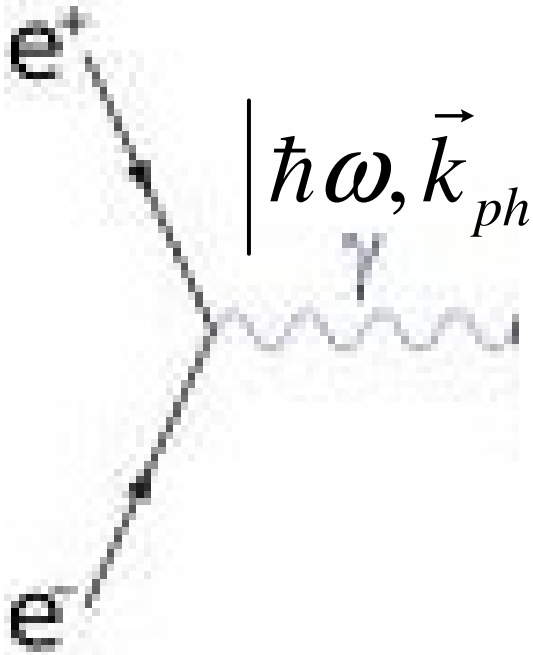
Assorbimento ed emissione

$$\left| E_h, \vec{k}_h \right\rangle$$

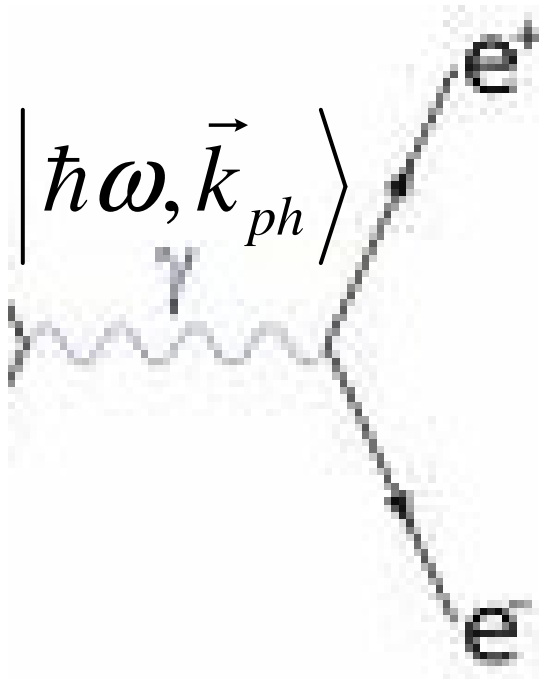
$$\left| \hbar\omega, \vec{k}_{ph} \right\rangle$$



$$\left| E_e, \vec{k}_e \right\rangle$$

$$\left| E_h, \vec{k}_h \right\rangle$$

$$\left| \hbar\omega, \vec{k}_{ph} \right\rangle$$

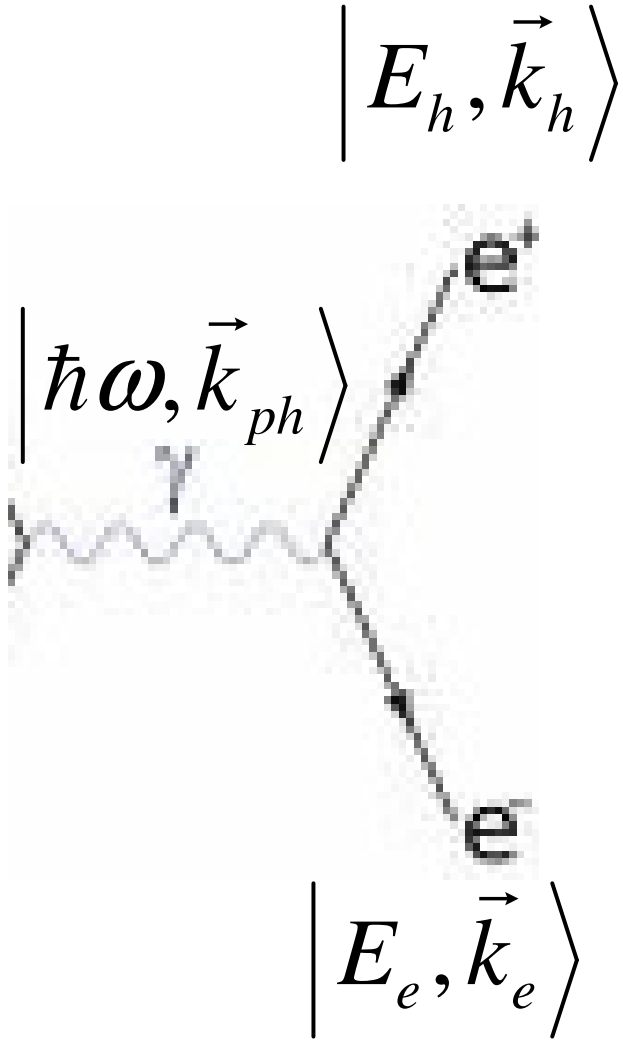


$$\left| E_e, \vec{k}_e \right\rangle$$

Assorbimento ed emissione

$$E_e + E_h = \hbar\omega$$

$$\vec{k}_e + \vec{k}_h = \vec{k}_{ph}$$



Assorbimento ed emissione

hole language

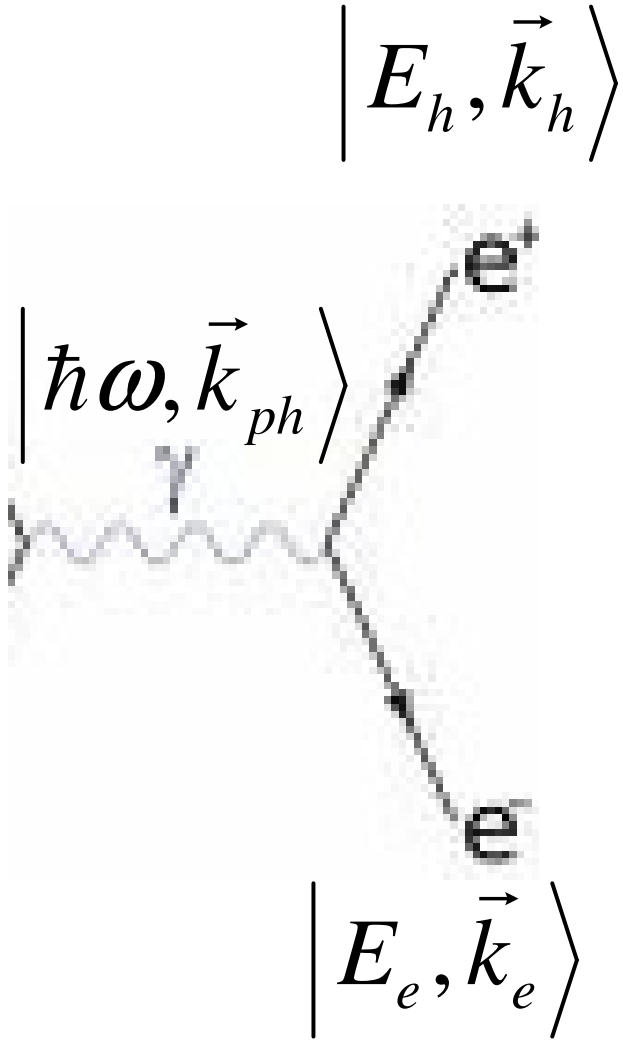
$$E_e + E_h = \hbar\omega$$

$$\vec{k}_e + \vec{k}_h = \vec{k}_{ph}$$

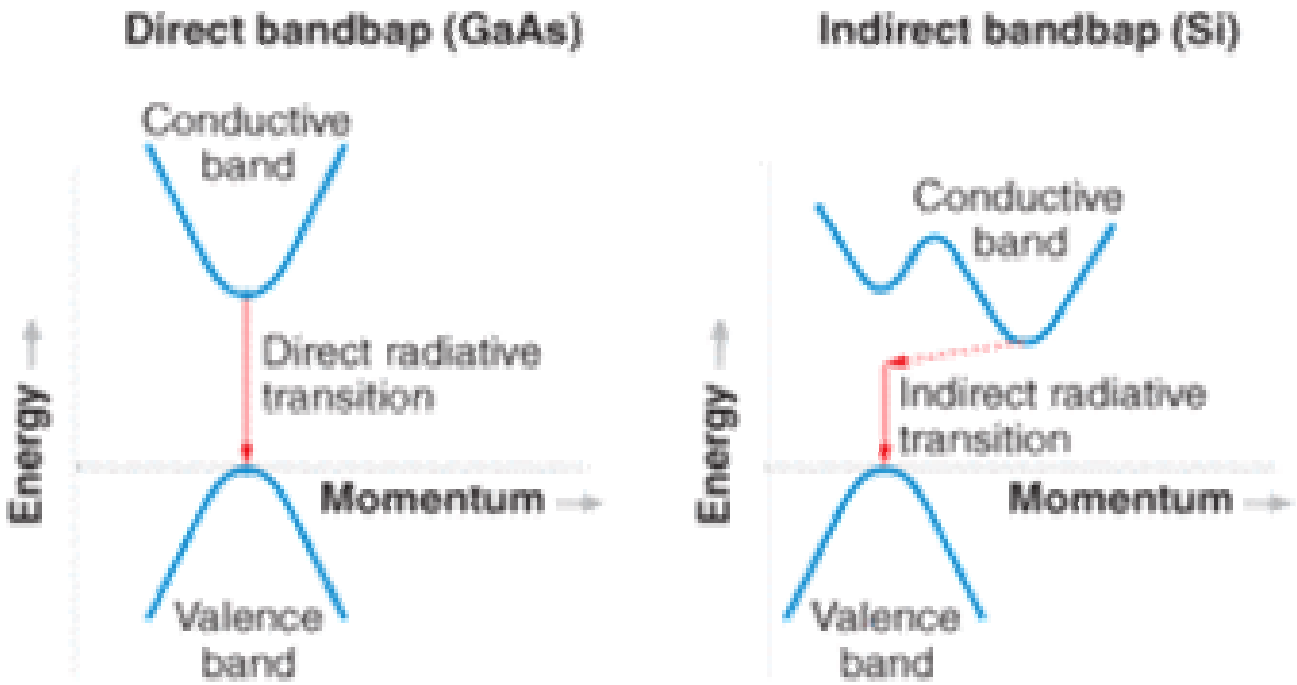
electron language

$$E_c - E_v = \hbar\omega$$

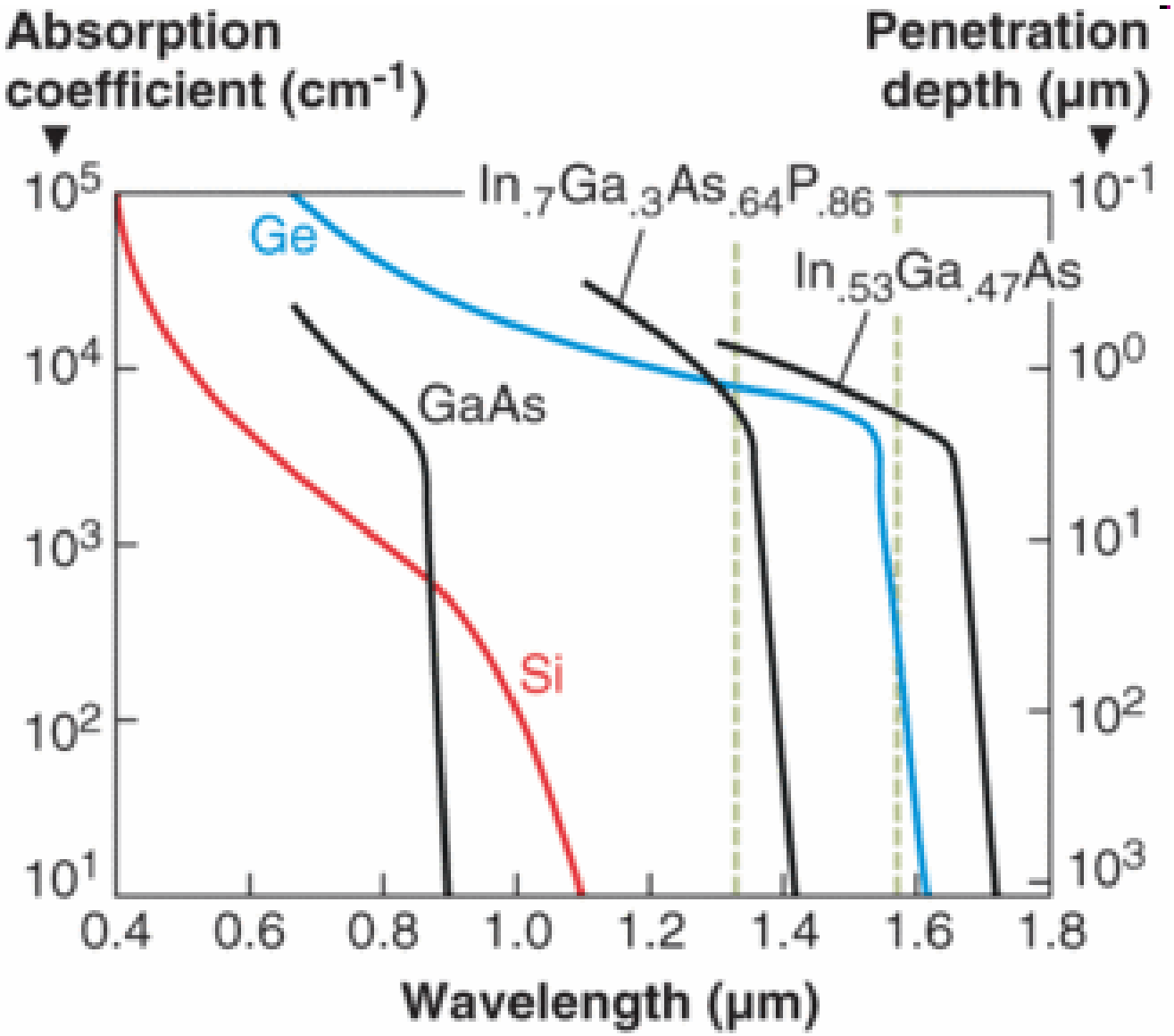
$$\vec{k}_c - \vec{k}_v = \vec{k}_{ph}$$



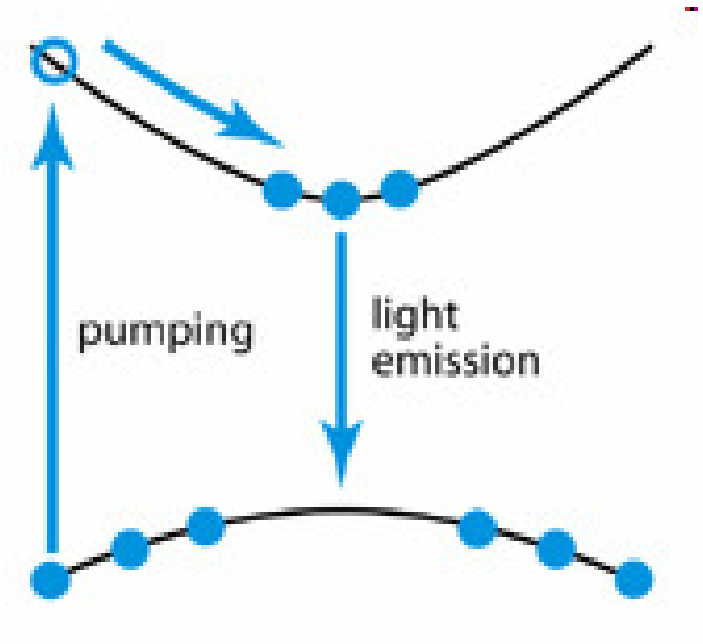
Semiconduttori diretti e indiretti

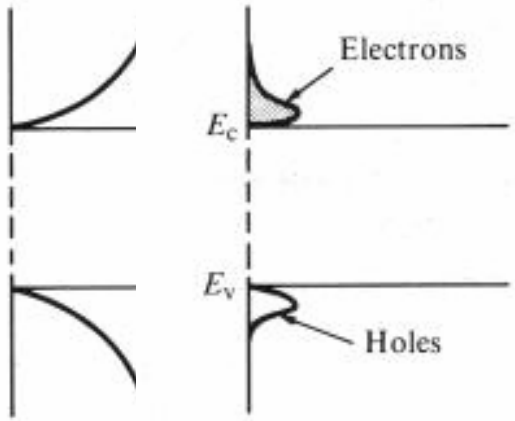


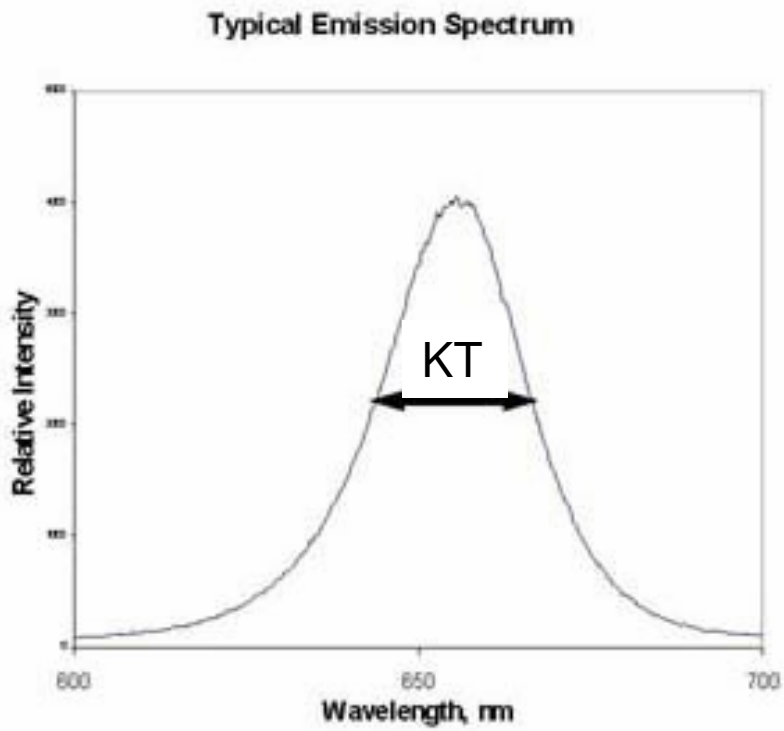
Assorbimento



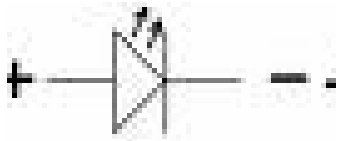
Emissione


pumping
light
emission


Electrons
E_c
E_v
Holes


Typical Emission Spectrum
Relative Intensity
KT
600
650
700
Wavelength, nm

Pompaggio elettrico LED



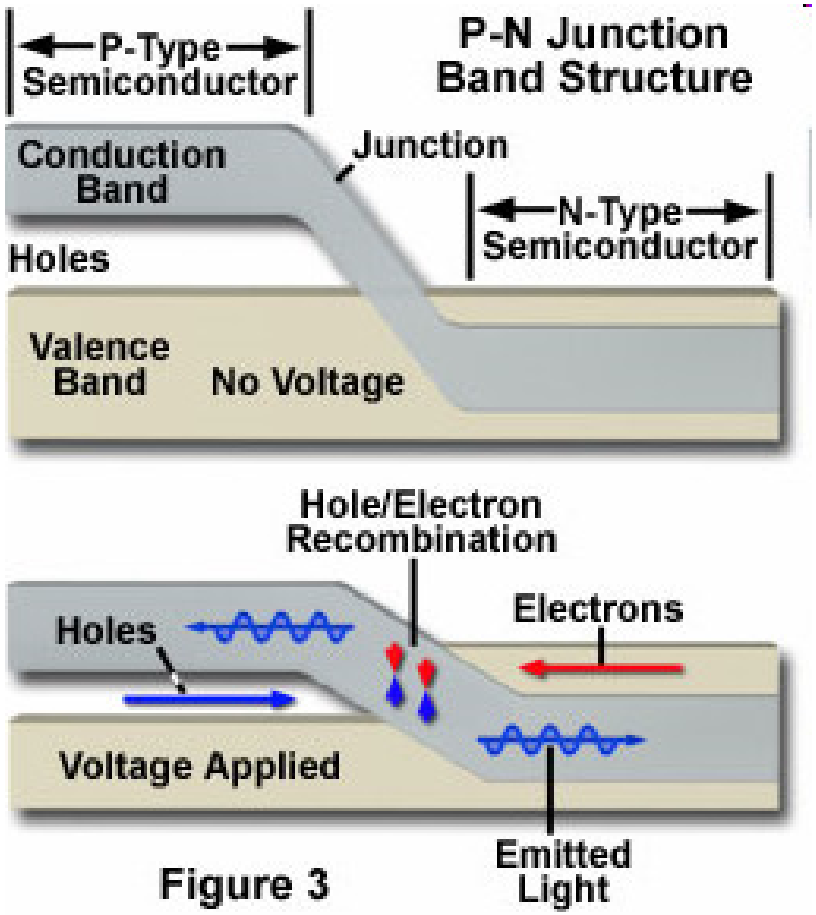
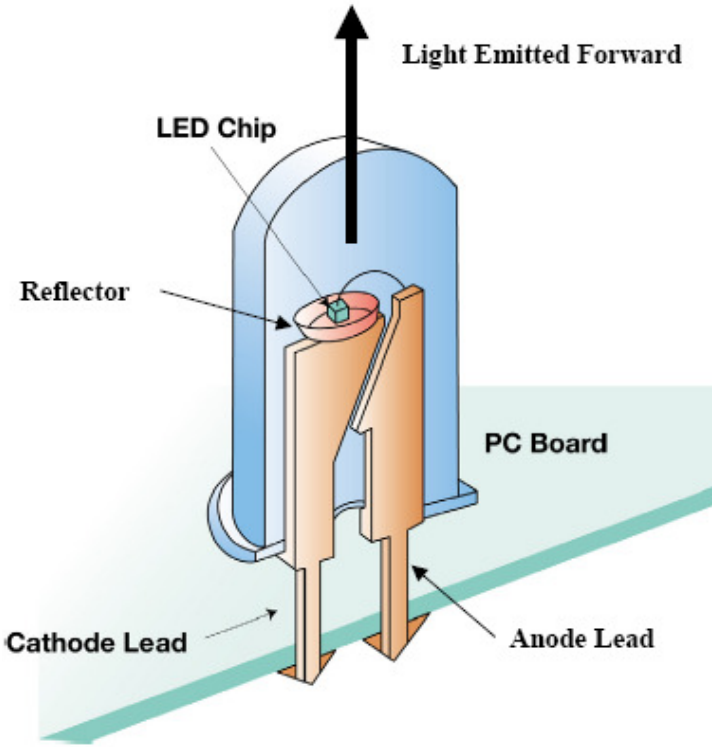
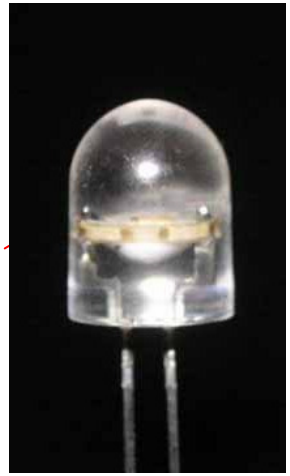
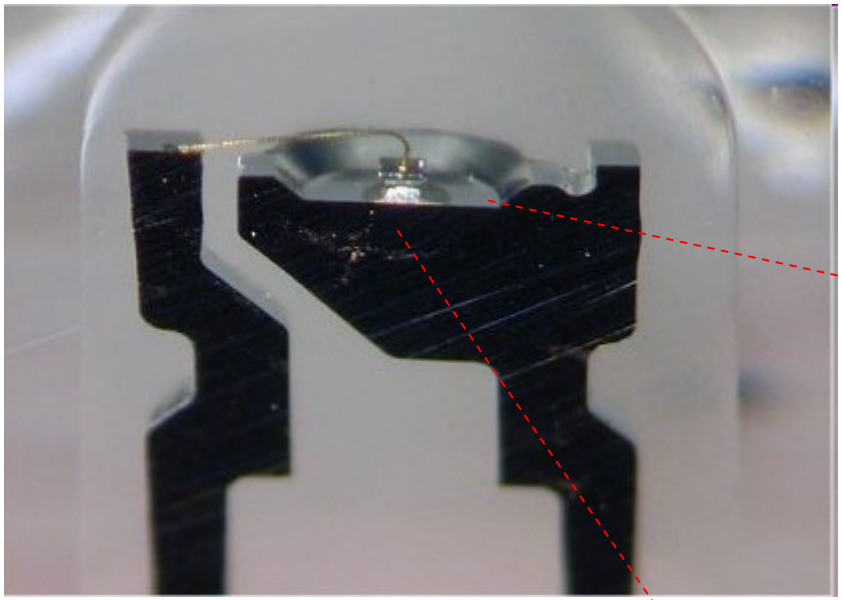


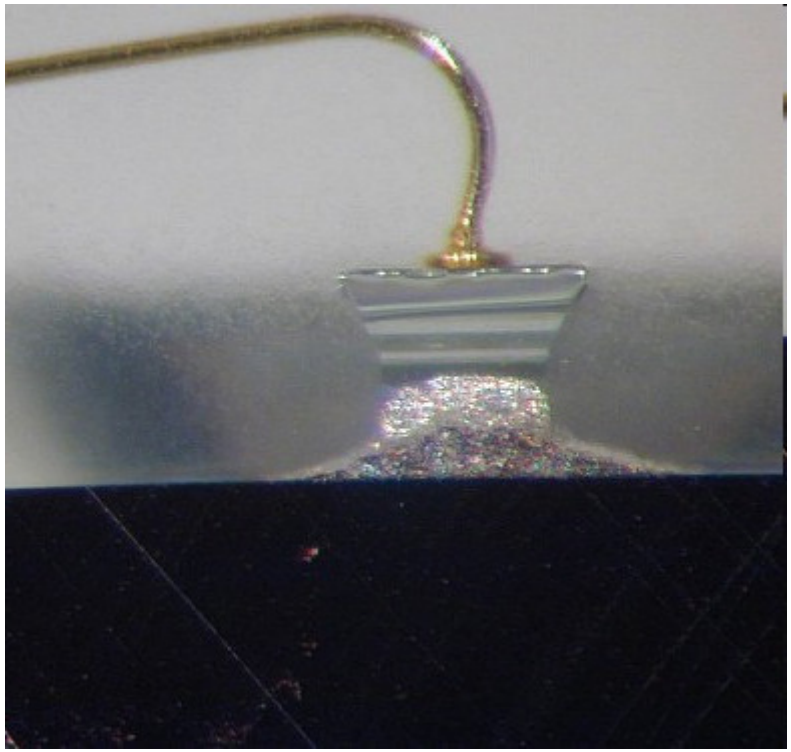
Figure 3



LED







LED for visible

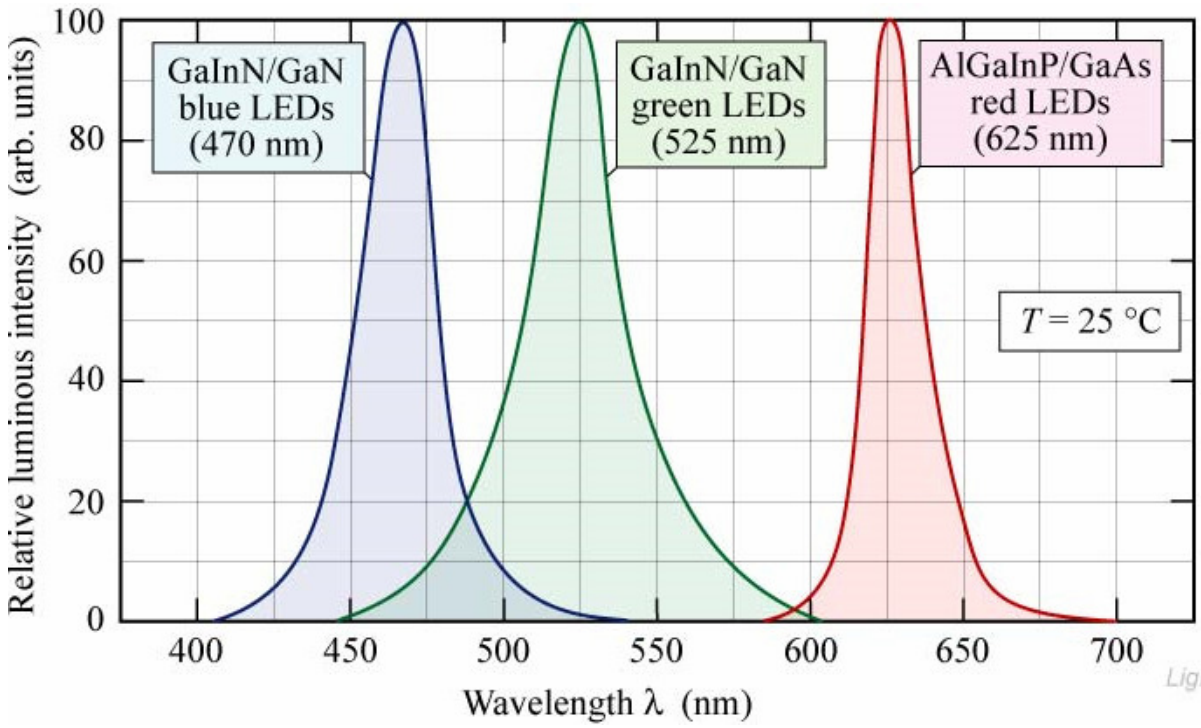


Fig. 12.16. Typical emission spectrum of GaInN/GaN blue, GaInN/GaN green, and AlGaInP/GaAs red LEDs at room temperature (after Toyoda Gosei Corp., 2000).

LED for visible: GaN family

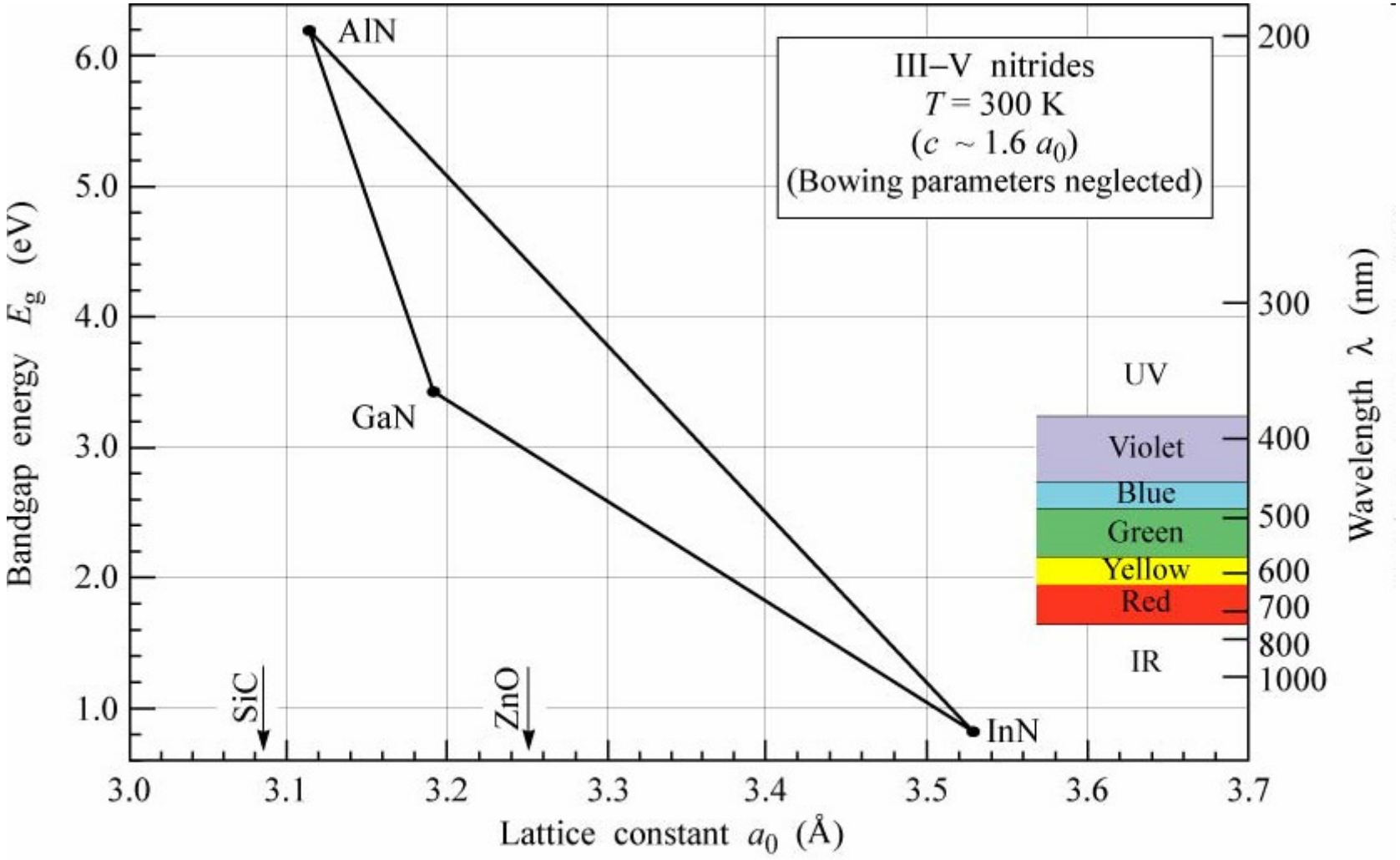
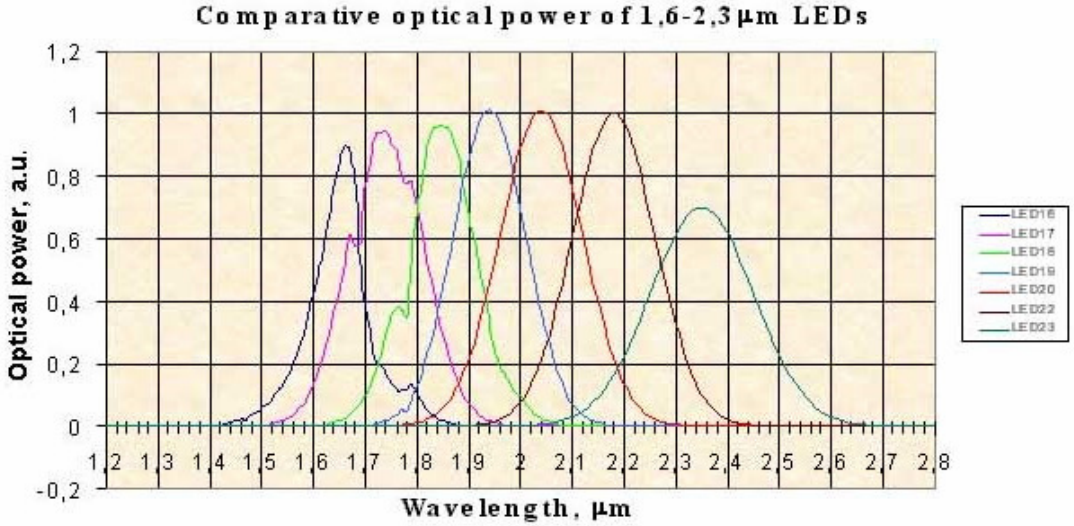
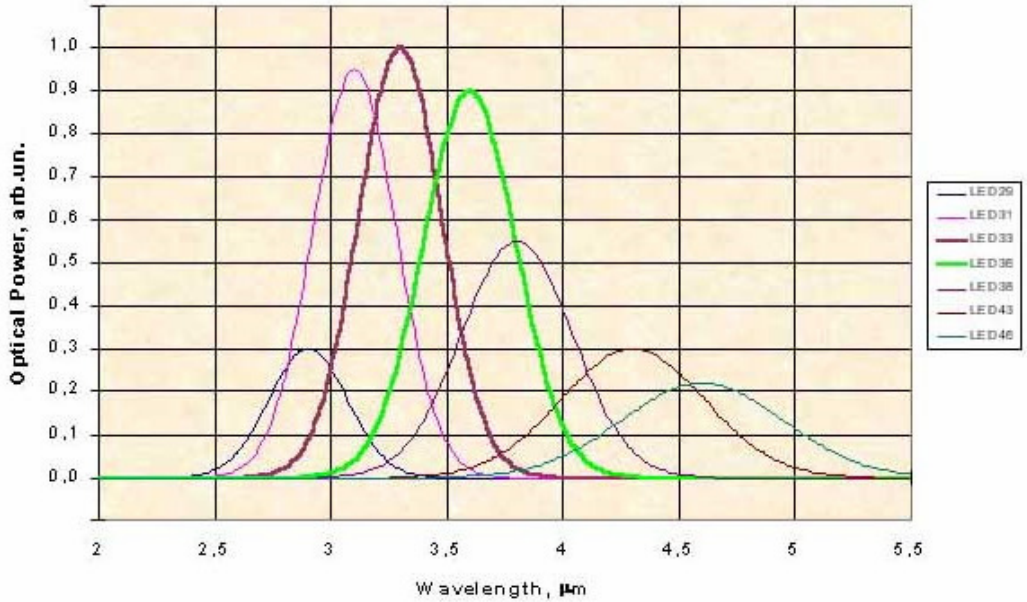


Fig. 12.12. Bandgap energy versus lattice constant of III–V nitride semiconductors at room temperature.

LED for IR



GaSb



InAs

Definizioni fotometriche

FLUSSO LUMINOSO prodotto tra la potenza emessa da una sorgente luminosa puntiforme e il coefficiente di visibilità dell'occhio umano. Il coefficiente di visibilità è ottenuto statisticamente come il valore atteso o medio tra un certo numero di soggetti testati.

LUMEN: Equivale al flusso luminoso rilevabile in un angolo solido di 1 steradiante emesso da una sorgente isotropa con intensità luminosa di 1 candela. Ne discende che la stessa sorgente isotropa con intensità luminosa di 1 candela emette un flusso luminoso totale di 4π lumen.

CANDELA: Una candela è pari all'intensità luminosa, in una data direzione, di una sorgente emettente una radiazione monocromatica di frequenza pari a $540 \ 10^{12}$ Hz (λ=555 nm) e di intensità in quella direzione di 1/683 di watt per steradiante.

Flusso luminoso

$$\eta_{lum} = \frac{\int_0^\infty \bar{y}(\lambda) I(\lambda) d\lambda}{\int_0^\infty I(\lambda) d\lambda}$$

(λ=450 nm) 40 lumen/watt

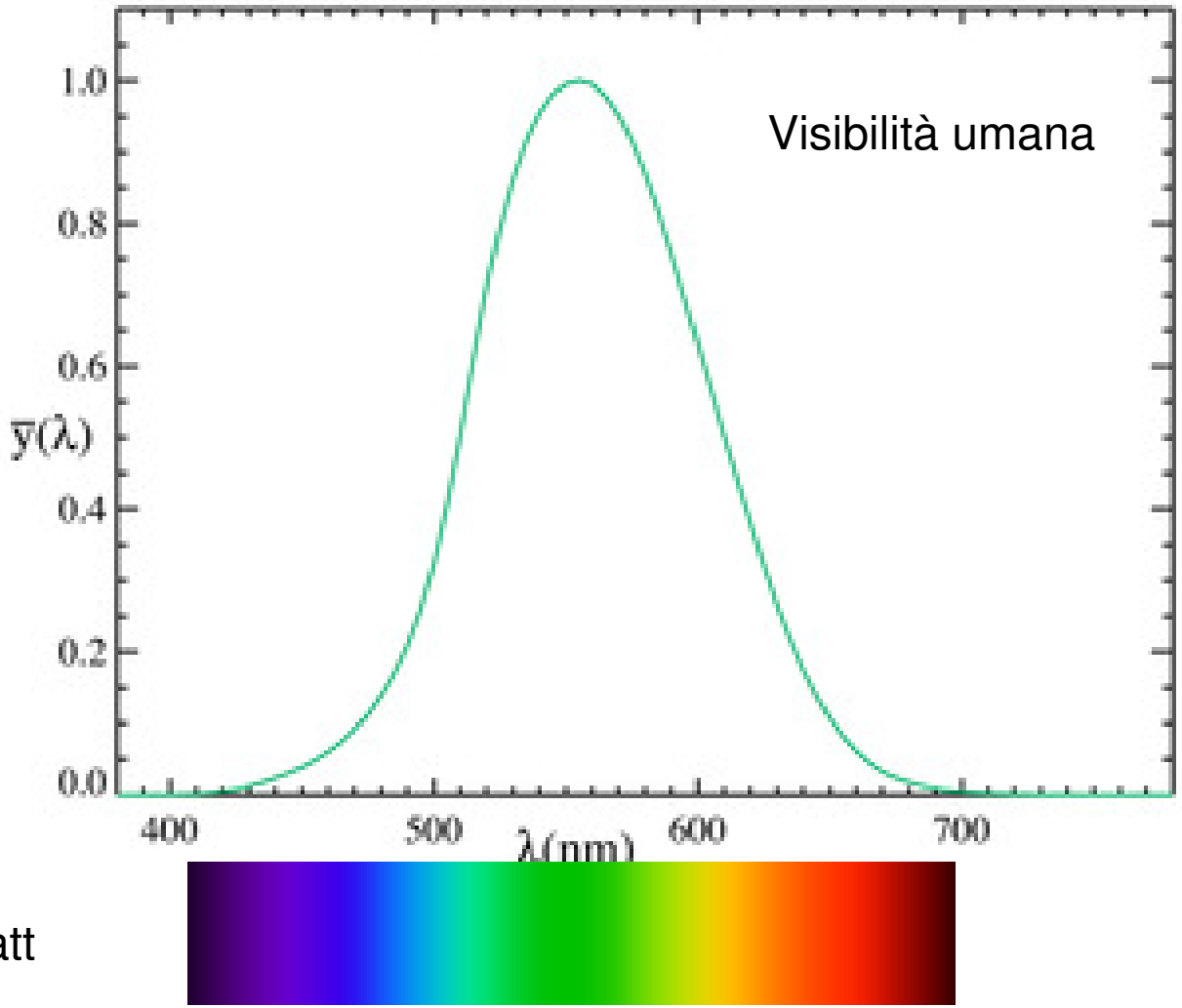
(λ=500 nm) 200 lumen/watt

(λ=555 nm) 683 lumen/watt

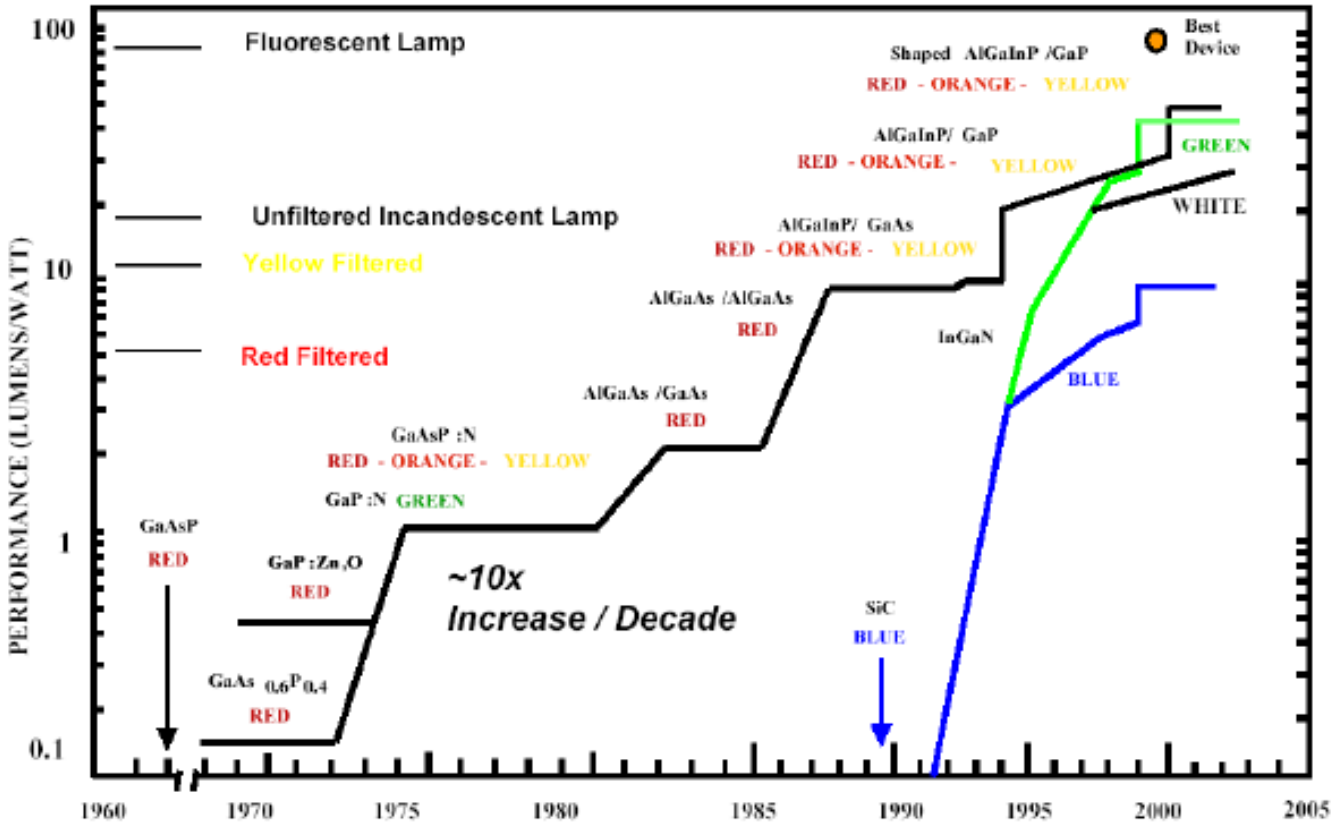
(λ=600 nm) 400 lumen/watt

(λ=650 nm) 70 lumen/watt

(Luce bianca) 250 lumen/watt



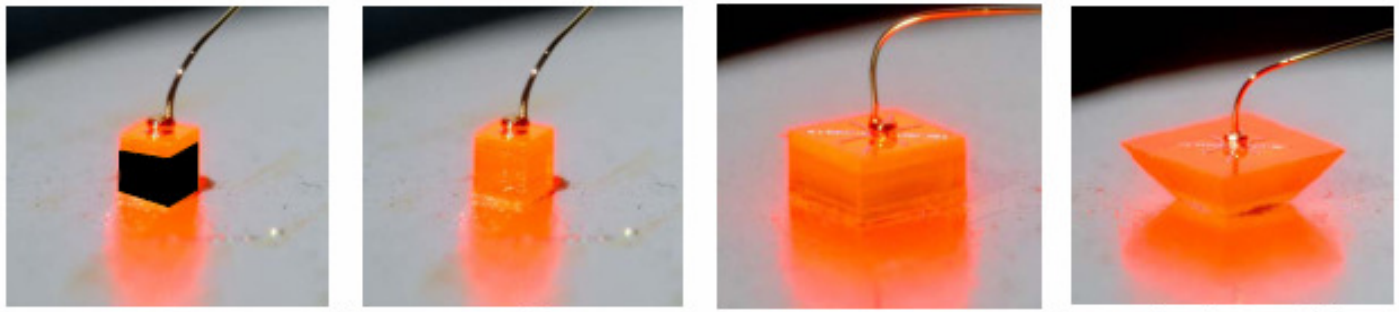
LED for visible: History



Cree Achieves 161 Lumens per Watt from a High-Power LED
High-performance R&D chip and package combine for record-setting efficacy

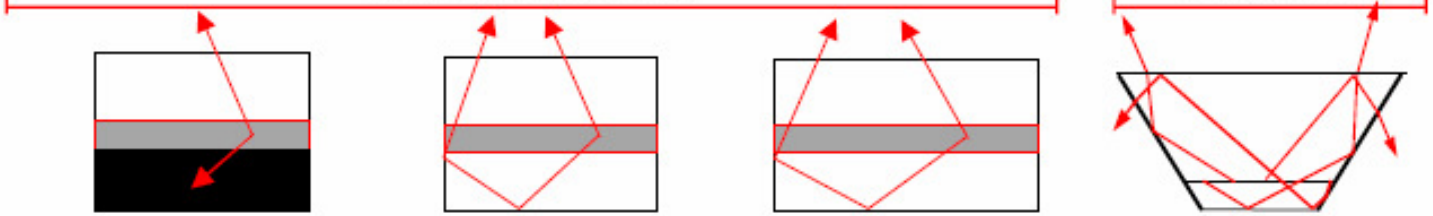
Historical Development - Better Light Extraction

Absorbing Substrate (1991)	Transparent Substrate (1994)	Batwing (1998)	Lambertian (mid 2001)



Increase surface area

Re-shape Chip



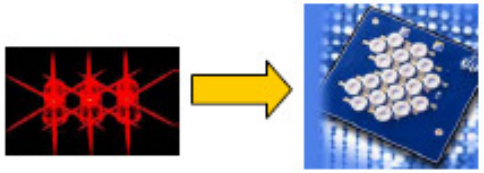
	~ 3x flux improvement	~ 15x flux improvement	~ 30x flux improvement

LUMILEDS

Evolution – Traffic Signal

Case in Point: …impact on Traffic Signals

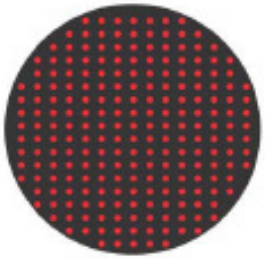
5mm Thru-Hole to Surface Mounted



1993
5mm LED

700 LEDs

1996
5mm LEDs



200 LEDs

1999
High Flux
Surface Mounted
LEDs

Lumileds Solution

18 LEDs
Red/Amber

2003: 12 RED LEDs

Courtesy io Lighting

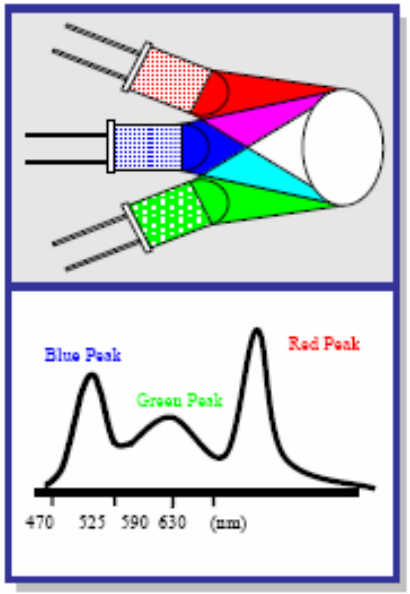
Applicazioni LED colorati

White Light from LEDs

Three methods of Generating LED White Light

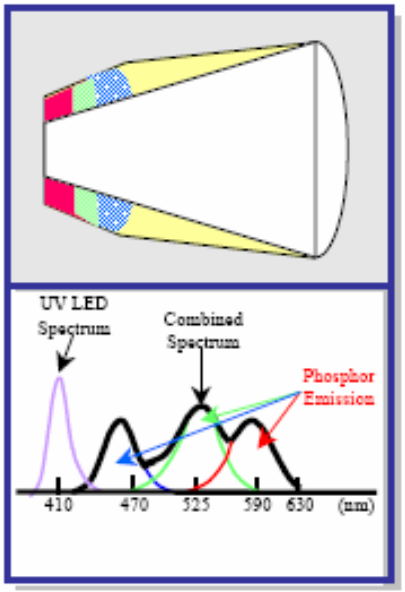
Each method has potential strengths!

Red + Green + Blue LEDs



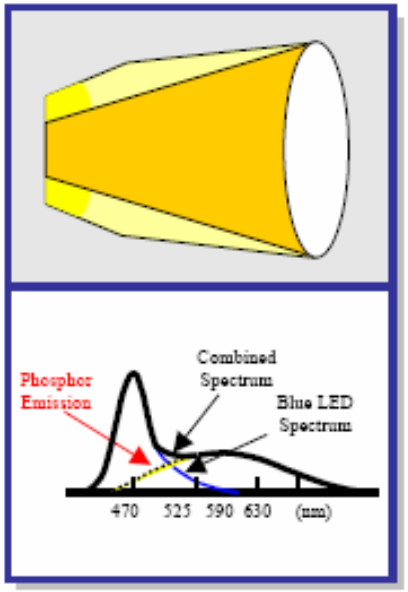
RGB LEDs

UV LED + RGB Phosphor



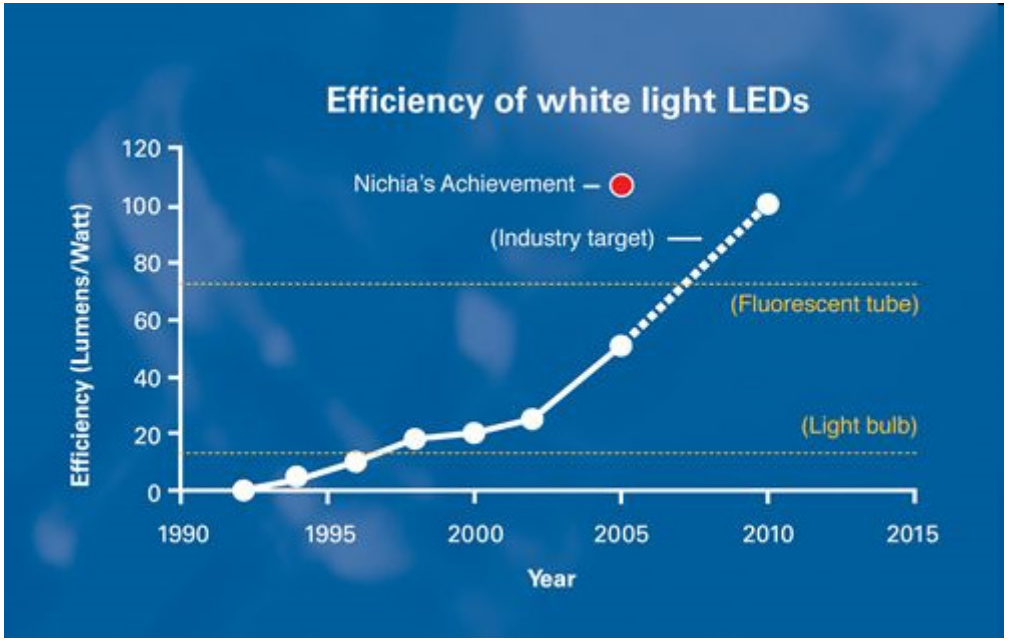
UV LED + RGB phosphor

Binary Complimentary



Blue LED + Yellow phosphor

LUMILEDS

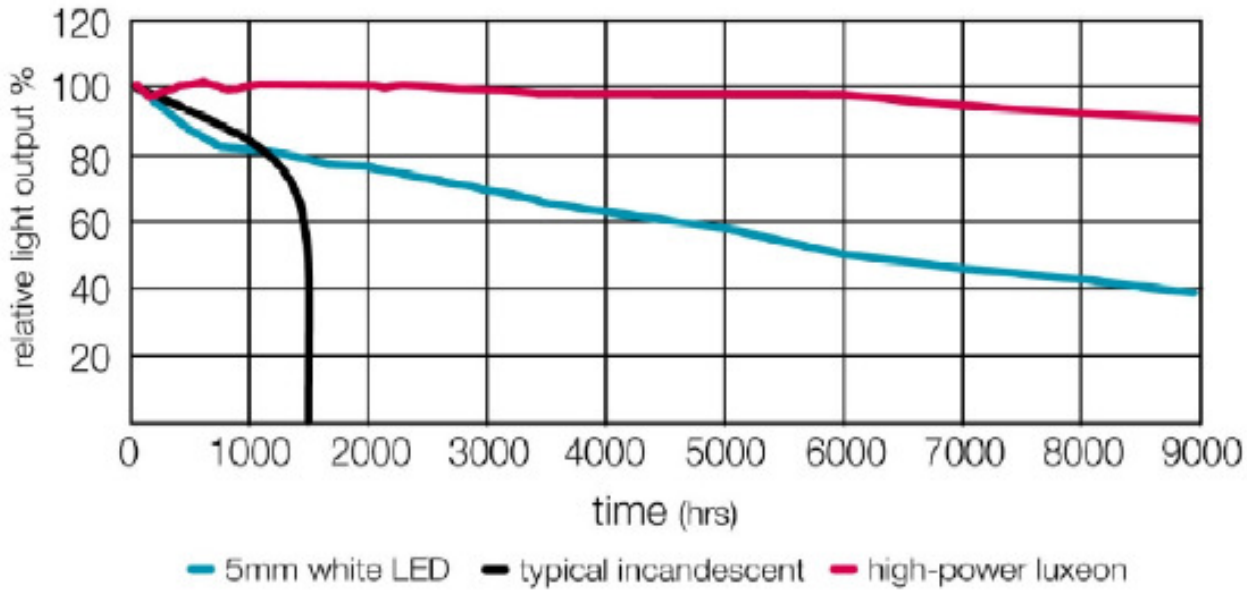

Efficiency of white light LEDs
Nichia's Achievement
(Industry target)
(Fluorescent tube)
(Light bulb)
Efficiency (Lumens/Watt)
120
100
80
60
40
20
0
1990
1995
2000
2005
2010
2015
Year


Saving


www.ocarled.com

Categoria	Tipo	Efficienza (lm/W)	Efficienza
Combustione	candela	0,3	0,04%
	lampada a gas	2	0,3%
Incandescente	100 W tungsteno, incandescente (	13,8	2,0%
	100 W tungsteno, alogena	16,7 [	2,4%
	500 W tungsteno, alogena	19,8 [	2,9%
Lampada ad arco	Lampada allo xeno	30–50	4,4–7,3%
	Lampade a mercurio-xeno	50–55	7,3–8,0%
Fluorescente	9–26 W fluorescente compatta	57–72	8–11%
	T8 tubo fluorescente	80–100	12–15%
Lampada a scarica	Lampada a vapori di sodio (alta pressione)	85–150	12–22%
	Lampada a vapori di sodio (bassa pressione)	100–200	15–29%
LED	LED bianco	10–160	1,5–24%
Massimo teorico	Luce bianca	250	36%
Massimo teorico	Luce monocromatica verde	683	100%

Durata


120
100
80
60
40
20
relative light output %
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
time (hrs)
5mm white LED
typical incandescent
high-power luxeon

Illumination in the Future

Fast forward: 25 years

LUMILEDS

ROADMAP

Product performance

		2002	2003	2007	2012	2020
Luminous Efficiency	lm/W	25	30 (20)	75	150	200
Lifetime	khrs	20	50*	20	100	100
Flux	lm	25	150 (24*)	200	1000	1500
Cost (Street Price)	$/klm	$200	$160*	$20	$5	$2
Color Rendering	Ra(8)	75	75 (90)	80	80	80
Markets Penetrated	-	low flux	low flux	incandescent	fluorescent	all
Source: OIDA 2002a			*1 W LEDs			

Cree Achieves 1,000 Lumens from a Single LED
DURHAM, NC, SEPTEMBER 7, 2007

Cree Achieves 161 Lumens per Watt from a High-Power LED
DURHAM, N.C., NOVEMBER 19, 2008

Assorbimento ed emissione spontanea e stimolata

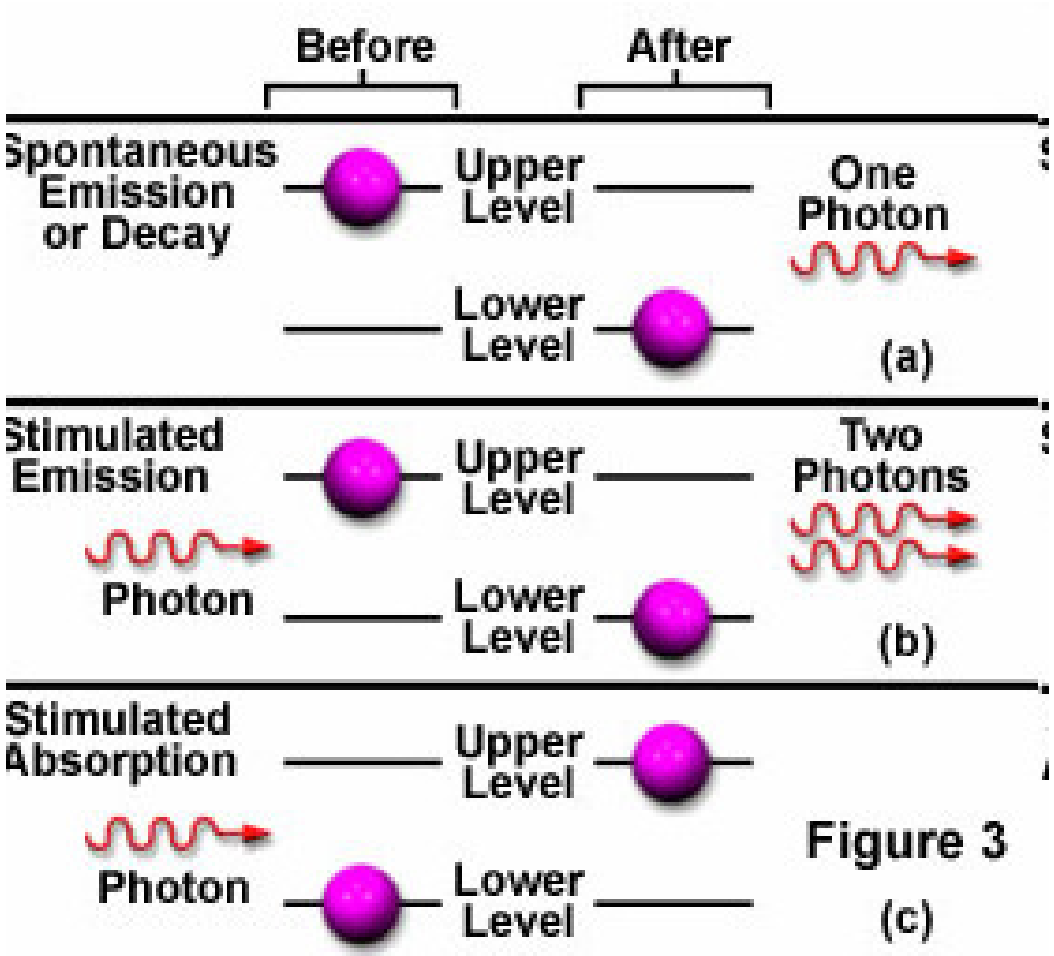
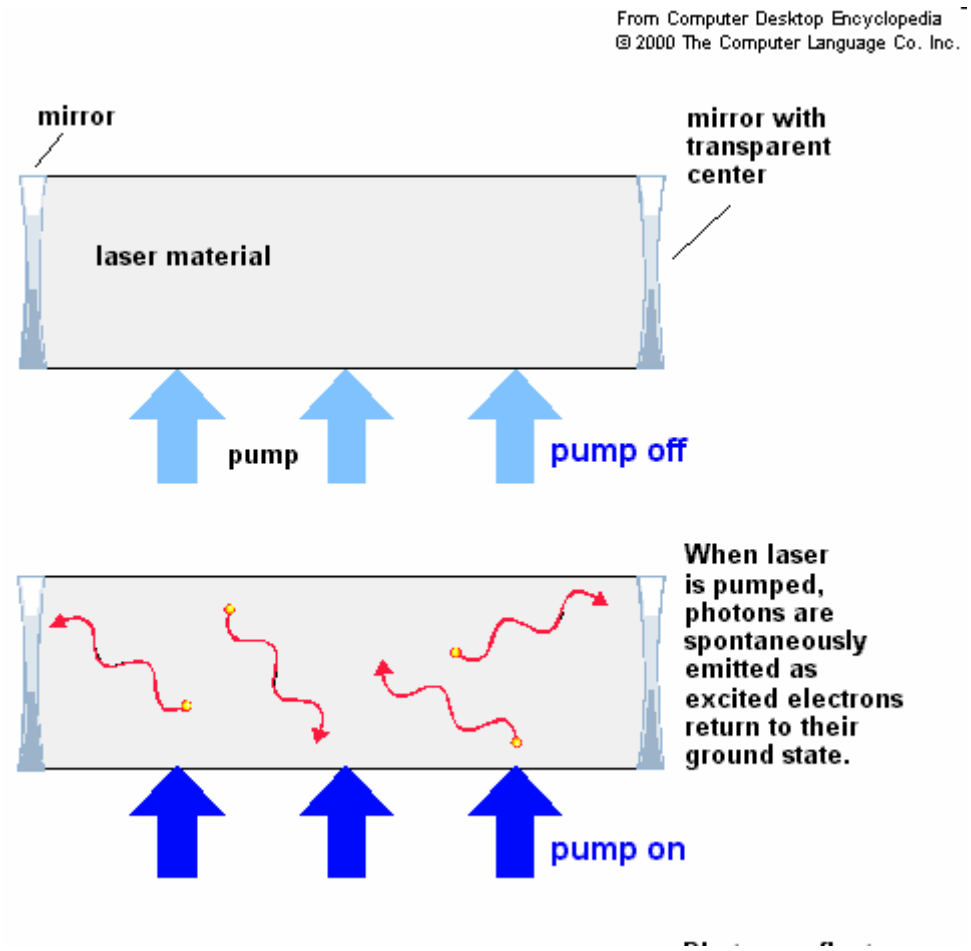
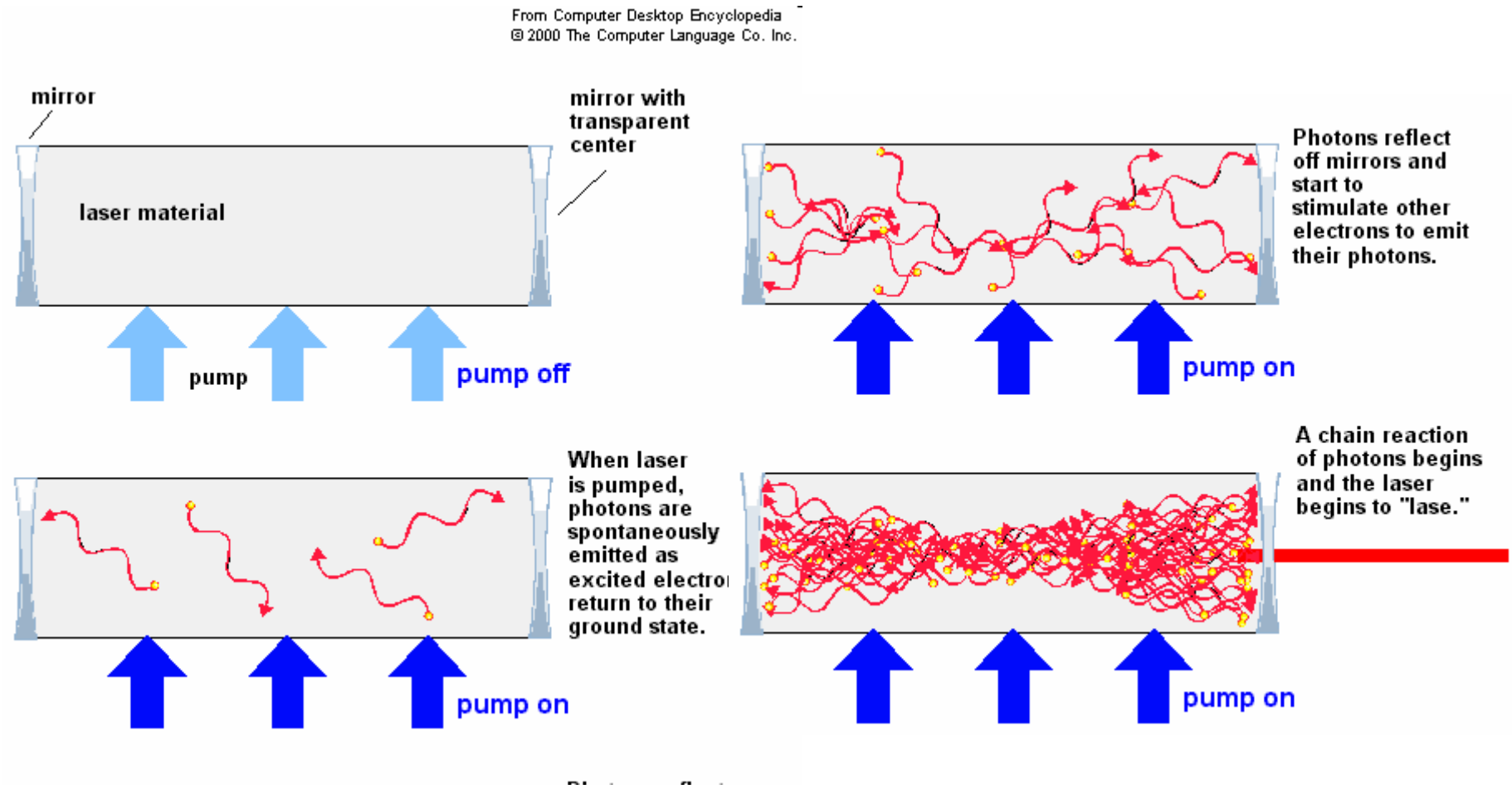


Figure 3

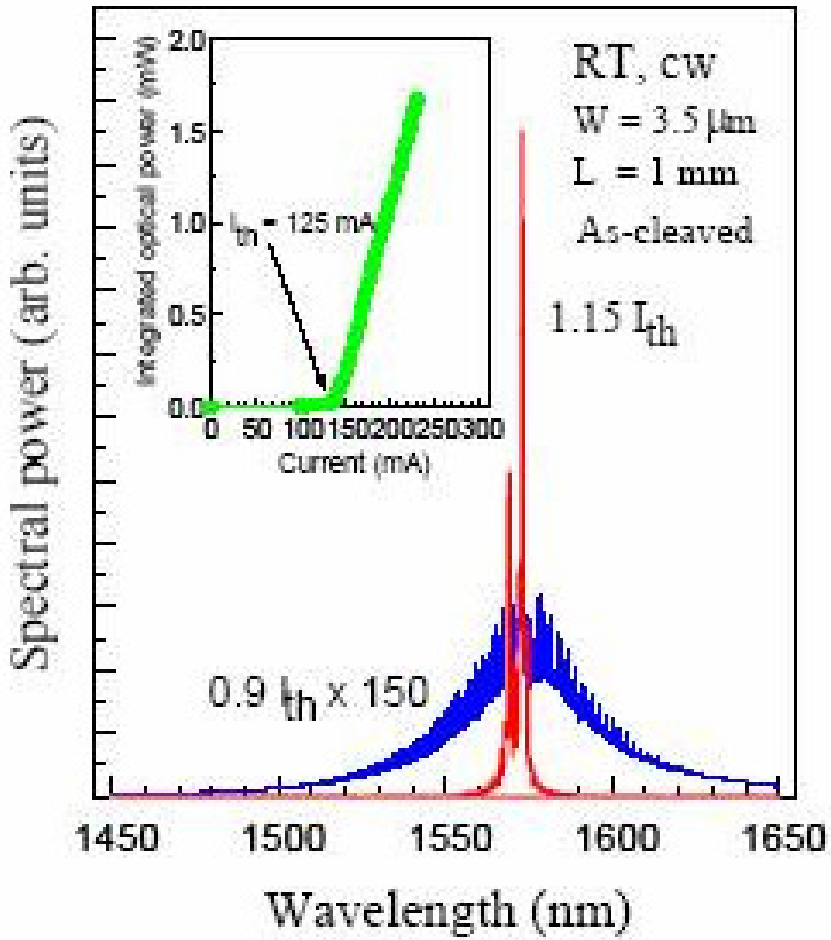
Azione della cavità



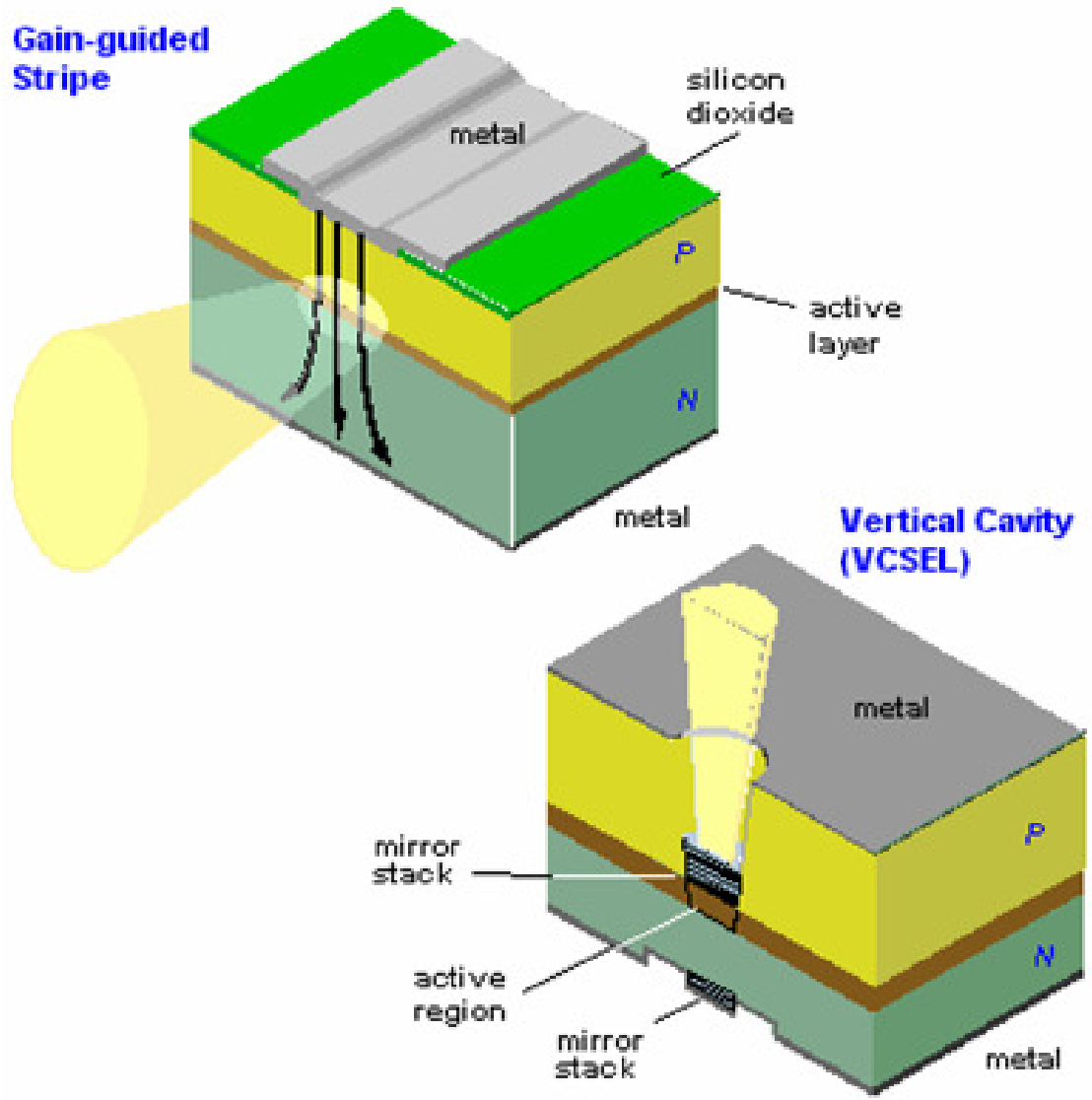
Azione della cavità



Elettroluminescenza e azione laser



Tipi di laser



Inversione di popolazione

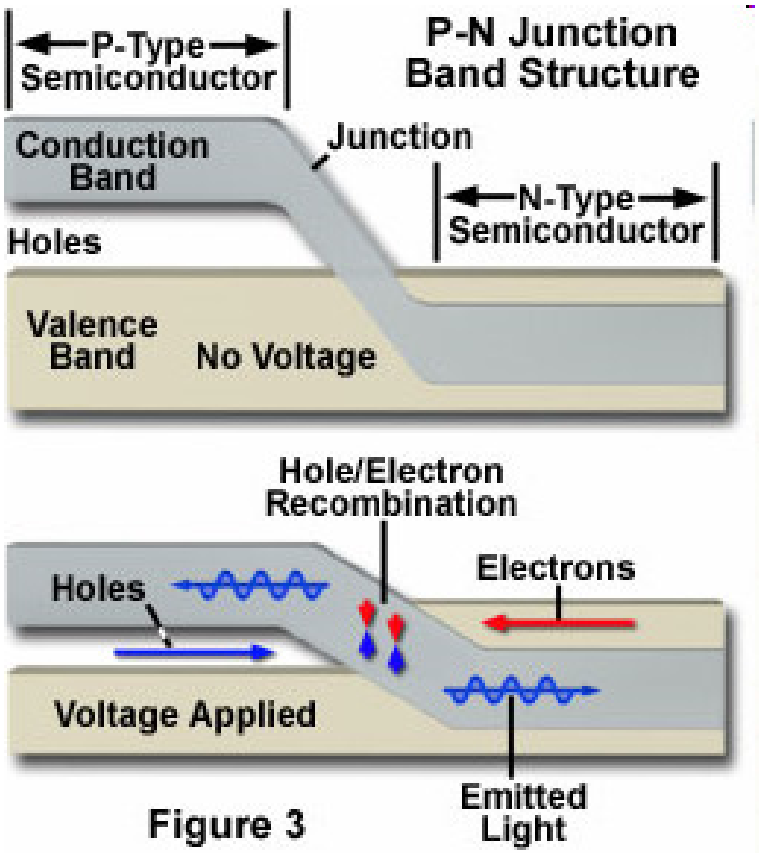


Figure 3

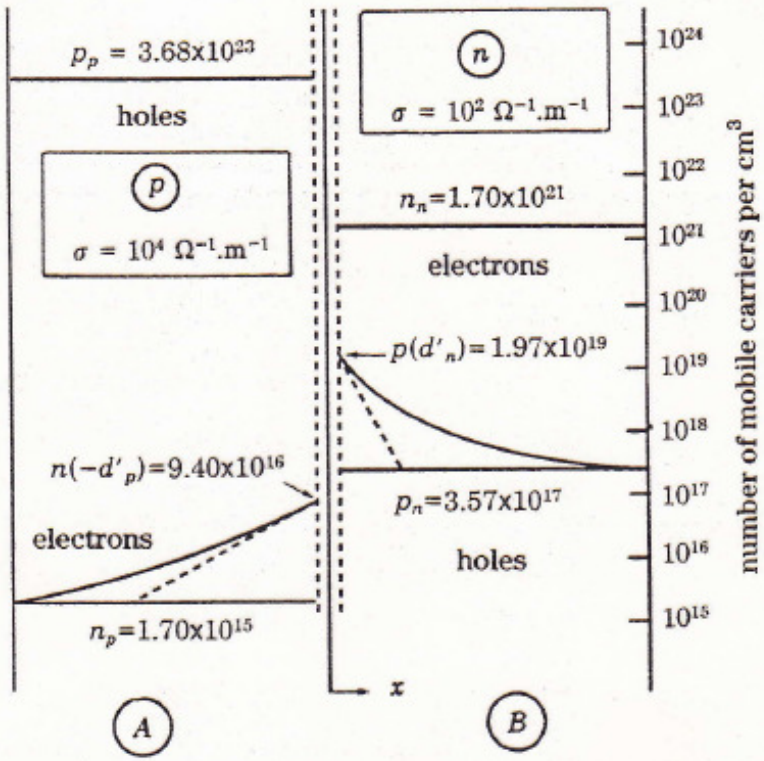


Fig. 8.12. Concentration profile in a forward biased germanium p–n junction (V_e = 0.1 V). (After Middlebrook, "An Introduction to Junction Transistor Theory," J. Wiley, 1957, 1965.)

Quasi Fermi-levels

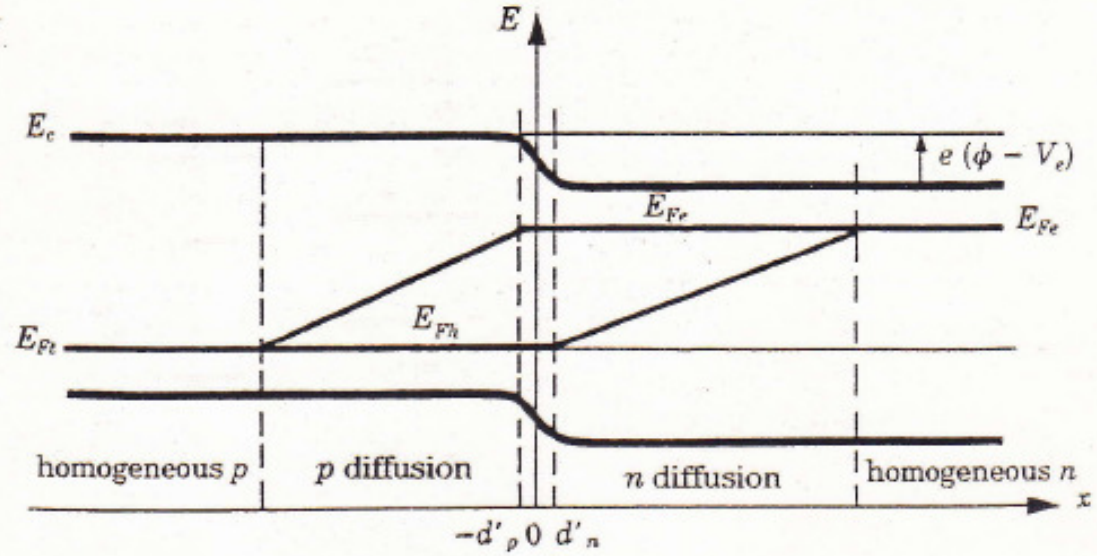


Fig. 8.13. Variation of the quasi-Fermi levels across a forward biased p–n junction. The slopes are not to scale. The width of the p (or n) diffusion zone is several times L_h (or L_e).