Light Emitting Diodes

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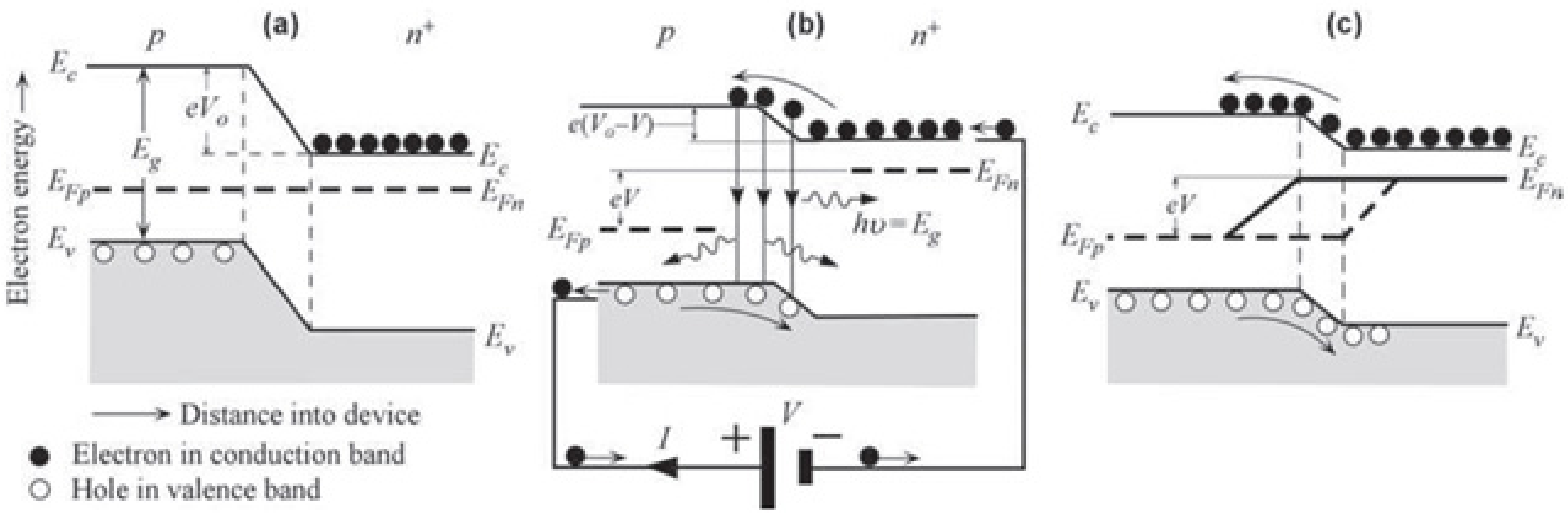
Course Overview

1. Homojunction LED
2. Heterostructure LED
3. LED Structures
4. Characteristic Parameters
5. I-V Curve
6. Organic LEDs

Ref:
Kasap, Optoelectronics and Photonics (Ed. 2), Chapter 3 (Section 3.11-3.17);

1. Homojunction LED (1)

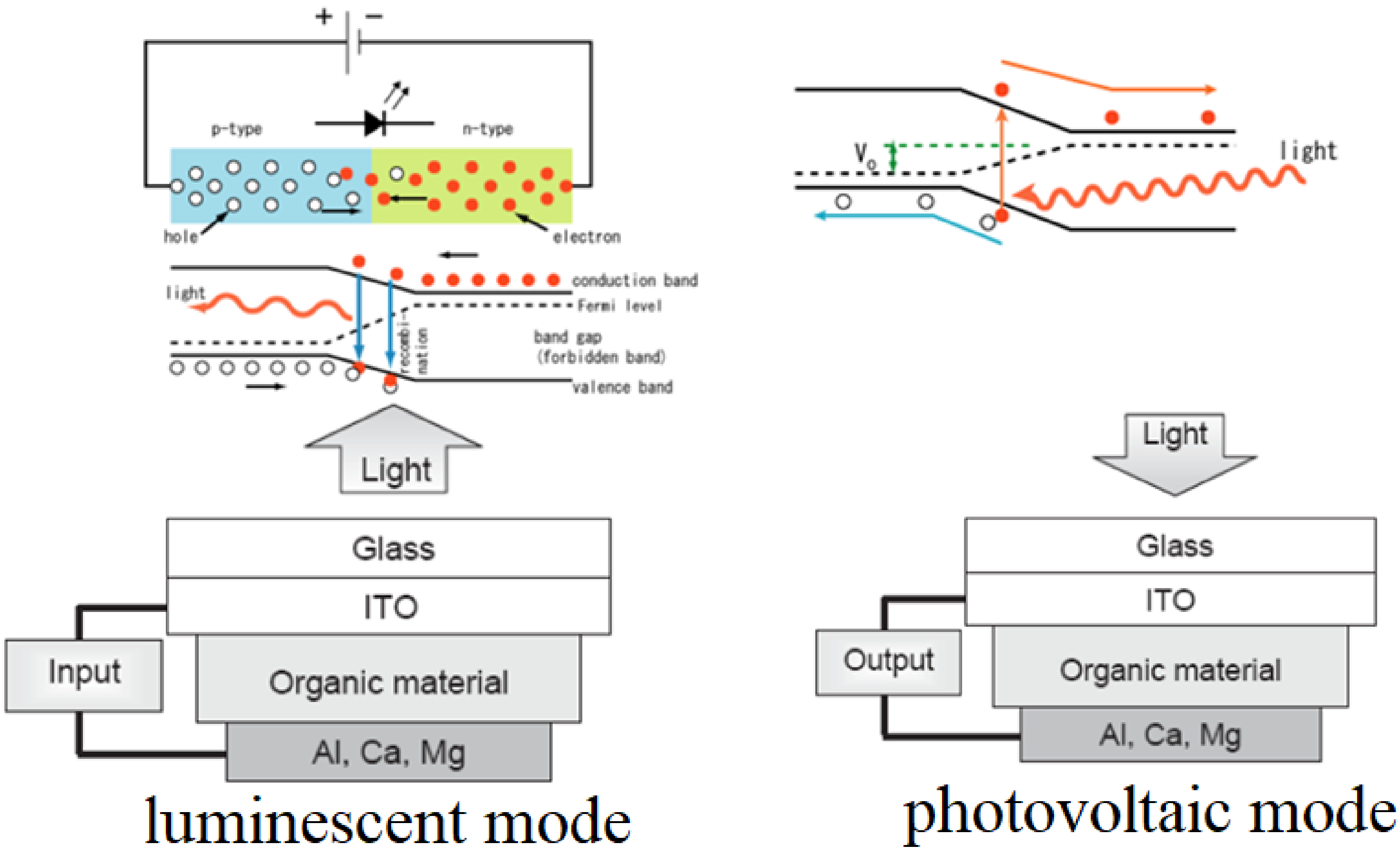
A light-emitting diode is essentially a *pn* junction diode typically made from a direct bandgap semiconductor, for example, GaAs, in which the e-h pair recombination results in the emission of a photon. The emitted photon energy is therefore approximately equal to the bandgap energy.



As soon as a forward bias V is applied, the built-in potential V_o is reduced to V_o - V, which then allows the electrons from the *n*+ side to diffuse, or become injected, into the *p*-side. (The hole injection from p into the n+ side is much smaller). The recombination of injected electrons in the depletion region as well as in the neutral p-side results in the spontaneous emission of photons. Recombination (active region) primarily occurs within the depletion region and the diffusion length L_e of the electrons in the p-side.

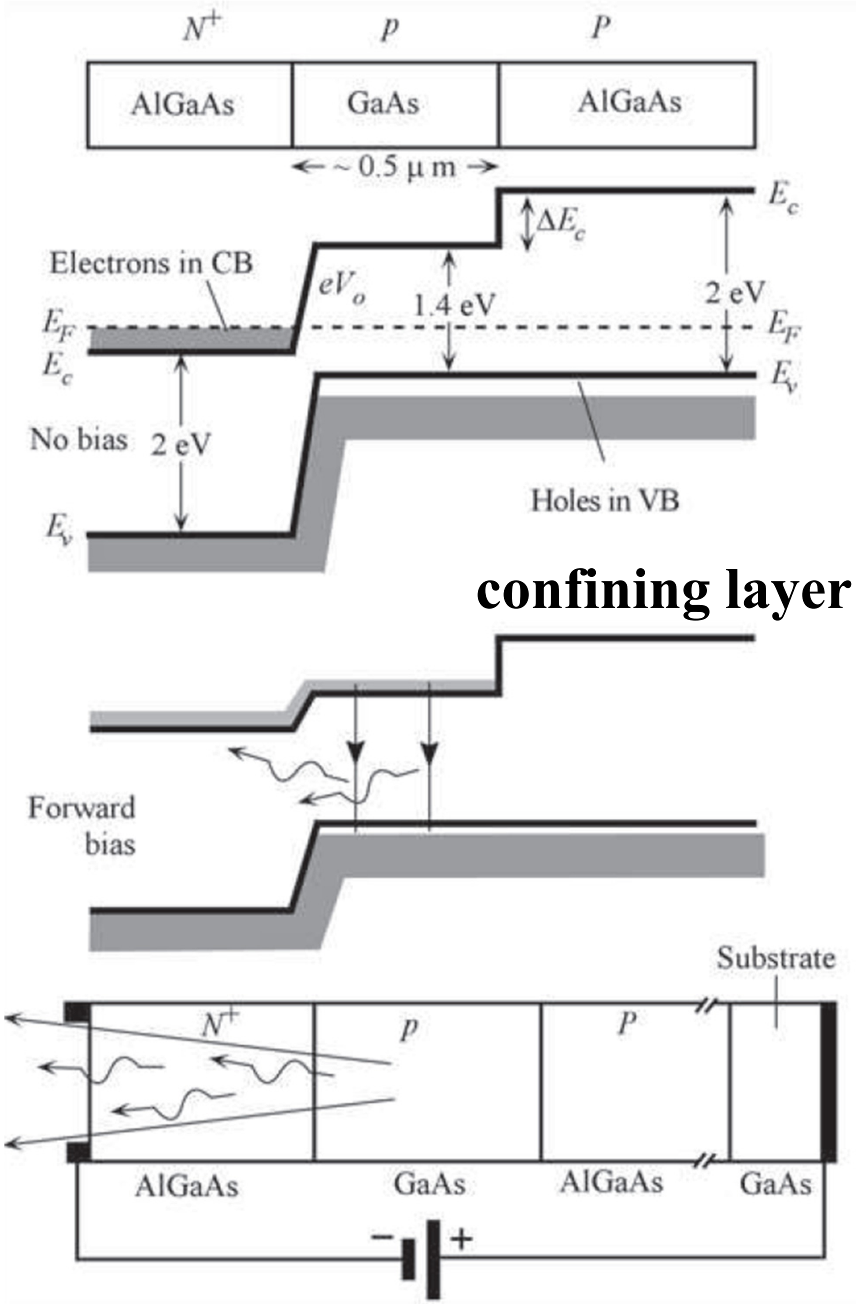
1. Homojunction LED (2)

Reciprocity of solar cells and light emitting diodes



the processes of charge carrier injection (relevant in the luminescent mode of operation) and charge carrier extraction (relevant in the photovoltaic mode of operation are reciprocal.

2. Heterostructure LED

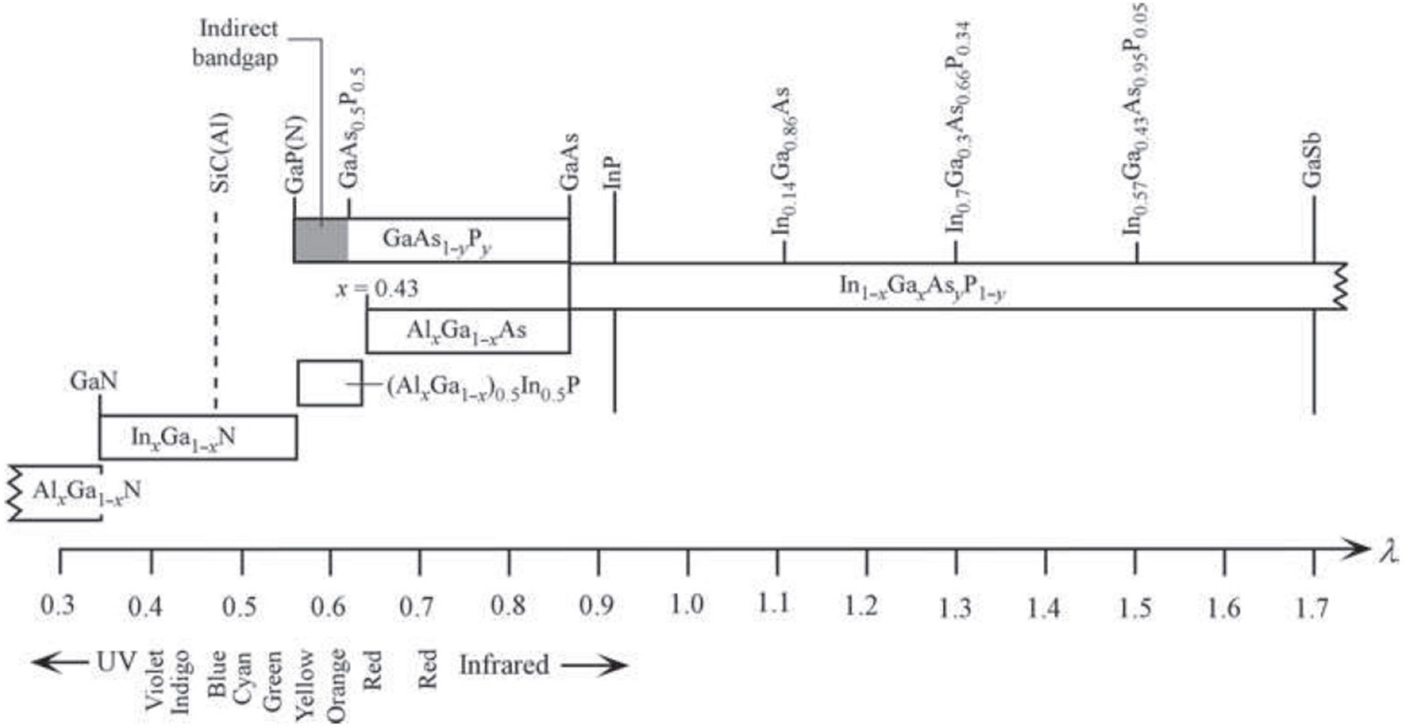


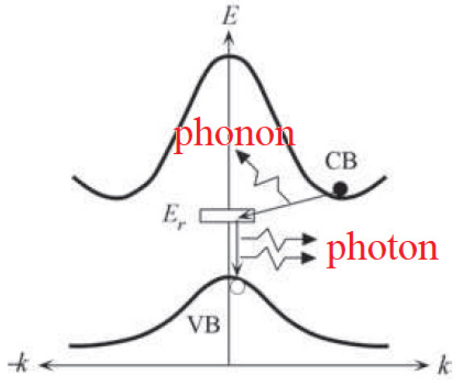
Weakness of p-n junction: The *p*-region must be narrow to allow the photons to escape without much reabsorption. When the *p*-side is narrow, some of the injected electrons in the *p*-side reach the surface by diffusion and recombine through crystal defects near the surface.

Merits of hetero-junction: Typically, a wider bandgap semiconductor has a lower refractive index. This means that by constructing LEDs from heterostructures, we can engineer a dielectric waveguide within the device and thereby channel photons out from the recombination region. Also, wide bandgap material layer acts as a confining layer that restricts injected carriers to make large radiative recombination.

3. LED Structures (1)

LED materials





There are various commercially important direct bandgap semiconductor materials that emit in the red and infrared wavelengths which are typically ternary (containing three elements) and quaternary (four elements) alloys based on Group III and V elements, so-called <u>III–V alloys</u>. For indirect bandgap alloys, if we add <u>isoelectronic impurities</u> such as nitrogen into the semiconductor crystal then the N-dopants can act as <u>recombination centers</u>. The emitted photon energy is only slightly less than Eg.

3. LED Structures (2)

Consideration: small non-radiative recombination; carrier confinement; good light extraction; lattice match; …

Fabrication: epitaxially growing doped semiconductor layers on a suitable substrate

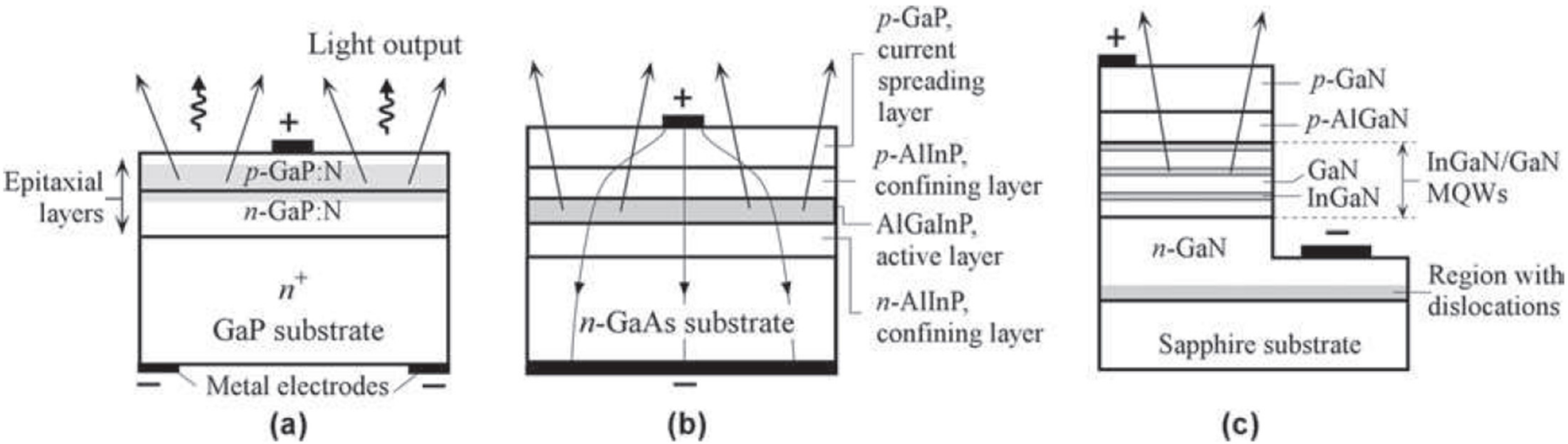
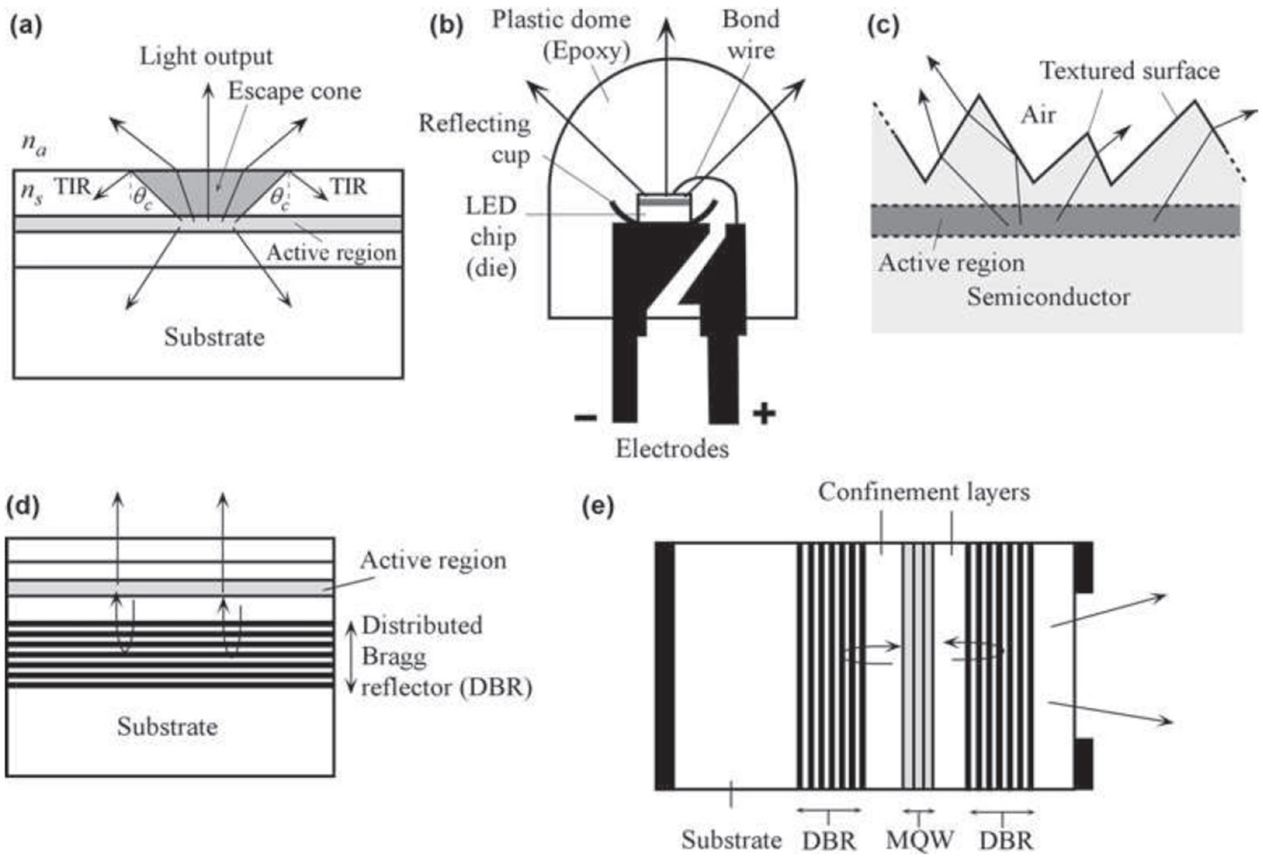


FIGURE 3.39 A schematic illustration of various typical LED structures. (a) A planar surface-emitting homojunction green GaP:N LED. (b) AlGaInP high-intensity heterostructure LED. (c) III-Nitride-based (GaN/InGaN) MQW LED for emission from the UV to green.

The top layer is p-GaP and serves to spread out the current to regions outside the top contact. Thus, radiative recombinations are avoided right under the top contact from which photons cannot be extracted.

3. LED Structures (3)

Light extraction structures

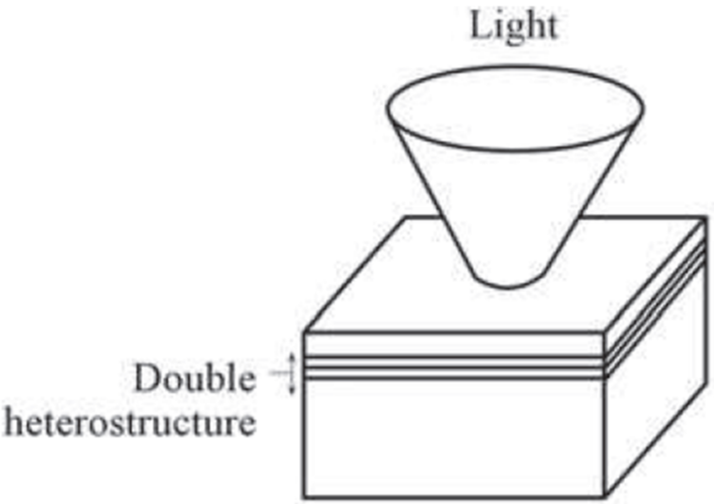


which structure has a narrower emission spectrum?

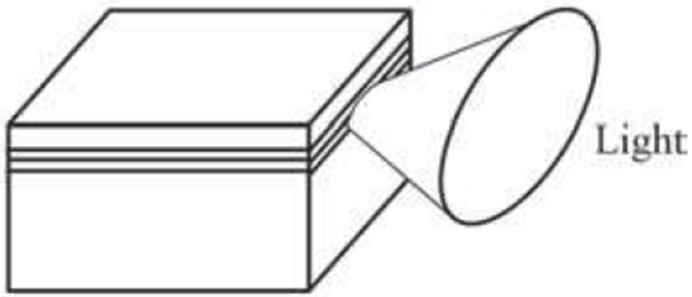
The optical cavity by two distributed Bragg reflectors is obviously wavelength-selective since only those special modes of the optical cavity that fall into the spontaneous emission spectrum can be supported or excited.

3. LED Structures (4)

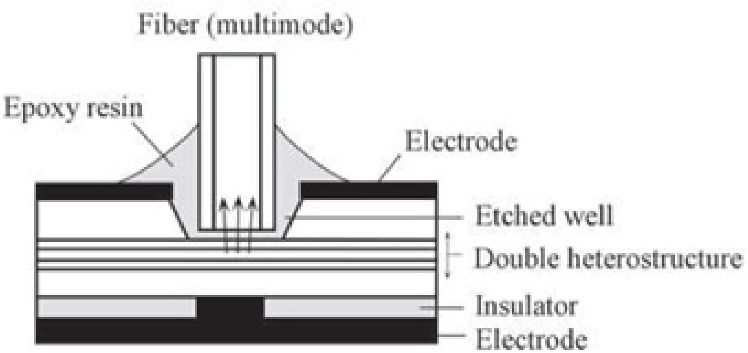
<u>Light emitting structures</u> (coupled to optical fiber)

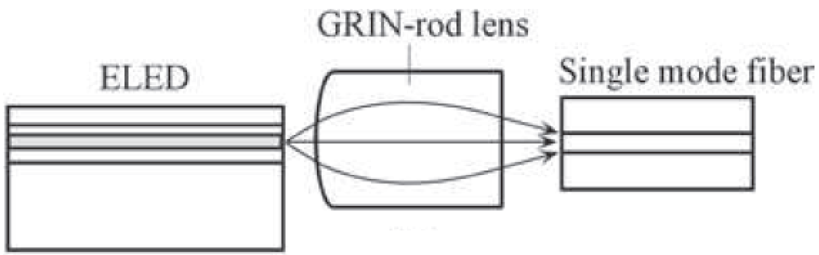


Surface-emitting LED



Edge-emitting LED





4. Characteristic Parameters (1)

external quantum efficiency

$$\boxed{\eta = \frac{P_0 / hv}{I / e}}$$

the efficiency of conversion from electrical quanta, *i.e.*, electrons, that flow into the LED to optical quanta, *i.e.*, photons, that are emitted into the outside world.

power conversion efficiency, gauges the overall efficiency of conversion from the input of electrical power to the output of optical power, *i.e.*,

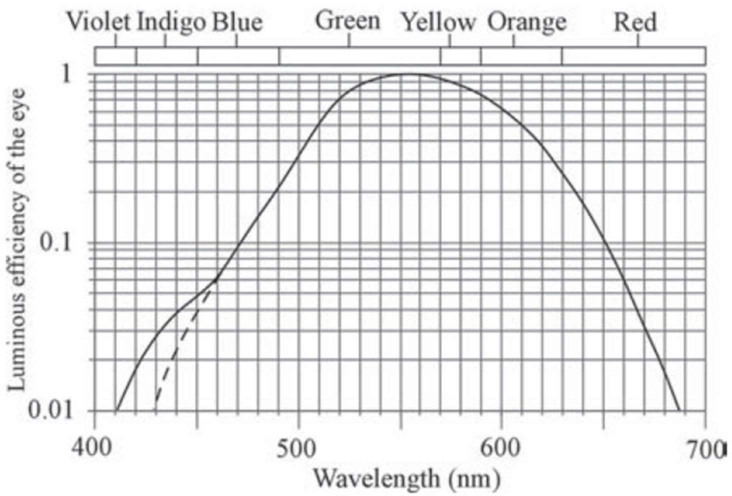
$$\eta_{\mathrm{PCE}} = \frac{\text{Optical output power}}{\text{Electrical input power}} = \frac{P_o}{IV} \approx \eta_{\mathrm{EQE}}\left(\frac{E_g}{eV}\right)$$

4. Characteristic Parameters (2)

luminous flux is a measure of *visual* **brightness**, in lumens (lm), and is defined by

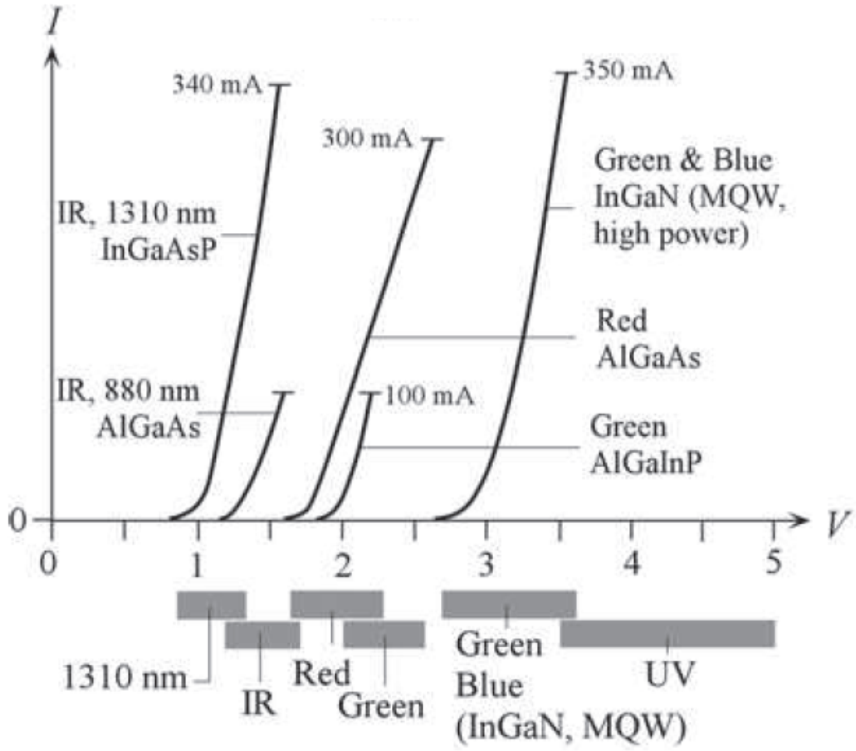
$$\Phi_v = P_o \times (633 \text{ lm W}^{-1}) \times V(\lambda)$$

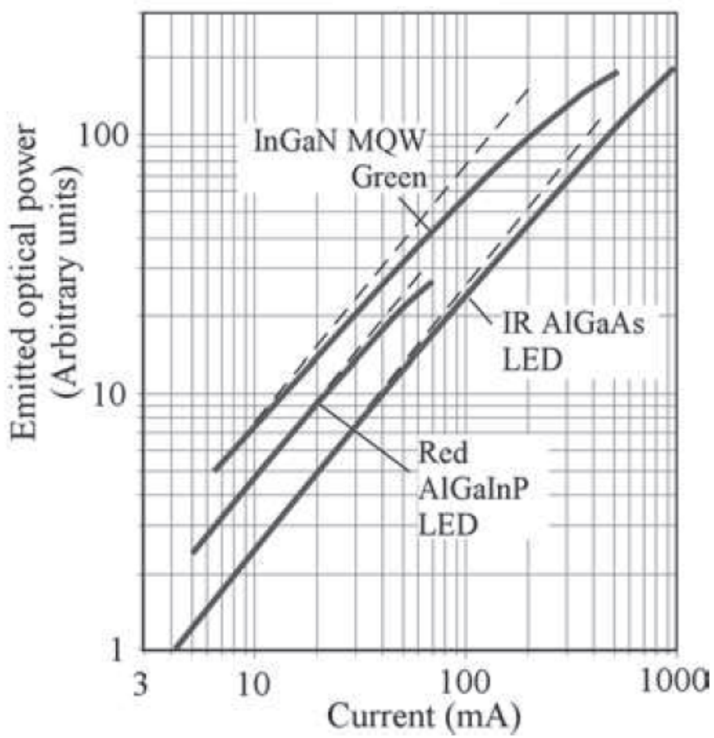
where P_o is the radiant flux or the radiation power emitted (in watts) and $V(\lambda)$ is the **relative luminous efficiency** (or the relative sensitivity) of an average light-adapted (photopic) eye, which depends on the wavelength and hence λ in parenthesis. The function $V(\lambda)$ is also called the **luminosity function** and the **visibility function**.



5. I-V Curve

The I–V characteristics do not always follow an exact exponential behavior that is often seen for a simple forward-biased p-n junction. it can be seen that there is an apparent turn-on voltage beyond which the current increases very sharply with voltage. Most LED manufacturers, however, quote the forward voltage V_F when the LED is operating fully. For comparison, the expected linear relationship, $P_o \propto I$, has been also shown for each device. In general, at high currents, Po vs. I relationship curves down from the expected linear, $P_o \propto I$, behavior.

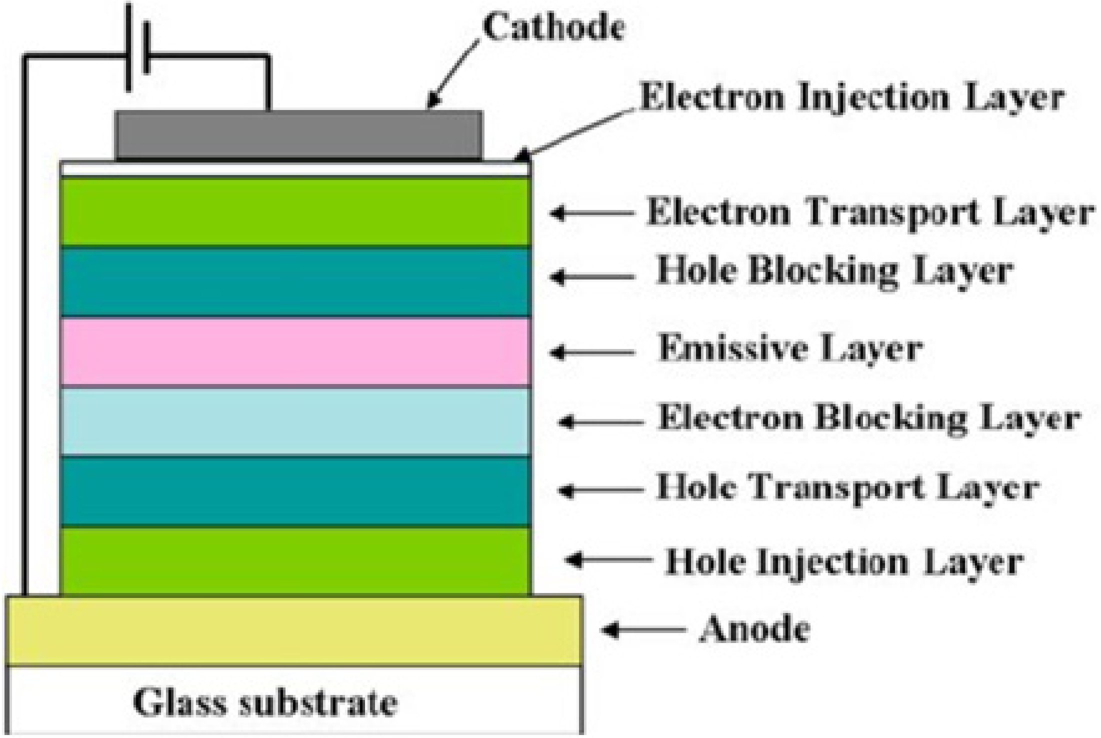




6. Organic LEDs (Optional)

OLED displays are not just thin and efficient - they provide the best image quality ever and they can also be made transparent, flexible, foldable and even rollable and stretchable. Compare to liquid crystal display, it has better contrast, higher brightness, fuller viewing angle, a wider color range, much faster refresh rates, and lower consumption power. But the life time is shorter and production cost is higher.

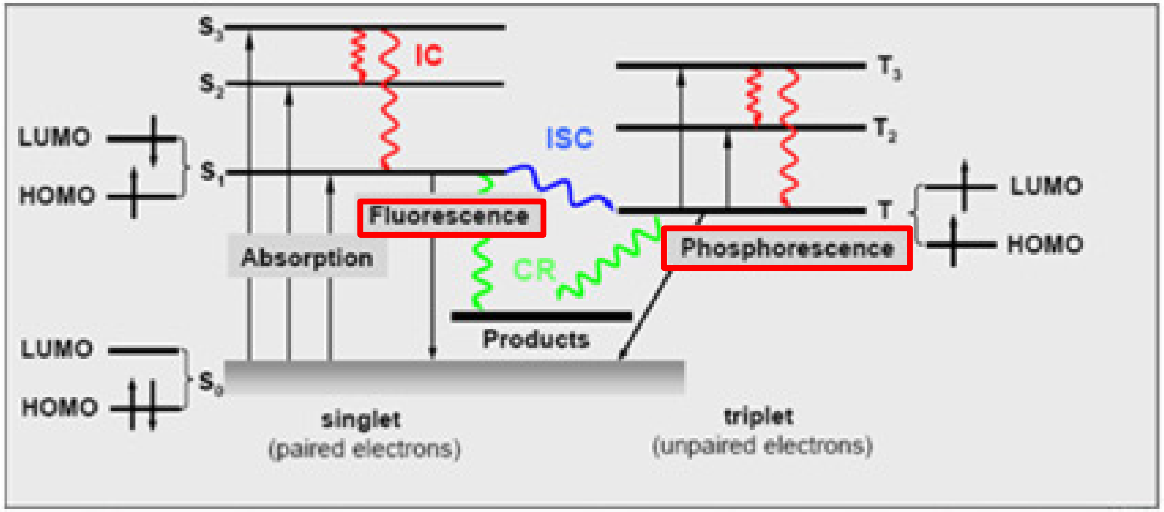
OLED television



6. Organic LEDs (Optional)

White OLED

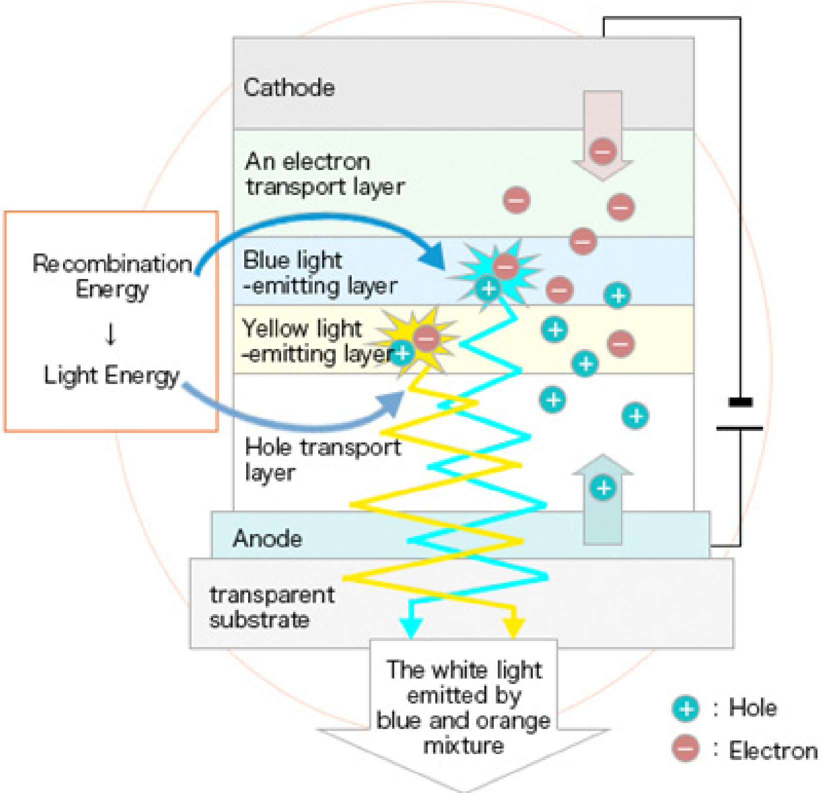
fluorescence and phosphorescence



IC: Internal conversion – radiation – less transition $S_2 \rightarrow S_1$

ISC: Inter-System crossing – radiation – less transition $S \rightarrow T$

CR: Photochemical reaction



S: singlet

T: triplet