Budapest University of Technology and Economics
Department of Electron Devices

Technology of IT Devices

Lecture 12

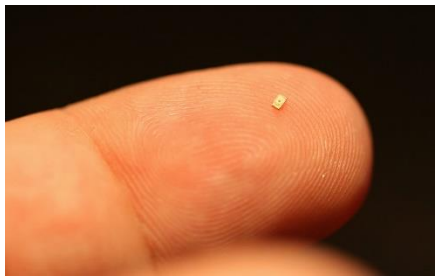
Light Emitting Diodes

Contents

- Light emitting diodes
- LED semiconductor materials
- LASER diode
- Electrical characteristics
- Packaging
- Driving

Light Emitting Diode

- Light Emitting Diode, LED
  - It is a semiconductor pn junction diode, which emits light when activated
    - Activated by the forward current
  - Electrically it is a diode
    - The I-V characteristic is the same (V_F differs)
- Applications
  - Solid-state lighting
    - Displays, LED lamps, LED flood light
    - Communication
    - IR communication (remote control)
    - Fiberglass
  - LASER
    - Distance/speed measurement
    - Optical data storage (CD, DVD)
    - LASER printers



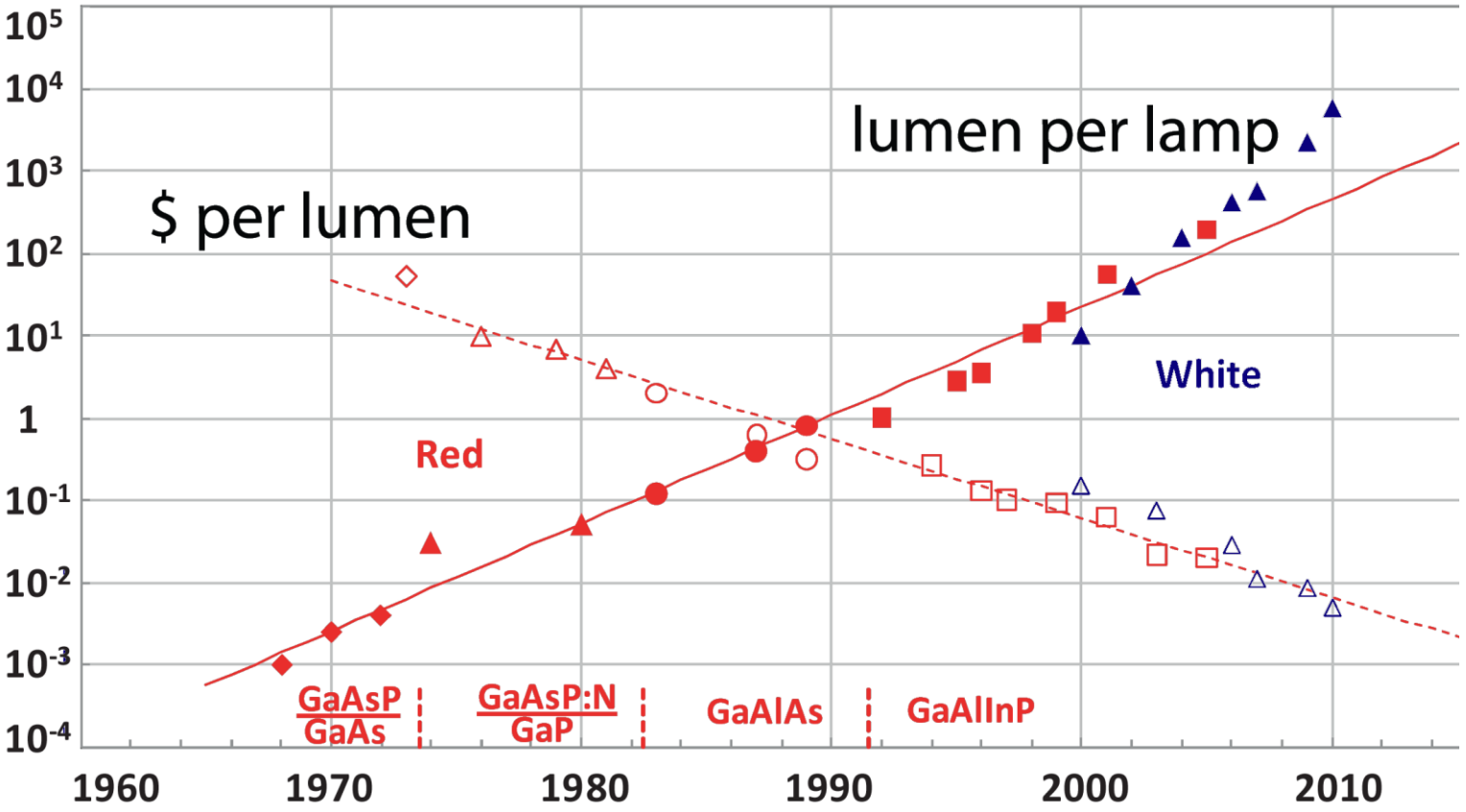
History of LEDs

- 1907 H.J. Round, UK: the electroluminescence phenomenon was discovered
- 1927 Oleg Loszev: reported creation of the first LED
- 1955 Rubin Braunstein, RCA: reported on infrared emission from gallium arsenide (GaAs) and other semiconductor alloys
- 1962 Nick Holonyak: The first visible-spectrum (red) LED
- 1972 Herbert Paul Maruska, RCA: the first blue LED
- 1994 Shuji Nakamure, Nichia Corporation: The first high-brightness blue LED was demonstrated

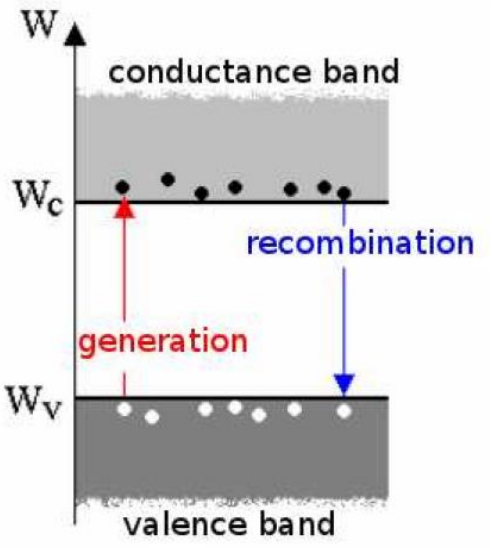
- Development
  - The luminous flux (a measure of the total quantity of visible light emitted by a source) increased by 20x every 10 years
  - Luminous flux: measured in Lumen [lm]
    - Weighted according to a model of the human eye's sensitivity to various wavelengths

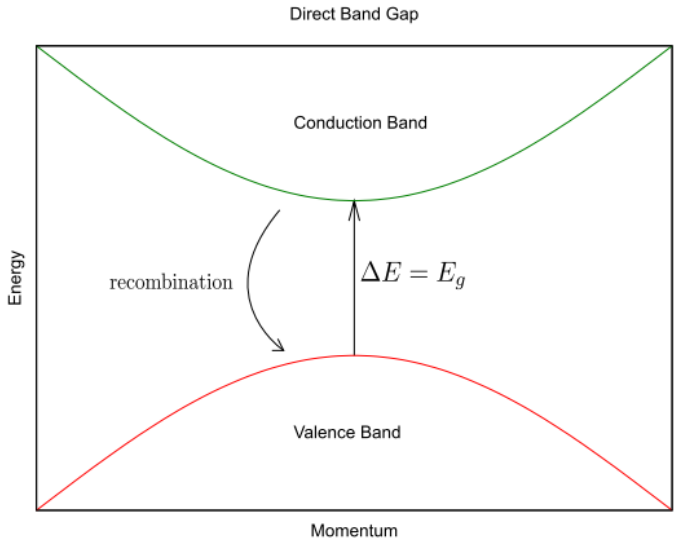
Haitz's law

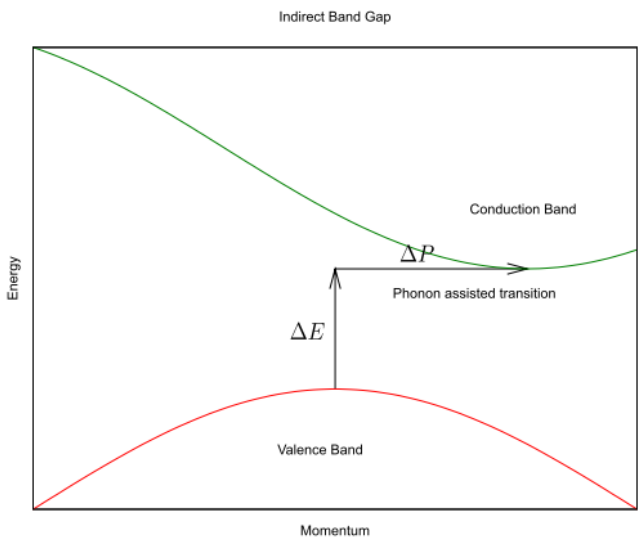
- **Haitz's law** is an observation and forecast about the steady improvement, over many years, of light-emitting diodes (LEDs)



The direct band gap

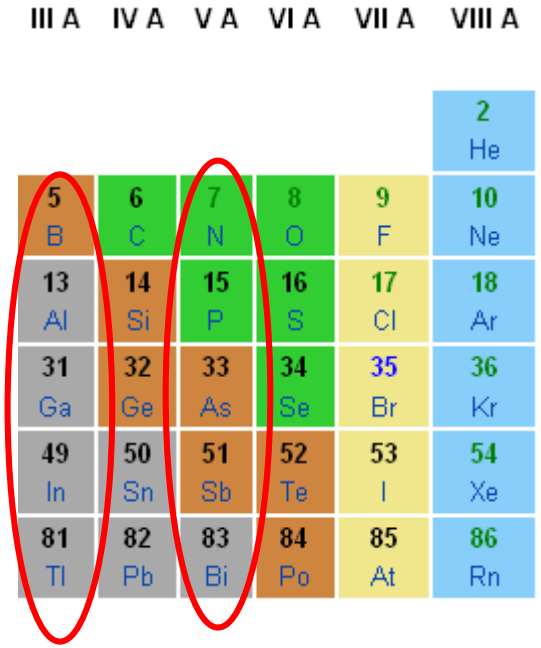






- Generation: happens when an electron gets to the conductance band from the valence band.
- Recombination: the opposite of generation – when an electron falls back to the valence band
  - In the case of direct band gaps: an electron can directly emit a photon during recombination

- LEDs are made of compound semiconductors.
- The components are found in the main groups of 3 and 5. For example:
  - Al, Ga, In
  - N, P, As
- The components determine
  - The width of the bandgap
  - The type (n or p)
- The wave-length (color) of the light depends on the width of the band gap (W_g)
  - The elements used in the compound,
  - The ratio of the elements



$$\lambda = \frac{c}{\nu} = \frac{hc}{W_g}$$

where h: Planck-constant, ν: frequency, c: speed of light, λ: wavelength

- Two material systems. The available colors:
  - InGaAlP system: (infrared) – red – yellow/green
  - InGaN/GaN system: (ultraviolet) – blue – blue/green

InGaN/GaN

Green

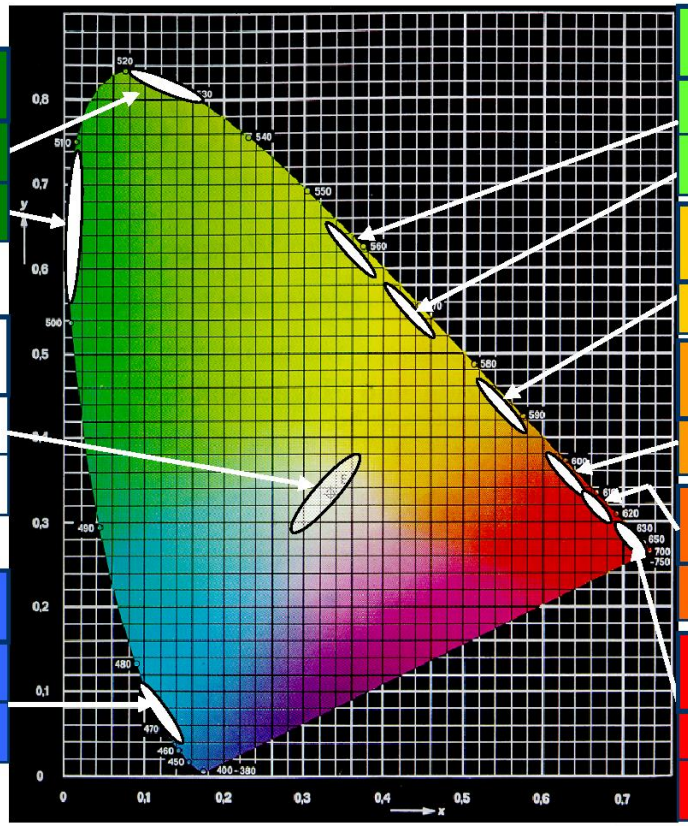
T = TrueGreen (InGaN)	525nm
V = VerdeGreen (InGaN)	505nm

White / CoD

W = White (GaN/InGaN)
Cx = Color on Demand (GaN/InGaN)

Blue

B = Blue (InGaN)	470nm
B = Blue (GaN)	466nm



InGaAlP

Green

P = PureGreen	560nm
G = Green	570nm

Yellow

Y = Yellow	587nm

Orange

O = Orange	605nm

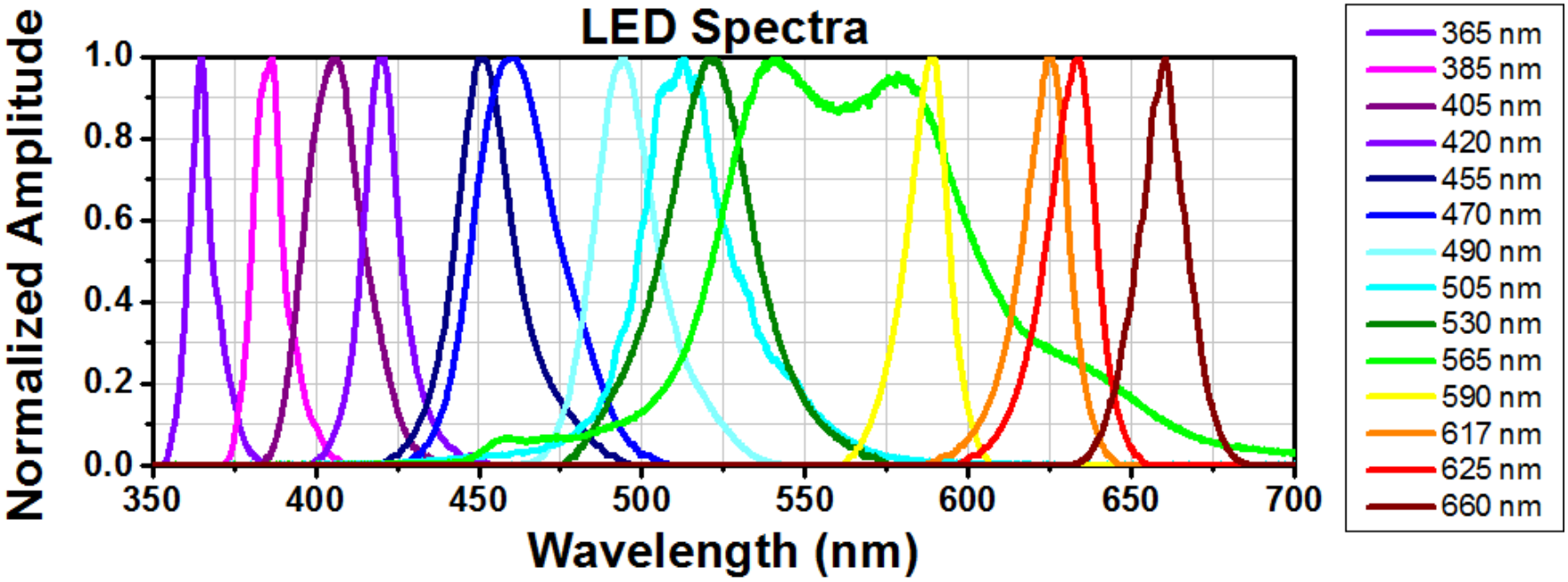
Orange Red

A = Amber	617nm

Red

S = Super-Red	630nm
H = Hyper-Red (GaAlAs)	645nm

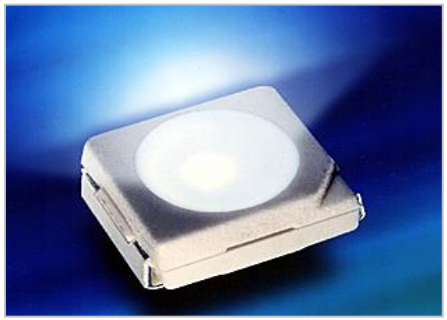
LED spectra

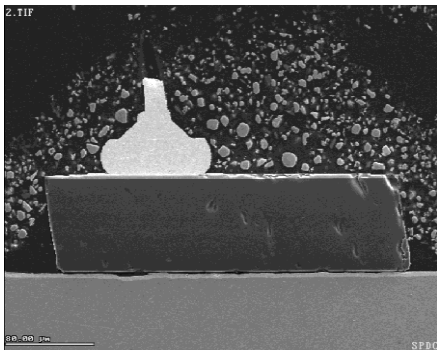


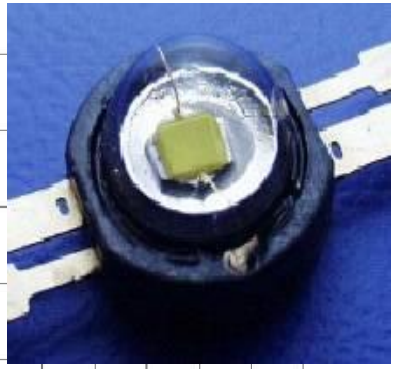
- The discreet LED spectrums

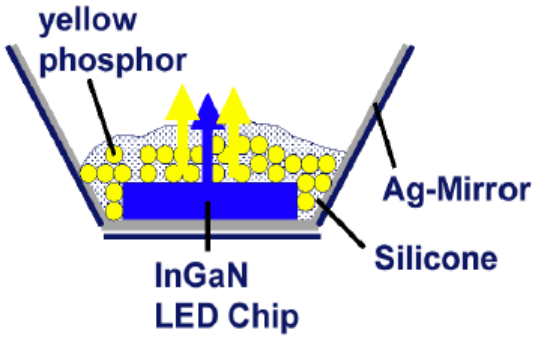
White LEDs

- RGB LED
  - Uses individual LEDs that emit each of the three primary colors which are then mixed to form white light
- UV LED + yellow phosphor
  - Use a phosphor material to convert monochromatic light from a blue or UV LED to broad-spectrum white light









Phosphor materials

- A **phosphor**, most generally, is a substance that exhibits the phenomenon of **luminescence**.

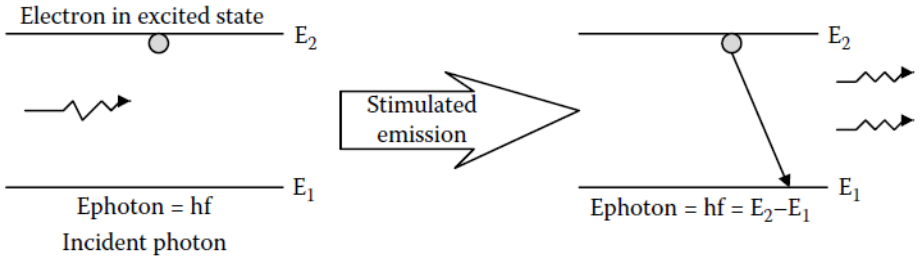
A material can emit light induced by excitation (photon or electron)

- It absorbs shorter wavelength light and emits longer wavelength light.
- Efficiency is lower than 100%

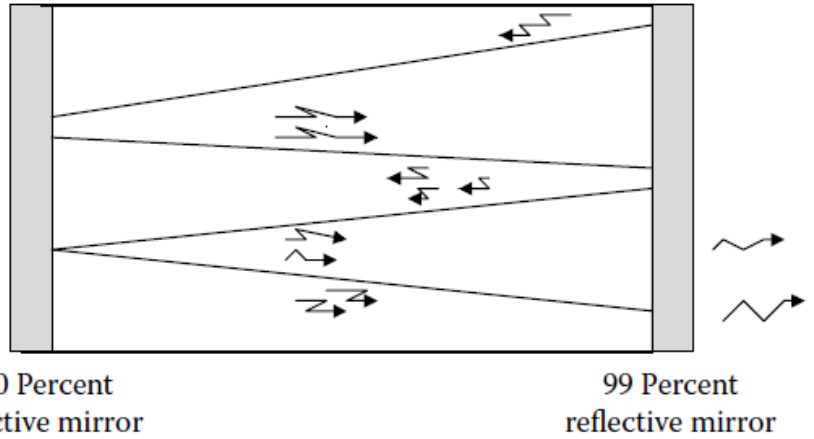
- Applications
  - Fluorescent lamps
  - Metal-halide lamps
  - Neon lamps and signs
  - Cathode ray tubes
  - White LEDs

LASER diodes

- LASER
  - Light Amplification by Stimulated Emission of Radiation



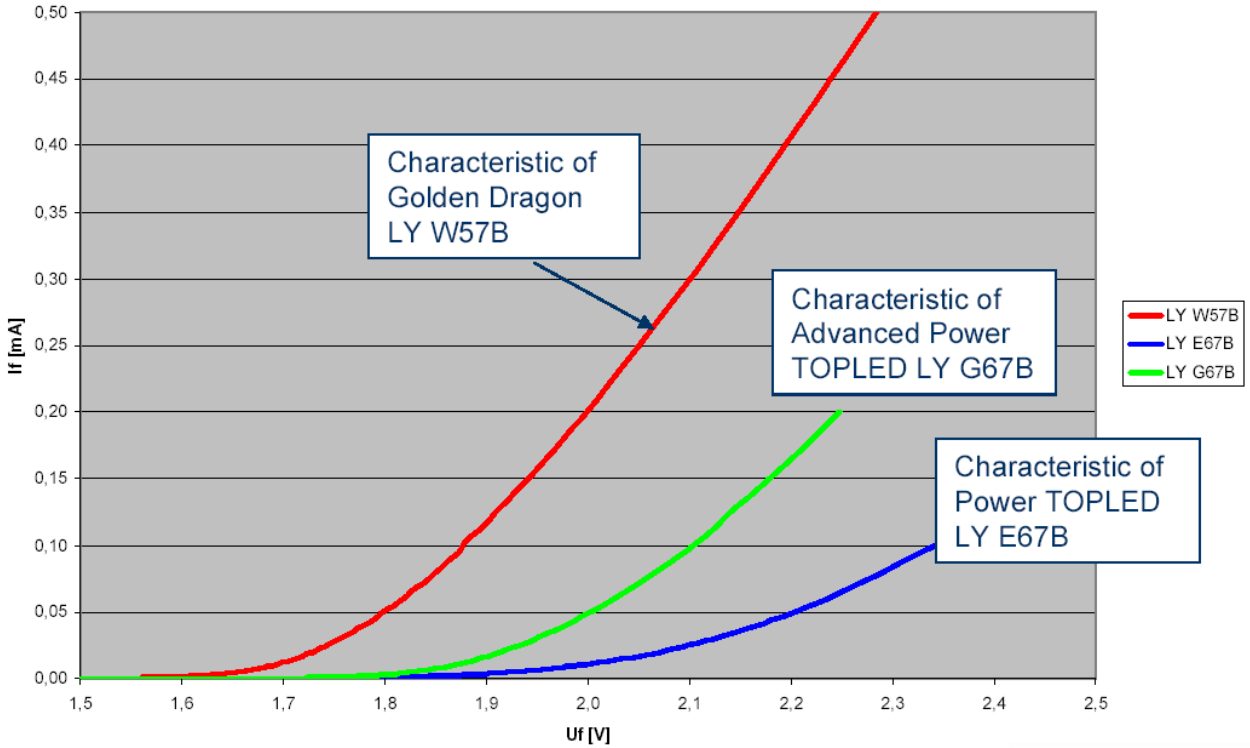
- It is an electrically pumped semiconductor laser in which the active laser medium is formed by a p-n junction of a semiconductor diode similar to that found in a light-emitting diode.
- An incident photon induces the stimulated emission when an electron falls back to the valence band
  - The energy is transported to a photon
- Principles
  - High electron density required
  - High photon density
    - Using an optical resonator



LASER diode vs LED

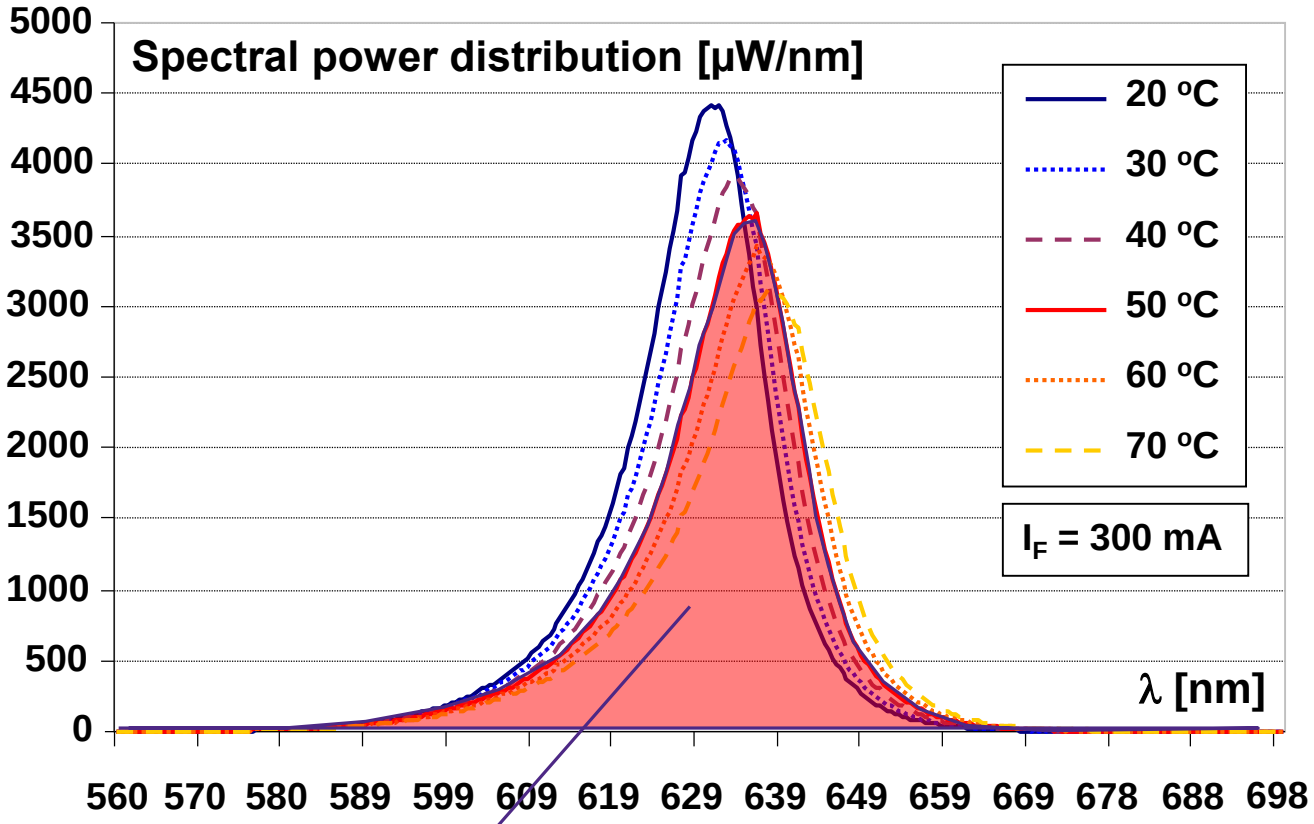
LASER diode	LED
Induced emission	Spontaneous emission
Narrow spectrum (<10nm)	Wide spectrum (40-200nm)
Coherent	Non-coherent

Electrical properties



- Acts like a (normal) diode
  - But higher forward voltage drop: (2.5—4 V) – depending on the color
  - Forward current:
    - Traditional, small power LEDs: ~10 mA,
    - Power LEDs: 300–800–1500 mA.

Luminous efficacy of LEDs



$$\Phi_e \approx \int_{380nm}^{780nm} S(\lambda)d\lambda$$

An increase in temperature causes a decrease in luminous efficacy.

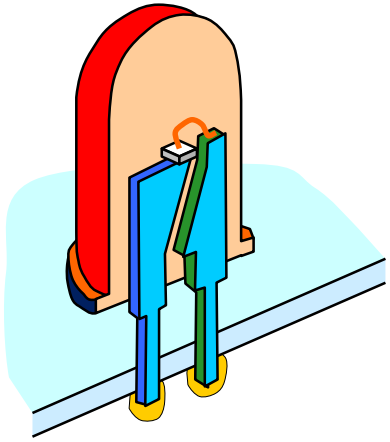
Luminous efficacy is a measure of how well a light source produces visible light.

Packaging

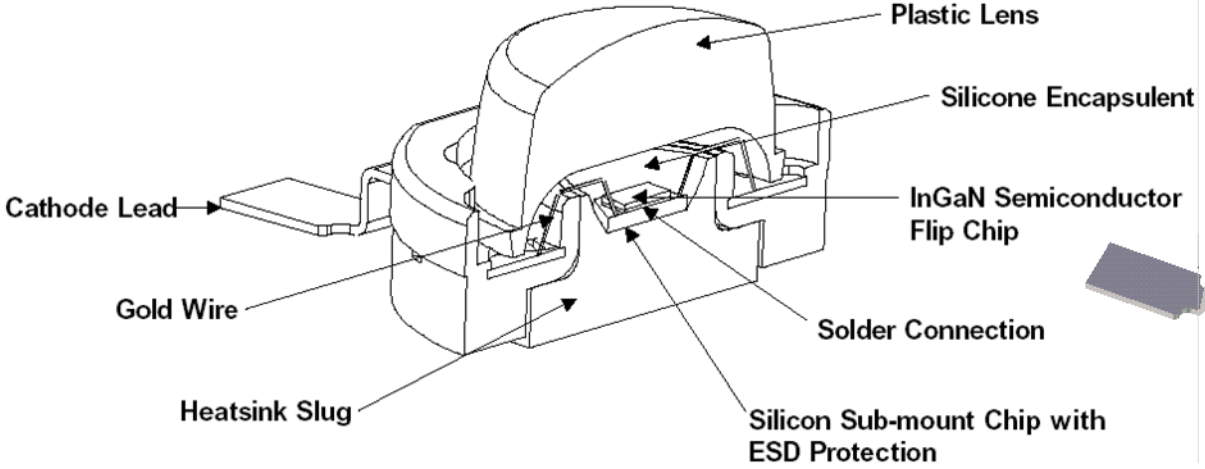
- Low power LEDs

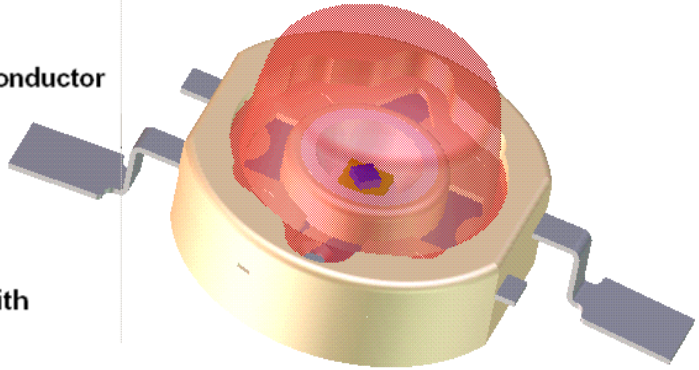
Radial LED

Chip 250 x 250 µm

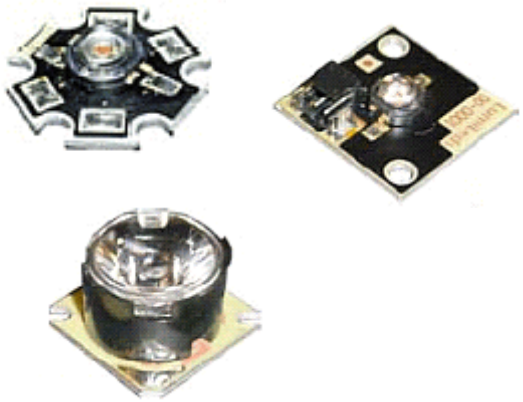


- Medium power LED w/ lens





High Power LEDs (light sources)



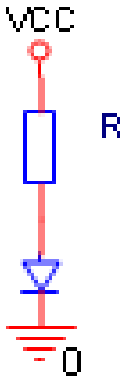
- MCPCB – metal core printed circuit board
  - The metal core of the thermal PCB can be aluminum (**aluminum core PCB**), copper (**copper core PCB** or a **heavy copper PCB**) or a mixture of special alloys. The most common is an **aluminum core PCB**.
  - **It is a good thermal conductor**

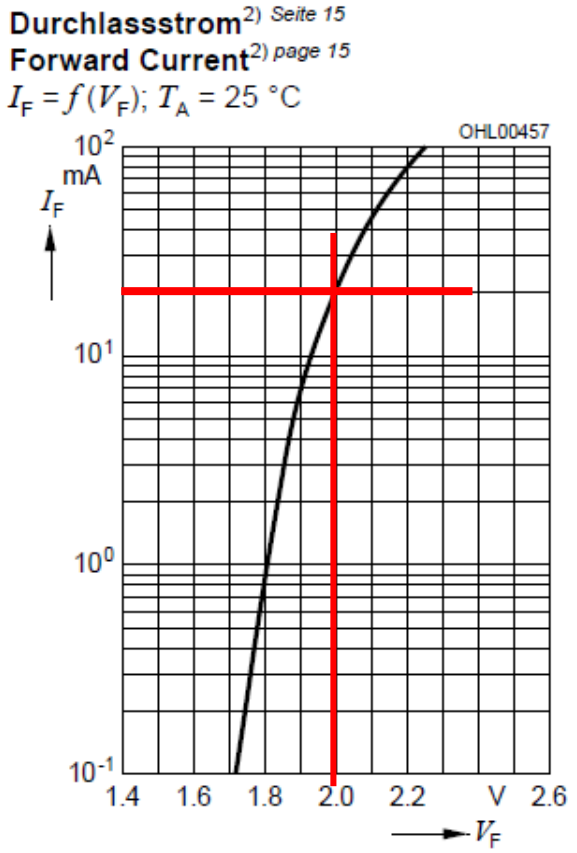
LED driving

- Definitions
  - WPE (Wall Plug Efficiency)
    - The ratio between the emitted optical power of the LED and the incoming power from the wall outlet
    - $WPE = \frac{P_{OPT}}{P_{EL}}$
- The I-V characteristic has an exponential I-V characteristic, so the current has to be regulated
  - Voltage generator + a series resistor
    - The power loss is high due to the dissipated power on the resistor
    - The input voltage variation causes current variation, thus the optical power intensity will change
  - Current generator
    - Using a DC/DC converter in current generator mode

LED driving - example

- The task is to operate a green LED at an operating point of 20 mA. The supply voltage is 3.3 V and the current-voltage characteristic of the LED is given as a curve.





- The operating point can be found in the figure: I_F = 20 mA is reached at V_F = 2 V
- The resistance needed can be calculated as follows:
  - $R = \frac{V_{CC} - V_F}{I_F} = \frac{3.3-2}{20} = 65\Omega$

LED driving - example

The efficiency of the LED is 35% @ 20mA. What is the efficiency of the whole system?

The electric power of the LED

$P_{EL} = VI = 2V \cdot 20mA = 40mW.$

The emitted optical power is:

$P_{OPT} = \eta P_{EL} = 14mW$

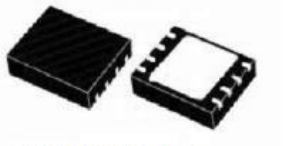
The power of the whole circuit:

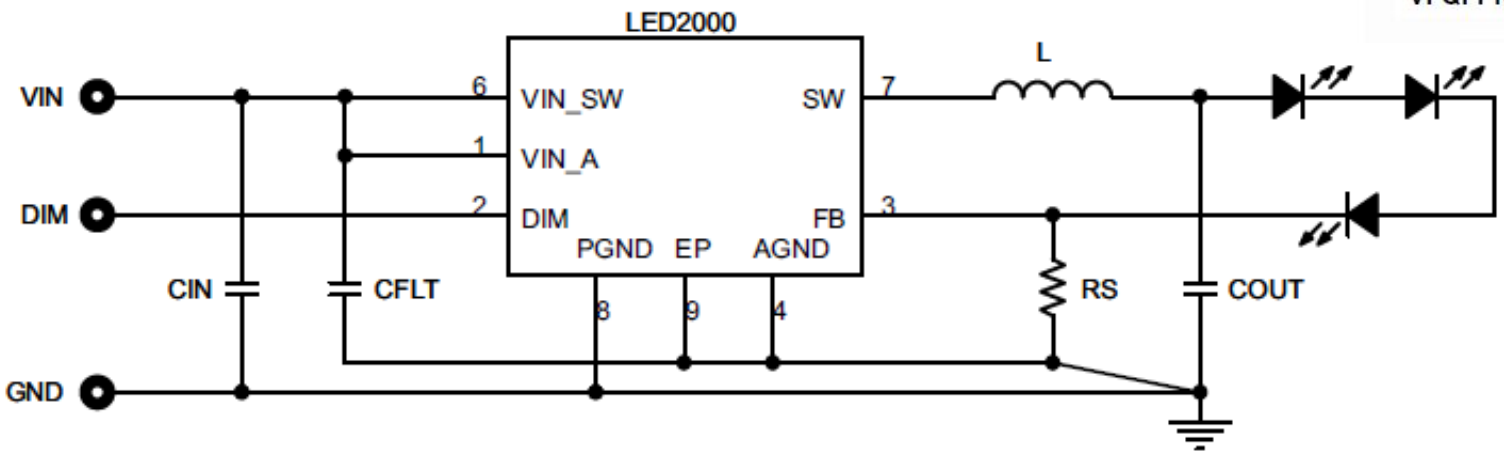
$P = V_{CC} I = 60mW$

The WPE is: 14/60= 23%

- The current limiting resistor decreases the efficiency
  - In high-power LED applications LED driver circuits are used.
  - They have higher efficiency
  - And they don’t generate heat

ST LED2000





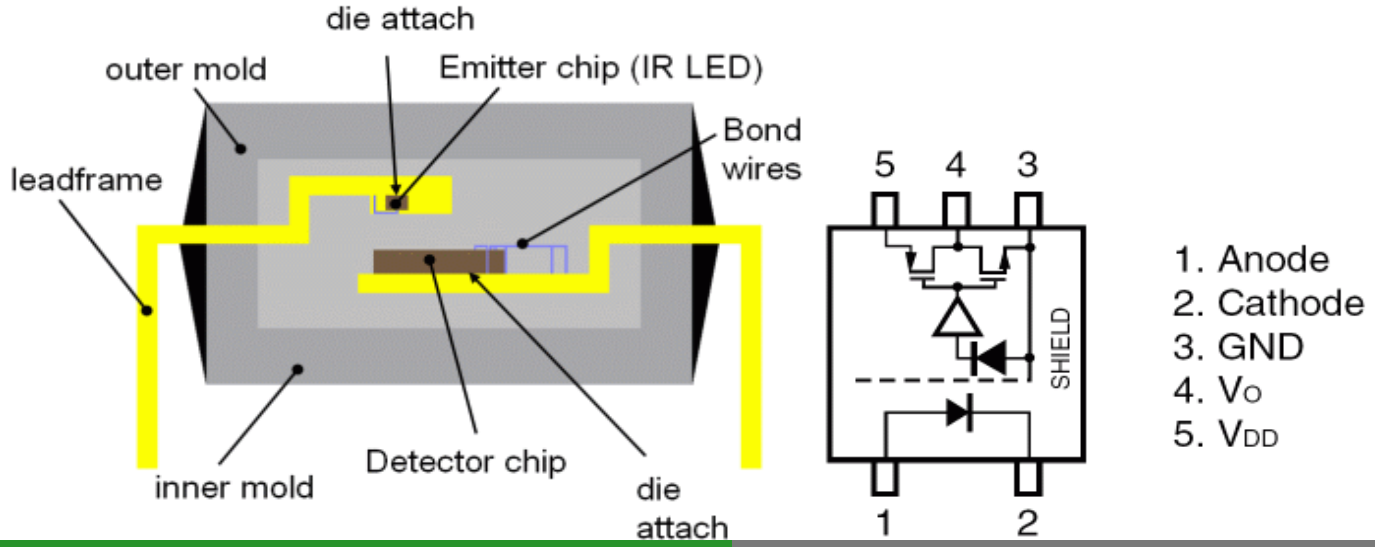
- Input voltage range: 3-18V, output current is 3A max.
- Switching frequency is 850kHz (it is a DC/DC converter)
- PWM dimmable (to vary the brightness of the LEDs)
- Package size: 4mm×4mm
- 3 capacitors and a coil required

Communication

- Wireless IR communication:
  - Simple structure, harmless frequency,
  - Line of sight is required for the operation.
- Communication through fiberglass:
  - Lasers are used instead of LEDs
  - The receiver is more than just a simple diode to increase speed
  - Bandwidth of several Tbps, length of several thousand km
  - Fiber-Channel infrastructure
  - Safe of electric noise and disturbances
- Opto coupling

Opto coupling

- Used to insert galvanic isolation into datapaths.
  - This means that charge carriers are blocked from flowing between two parts of a circuit but the signals get through due to the fact that they are transmitted optically. It helps to prevent circuits from large current peaks.
- Enables large transmission speeds (15 Mbps).
- Input: GaAs LED
- Output: Si photodiode and an output interface (e.g. CMOS logic).



Visiting the LED test lab