

# Optoelectronică, structuri și tehnologii

Curs 8  
2015/2016

# Disciplina 2015/2016

- ▶ 2C/1L Optoelectronică, structuri și tehnologii, **OSTC**
- ▶ **Minim 7 prezente (C+L)**
- ▶ Curs – **sl. Radu Damian**
  - an IV  $\mu$ E
  - Luni 18–20, P5
  - E – 66% din nota
  - probleme + (~~?-1-subiect teorie~~) + (2p prez. curs)
  - toate materialele permise
- ▶ Laborator – **sl. Daniel Matasaru**
  - an IV  $\mu$ E, an IV Tc
    - Luni 16-18 impar
    - Marti 18-20
    - Joi 8-12 impar
  - L – 17% din nota
  - T – 17% din nota

# Capitolul 11

- ▶ Behzad Razavi  
Design of Integrated Circuits for Optical Communications
- ▶ carte1.pdf (2,3)
- ▶ 29 pg.

+1 / 2 probleme

# Lista subiecte

- ▶ Amplificatoare transimpedanță
  - 4.1
  - 4.1.1
  - 4.2
  - 4.2.1
  - 4.3
  - 4.3.1
- ▶ Circuite pentru controlul emițătoarelor optice
  - 10.3
  - 10.3.1
  - 10.4
  - 10.4.1

**+1 / 2 probleme**

# Fotografii +0.5p

Start Didactic Master Colectiv Cercetare **Studenti** Admin

Note Lista Studenti Fotografii Statistici

Grupa 5403

Nr.	Student	Prezent	Nr.	Student	Prezent	Nr.	Student	Prezent
1	ANGHELUS IONUT-MARIUS	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	2	ANTIGHIN FLORIN-RAZVAN	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	3	ANTONICA BIANCA	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:
4	APOSTOL PAVEL-MANUEL	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	5	BALASCA BULIAN-PETRU	<input checked="" type="checkbox"/> Puncte: 0 Nota: 0 Obs:	6	BOSTAN ANDREI-PETRICIA	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:
7	BOTESZAT EMANUEL	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	8	BUTUNOI GEORGE-MADALIN	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	9	CHILEA SALUCA-MARIA	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:
10	CHERITOIU ECATERINA	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	11	COJOC MARIUS	<input checked="" type="checkbox"/> Puncte: 0 Nota: 0 Obs:	12	COJOCARIU AURA-FLORINA	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:

Nr.	Student	Prezent
2	ANTIGHIN FLORIN-RAZVAN	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:

# Reprezentare logaritmică!!!

$$\text{dB} = 10 \cdot \log_{10} (P_2 / P_1)$$

$$\text{dBm} = 10 \cdot \log_{10} (P / 1 \text{ mW})$$

$$0 \text{ dB} = 1$$

$$0 \text{ dBm} = 1 \text{ mW}$$

$$+ 0.1 \text{ dB} = 1.023 (+2.3\%)$$

$$3 \text{ dBm} = 2 \text{ mW}$$

$$+ 3 \text{ dB} = 2$$

$$5 \text{ dBm} = 3 \text{ mW}$$

$$+ 5 \text{ dB} = 3$$

$$10 \text{ dBm} = 10 \text{ mW}$$

$$+ 10 \text{ dB} = 10$$

$$20 \text{ dBm} = 100 \text{ mW}$$

$$-3 \text{ dB} = 0.5$$

$$-3 \text{ dBm} = 0.5 \text{ mW}$$

$$-10 \text{ dB} = 0.1$$

$$-10 \text{ dBm} = 100 \mu\text{W}$$

$$-20 \text{ dB} = 0.01$$

$$-30 \text{ dBm} = 1 \mu\text{W}$$

$$-30 \text{ dB} = 0.001$$

$$-60 \text{ dBm} = 1 \text{ nW}$$

$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

$$[\text{dBm/Hz}] + [\text{dB}] = [\text{dBm/Hz}]$$

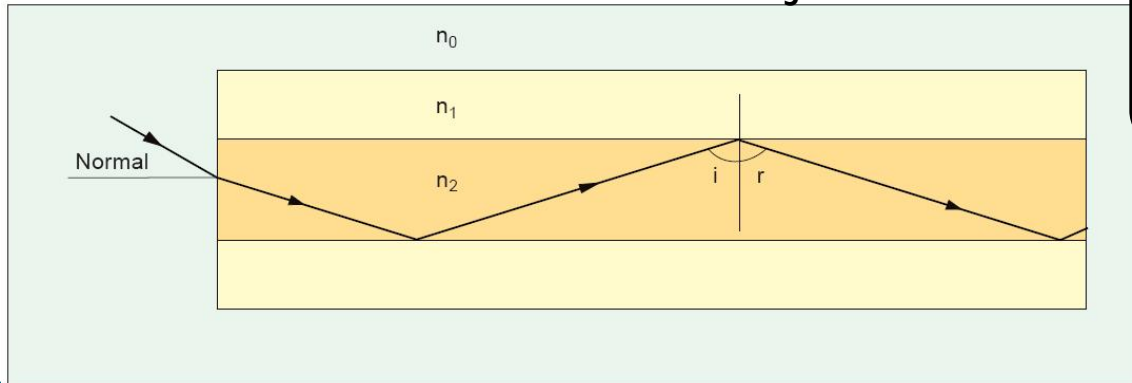
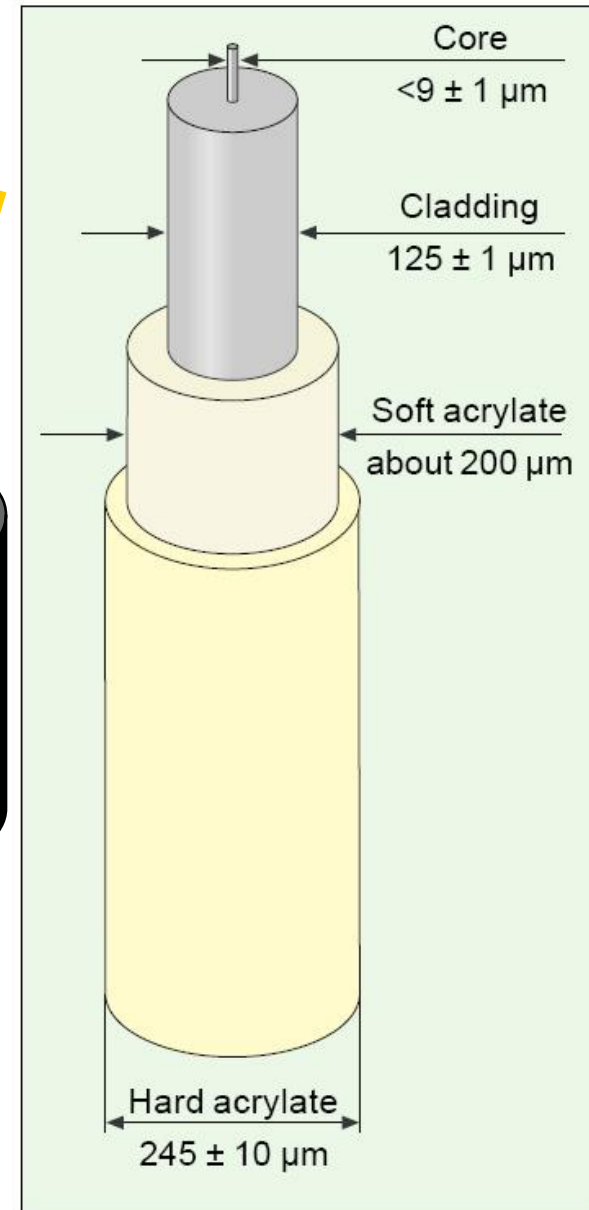
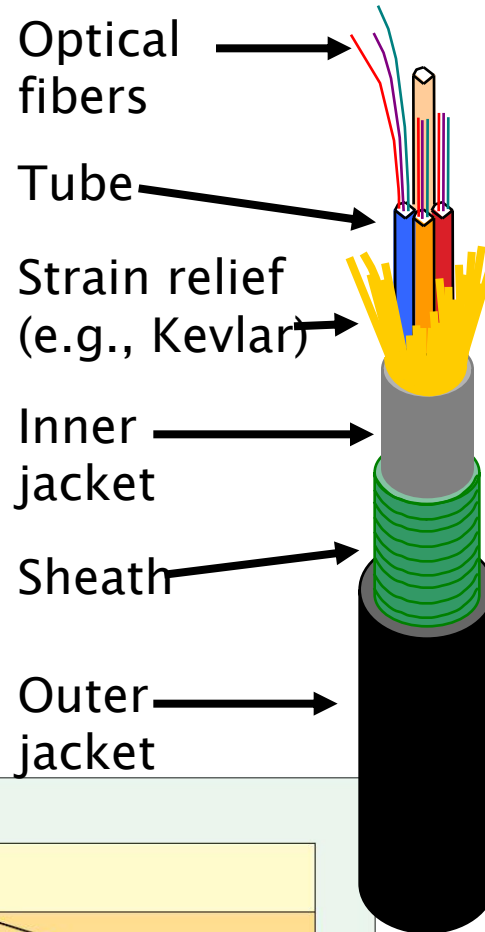
$$[\text{x}] + [\text{dB}] = [\text{x}]$$

# Recapitulare

Curs 7

# Fibra optica

- ▶ un ghid de unda dielectric
  - miez
  - teaca



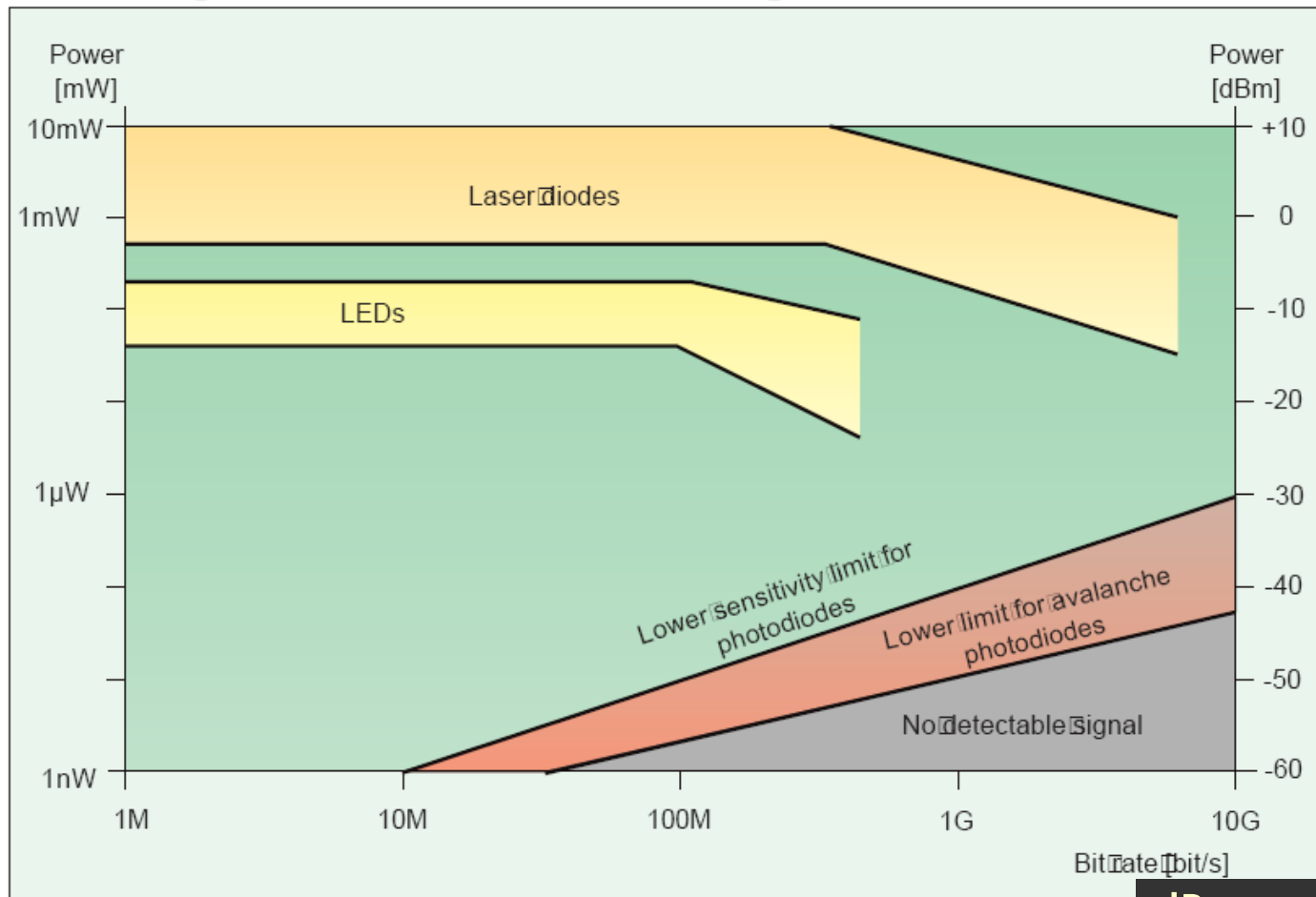


# Dimensionarea unei legături pe fibra optică

Capitolul 7



# Limite putere/bandă a dispozitivelor optoelectronice

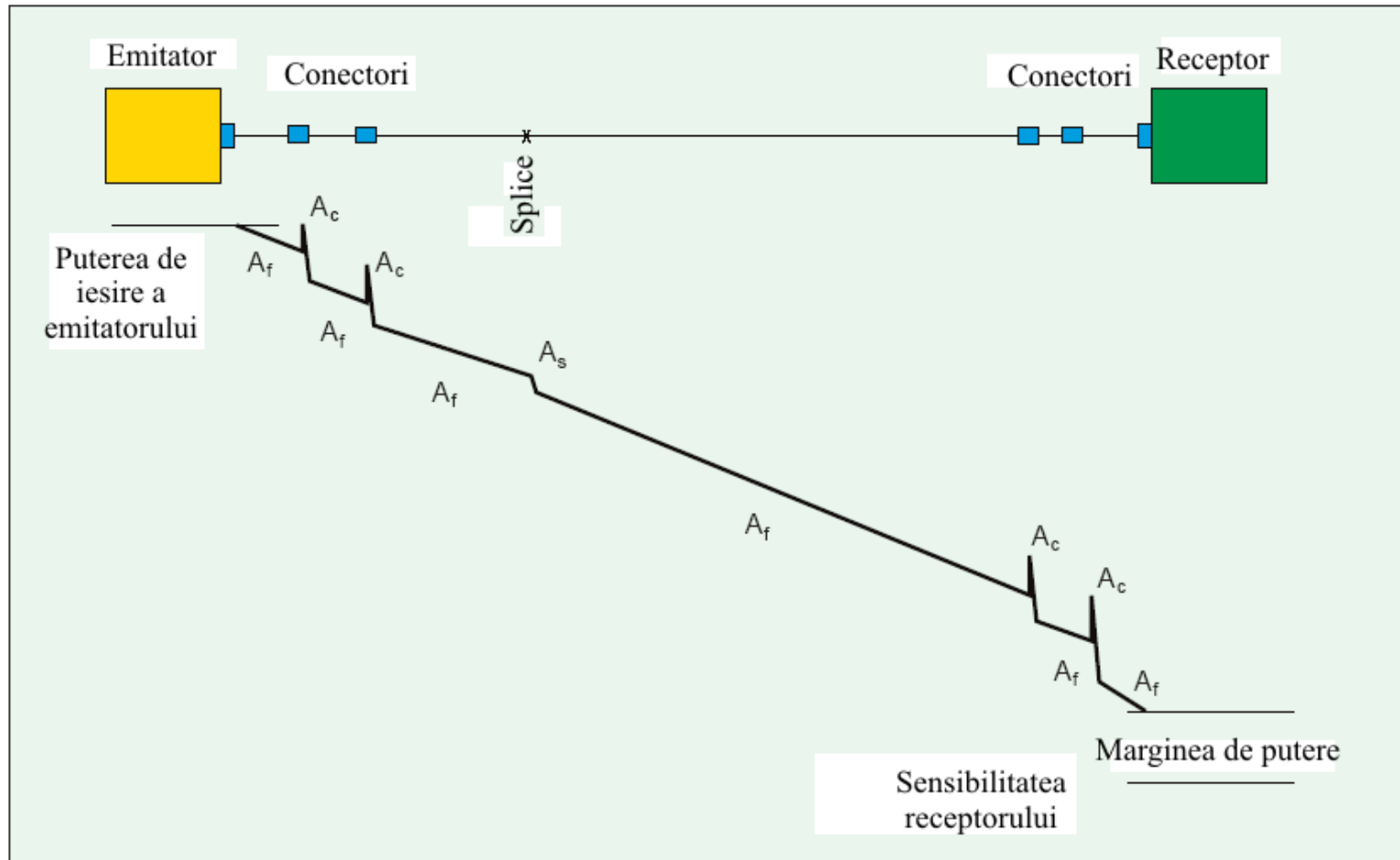


$$\text{dB} = 10 \cdot \log_{10} (P_2 / P_1)$$

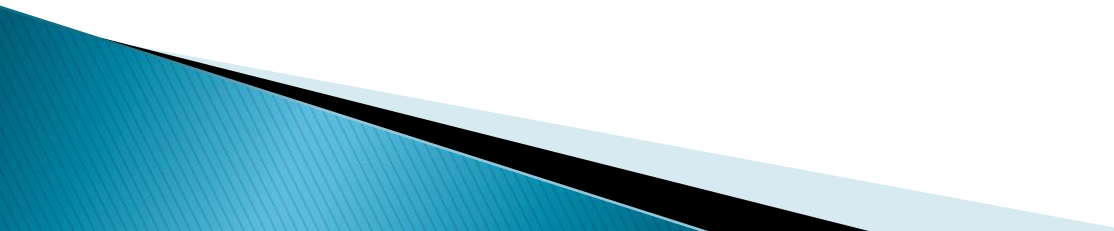
$$\text{dBm} = 10 \cdot \log_{10} (P / 1 \text{ mW})$$

$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

# Legatura pe fibra optica



# Sistem

- ▶ 1. Emitator
  - ▶ 2. Cablu 1 de conexiune
  - ▶ 3. Fibra 3 (2 cabluri a 5 km fiecare: 3a,3b)
  - ▶ 4. Fibra 4 (4 cabluri a 10 km fiecare: 4a,4b,4c,4d)
  - ▶ 5. Cablu 2 de conexiune
  - ▶ 6. Receptor
- 

# Atenuare

## ▶ Distribuita

- microcurburi
- imprastiere
- absorbtie

$$\text{Atenuare}_D [\text{dB/km}] = \frac{\text{Pierderi}[\text{dB}]}{\text{lungime}[\text{km}]}$$

## ▶ Localizata

- macrocurburi
- conectori
- splice
- tranzitii

$$\text{Atenuare}_L [\text{dB}] = \text{Pierderi}[\text{dB}]$$

$$A_{\text{TOT}} [\text{dB}] = A_L [\text{dB}] + A_D [\text{dB/km}] \cdot L [\text{km}]$$

# Pierderi

- ▶ Atenuare in fibra
- ▶ Atenuare datorata conectorilor
- ▶ Atenuare datorata splice-urilor
- ▶ Atenuare datorata diferentelor de apertura numerica
  - apare **numai** la trecerea de la un dispozitiv cu NA mai mare la un dispozitiv cu NA mai mic
  - **neglijabil** intre 2 fibre monomod sudate
- ▶ Atenuare datorata diferentelor de diametru
  - apare **numai** la trecerea de la un dispozitiv cu diametru mai mare la un dispozitiv cu diametru mai mic
  - **bidirectional** la fibre monomod sudate

# Dispersie

$$\Delta\tau_{\text{mod}} \cong \frac{L \cdot n_2 \cdot \Delta}{2\sqrt{3} \cdot c} \approx \frac{L \cdot NA^2}{4\sqrt{3} \cdot c \cdot n_2}$$

$$\Delta\tau_{\text{mod}} \cong \frac{L \cdot n_2 \cdot \Delta^2}{4\sqrt{3} \cdot c} \cong \frac{L \cdot NA^4}{16\sqrt{3} \cdot c \cdot n_2^3}$$

$$\Delta\tau_{cr} = D(\lambda) \cdot \Delta\lambda \cdot L$$

$$D(\lambda) = \frac{S_0}{4} \cdot \left( \lambda - \frac{\lambda_0^4}{\lambda^3} \right)$$

$$\Delta\tau_{tip} = \sum_i \Delta\tau_i$$

$$\Delta\tau_{tot} = \sqrt{\Delta\tau_{cr}^2 + \Delta\tau_{mod}^2}$$

$$B_{opt} = \frac{0.44}{\Delta\tau_{tot} [ns]} [GHz]$$

$$B_{opt} = \sqrt{2} B_{el}$$

$$V [Gb/s] \cong 2 \cdot B_{el}$$

$$B_{3dB,electric} (GHz) = \frac{0.35}{T(ns)}$$

$$NRZ_{viteza\ date} (Gbit/s) = \frac{1}{T_{impuls}(ns)} \leq \frac{0.67}{T(ns)}$$

# Lungime maxima

- ▶ **limitata de atenuare**  $L_{\max}^a$  [km]
- ▶ **limitata de viteza**  $L_{\max}^v$  [km]

- ▶ lungimea cea mai mare la care pot face transmisia este obtinuta in cazul cel mai defavorabil (din cele doua limitari)

$$L_{\max} [\text{km}] = \min(L_{\max}^a [\text{km}], L_{\max}^v [\text{km}])$$

- ▶ **de obicei**
  - monomod: limita impusa de atenuare
    - cu exceptia cazurilor in care nu se functioneaza la  $\lambda$  optim dpdv al dispersiei
  - multimod: limita impusa de viteza



# LED

Dioda electroluminescenta

Capitolul 8

# Caracteristici LED

## ▶ Dezavantaje

- Putere redusa (cuplata in fibra)  $\sim 100\mu\text{W}$
- Banda (viteza) reduse  $\sim 150\text{MHz}$  (300Mb/s)
- Spectru larg  $\sim 0.05 \lambda$
- Lumina necoerenta si nedirectiva

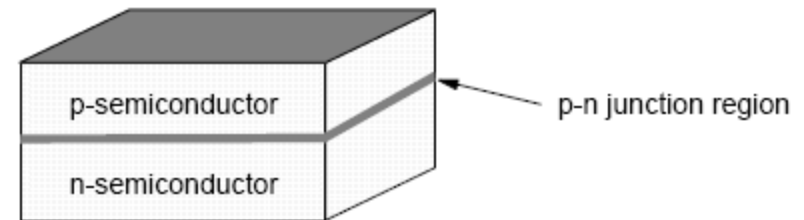
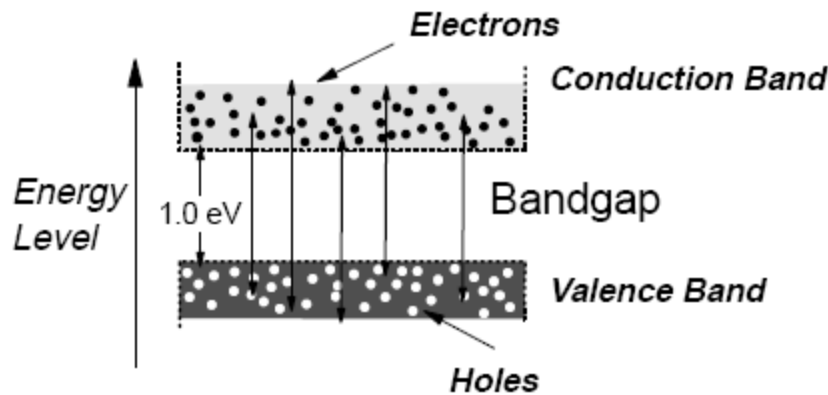
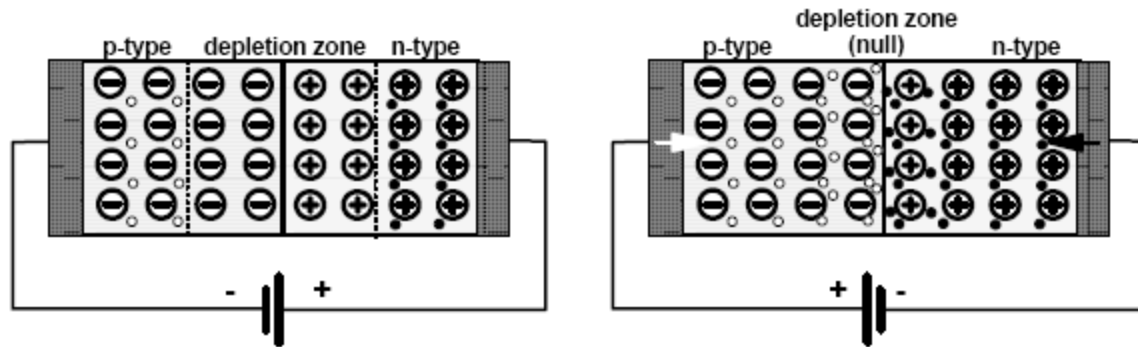
## ▶ Avantaje

- Structura interna mult mai simpla (fara suprafete reflective, straturi planare)
- Cost (dispozitiv si circuit de comanda)
- Durata de viata
- Insensibilitate la temperatura
- Liniaritate (modulatie analogica)

# Aplicatii majore LED

- ▶ Comunicatii
  - Infrarosu (InGaAsP)
- ▶ Vizibil
  - Spectru vizibil (GaAlAs)
- ▶ Iluminare
  - Putere ridicata, lumina alba (GaN)

# LED – Principiul de operare



# LED – Principiul de operare

- ▶ Lumina este generata de o recombinare radiativa dintre un electron si un gol
- ▶ Recombinarea neradiativa transforma energia in caldura
- ▶ Eficienta cuantica  $\eta = \frac{R_r}{R_r + R_{nr}}$
- ▶ La recombinarea radiativa  $E_g = h\nu; \lambda = \frac{hc}{E_g}$
- ▶ Recombinare eficienta:
  - alegerea judicioasa a materialului
  - concentrarea purtatorilor in zona jonctiunii
- ▶ Lungimea de unda depinde de temperatura de functionare a dispozitivului:  $0.6\text{nm}/^\circ\text{C}$

# Lățimea benzii interzise/lungime de undă pentru materialele uzuale

Material	Formula	Wavelength Range $\lambda$ ( $\mu\text{m}$ )	Bandgap Energy $W_g$ (eV)
Indium Phosphide	InP	0.92	1.35
Indium Arsenide	InAs	3.6	0.34
Gallium Phosphide	GaP	0.55	2.24
Gallium Arsenide	GaAs	0.87	1.42
Aluminium Arsenide	AlAs	0.59	2.09
Gallium Indium Phosphide	GaInP	0.64-0.68	1.82-1.94
Aluminium Gallium Arsenide	AlGaAs	0.8-0.9	1.4-1.55
Indium Gallium Arsenide	InGaAs	1.0-1.3	0.95-1.24
Indium Gallium Arsenide Phosphide	InGaAsP	0.9-1.7	0.73-1.35

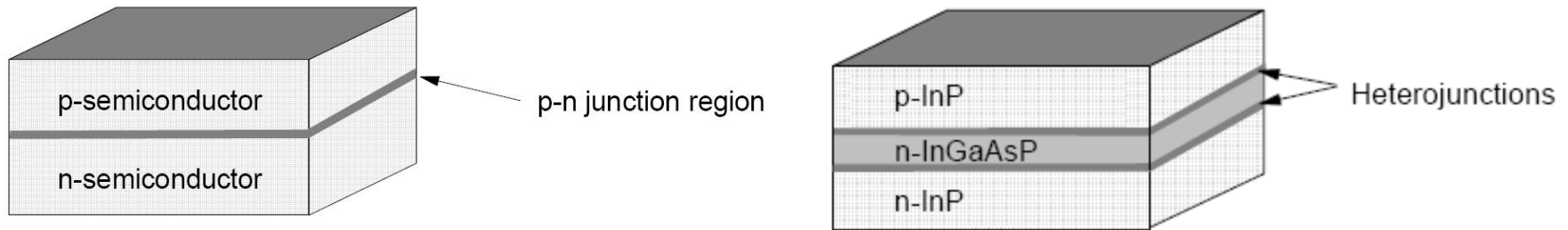
$$E_g = h\nu; \quad \lambda = \frac{hc}{E_g}; \quad \lambda[\mu\text{m}] = \frac{1.240}{E_g[\text{eV}]}$$

- ▶  $h$  constanta lui Plank  
 $6.62 \cdot 10^{-32} \text{ W s}^2$
- ▶  $c$  viteza luminii **in vid**  
 $2.998 \cdot 10^8 \text{ m/s}$
- ▶ benzi energetice:  $\lambda_0$ ,  $\Delta\lambda$

# Detalii constructive – 1

- ▶ Recombinarea unei perechi electron–gol necesita conservarea "impulsului rețelei" (cvasiimpuls)
  - ▶ In Si si Ge aceasta conditie presupune aparitia unui fonon intermediar (tranzitie indirecta) a carui energie se transforma in caldura
  - ▶ Majoritatea aliajelor de aluminiu Al de asemenea au tranzitie indirecta
- ▶ Se utilizeaza aliaje de Ga Al As sau In Ga As P
- ▶ Materialele utilizate trebuie sa fie "transparente" la lungimile de unda emise

# LED cu heterojunțiuni – principiu

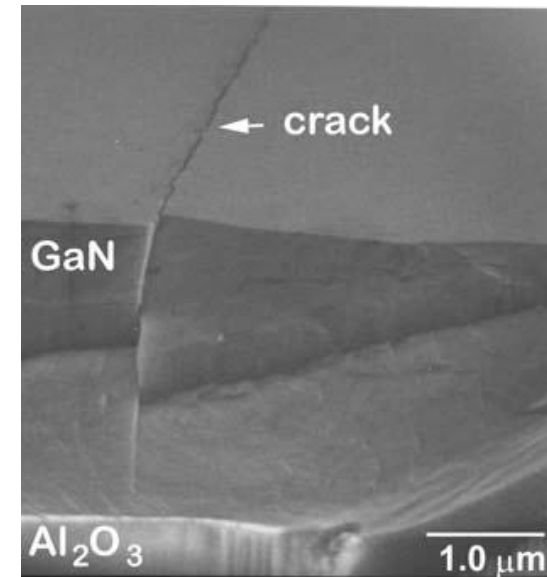


- ▶ **Orice** jonctiune p–n emite lumina
- ▶ O jonctiune p–n obisnuita este foarte subtire
  - volumul in care apar recombinari este foarte mic
  - eficienta luminoasa, redusa
- ▶ lumina este emisa in toate directiile
  - cantitatea de lumina utilizabila (intr–o anumita directie) este redusa

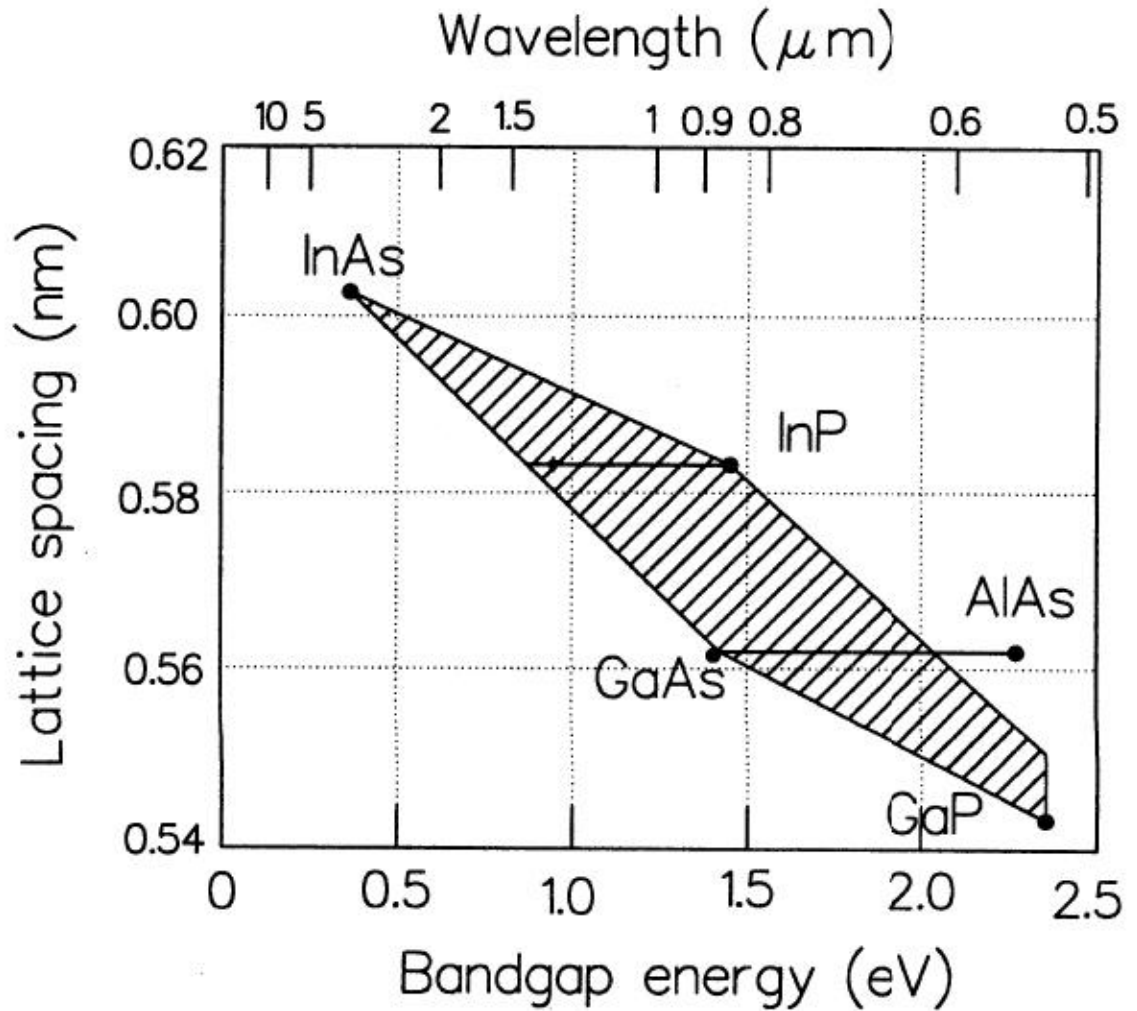
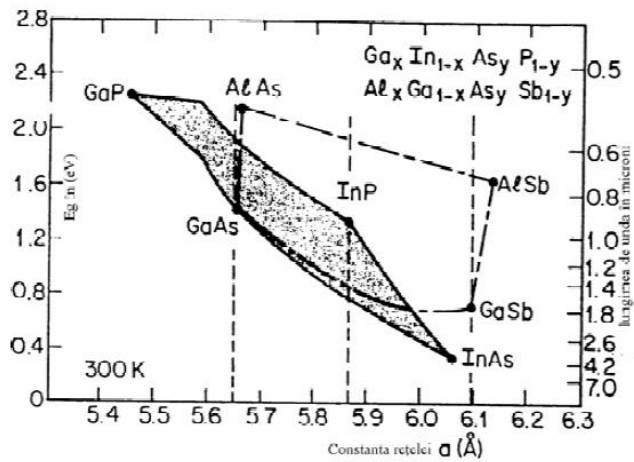


# Detalii constructive – 2

- ▶ Spatierea atomilor in diferitele straturi trebuie sa fie egala (toleranta 0.1%) pentru a nu se introduce defecte mecanice la jonctiune
  - limitare a aliajelor utilizabile
  - aparitia defectelor
    - creste ineficienta (recombinari neradiative)
    - scade durata de viata a dispozitivului



# Dependența benzii interzise de constanta rețelei



# Materiale

- ▶ Lungimi de unda mici (spectru vizibil – 1000nm)
  - GaP (665nm),  $\text{GaAs}_y\text{P}_{1-y}$
  - GaAs (900nm),  $\text{Ga}_{1-x}\text{Al}_x\text{As}$  (AlAs – 550nm)
- ▶ Lungimi de unda mari (1000÷1700nm)
  - $\text{In}_x\text{Ga}_{1-x}\text{As}_y\text{P}_{1-y}$
  - x,y concentratii relative in aliaj a materialelor corespunzatoare
  - x,y alese din considerente privind
    - lungimea de unda
    - spatierea atomilor
- ▶ Ultraviolet – Albastru: GaInN

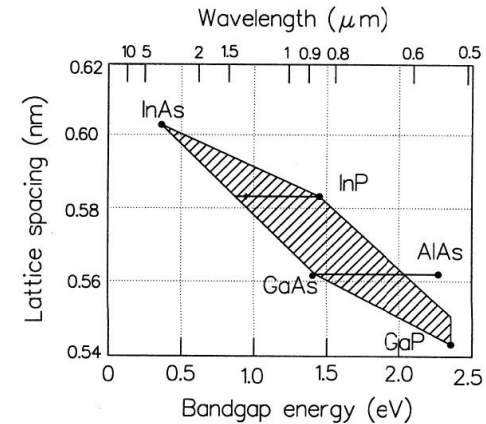
# Materiale

## ▶ Lungimi de unda mici

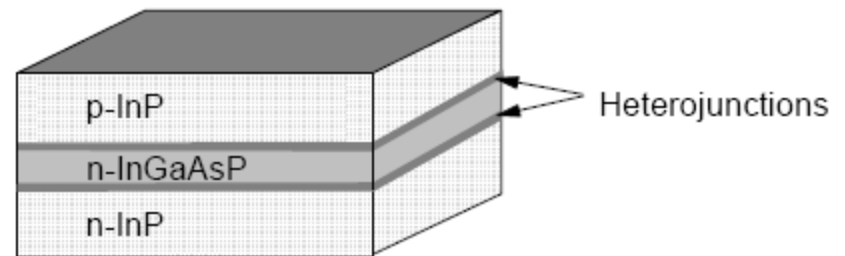
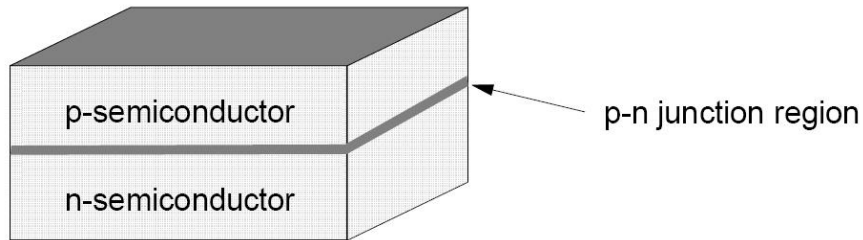
- $\text{Ga}_{1-x}\text{Al}_x\text{As}$
- $E_g$  (in eV)  $E_g = 1.424 + 1.266 \cdot x + 0.266 \cdot x^2$
- limitare pentru tranzitie directa  $0 < x < 0.37$

## ▶ Lungimi de unda mari

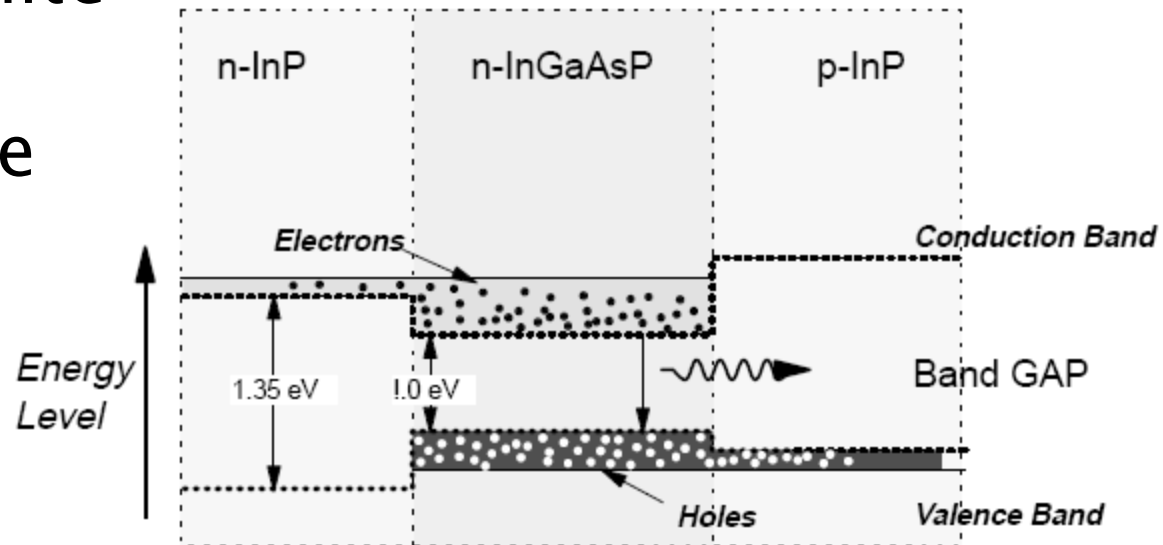
- $\text{In}_x\text{Ga}_{1-x}\text{As}_y\text{P}_{1-y}$
- $E_g$  (in eV)  $E_g = 1.35 - 0.72 \cdot y + 0.12 \cdot y^2$
- Tipic substratul este InP
  - Spatierea atomilor (lattice spacing) corespunzatoare InP  $x = \frac{0.4526}{1 - 0.031 \cdot y}$
- Exemplu: 1300nm se obtine cu  $y=0.589$  si  $x=0.461$ ,
  - $\text{In}_{0.461}\text{Ga}_{0.539}\text{As}_{0.589}\text{P}_{0.411}$



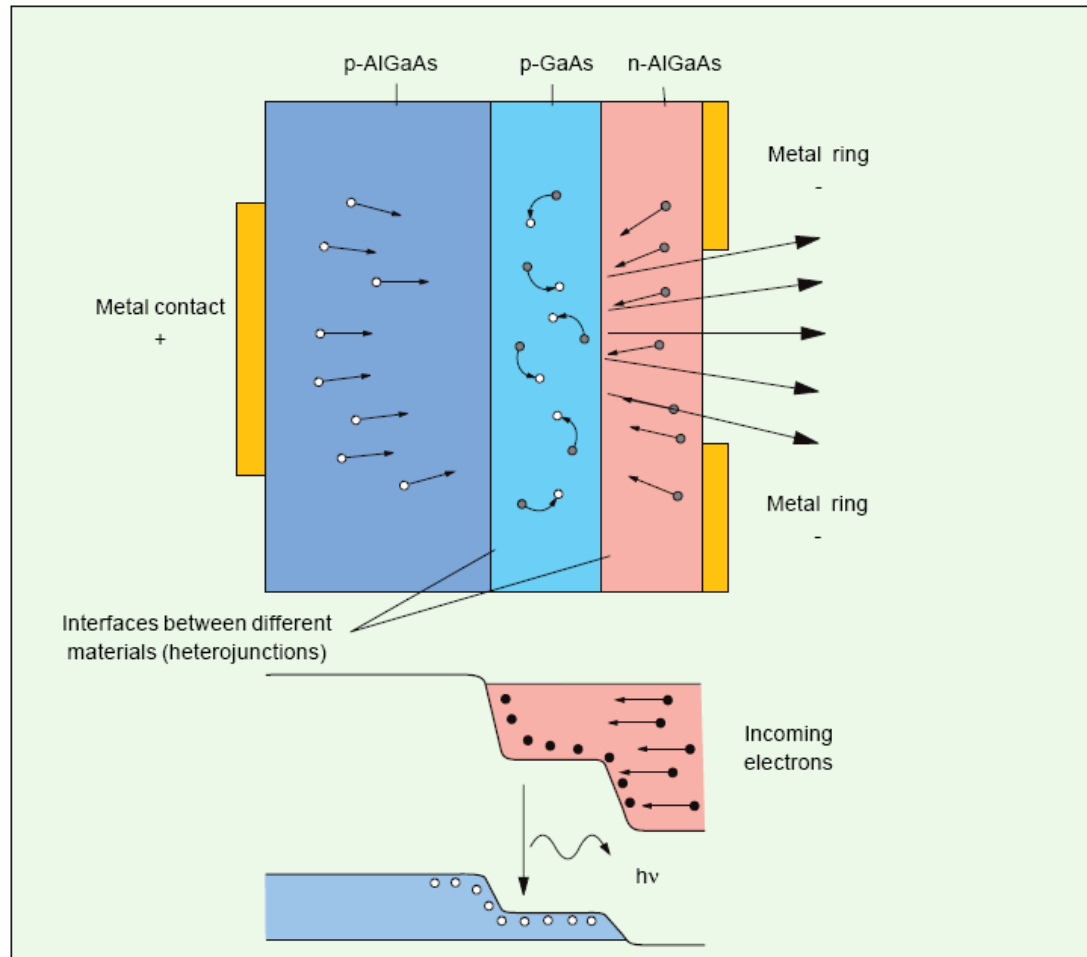
# LED cu heterojunțiuni – principiu



- ▶ Structura de nivele energetice permite capturarea purtătorilor între cele două heterojunțiuni

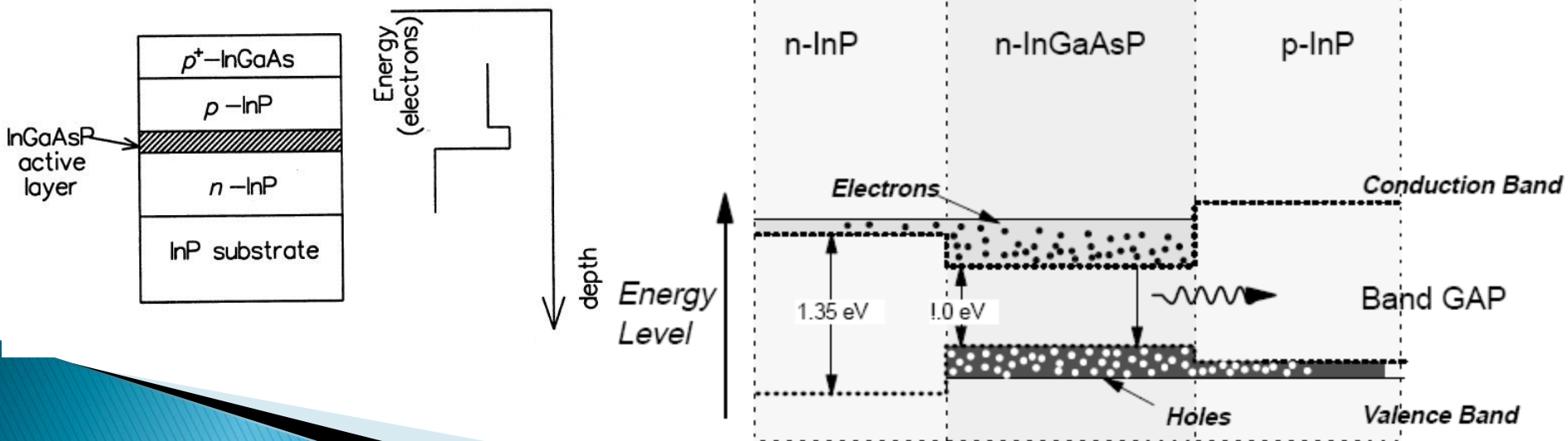


# LED cu heterojunțiuni – principiu



# LED cu heterojunțiuni – principiu

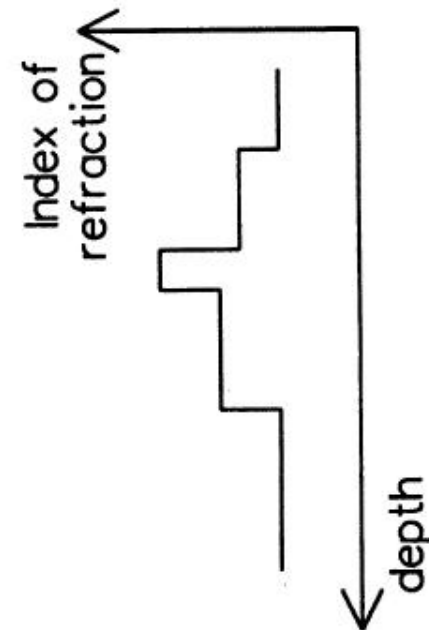
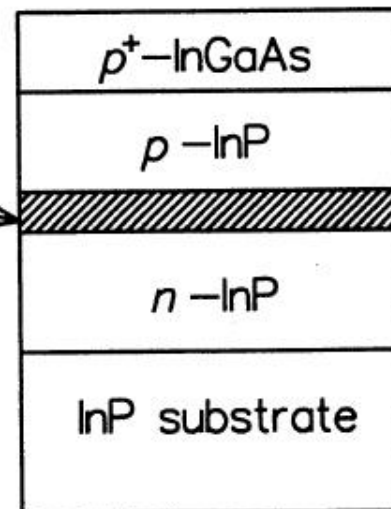
- ▶ Concentrare verticală a purtătorilor
  - Electronii sunt atrași din zona n în zona activă
  - O barieră energetică existentă între zona activă și zona n concentrează electronii în zona activă
  - Situație similară corespunzătoare golurilor
  - Purtătorii sunt concentrați în zona activă, crescând eficiența



# LED cu heterojunțiuni – principiu

- ▶ Concentrare verticală a luminii
  - în general la diode laser (eficiența procesului LASER depinde de intensitatea luminoasă)
  - prezenta și la LED pentru creșterea eficienței luminoase: dirijarea luminii spre exterior și evitarea absorbției interne

- ▶ Straturile din materiale diferite au indici de refracție diferiți formând un ghid dielectric

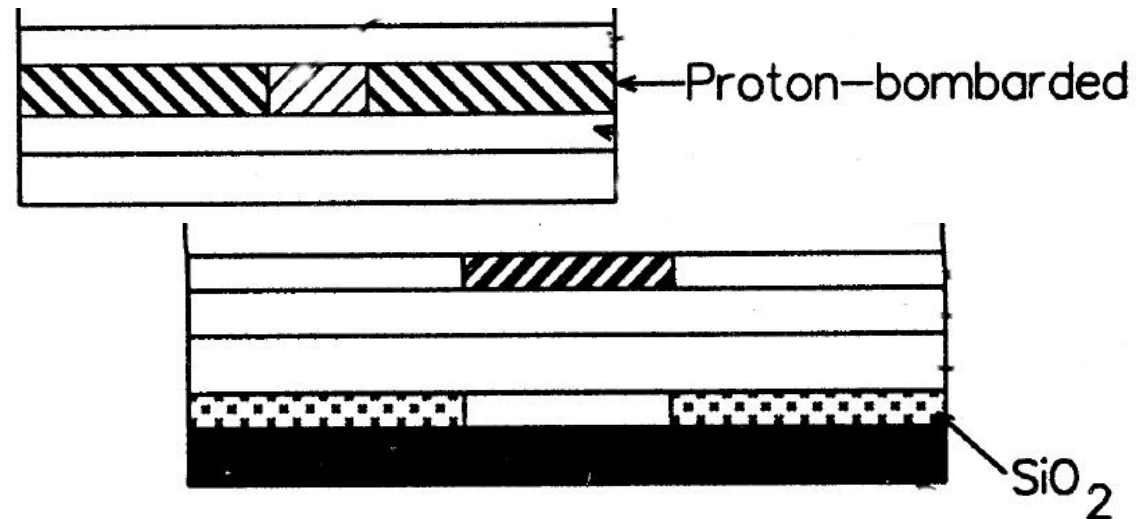




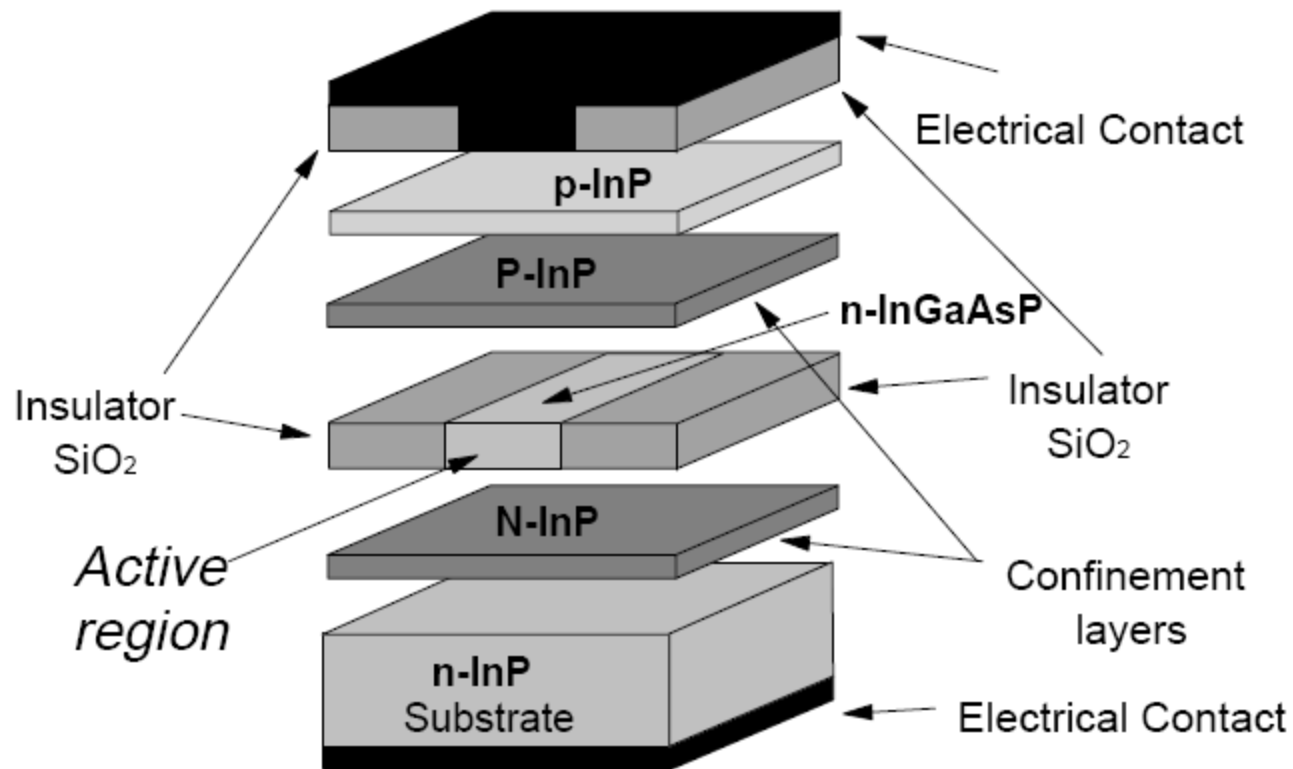
# LED cu heterojunțiuni – principiu

## ► Concentrare orizontală a curentului

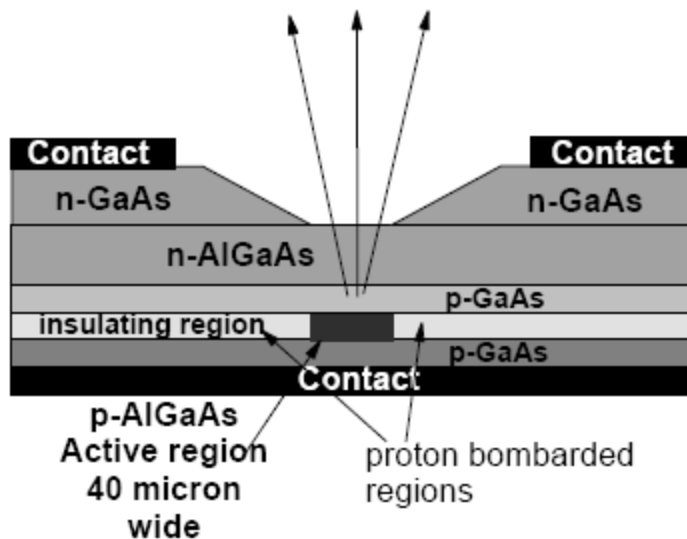
- Eficiența conversiei depinde de concentrația de purtători, deci e necesară creșterea densității de curent în zona activă (20–50 μm)
- Se utilizează:
  - strat izolator (tipic  $\text{SiO}_2$ ) cu o deschidere în dreptul zonei active
  - Bombardarea cu protoni a regiunii din jurul zonei active
- Alte metode:
  - eliminarea materialului în jurul zonei active (mesa structure)
  - difuzie de Zn în zona centrală



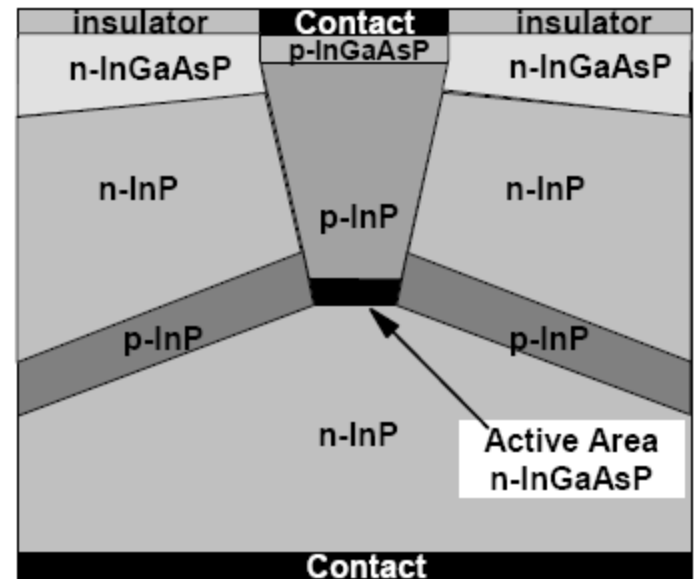
# LED cu heterojunțiuni – detalii



# Structuri constructive pentru LED

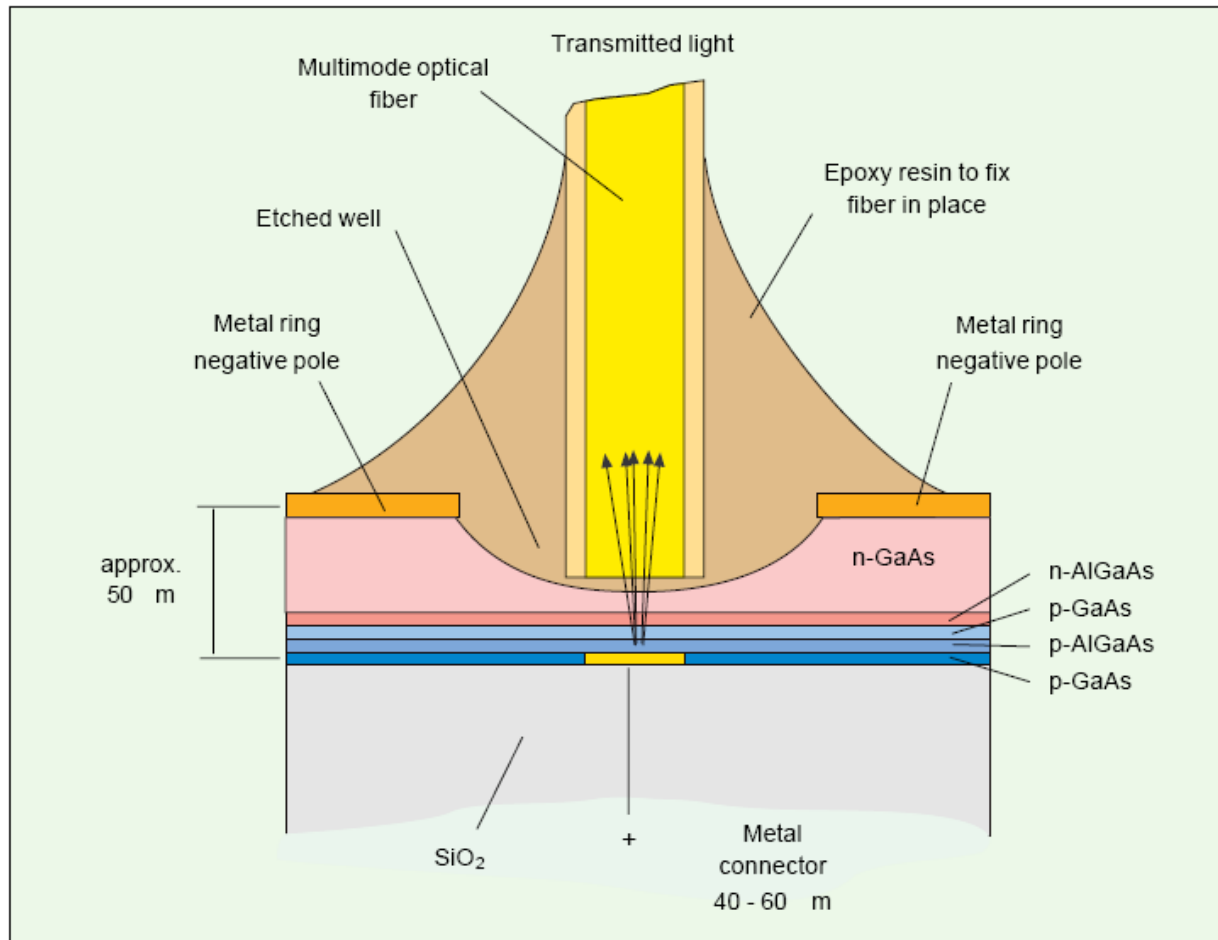


Burrus Surface Emitting LED (SLED)



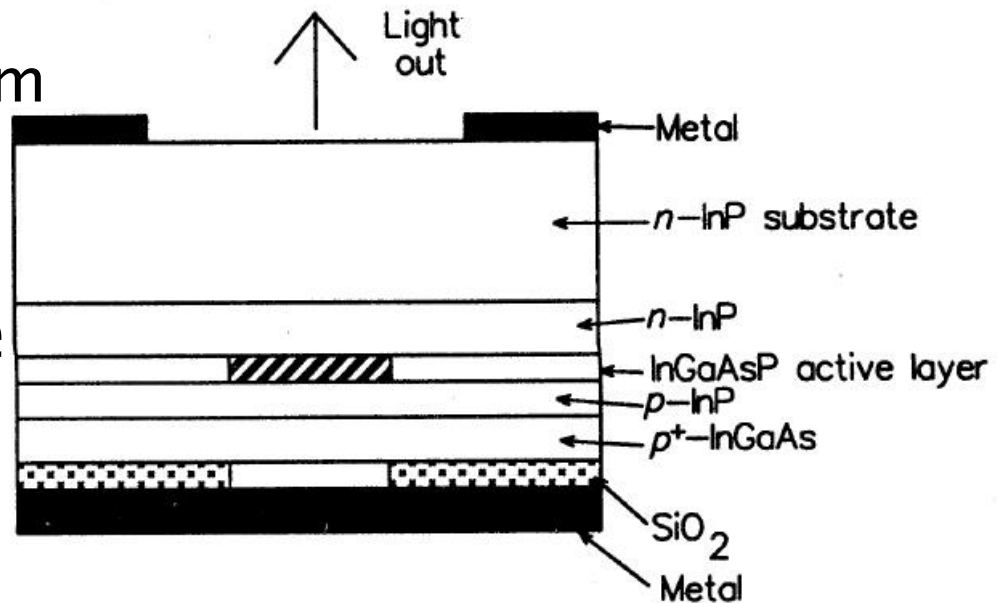
Edge Emitting LED (ELED)

# LED cu emisie de suprafață



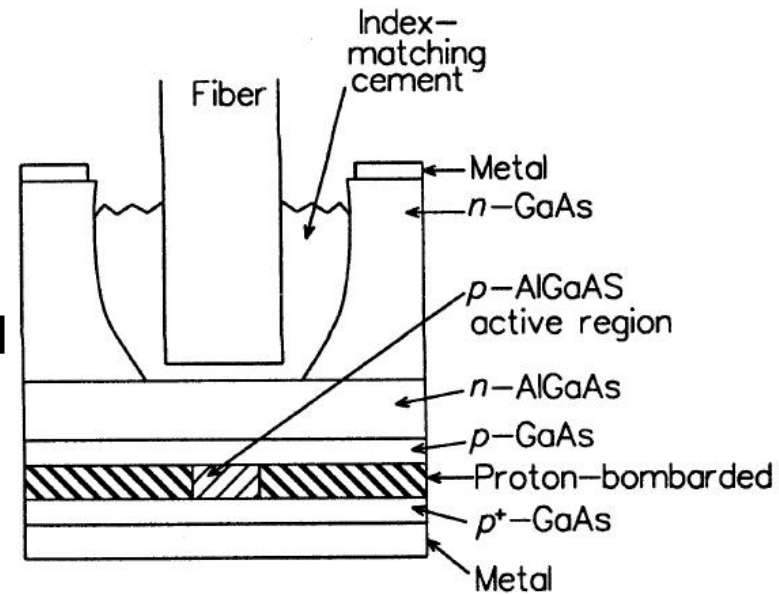
# SLED InGaAsP – constructie

- ▶ InGaAsP
- ▶ 4 straturi
  - n InP  $\sim 2 \div 5 \mu\text{m}$
  - p InGaAsP  $\sim 0.4 \div 1.5 \mu\text{m}$
  - p InP  $\sim 1 \div 2 \mu\text{m}$
  - p<sup>+</sup> InGaAs  $\sim 0.2 \mu\text{m}$
- ▶ Latimea zonei active
  - $\sim 20 \div 50 \mu\text{m}$  diametru

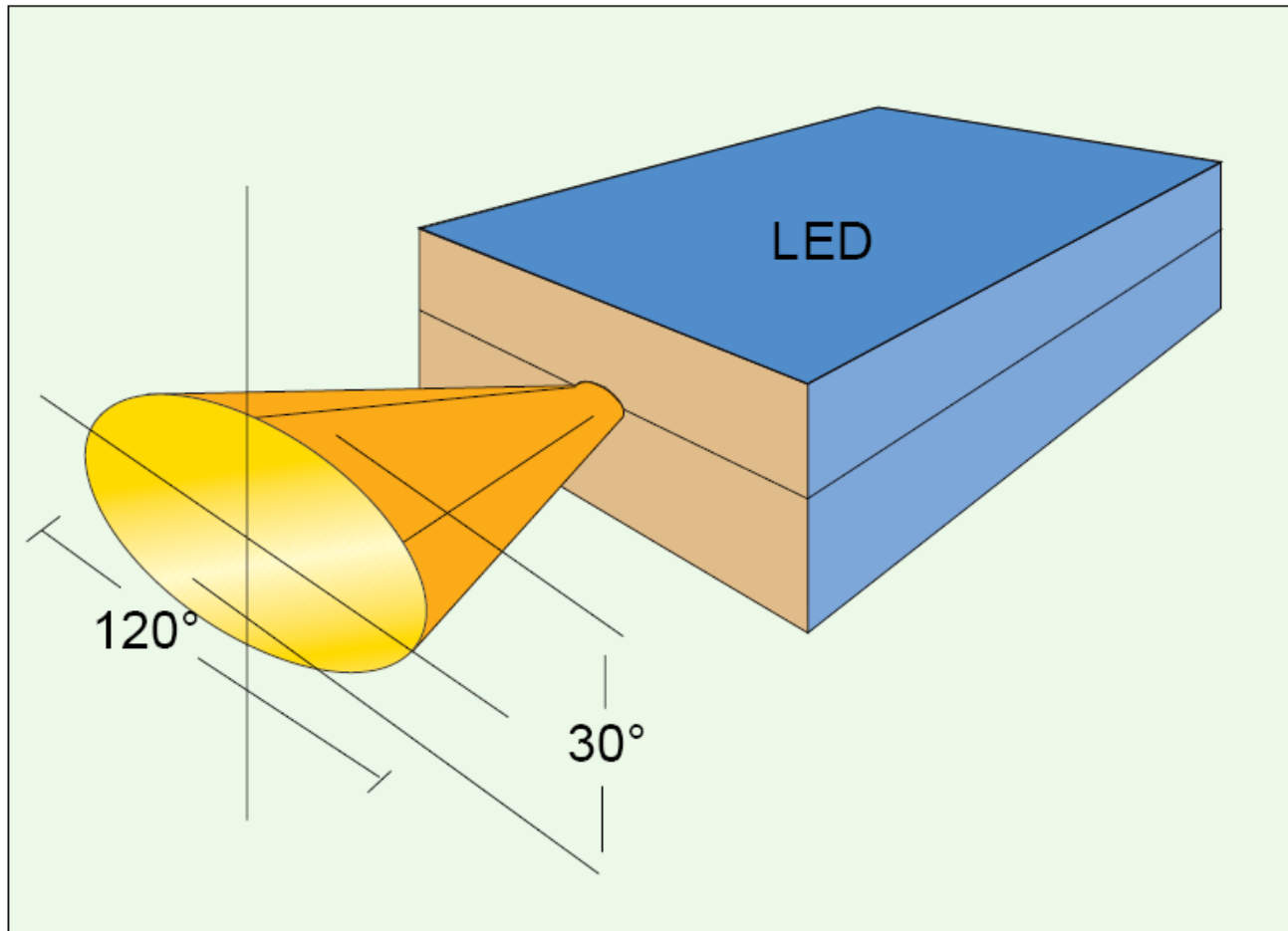


# SLED GaAlAs – constructie

- ▶ GaAlAs
- ▶ diferenta principala e data de absorbtia crescuta a substratului GaAs, care este eliminat partial pentru a permite accesul luminii spre exterior

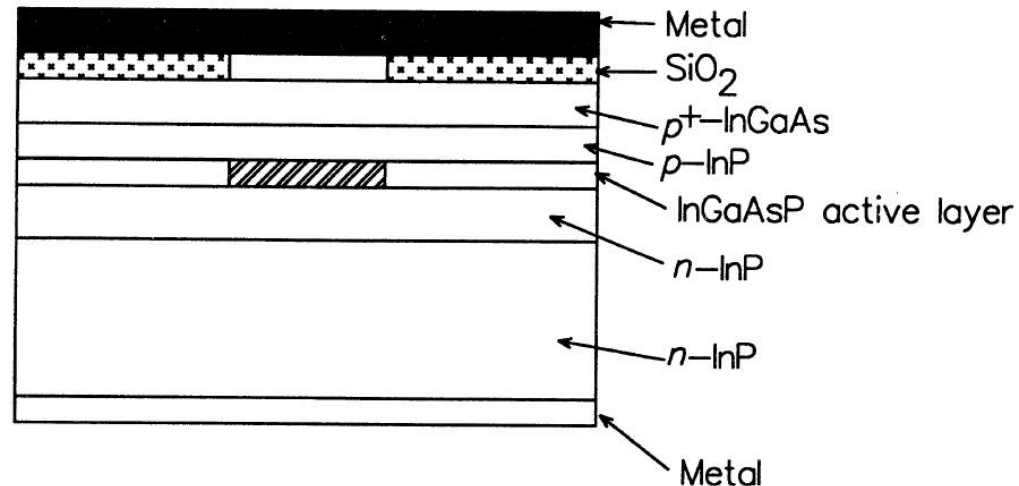


# LED cu emisie laterală



# ELED – constructie

- ▶ InGaAsP
- ▶ strict pentru comunicatii
- ▶ Cele patru straturi sunt in general similare
- ▶ Stratul activ este mult mai subtire decat la SLED  $\sim 0.05 \div 0.25 \mu\text{m}$
- ▶ Regiunea activa
  - latime  $50 \div 70 \mu\text{m}$
  - lungime  $100 \div 150 \mu\text{m}$
  - p InP  $\sim 1 \div 2 \mu\text{m}$
  - p<sup>+</sup> InGaAs  $\sim 0.2 \mu\text{m}$
- ▶ Apare concentrarea verticala a luminii





# Emisia luminii spre exterior

- ▶ Indici de refractie ridicati
  - InP  $n=3.4$
  - GaAs  $n=3.6$
- ▶ Doua probleme generate
  - pierderi prin reflexie ridicate
  - unghi critic de numai  $15^\circ$

# Emisia luminii spre exterior

## ▶ Solutii

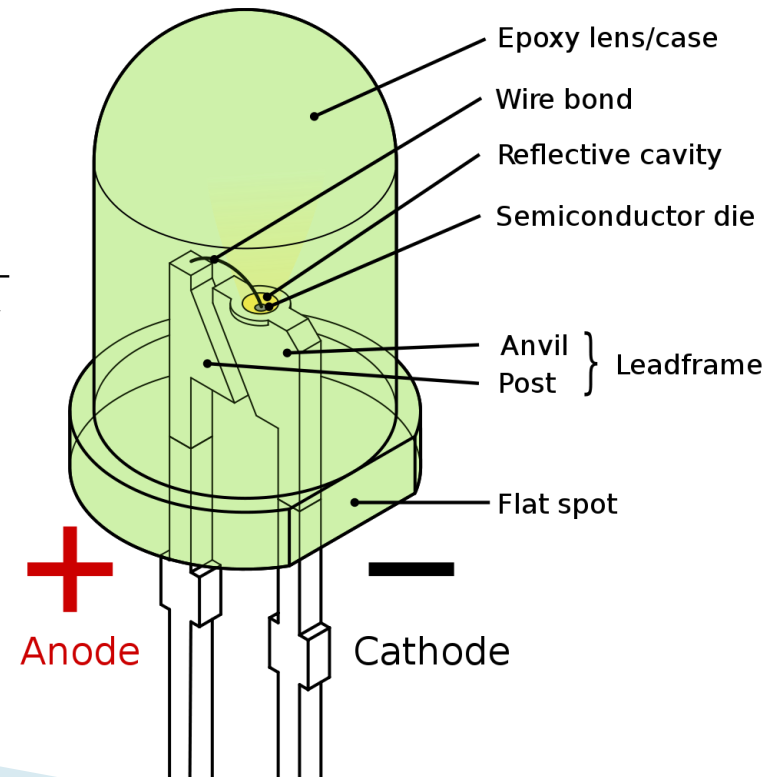
- utilizarea unui material intermediar pentru adaptarea indicelui de refractie (rasina epoxidica)
- adaptarea formei de iesire din dispozitiv – forma de dom
  - eficienta de cuplaj

interfata plana  
semiconductor  
aer

$$\frac{1}{n \cdot (n+1)^2}$$

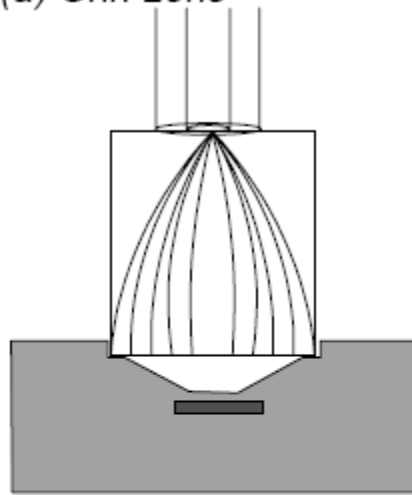
dom

$$\frac{2n}{(n+1)^2}$$

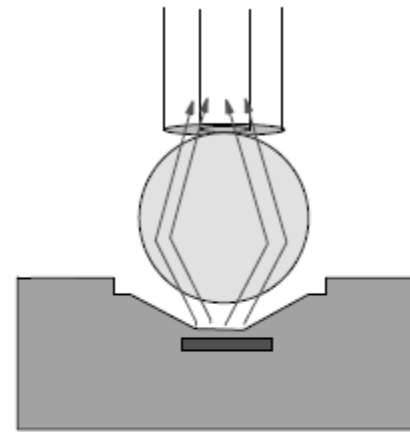


# Cuplarea luminii în fibră

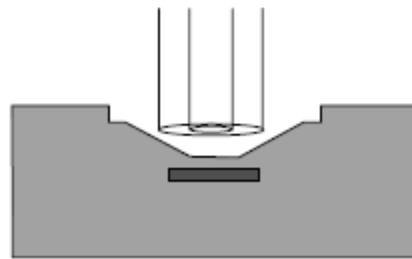
(a) Grin Lens



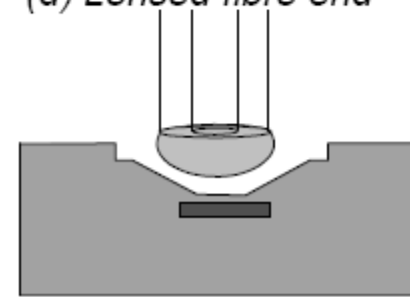
(b) Ball Lens



(c) Direct coupling



(d) Lensed fibre end



numai pentru fibre multimod cu salt de indice

# Directivitatea radiatiei exterioare

## ▶ SLED

- radiatia este emisa cu simetrie circulara, in interiorul unui con cu unghi la varf tipic de  $60^\circ$
- Viewing Half Angle  $\sim 10 \div 15^\circ$

## ▶ ELED

- radiatia emisa nesimetric in forma de con eliptic
  - perpendicular pe jonctiune  $\sim 60^\circ$
  - paralel cu jonctiunea  $\sim 30^\circ$

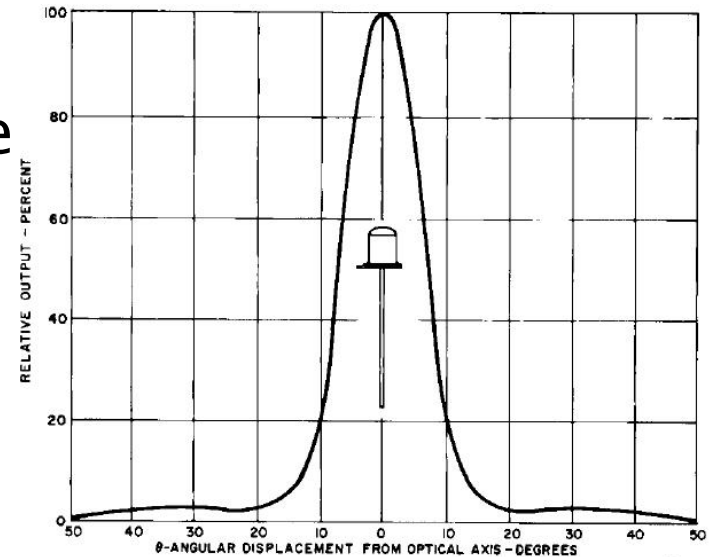
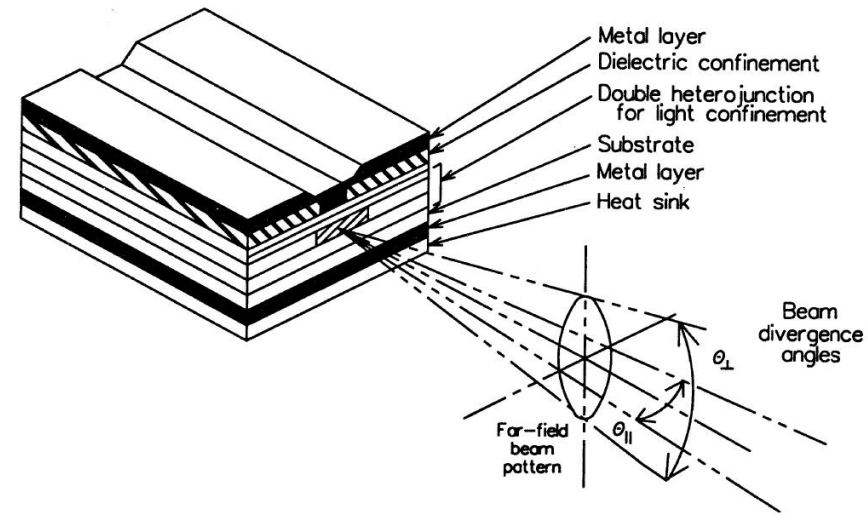


Fig. 5. Typical Radiation Pattern

ST1054



# Directivitatea radiatiei exterioare

- ▶ Sursa lambertiana

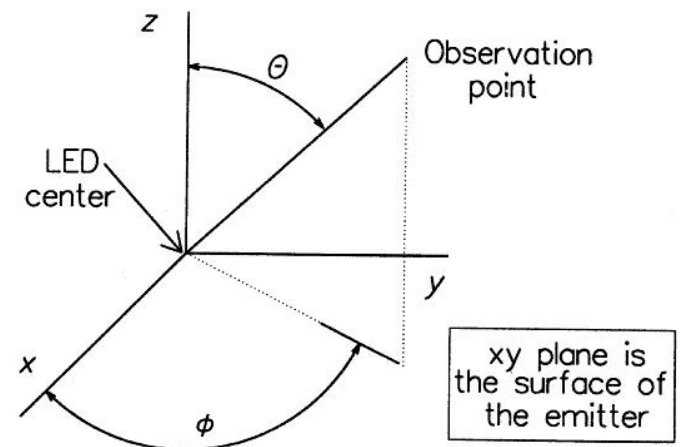
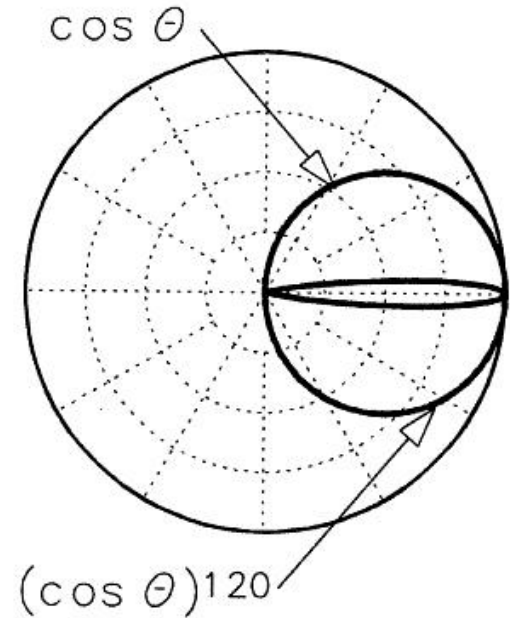
$$P(\theta) = P_0 \cdot \cos \theta$$

- ▶ Aproximatie Lambertiana pentru surse cu directivitate crescuta

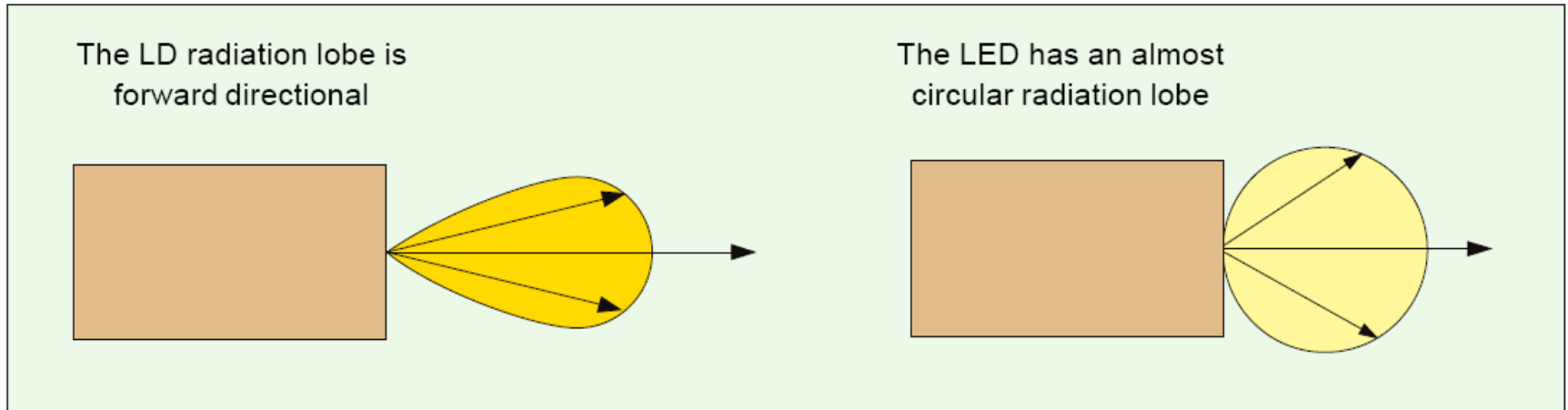
$$P(\theta) = P_0 \cdot \cos^n \theta$$

- ▶ Surse cu emisie asimetrica

$$P(\theta) = \frac{P_0}{\frac{\sin^2 \phi}{\cos^T \theta} + \frac{\cos^2 \phi}{\cos^L \theta}}$$

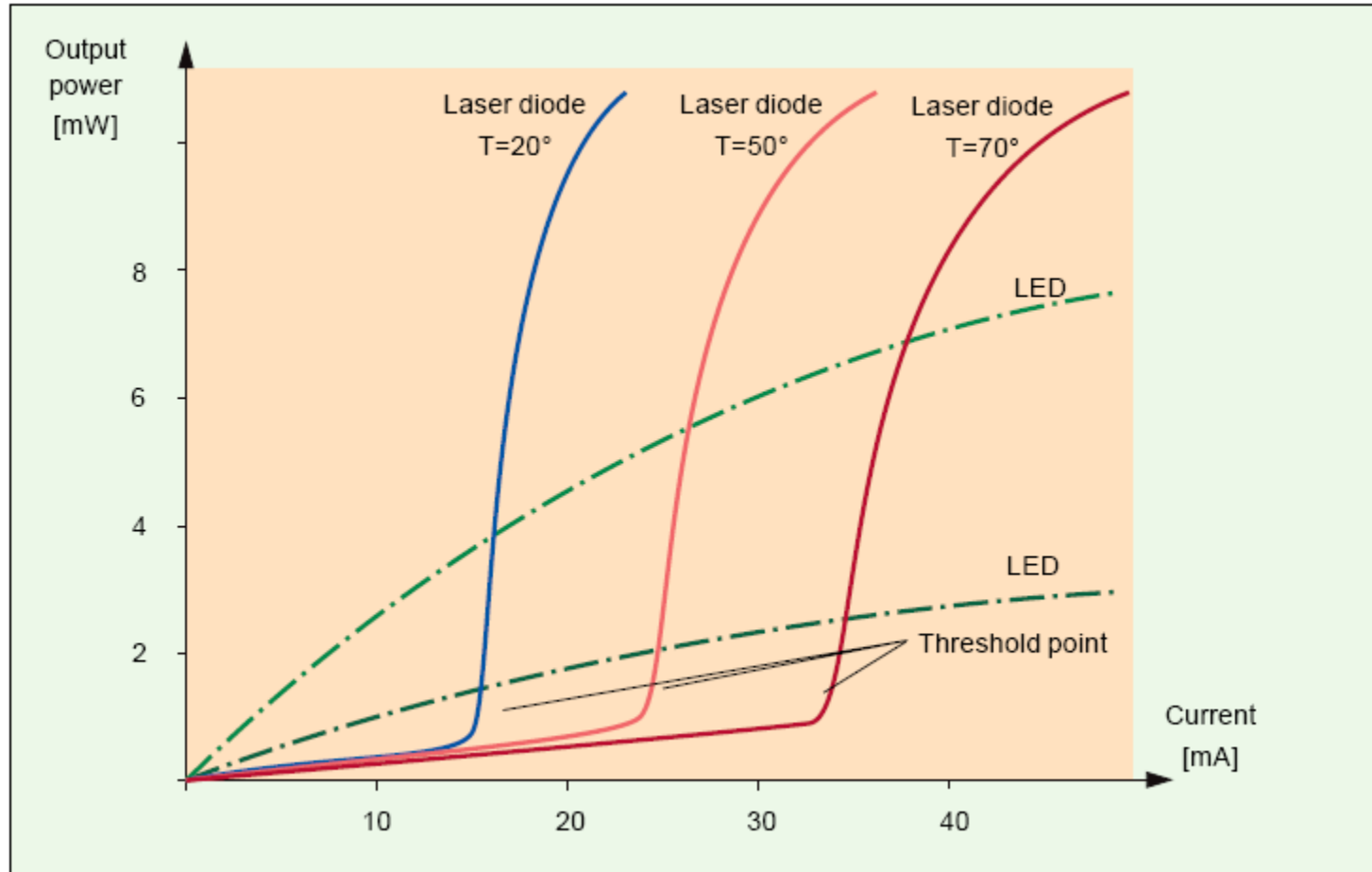


# Profil de radiație a emițătorilor optici



- ▶ Apertura numerică poate varia de la 0.9 pentru un LED de unghi foarte larg, la 0.2 pentru un LED prevăzut cu lentilă.
- ▶ Chiar și pentru un NA de 0.2, aria emisivă este mare comparativ cu a unui laser. În consecință, densitatea de putere emisă este mică astfel încât se reduce drastic puterea care poate fi cuplată într-o fibră cu indice gradat, și devine practic imposibilă cuplarea cu o fibră monomod.

# Caracteristici putere optică/curent a emițătorilor optici



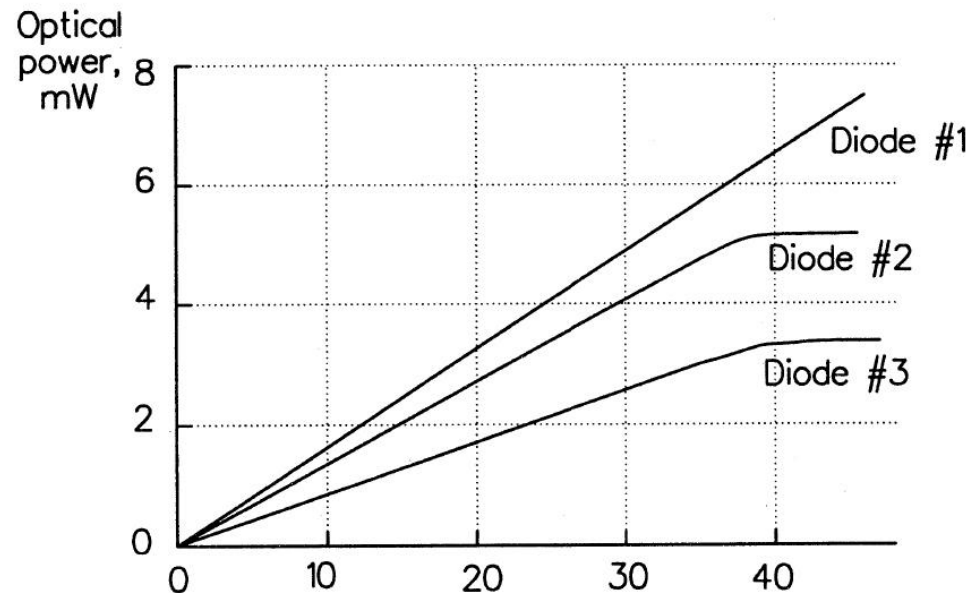
# Caracteristica de raspuns a LED-urilor

- ▶ Caracteristica putere optica emisa functie de curentul direct prin LED este liniara la nivele mici ale curentului.
- ▶ Nu exista curent de prag
- ▶ La nivele foarte mari puterea optica se satureaza

- ▶ Responzivitatea

$$r = \frac{P_o}{I} \left[ \frac{W}{A} \right]$$

- ▶ Tipic  $r = 50 \mu W / mA$





# Caracteristica de raspuns a LED-urilor

- ▶ Tipic SLED au eficienta mai buna decat ELED

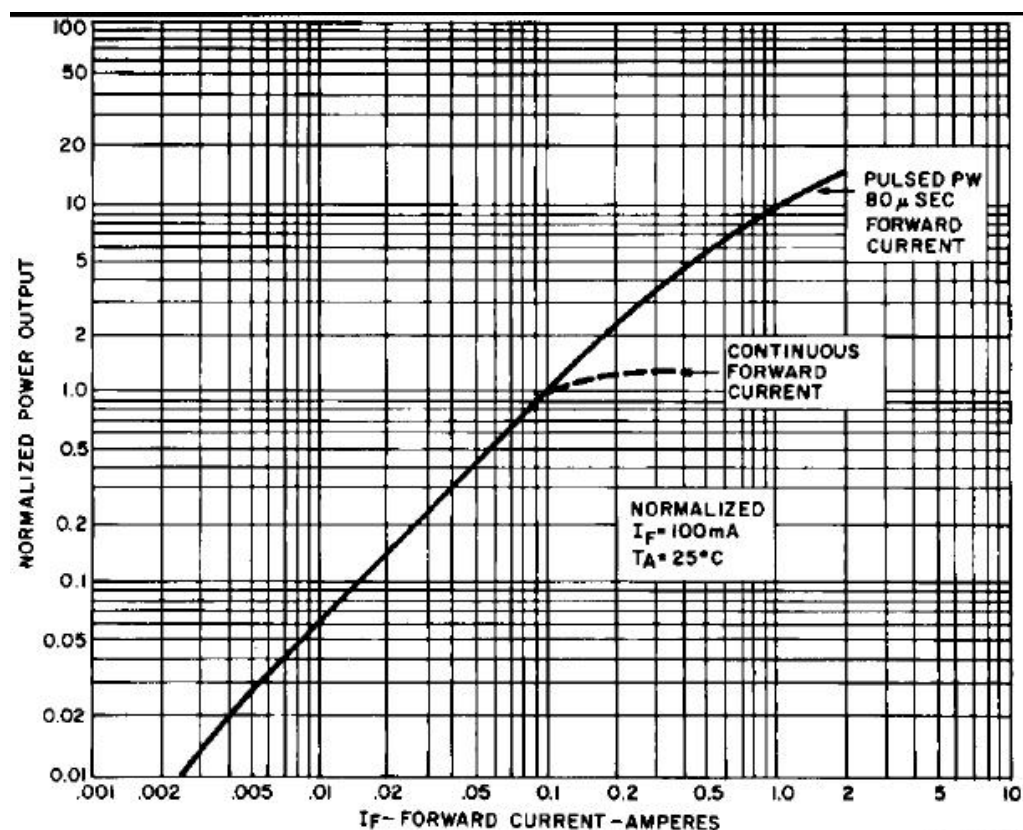
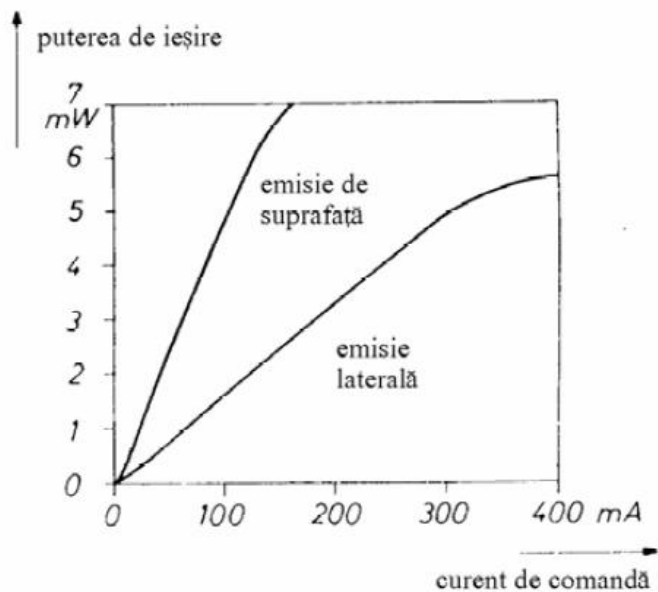


Fig. 1. Power Output vs. Input Current

ST1052

# Probleme

- ▶ Un dispozitiv de semnalizare e realizat cu 100 LED-uri care emit lungimea de undă dominantă  $\lambda_0 = 590\text{nm}$  sub un con cu unghi la vârf de  $5.2^\circ$  (emisie presupusă **uniformă** în acest con). O diodă are rezonanzivitatea de  $90\mu\text{W}/\text{mA}$  și este parcursă de un curent de  $85\text{mA}$ .
- ▶ a) Estimați intensitatea luminoasă a dispozitivului pe direcție normală.
- ▶ Dacă se consideră emisia **uniformă** în interiorul conului de emisie, fluxul optic energetic este constant în interiorul acestui con și va fi egal cu puterea optică emisă (ambele mărimi reprezintă viteze ale energiei, măsurate în W, cu diferența că puterea optică reprezintă o medie a fluxurilor emise după diferite direcții, valoarea medie a unei mărimi constante fiind egală cu acea mărime)

# Aplicatii majore LED

## ▶ Comunicatii

- Infrarosu (InGaAsP)

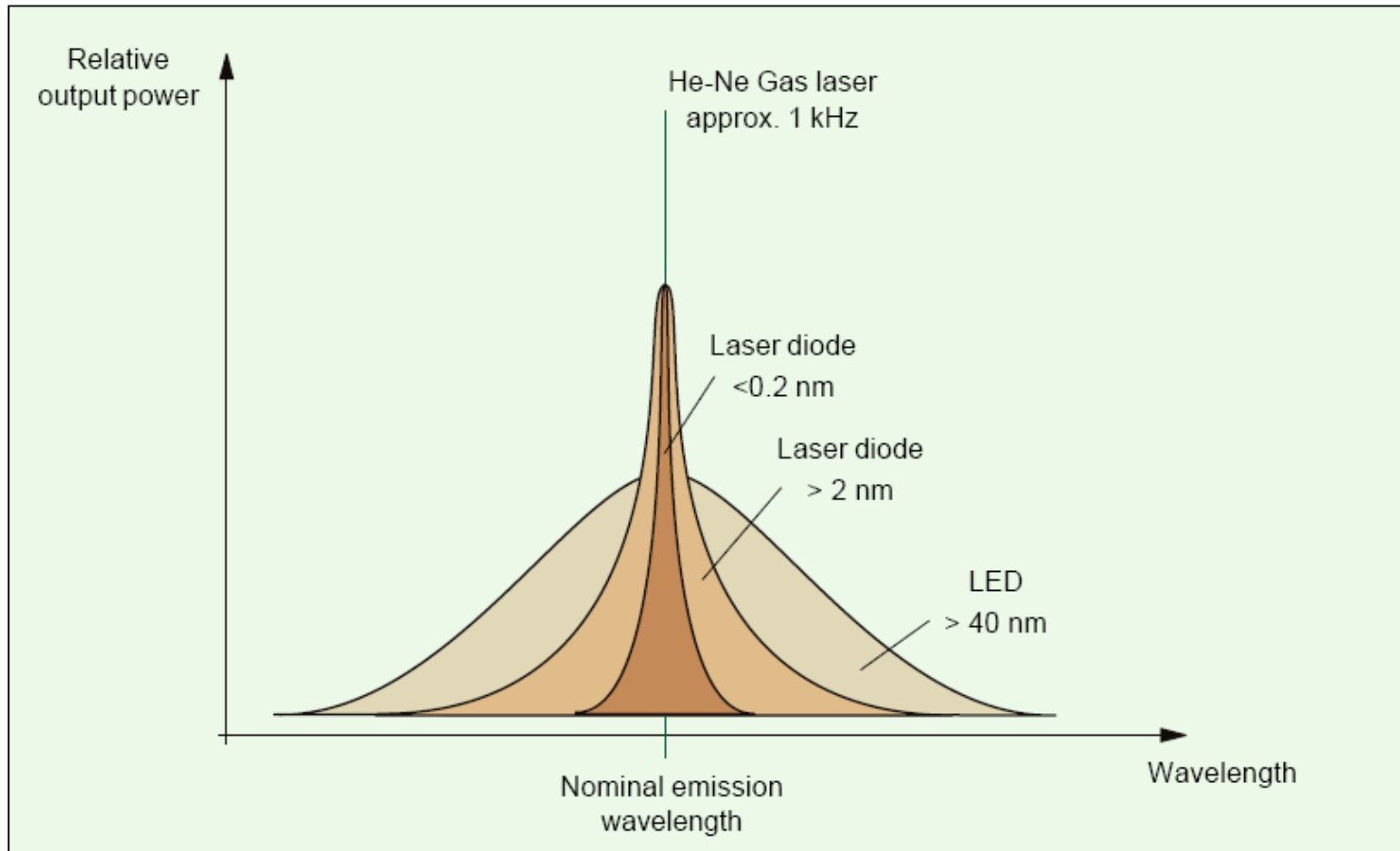
## ▶ Vizibil

- Spectru vizibil (GaAlAs)

## ▶ Iluminare

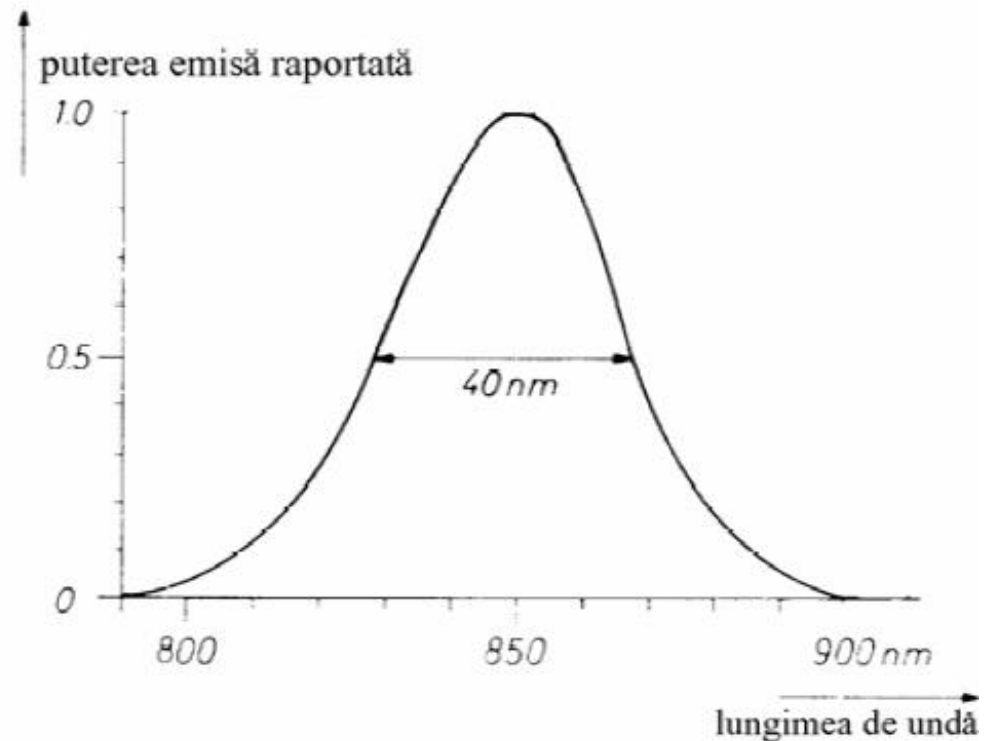
- Putere ridicata, lumina alba (GaInN)

# Calitatea spectrală a emițătorilor optici



# Latimea spectrala a LED-urilor

- ▶ Aproximativ  $\Delta\lambda \approx 0.05\lambda$
- ▶ Relatie empirica  $\Delta\lambda[\mu m] \approx 1.45\lambda^2[\mu m](kT)[eV]$
- ▶ Tipic
  - GaAlAs – 20–40 nm
  - InGaAsP
    - SLED – 100 nm
    - ELED – 60–80 nm
  - GaInN – 30–40 nm (10%)



# Comportare dinamica a LED

- ▶ Puterea de iesire la modulatia cu un semnal sinusoidal cu  $\omega$

$$P_{out} = \frac{P_o}{1 + \omega^2 \tau_{lf}^2}$$

- Puterea electrica variaza proportional cu patratul curentului
- Puterea optica variaza proportional cu curentul
- ▶ Banda la 3 dB electrica

$$\frac{P_{out}^2}{P_o^2} = \frac{1}{2}$$

$$f_{3dB-el} = \frac{1}{2 \cdot \pi \cdot \tau_{lf}}$$

- Banda la 3 dB optic

$$\frac{P_{out}}{P_o} = \frac{1}{2}$$

# Comportare dinamica a LED

- ▶ Cand curentul care trece prin dispozitiv e mic timpul de viata al purtatorilor e independent de curent si este dependent liniar de nivelul de dopare in regiunea activa
- ▶ Cand curentul este mare timpul de viata al purtatorilor este proportional cu  $\sqrt{d}$  si invers proportional cu  $\sqrt{J}$
- ▶ Banda poate fi crescuta
  - Crescand nivelul de dopare
  - Reducand inaltimea zonei active
  - Crescand densitatea de curent

# Comportare dinamica a LED

- ▶ In domeniul timp
- ▶ Timpul de crestere (rise time)

$$t_r = 2.20 \cdot \left( \frac{2 \cdot k \cdot T \cdot C_s}{e \cdot I_p} + \tau_{lf} \right)$$

- ▶ Capacitatea asociata sarcinilor in regiunea activa: 350 ÷ 1000pF
- ▶ Produs Putere × Banda

$$P \times \Delta f = \frac{h \cdot c}{2 \cdot \pi \cdot e \cdot \lambda} \cdot \frac{J}{\tau_{lf}}$$



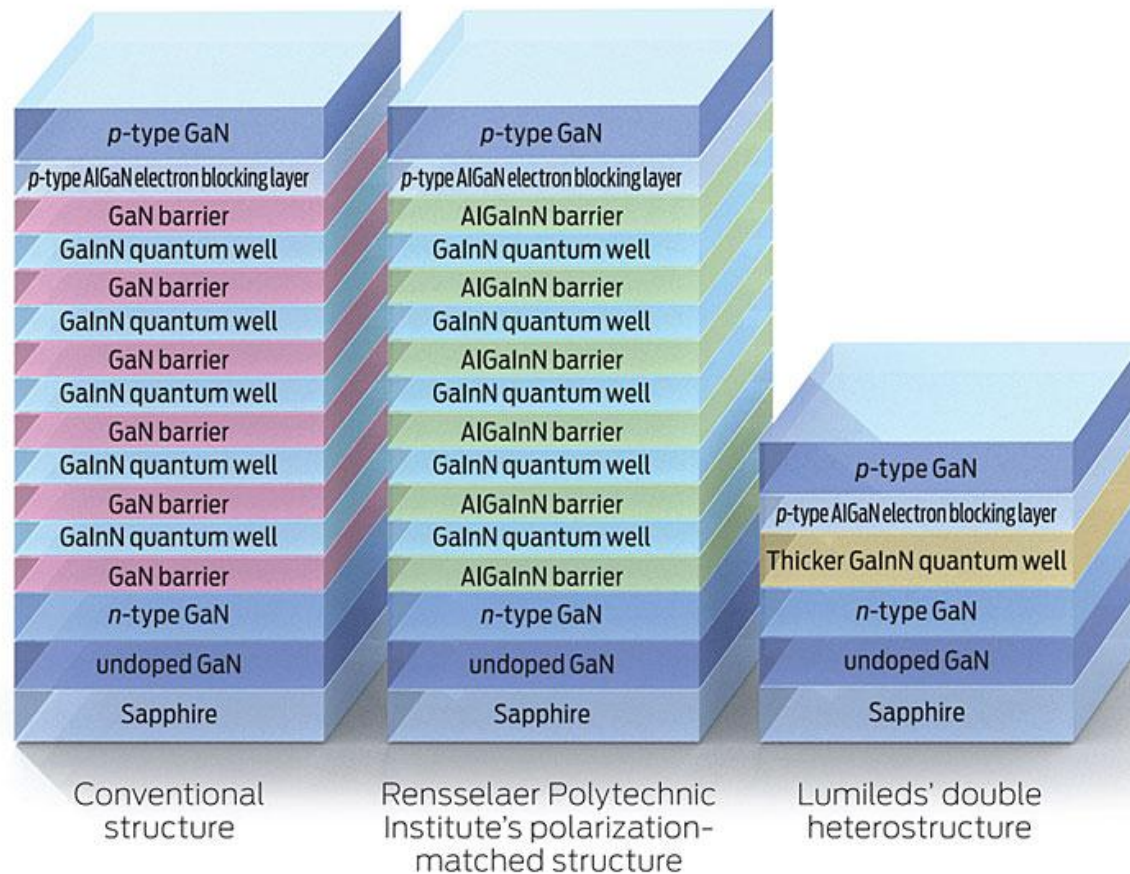
# Aplicatii majore LED

- ▶ Comunicatii
  - Infrarosu (InGaAsP)
- ▶ Vizibil
  - Spectru vizibil (GaAlAs)
- ▶ Iluminare
  - Putere ridicata, lumina alba (GaInN)



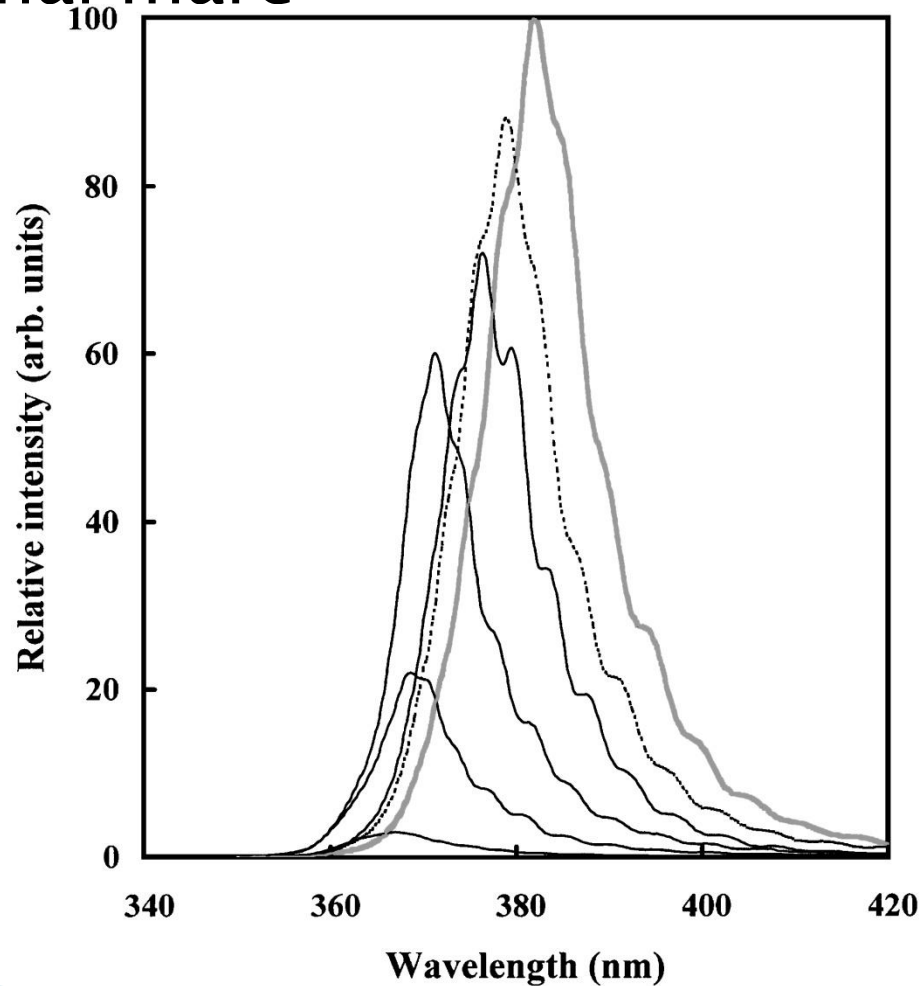
# LED albastru

- ▶ realizare: GaInN Quantum Well/GaN

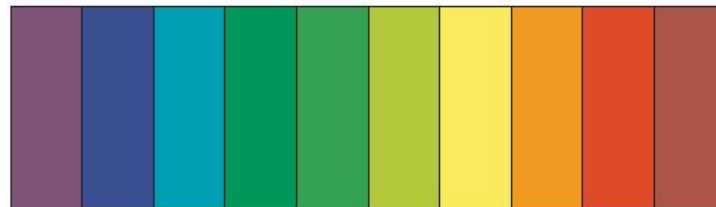
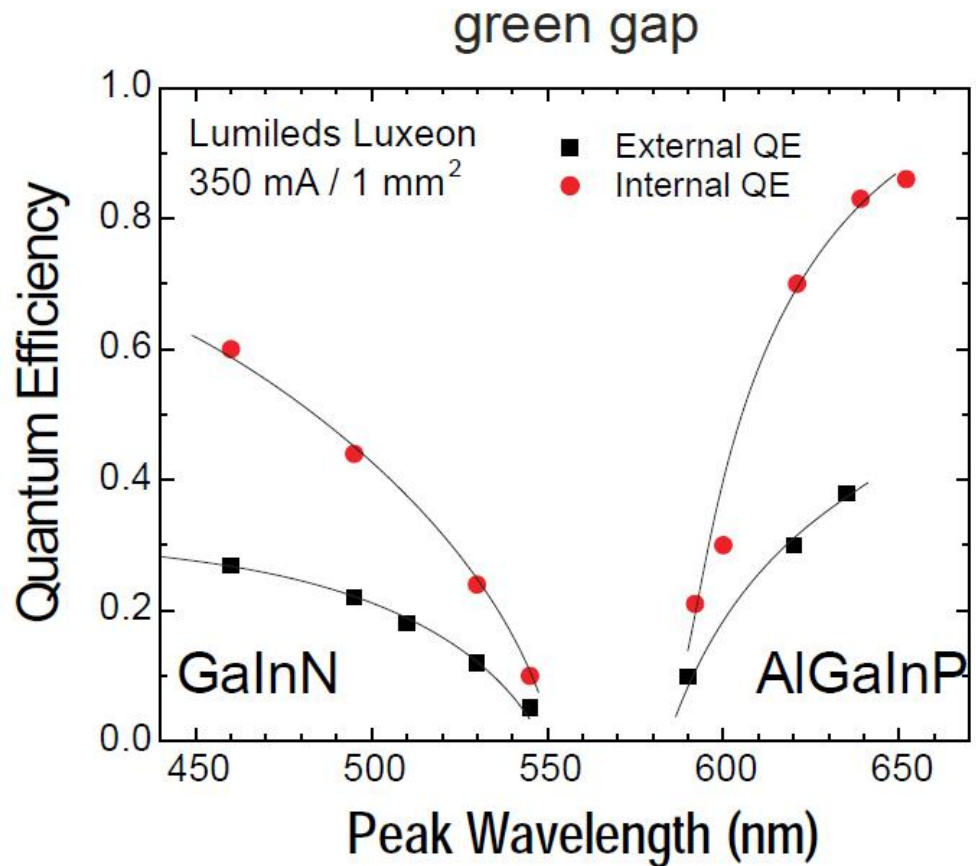


# Spectru LED albastru

- ▶  $\Delta\lambda$  relativ la  $\lambda$  mai mare



# Eficiencia cuantica




# Culori/materialiale - 1

Color	Wavelength (nm)	Voltage (V)	Semiconductor Material
Infrared	$\lambda > 760$	$\Delta V < 1.9$	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)
Red	$610 < \lambda < 760$	$1.63 < \Delta V < 2.03$	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Orange	$590 < \lambda < 610$	$2.03 < \Delta V < 2.10$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Yellow	$570 < \lambda < 590$	$2.10 < \Delta V < 2.18$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Green	$500 < \lambda < 570$	$1.9 < \Delta V < 4.0$	Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN) Gallium(III) phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP)

# Culori/materiale - 2

Color	Wavelength (nm)	Voltage (V)	Semiconductor Material
Blue	$450 < \lambda < 500$	$2.48 < \Delta V < 3.7$	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate — (under development)
Violet	$400 < \lambda < 450$	$2.76 < \Delta V < 4.0$	Indium gallium nitride (InGaN)
Purple	multiple types	$2.48 < \Delta V < 3.7$	Dual blue/red LEDs, blue with red phosphor, or white with purple plastic
Ultraviolet	$\lambda < 400$	$3.1 < \Delta V < 4.4$	Diamond (235 nm) Boron nitride (215 nm) Aluminium nitride (AlN) (210 nm) Aluminium gallium nitride (AlGaInN) — (down to 210 nm)
White	Broad spectrum	$\Delta V = 3.5$	Blue/UV diode with yellow phosphor

# Denumiri tipice – LED



Wavelength (nm)	Color Name
940	Infrared
880	Infrared
850	Infrared
660	Ultra Red
635	High Eff. Red
633	Super Red
620	Super Orange
612	Super Orange
605	Orange
595	Super Yellow
592	Super Pure Yellow
585	Yellow
4500K	"Incandescent" White
6500K	Pale White
8000K	Cool White
574	Super Lime Yellow
570	Super Lime Green
565	High Efficiency Green
560	Super Pure Green
555	Pure Green
525	Aqua Green
505	Blue Green
470	Super Blue
430	Ultra Blue



# Aplicatii majore LED

- ▶ Comunicatii
  - Infrarosu (InGaAsP)
- ▶ Vizibil
  - Spectru vizibil (GaAlAs)
- ▶ Illuminare
  - Putere ridicata, lumina alba (GaN)

# Premiul Nobel, Fizica, 2014



The image is a graphic announcement for the Nobel Prize in Physics 2014. It features a blue background with a gold Nobel Prize medal icon in the top left. The text is in both Swedish and English. At the top, it says "Nobelpriset i fysik 2014" and "The Nobel Prize in Physics 2014". Below this, the Swedish text "Nobelpriset i fysik 2014" is prominently displayed. To the right is the logo of the Royal Swedish Academy of Sciences, "KUNGL. VETENSKAPSKAS AKADEMIEN". Three portraits of the laureates are shown in a row: Isamu Akasaki, Hiroshi Amano, and Shuji Nakamura. Each portrait is accompanied by their name and affiliation. Below the portraits, the award citation is given in Swedish and English. At the bottom left, the date "2014-10-07" is shown, and at the bottom right, the copyright notice "© Kungl. Vetenskapsakademien" is present.

Nobelpriset i fysik 2014

The Nobel Prize in Physics 2014

KUNGL. VETENSKAPSKAS AKADEMIEN  
THE ROYAL SWEDISH ACADEMY OF SCIENCES

**Isamu Akasaki**  
Meijo University, Nagoya, Japan  
Nagoya University, Japan

**Hiroshi Amano**  
Nagoya University, Japan

**Shuji Nakamura**  
University of California,  
Santa Barbara, CA, USA

*"För uppfinningen av effektiva blå lysdioder vilka möjliggjort ljusstarka och energisnåla vita ljuskällor"*

*"For the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"*

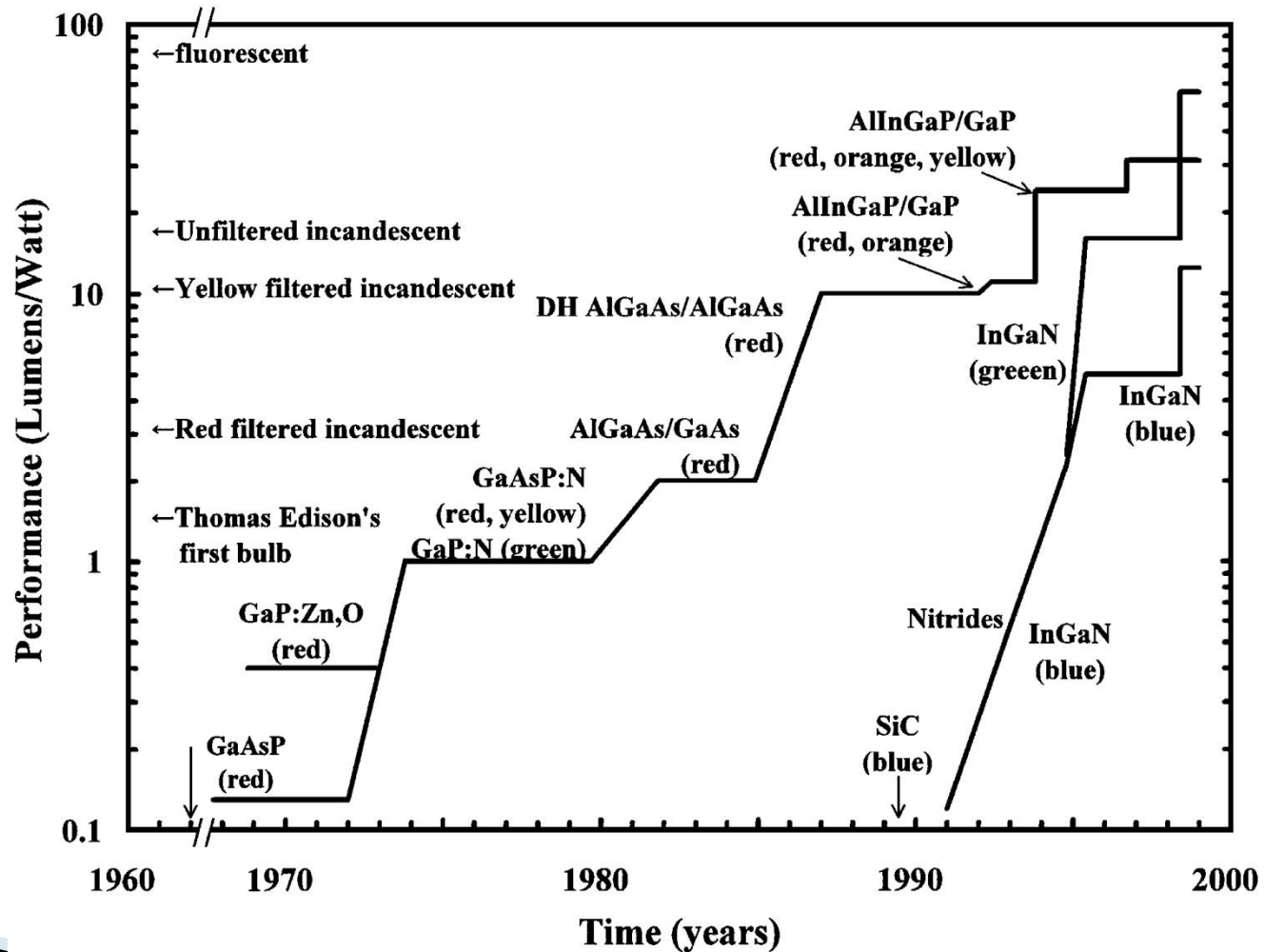
2014-10-07

© Kungl. Vetenskapsakademien

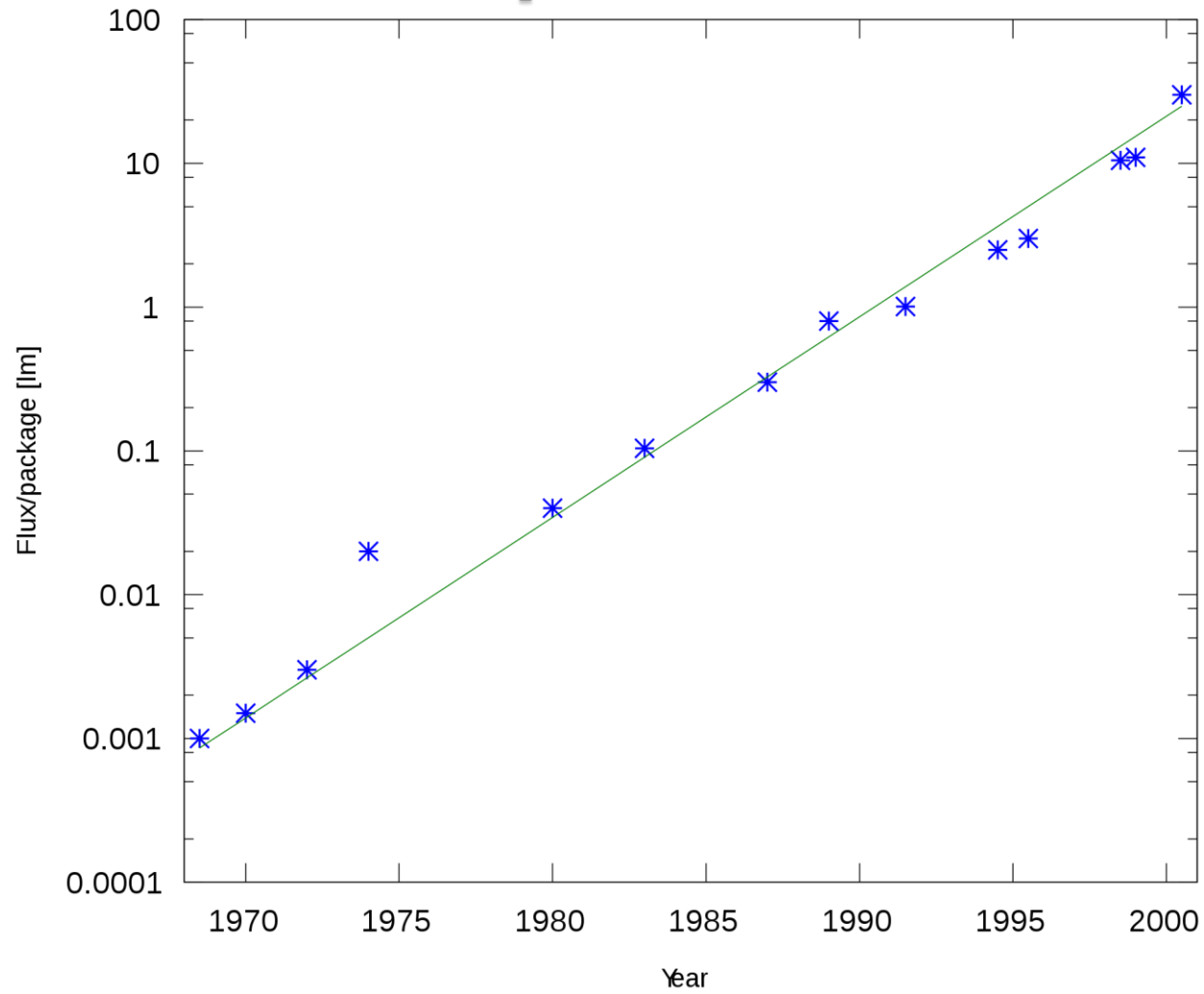
# Eficiența

- ▶ Bec cu incandescenta
  - 16 lm/W
- ▶ Tub fluorescent
  - 100 lm/W
- ▶ LED
  - curent: 250 lm/W
  - curand: 300 lm/W

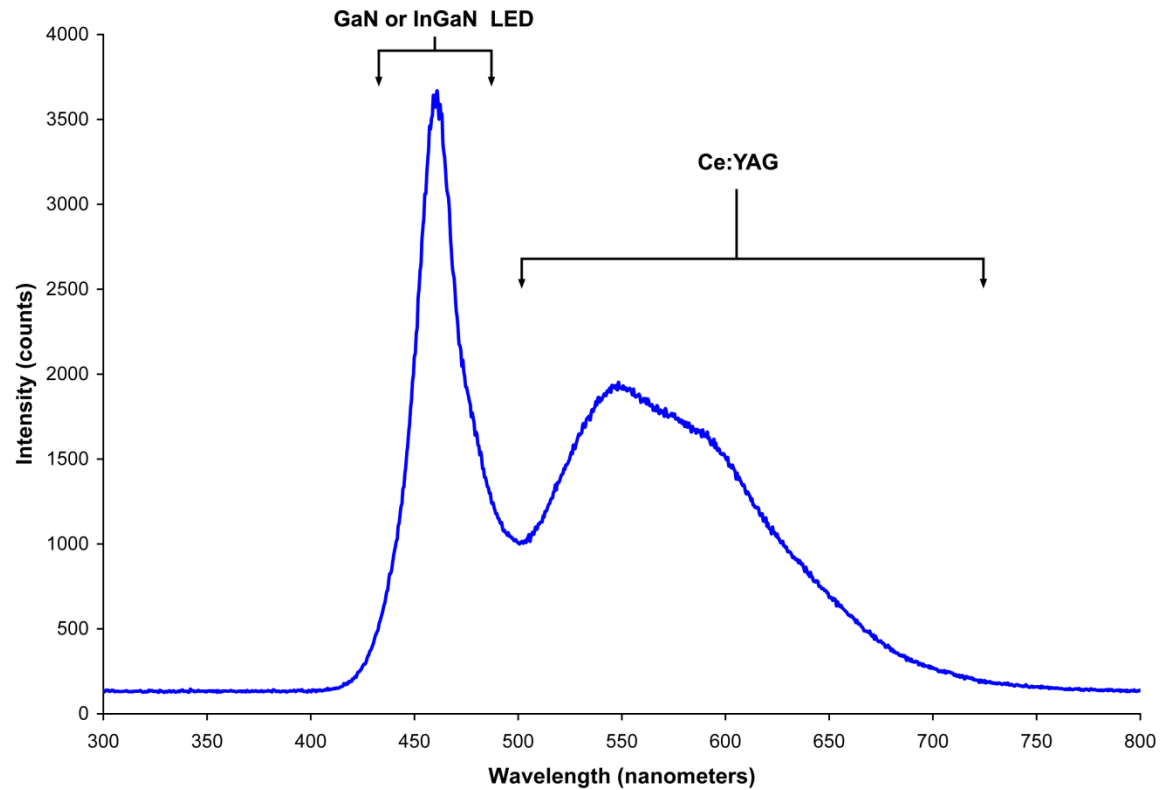
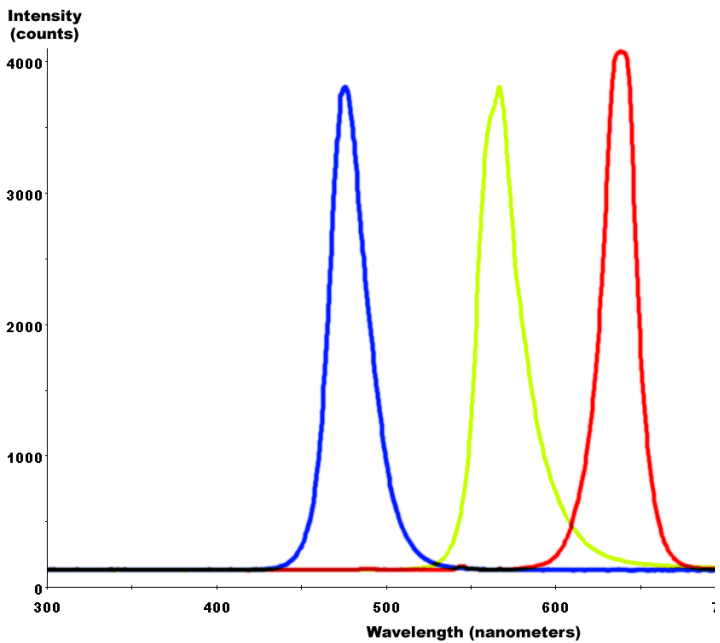
# Eficienta in timp



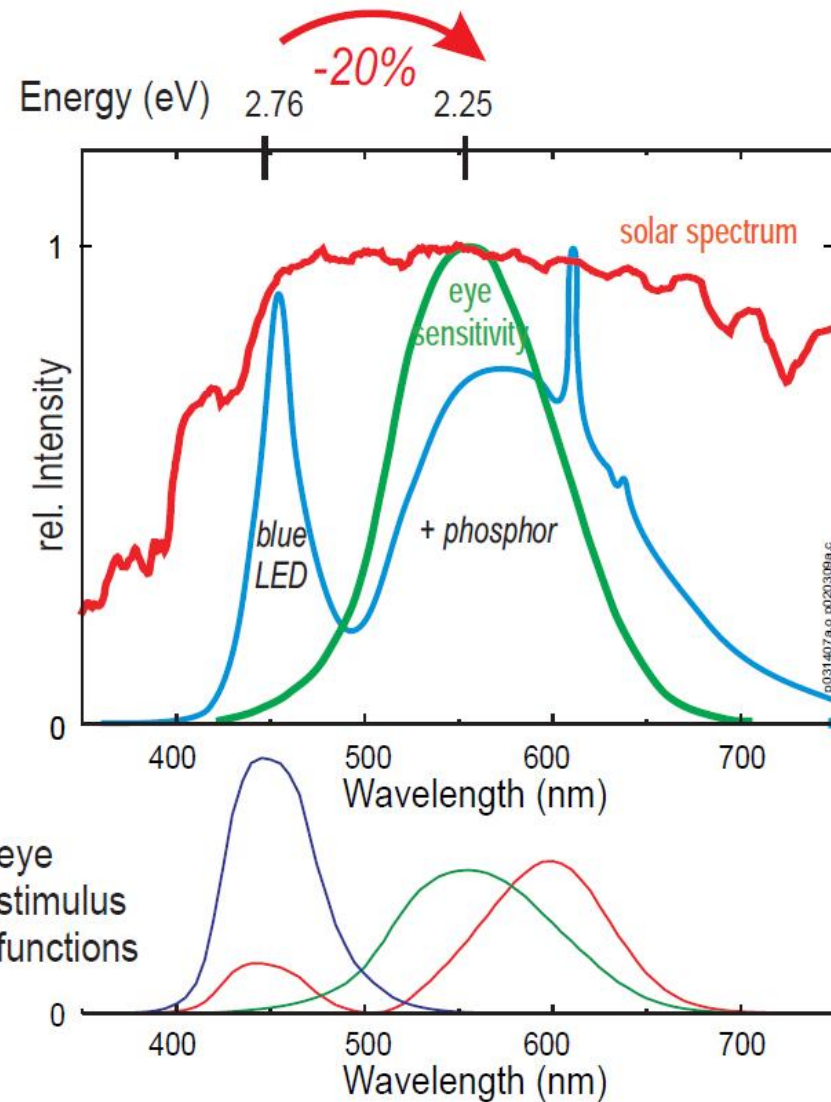
# Eficienta in timp



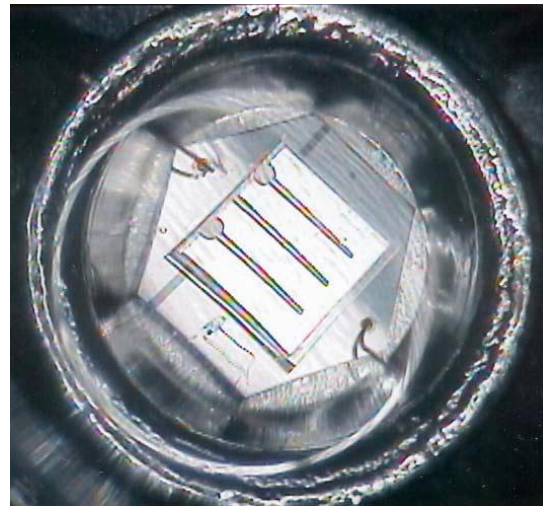
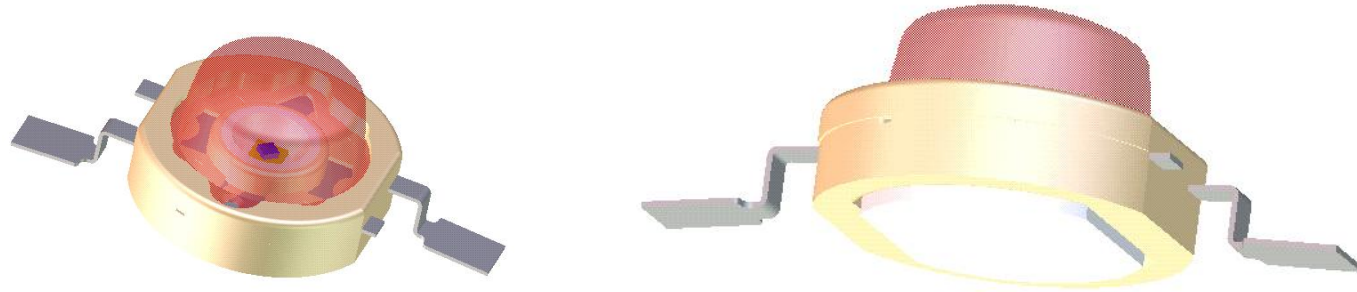
# Culoare alba



# Fosfor activat de LED albastru/UV

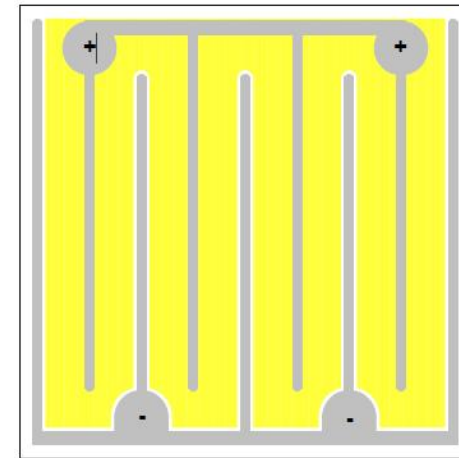
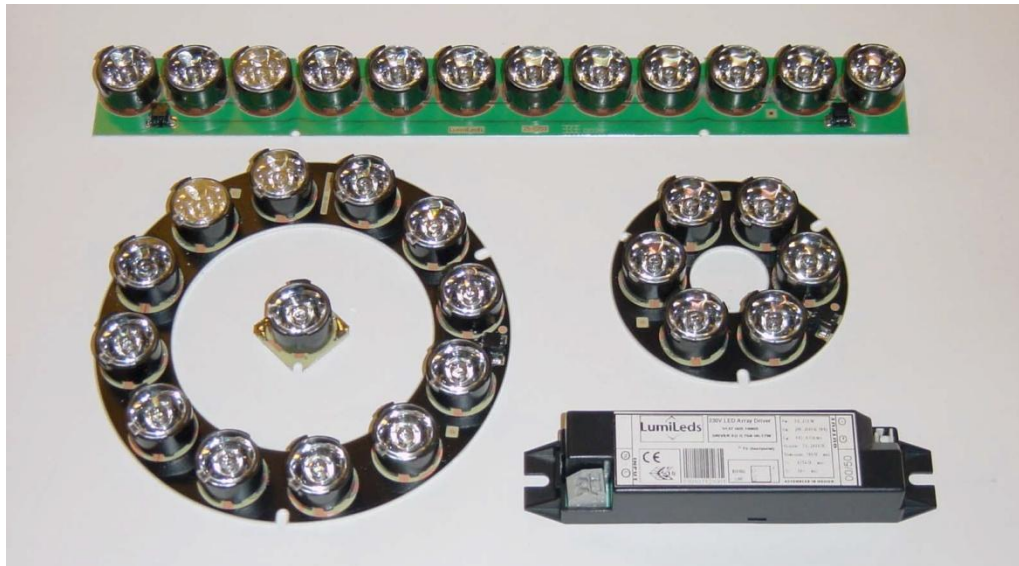


# Realizare LED de putere

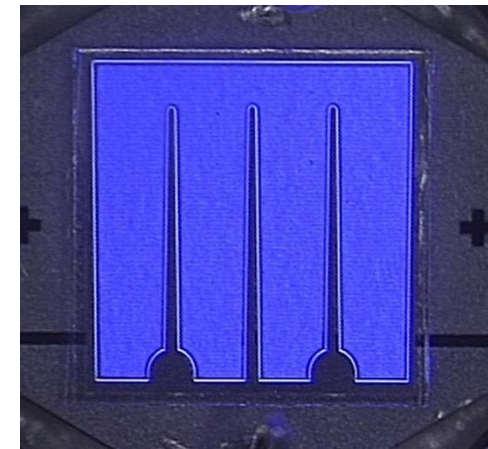
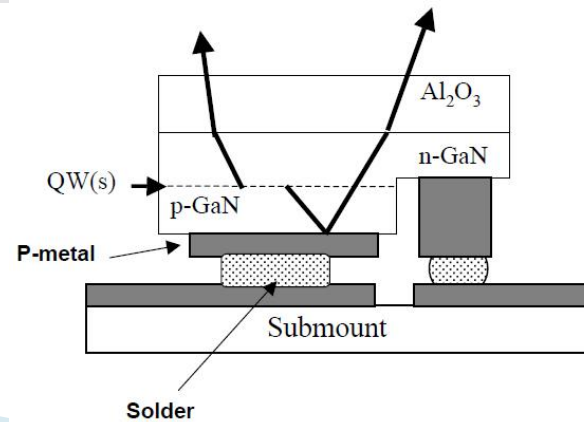




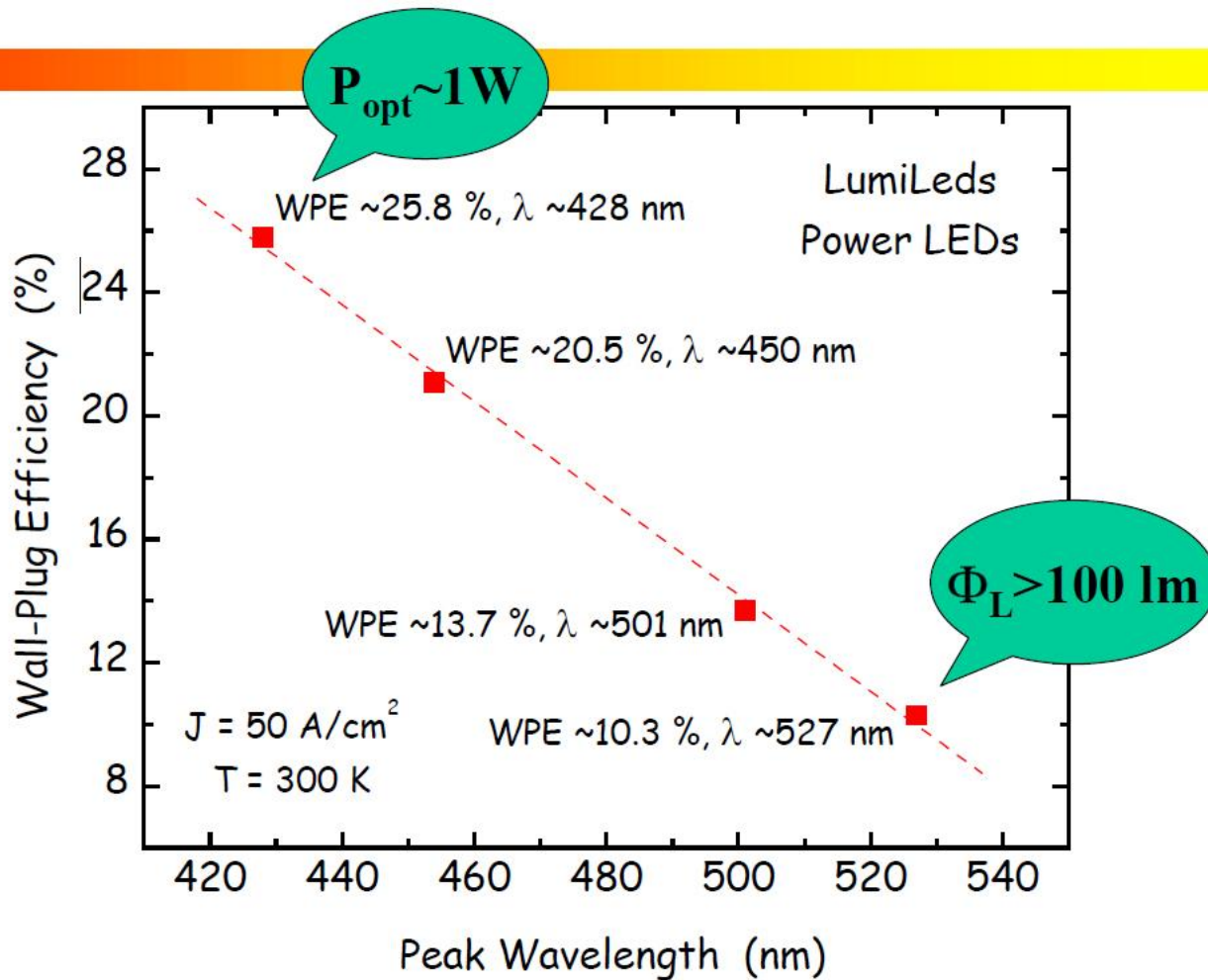
# Realizare LED de putere



$A_{\text{chip}} \sim 1 \times 1 \text{ mm}^2$ ;  $N = 4$



# Performanta

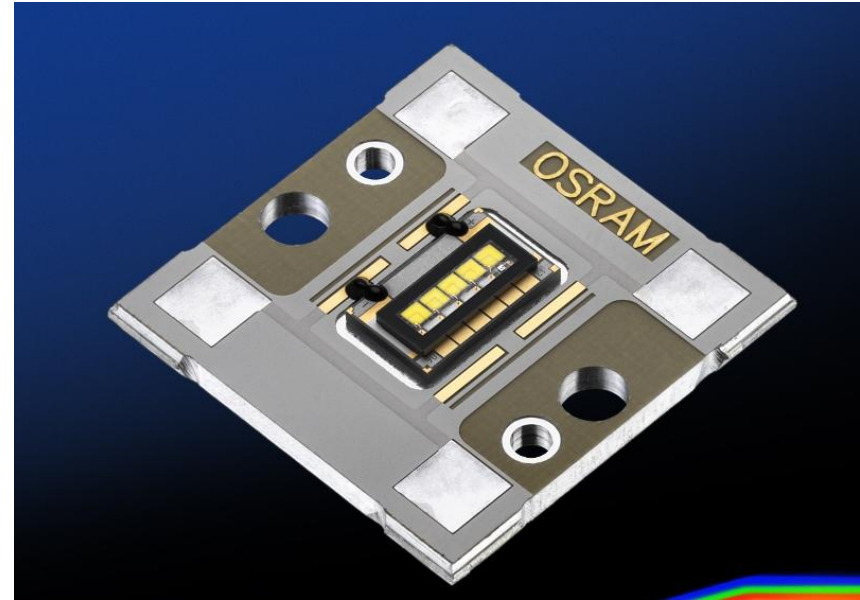


# Aplicatii

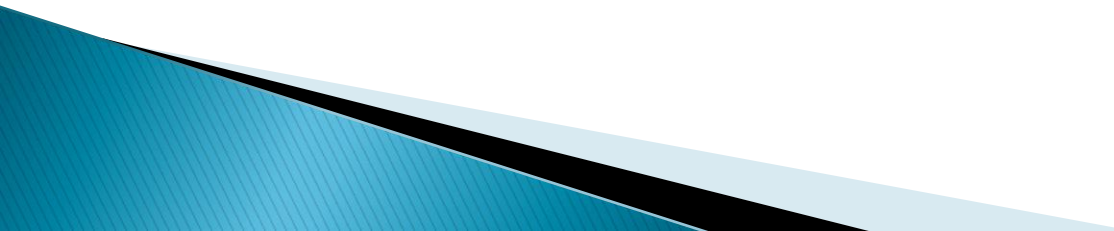
- ▶ auto



# Aplicatii

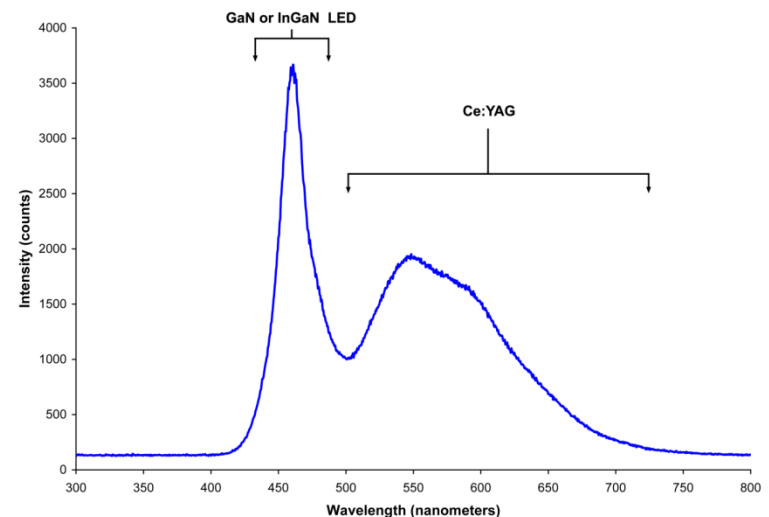
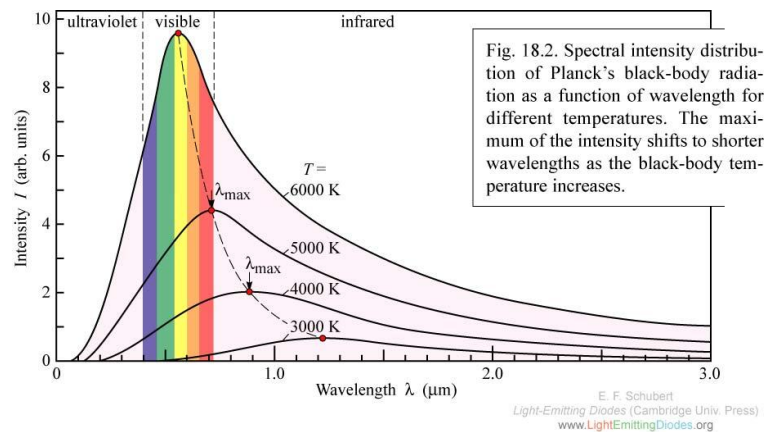


# Avantaje

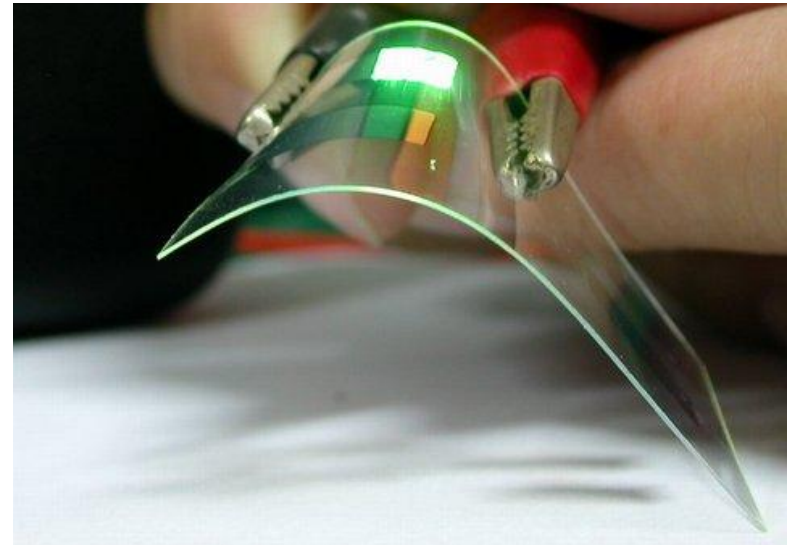
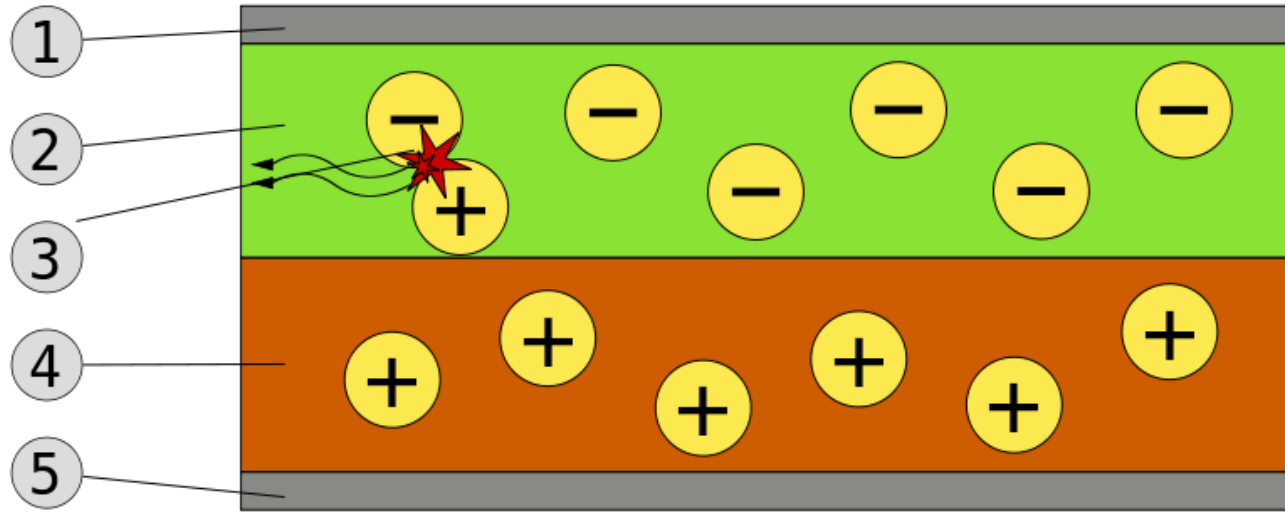
- ▶ Eficienta
  - ▶ Culoare usor de implementat (nativ)
  - ▶ Dimensiune
  - ▶ Timp de raspuns
  - ▶ Reglaj al intensitatii luminoase
  - ▶ Radiatie de caldura (IR) redusa
  - ▶ Timp de viata
  - ▶ Rezistenta la socuri
  - ▶ Directivitatea luminii (nativ)
- 

# Dezavantaje

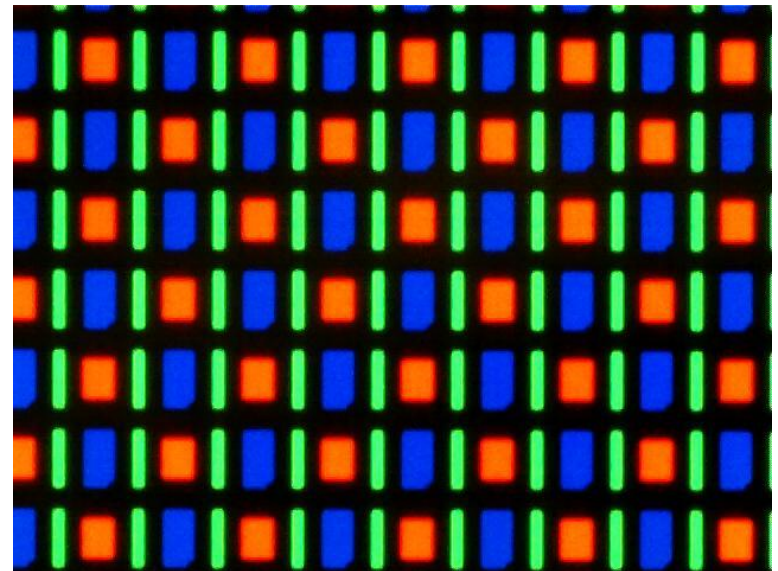
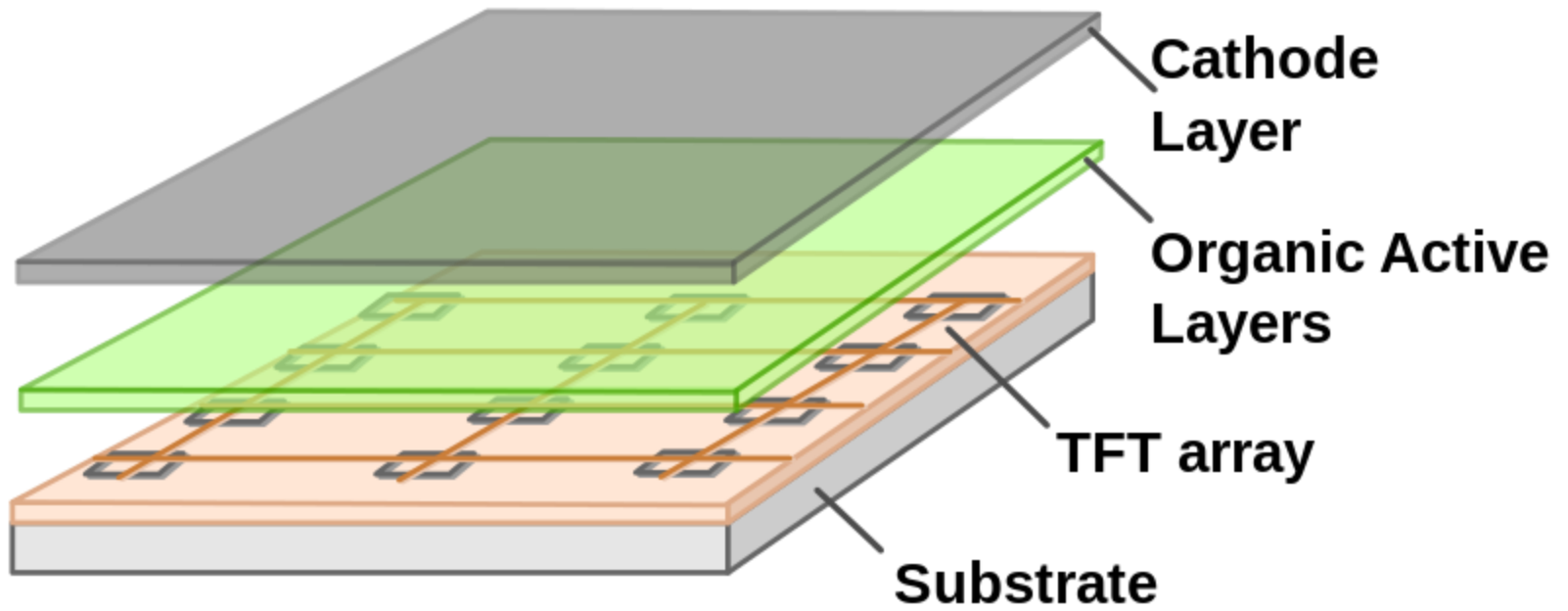
- ▶ Pret
- ▶ Dependenta de temperatura
- ▶ Sensibilitate la tensiune (prag)
- ▶ Calitatea luminii (corp negru)
- ▶ Directivitate (sursa de suprafata/punctuala)



# OLED



# AMOLED





# Contact

- ▶ Laboratorul de microunde si optoelectronica
- ▶ <http://rf-opto.etti.tuiasi.ro>
- ▶ [rdamian@etti.tuiasi.ro](mailto:rdamian@etti.tuiasi.ro)