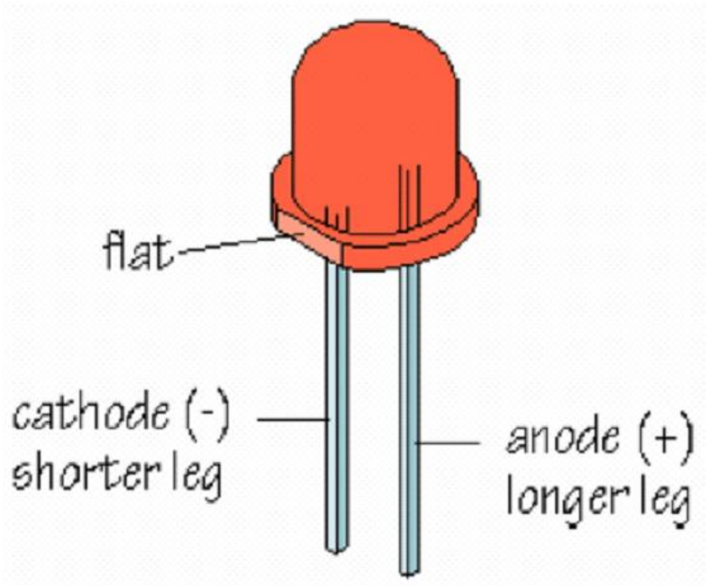


Parts of LED

Parts of an LED.



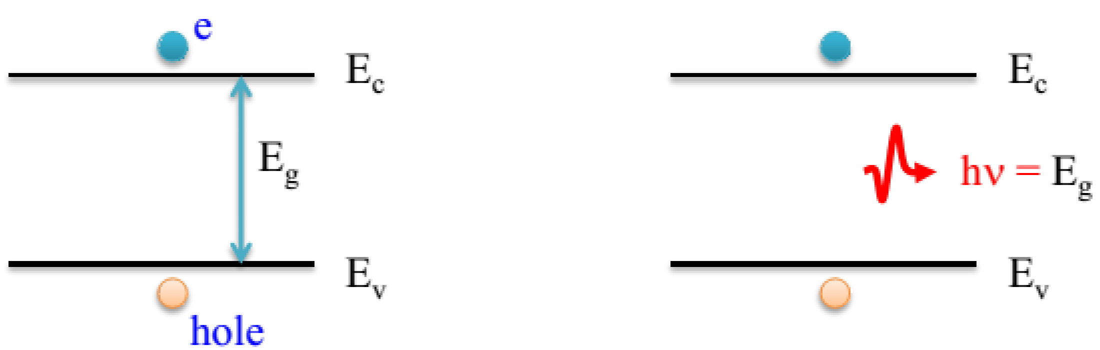




- A light emitting diode (LED) is essentially a PN junction opto-semiconductor that emits a monochromatic (single color) light when operated in a forward biased direction.

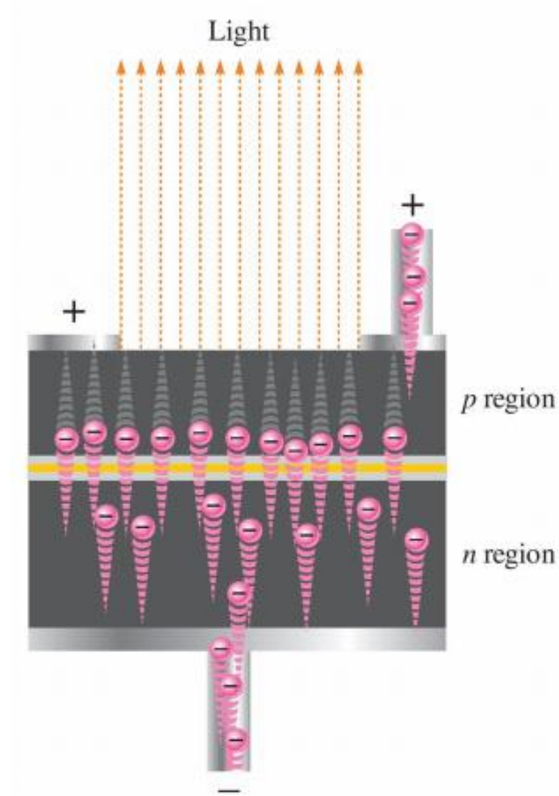
- LEDs convert electrical energy into light energy. They are frequently used as "pilot" lights in electronic appliances to indicate whether the circuit is closed or not.

Operation of LED



Luminescence

- When the device is forward-biased, electrons cross the pn junction from the n-type material and recombine with holes in the p-type material.
- These free electrons are in the conduction band and at a higher energy than the holes in the valence band.
- When recombination takes place, the recombining electrons release energy in the form of photons.
- The emitted light tends to be monochromatic (one color) that depends on the band gap (and other factors).
- This process, called electroluminescence
- Various impurities are added during the doping process to establish the wavelength of the emitted light. The wavelength determines the color of visible light



- In Si and Ge diodes the greater percentage of the energy converted during recombination at the junction is dissipated in the form of heat within the structure, and the emitted light is insignificant.
- Diodes constructed of GaAs emit light in the infrared (invisible) zone during the recombination process at the p–n junction.
- Through other combinations of elements a coherent visible light can be generated.
- The Table provides a list of common compound semiconductors and the light they generate.

- فوسفيد الألومنيوم والغاليوم والإنديوم
- نترات جاليوم
- فوسفيد جاليوم
- فوسفيد جاليوم ارسنايد

Light-Emitting Diodes

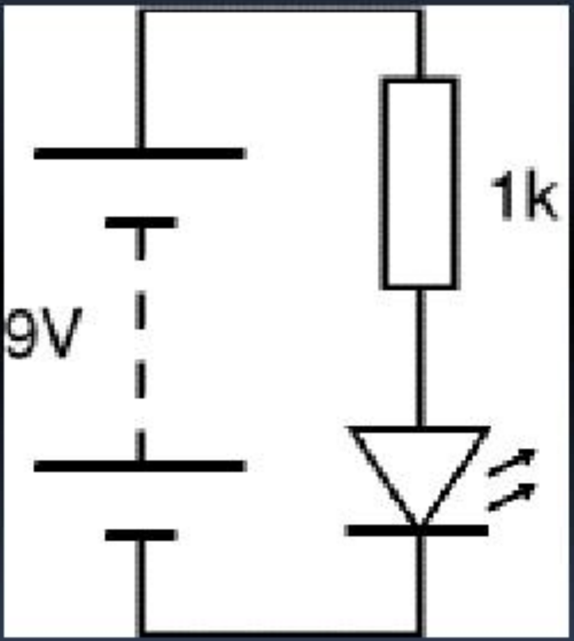
Color	Construction	Typical Forward Voltage (V)
Amber	AlInGaP	2.1
Blue	GaN	5.0
Green	GaP	2.2
Orange	GaAsP	2.0
Red	GaAsP	1.8
White	GaN	4.1
Yellow	AlInGaP	2.1

Testing LEDs

Never connect an LED directly to a battery or power supply! It will be destroyed almost instantly because too much current will pass through and burn it out.

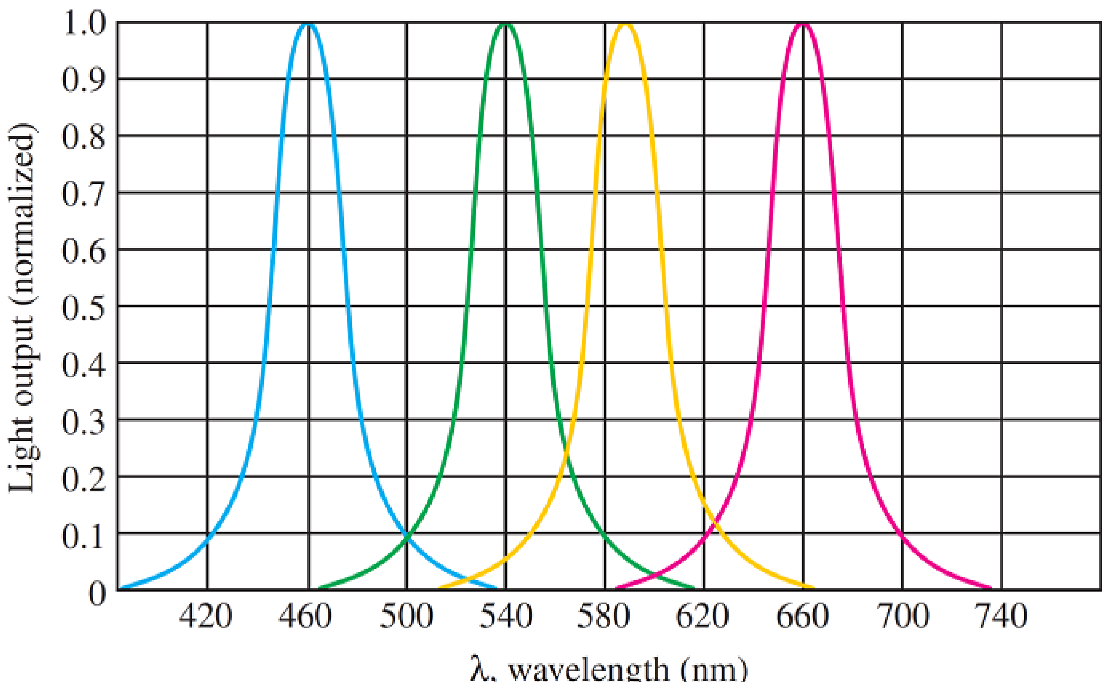
LEDs must have a resistor in series to limit the current to a safe value, for quick testing purposes a 1k resistor is suitable for most LEDs if your supply voltage is 12V or less.

Remember to connect the LED the correct way round!

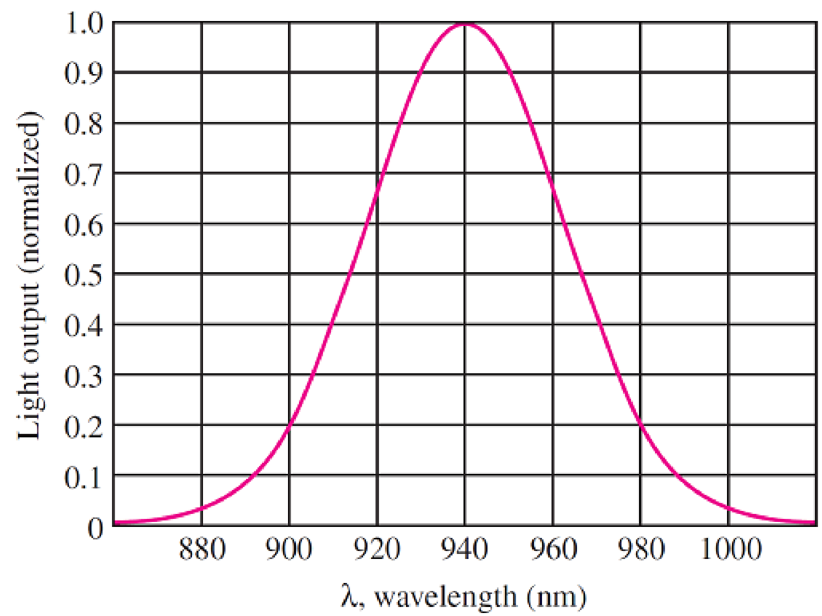


Light emission

- A LED emits light over a specified range of wavelengths.
- The color of the output light depends on the material used in fabrication the LED & Energy gap.
- The output light may be visible (red, blue, . . . etc) or may be invisible (Infra Red).



Visible Lights

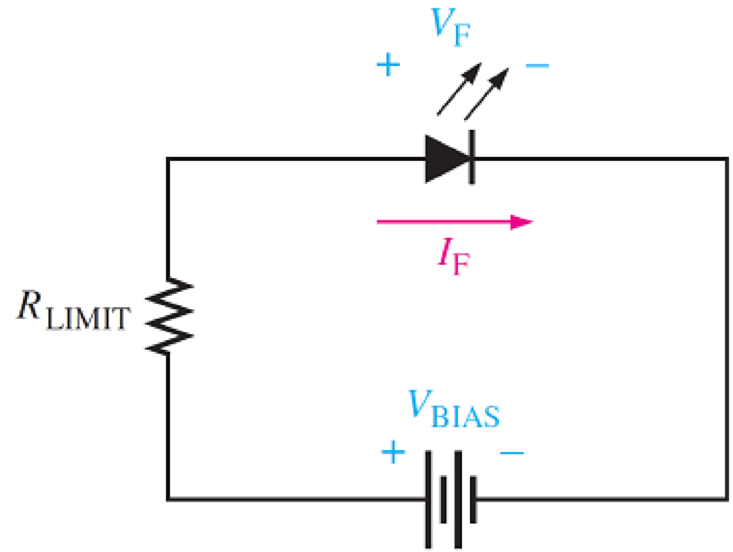


(b) Infrared (IR)

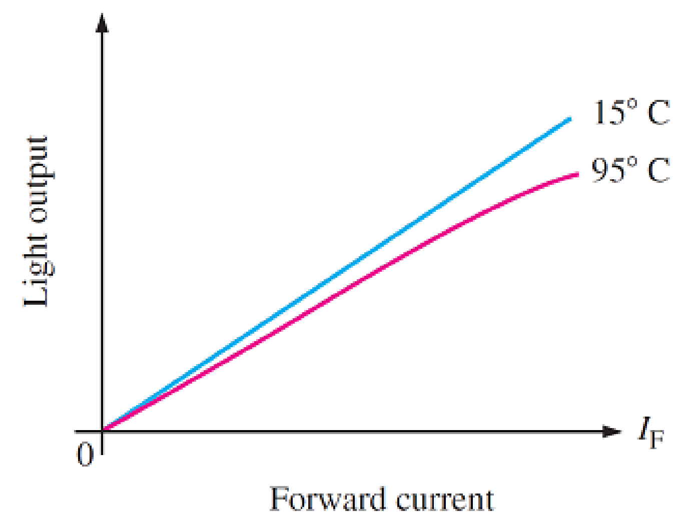
Power Spectrum of LED

LED Biasing

- The maximum VF for LEDs is between 1.2 V and 5V , depending on the material.
- Reverse breakdown for an LED is much less than for a silicon rectifier diode (3 V to 10 V is typical).
- Light intensity is proportional with forward current.
- Also Light intensity goes down with higher temperature as indicated in the figure.



(a) Forward-biased operation



(b) General light output versus forward current for two temperatures

LED Applications

Applications

- Sensor Applications
- Mobile Applications
- Sign Applications
- Automative Uses
- LED Signals
- Illuminations
- Indicators

Sensor Applications

Mobile Applications

Applications of green LEDs

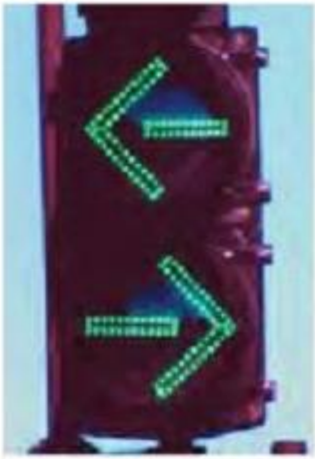
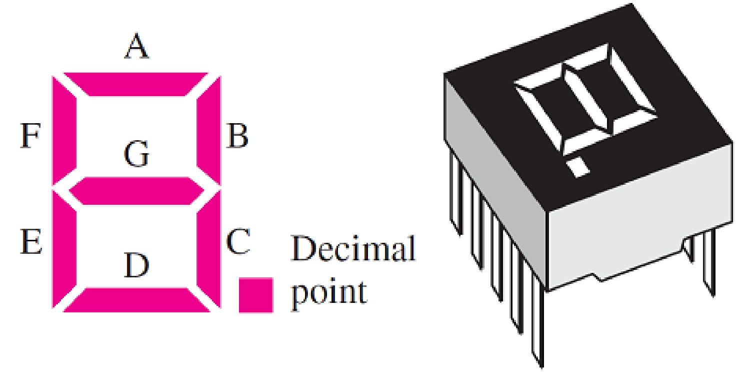


Fig. 1.17. Pedestrian sign indicating number of seconds left to cross street located in Taipei, Taiwan.

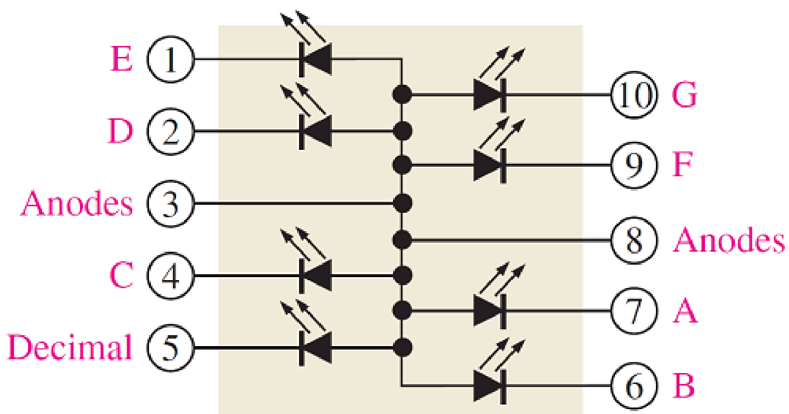
- High-brightness LEDs for outdoor applications

Applications

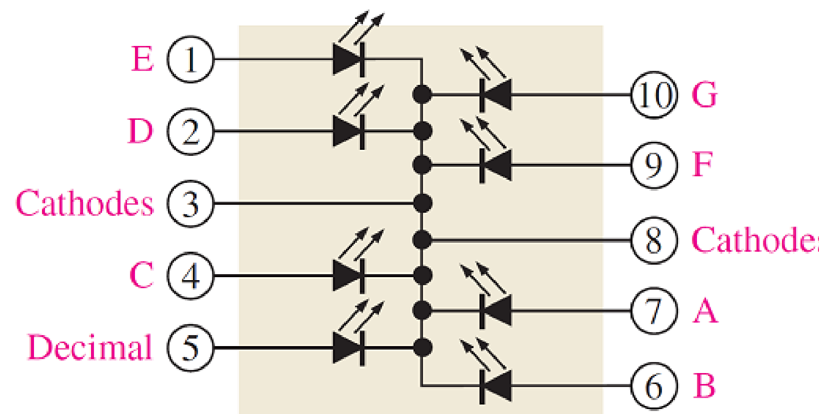
- indicator lamps
- readout displays (the **seven-segment display**)



(a) LED segment arrangement and typical device



(b) Common anode



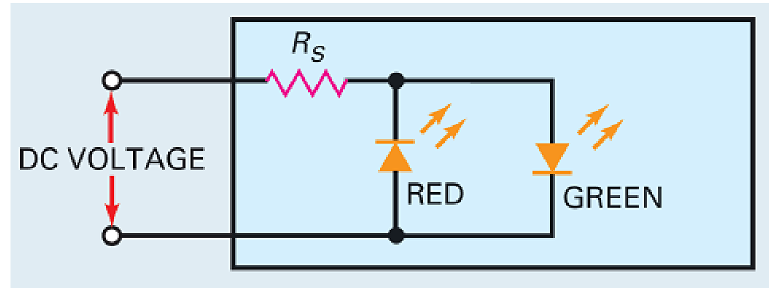
(c) Common cathode

TV Remote Control Unit:

- One common application of an infrared LED is in remote control units for TV and DVD.
- The IR LED sends out a beam of invisible light that is sensed by the receiver in your TV.
- For example, For each button on the remote control unit, there is a unique code. When a specific button is pressed, a coded electrical signal is generated that goes to the LED, which converts the electrical signal to a coded infrared light signal.
- The TV receiver recognizes the code and takes appropriate action, such as changing the channel or increasing the volume.

Application Example

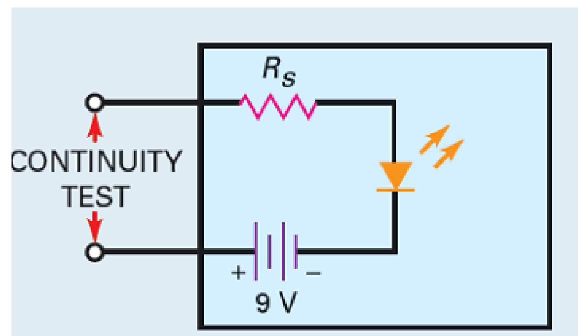
- Figure1 shows ***a voltage-polarity tester***. It can be used to test a dc voltage of unknown polarity.
- When the dc voltage is positive, the green LED lights up.
- When the dc voltage is negative, the red LED lights up.
- What is the approximate LED current if the dc input voltage is 50 V and the series resistance is 2.2 kΩ?



$$I_S = \frac{50\text{ V} - 2\text{ V}}{2.2\text{ k}\Omega} = 21.8\text{ mA}$$

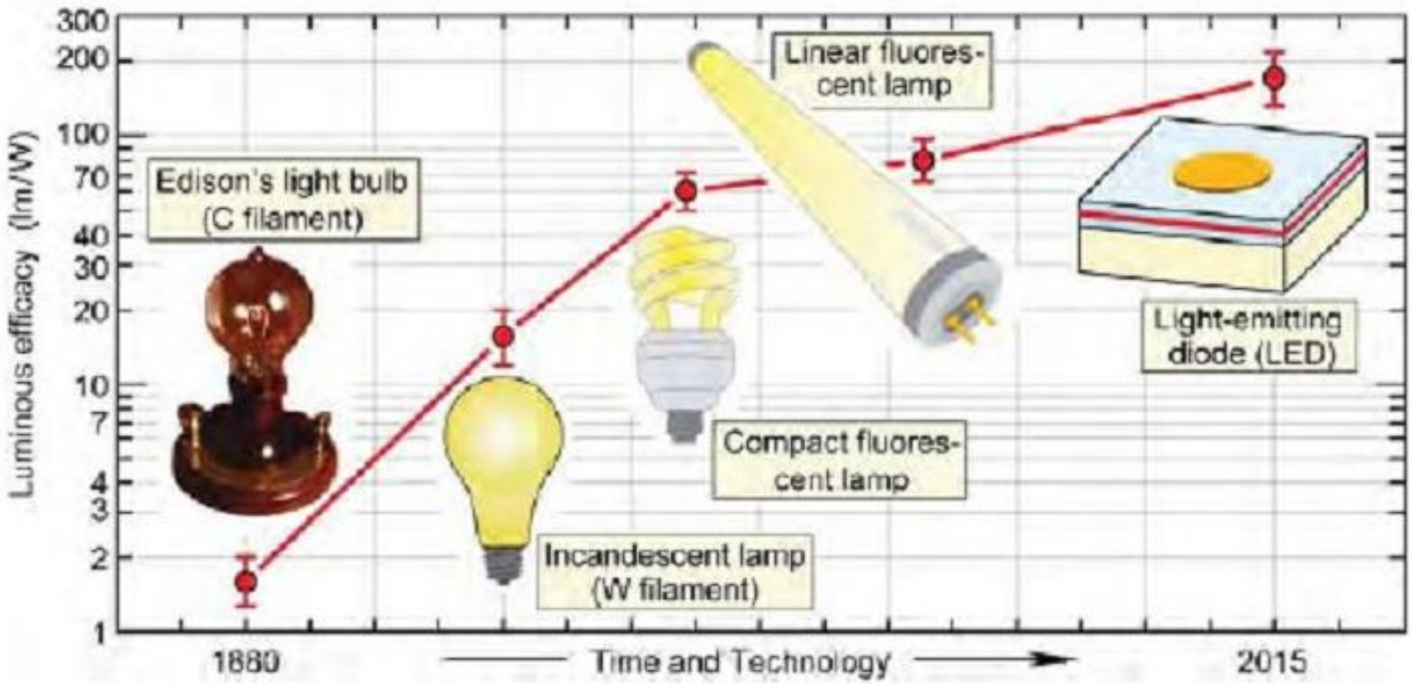
- Figure 2 is **a continuity tester**. You can use this circuit to check for the continuity of cables, connectors, and switches.
- How much LED current is there if the series resistance is 470 V?

$$I_S = \frac{9\text{ V} - 2\text{ V}}{470\ \Omega} = 14.9\text{ mA}$$



LED Efficiency

Comparison – Efficiency of LEDs versus other light sources



- Luminous efficacy of LEDs, to be attained by 2015, is based on the expectation that LEDs will be able to attain 50% to 70% of the theoretical maximum. The theoretical maximum of the luminous efficacy is 300 lm/W.

ADVANTAGES

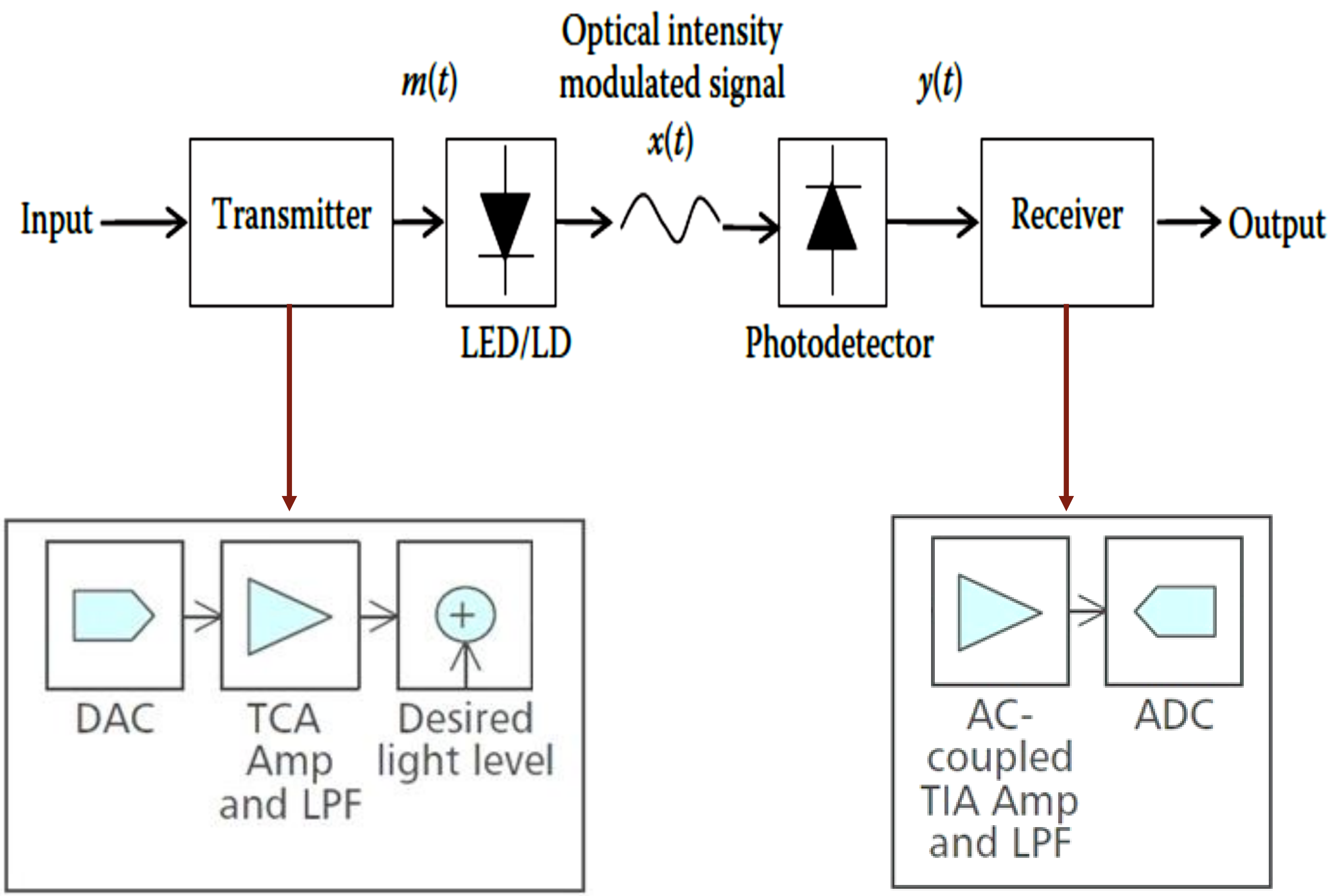
- Save up to 90% energy
- No warm up, 100% brightnes immidiately
- lasts up to 30x longer than incandescent bulbs
- fits into any standard lamp socket
- max. bulb temperature 55 ° C
- Non-toxic, no pollution
- Full dimmable
- No IR and UV radiation
- Warm White Light Color
- Viewing angle 240 °

Considerations ...

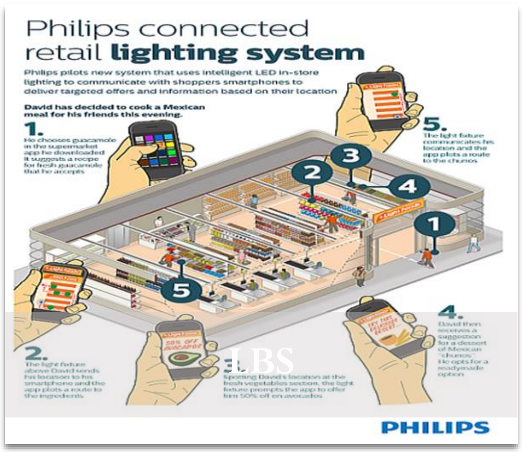
- **Linearity** (output light power **proportional** to driving current) → **important for analog systems**
- **Stability** → **LED better** than **LASER** !!!
- **Driving circuit issues** → **impedance matching**
- **Reliability** (life time) and cost

VLC

Visible Light Communications (VLC)

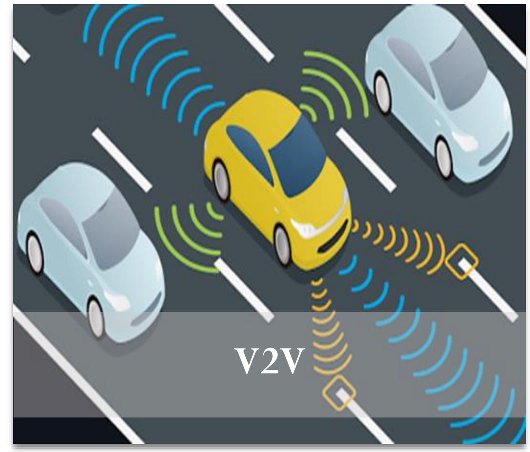


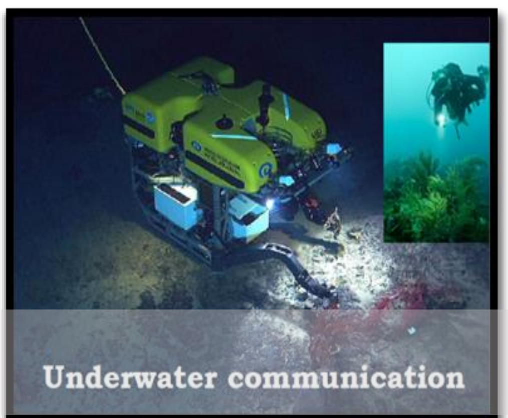
APPLICATIONS OF VLC



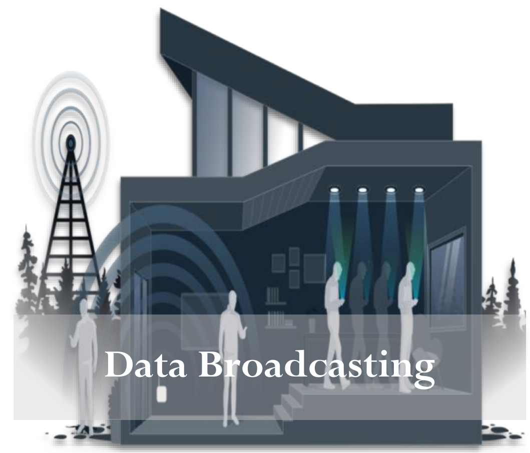
LBS


Navigation


V2V


Underwater communication


EMI Sensitive Environment


Data Broadcasting

LIFI

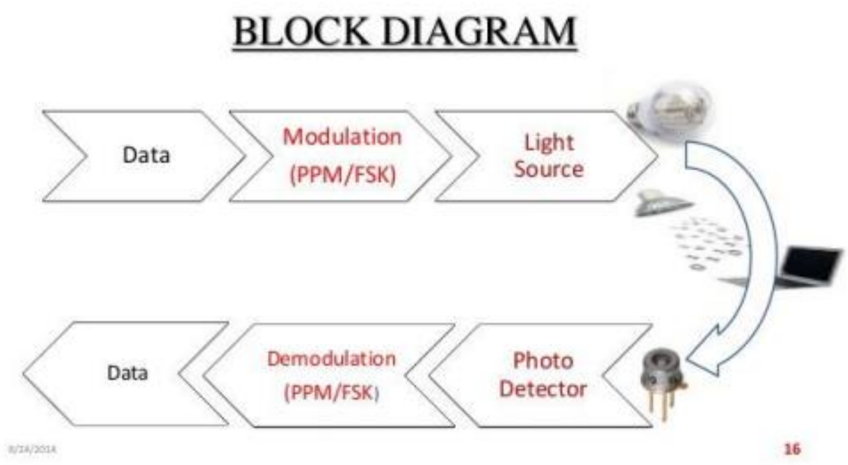


Fig2: Block Diagram of Li-Fi Technology

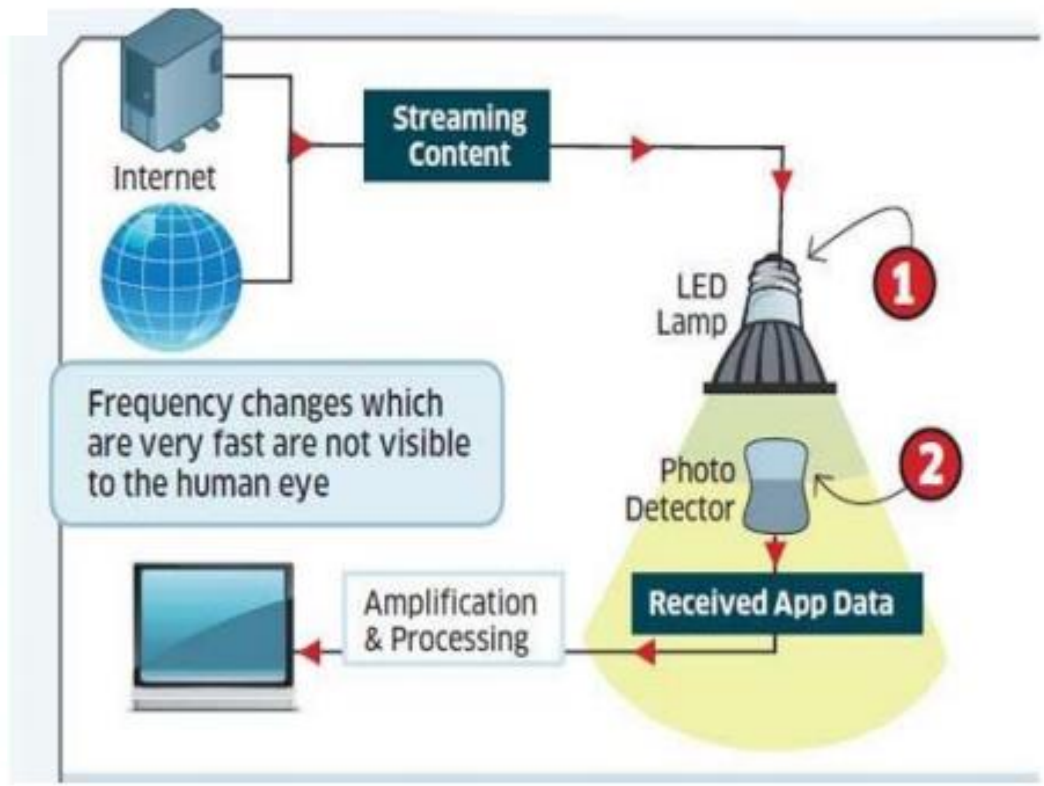


TABLE I: Comparison of Bluetooth, Wi-Fi & Li-Fi.

Characteristic	Bluetooth	Wi-Fi	Li-Fi
Frequency	2.4 GHz	2.4 GHz to 5 GHz	No frequency for light
Standard	IEEE 802.15	IEEE 802.11	IEEE 802.15
Range	10 meters	100 meters	Base on LED light
Primary application	Wireless public area networking	Wireless local area networking	Wireless local area networking
Data transfer rate	800 Kbps	11 Mbps	>1Gbps
Power consumption	Low	Medium	LOW
Cost	Low	Medium	high
Security	Its less secure	Its medium secure	Its high secure
Primary devices	Mobile phones, mouse, keyboards, office and industrial automatic devices , PDAs, consumer Electronics, and others offices.	Notebook computers, desktop computers, servers, TV, Latest Wi-Fi mobiles.	Mobile phones, office and industrial automatic devices, notebook computers, desktop computers , servers computers, TV and latest upcoming devices with Li-Fi
Primary users	Traveling employees; electronics consumers; office and industrial workers	Corporate campus users, homes and others public places	Traveling employees ,home users ,others public places ,office and industrial workers,
Usage location	Anywhere at least two Bluetooth devices exist — ideal for roaming outside buildings	Within range of WLAN infrastructure, usually inside a Building	Where ever light is available, it may a public place ,home, office and road etc
Development started	1998	1990	2011

LED & LCD dsplays

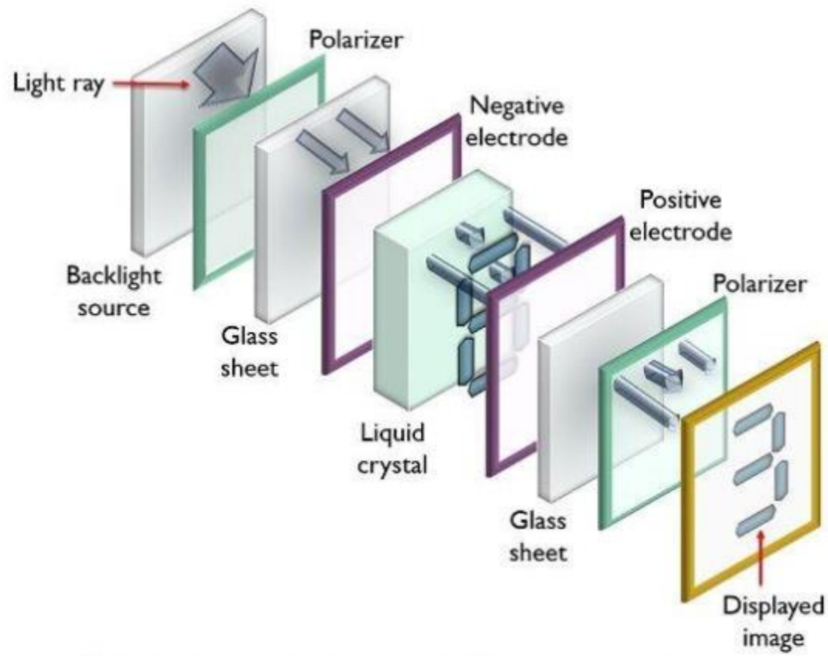
Difference between LCD and LED monitors

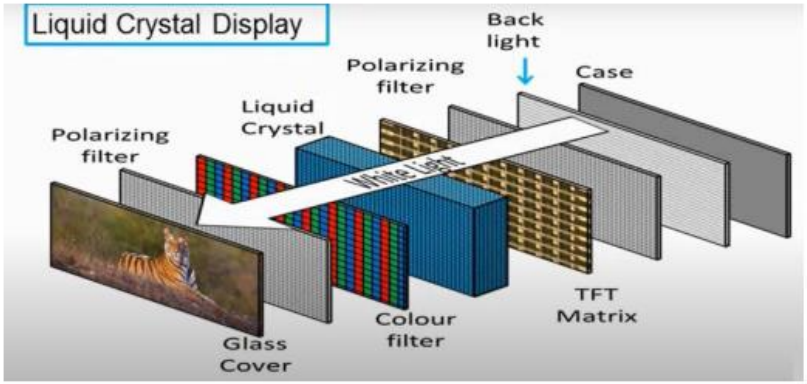
➢ The LED (light emitting diode) monitors also uses liquid crystals, so the name is somewhat misleading. Technically, an “LED monitor” should really go by the name, “LED LCD monitor.”

- Both types of LCD and LED displays use liquid crystals to create an image.
- The difference is in the backlights:
  - A standard LCD monitor uses fluorescent backlights.
  - An LED monitor uses light-emitting diodes for backlights. LED monitors usually have superior picture quality.

Main components of LCDs

1. backlight source
2. Vertical polarizer
3. Glass sheet (thin film transistor matrix -TFT matrix)
4. Negative electrode
5. Liquid crystal $(10 - 12\ \mu m)$
6. Positive electrode
7. Glass sheet (color filter)
8. Horizontal polarizer
9. Display screen

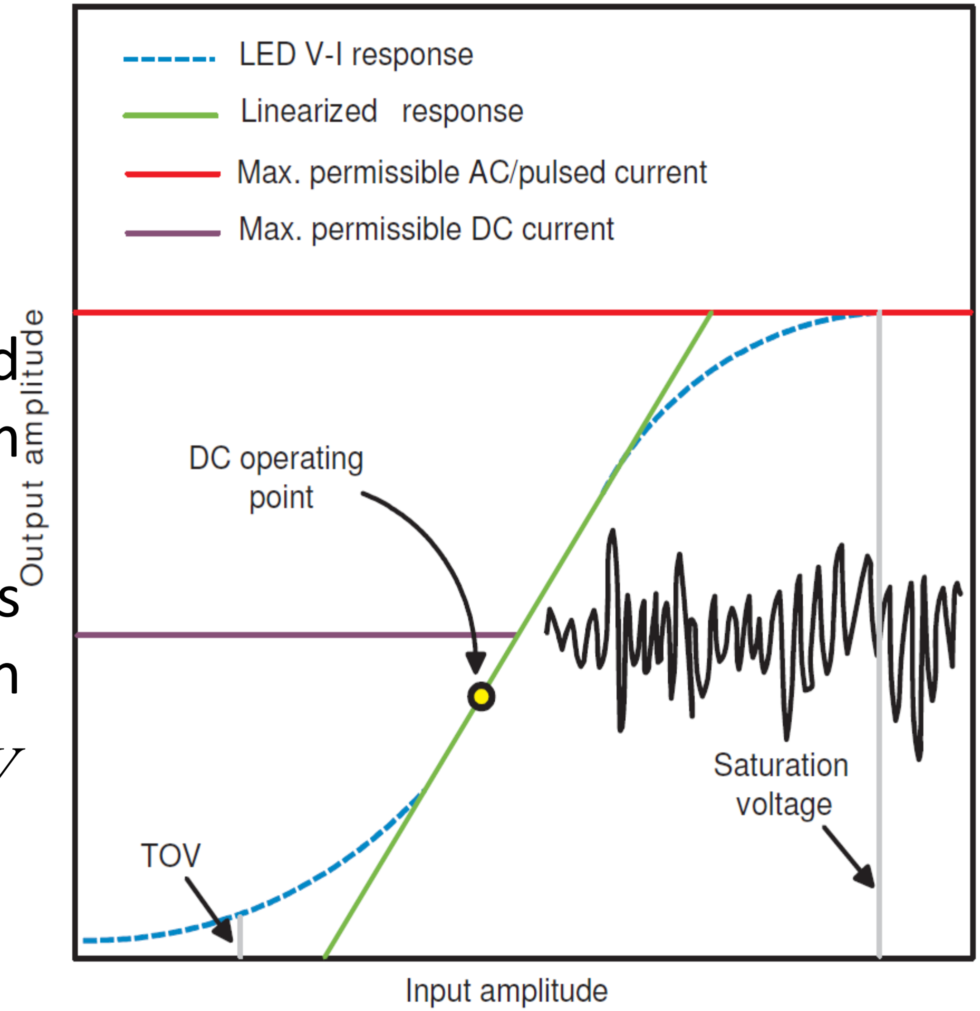




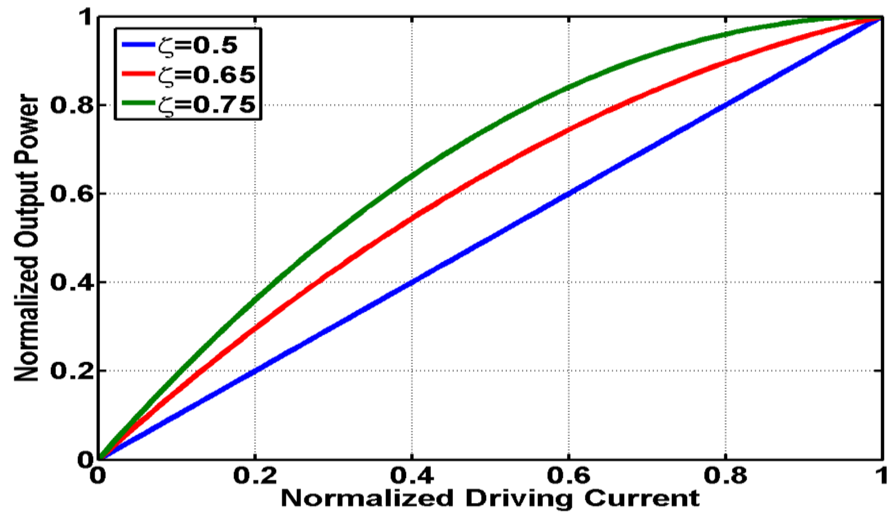
LED Non-Linearity

I-V Characteristics of LED

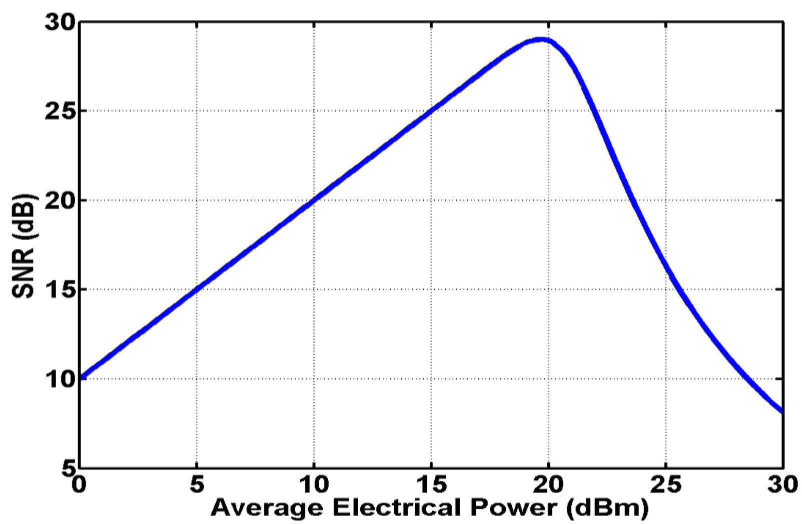
- The LED has a relatively reduced dynamic range extending from V_{TOV} to V_{Sat}.
- Thus, the applied signal is exposed to amplitude distortion caused by peaks lower than V_{TOV} and peaks higher than V_{Sat}.

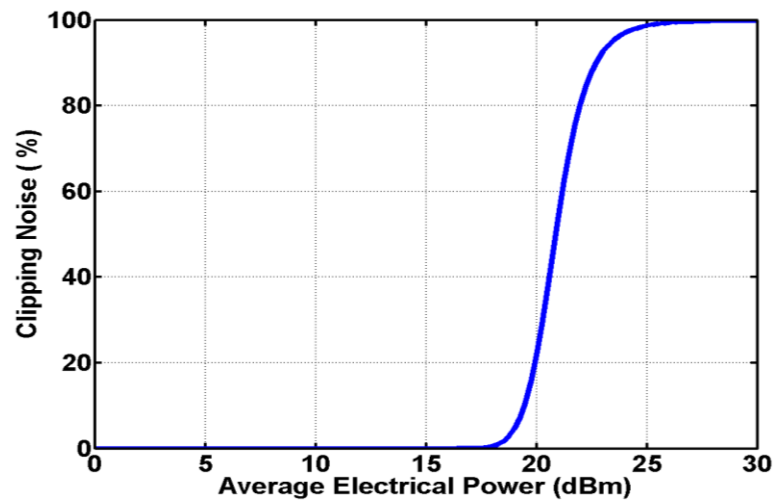


EFFECT OF NONLINEARITY PARAMETER

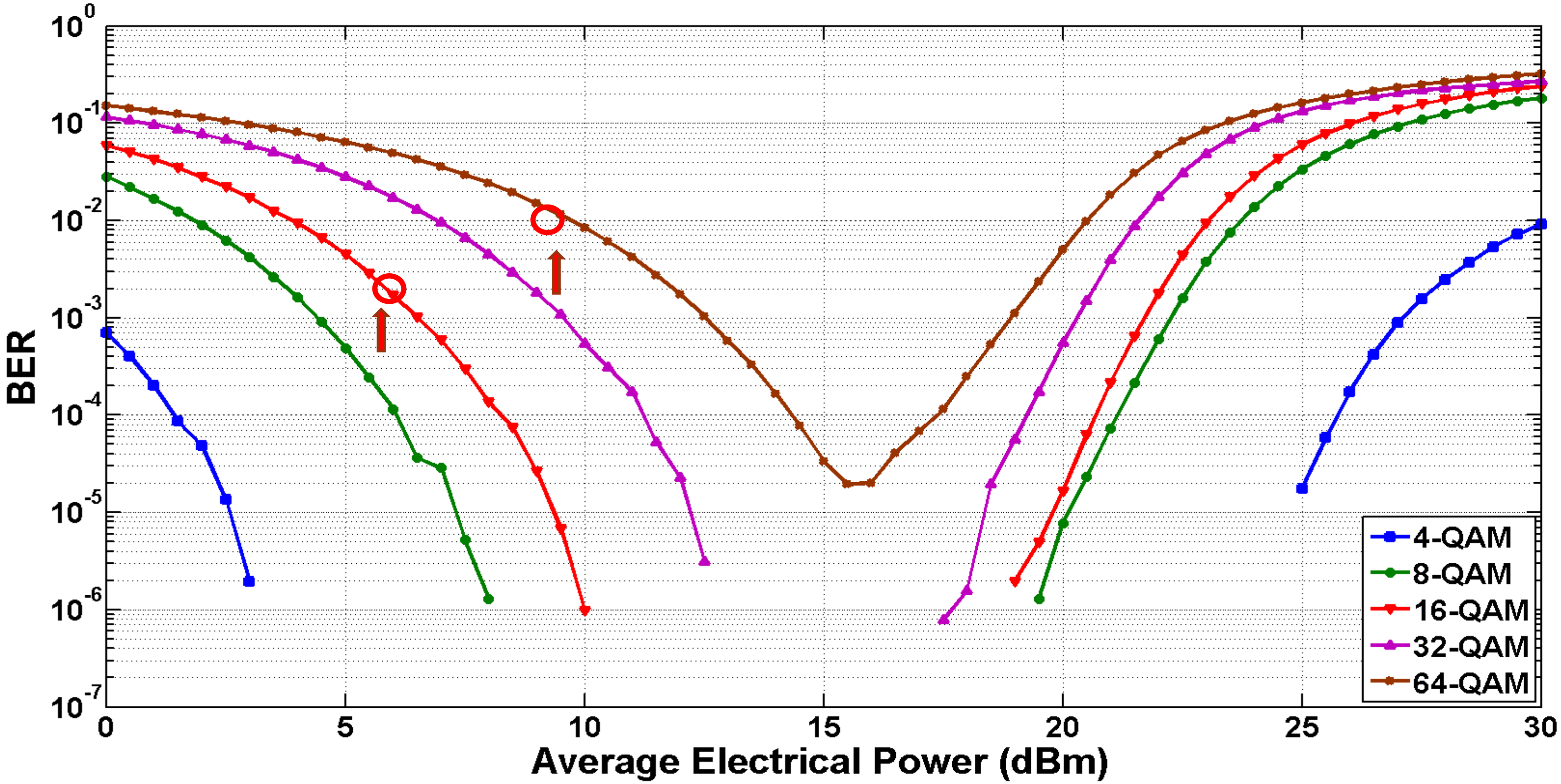


SNR

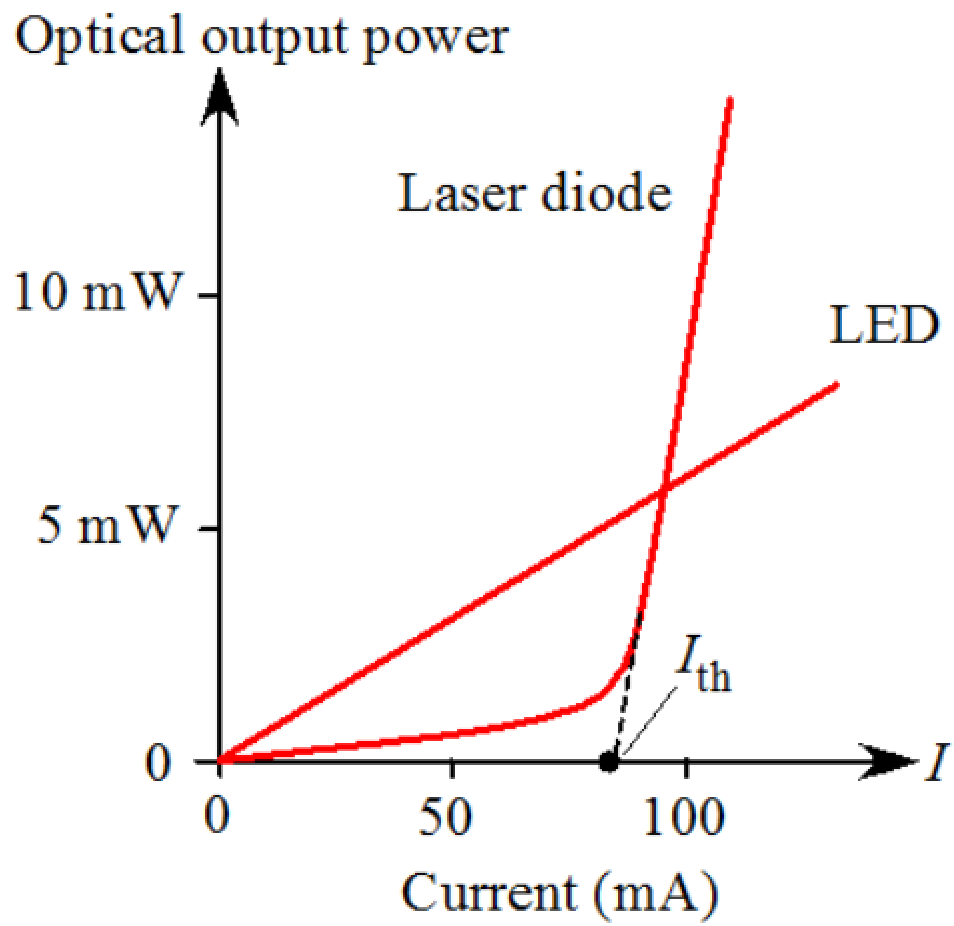




CLIPPING DISTORTION (LINEAR LED MODEL)



Linearity of LEDs and Laser Diodes

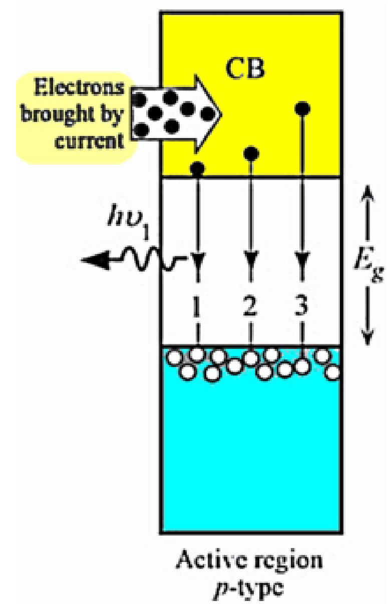


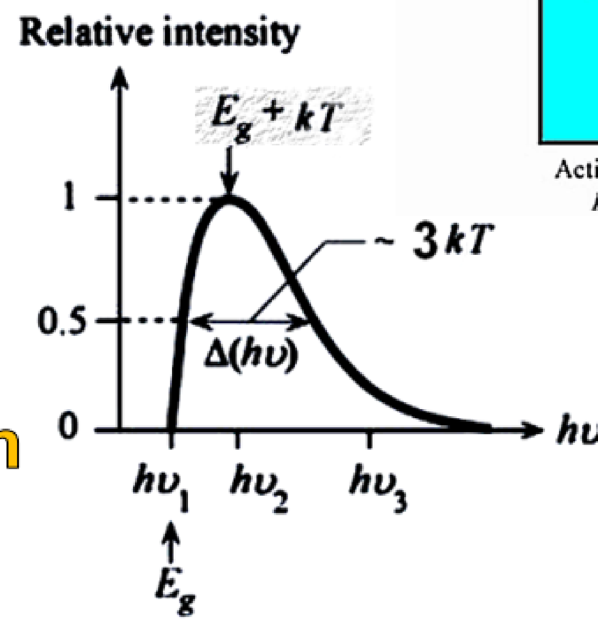
LED Power Spectrum

LED spectral linewidth

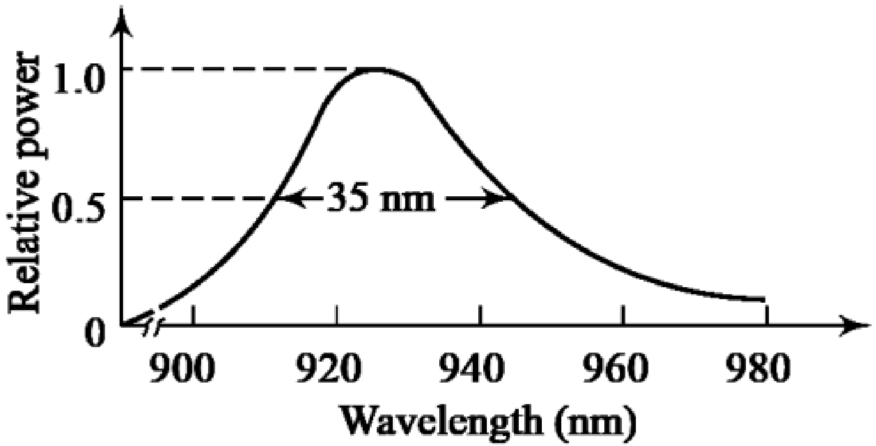
The spread in the output wavelengths is related to the spread in the emitted photon energies.

the spread in the photon energies $\Delta(h\nu) \approx 3kT$ between the half intensity points.



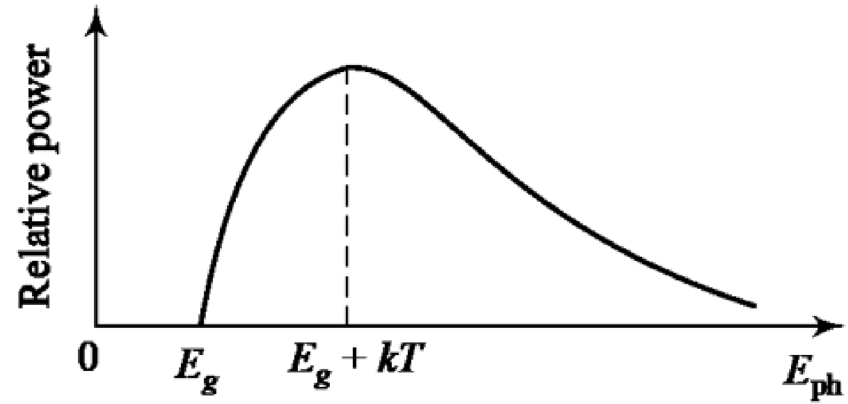


LED spectral linewidth (contd.)



Actual power distribution for a typical GaAs LED.

$$\Delta\lambda = \frac{\lambda_o^2}{hc}\Delta(h\upsilon) = \lambda_o^2\frac{3kT}{hc}$$



$$P = \alpha(E_{ph} - E_g)\exp[-(E_{ph} - E_g)/kT]$$

Theoretical spectral power distribution as a function of photon energy.

The Power Efficiency

power conversion efficiency (PCE)

The power efficiency power conversion efficiency (PCE):

It combines the **overall efficiency of conversion from the input electrical power to the output of optical power.**

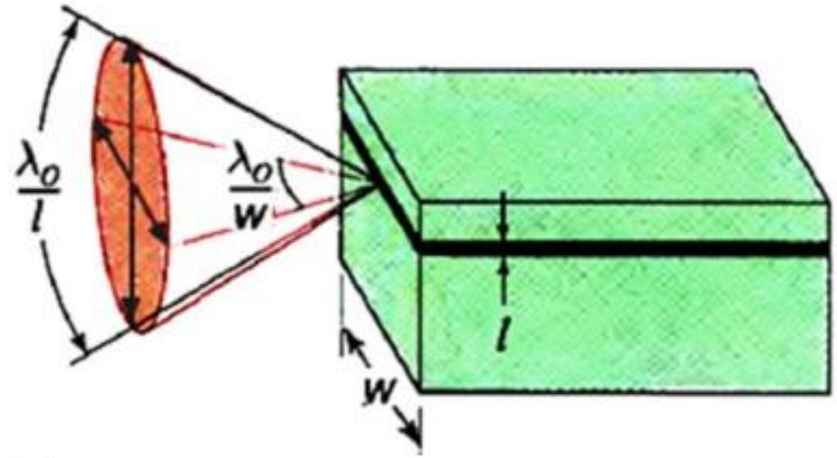
where ***IV*** is the **electrical power** supplied to the LED.

$$\eta_{power} = \frac{P}{IV}$$

The Radiation Pattern

Radiation Intensity

The **INTENSITY** I_s of Photon emission is the **total source power** P_{source} divided by the surface area of a sphere with radius r :



$$I_s = \frac{P_{source}}{4\pi r^2}$$

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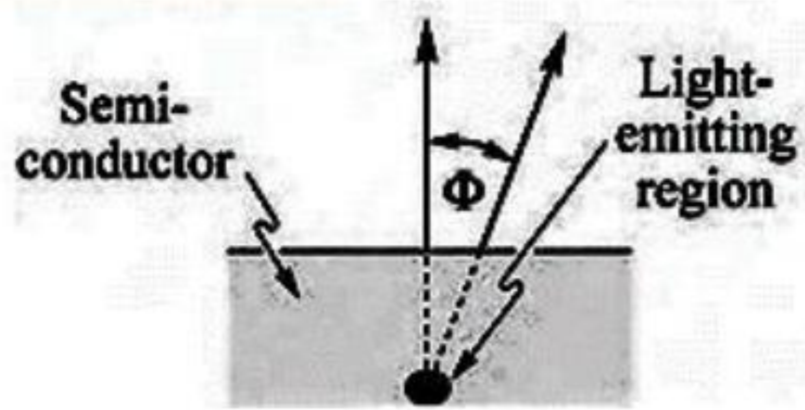
Lambertian Radiation Pattern

The light intensity in air is given by:

$$I_{air} = \frac{P_{source}}{4\pi r^2}\frac{n_{air}^2}{n_s^2}\cos\Phi = I_S \frac{n_{air}^2}{n_s^2}\cos\Phi$$



This is called **lambertian emission pattern**.

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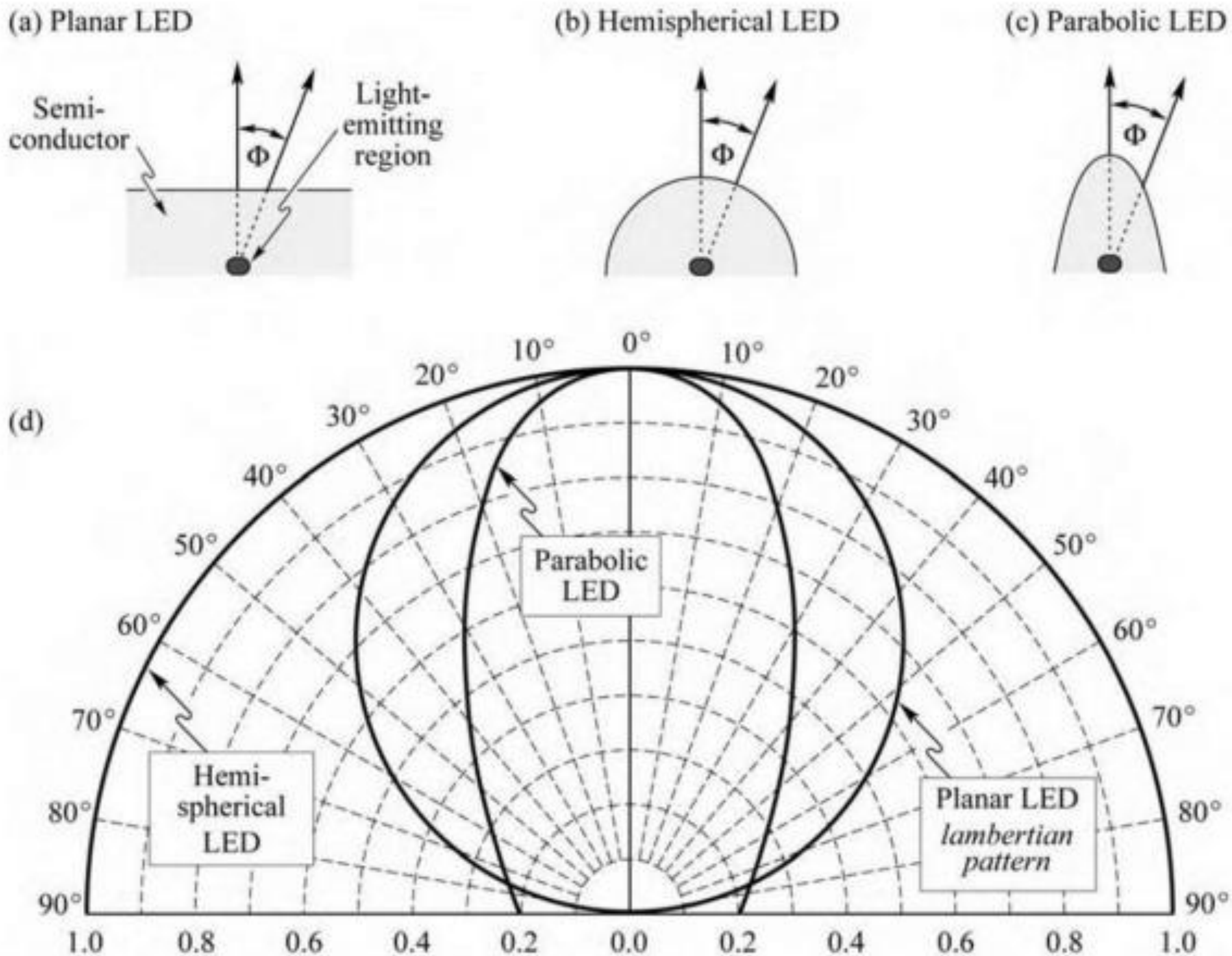
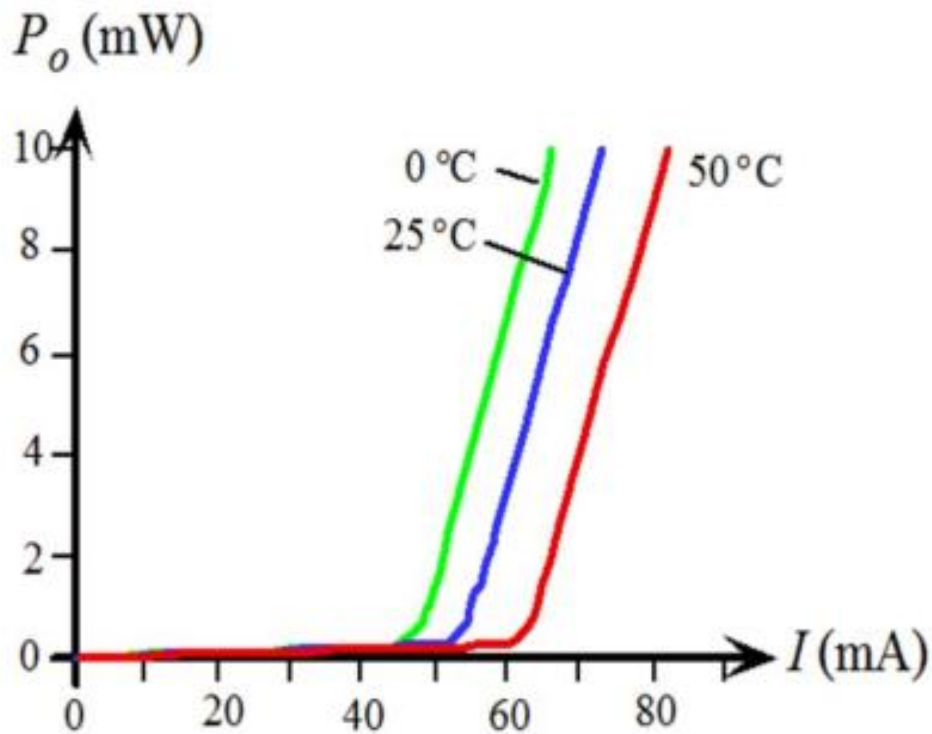


(a) Planar LED
Semi-
conductor
Φ
Light-
emitting
region
(b) Hemispherical LED
Φ
(c) Parabolic LED
Φ
(d)
0°
10°
10°
20°
20°
30°
30°
40°
40°
50°
50°
60°
60°
70°
70°
80°
80°
90°
90°
Parabolic
LED
Hemi-
spherical
LED
Planar LED
lambertian
pattern
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0

Temperature Dependence of Threshold Current



Output optical power vs. diode current as three different temperatures. The threshold current shifts to higher temperatures.

Thank you for your attention