Optoelectronică, structuri şi tehnologii

Curs 10
2015/2016

Examen/Colocviu

- Examen
  - Luni, S14, ora 18
  - Sambata, S14, ora 10

Recapitulare

Curs 9

Dioda Laser

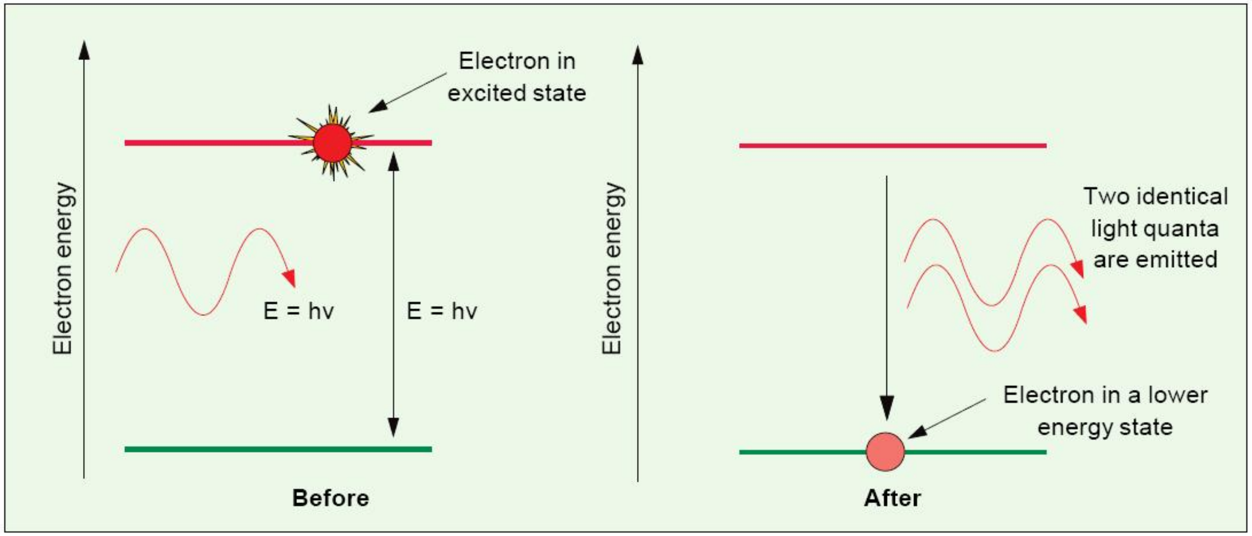
Capitolul 9

Caracteristici dioda laser

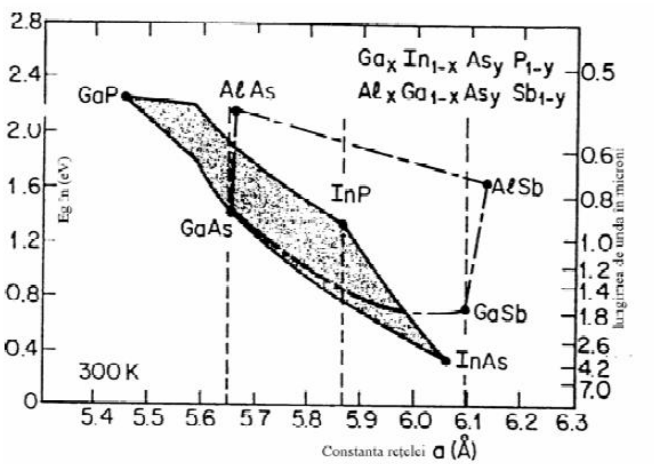
- Avantaje
  - Putere optica ridicata (50mW functionare continua, 4W functionare in impulsuri)
  - Precizie ridicata a controlului (impulsuri cu latimea de ordinul fs – femptosecunde) – viteza mare de lucru
  - Spectru ingust, teoretic LASER ofera o singura linie spectrala
  - Lumina coerenta si directiva (~80% poate fi cuplata in fibra)
- Dezavantaje
  - Cost (dispozitiv si circuit de comanda: controlul puterii si al temperaturii)
  - Durata de viata
  - Senzitivitate crescuta cu temperatura
  - Modulatie analogica dificila (de obicei cu dispozitive externe)
  - Lungime de unda fixa

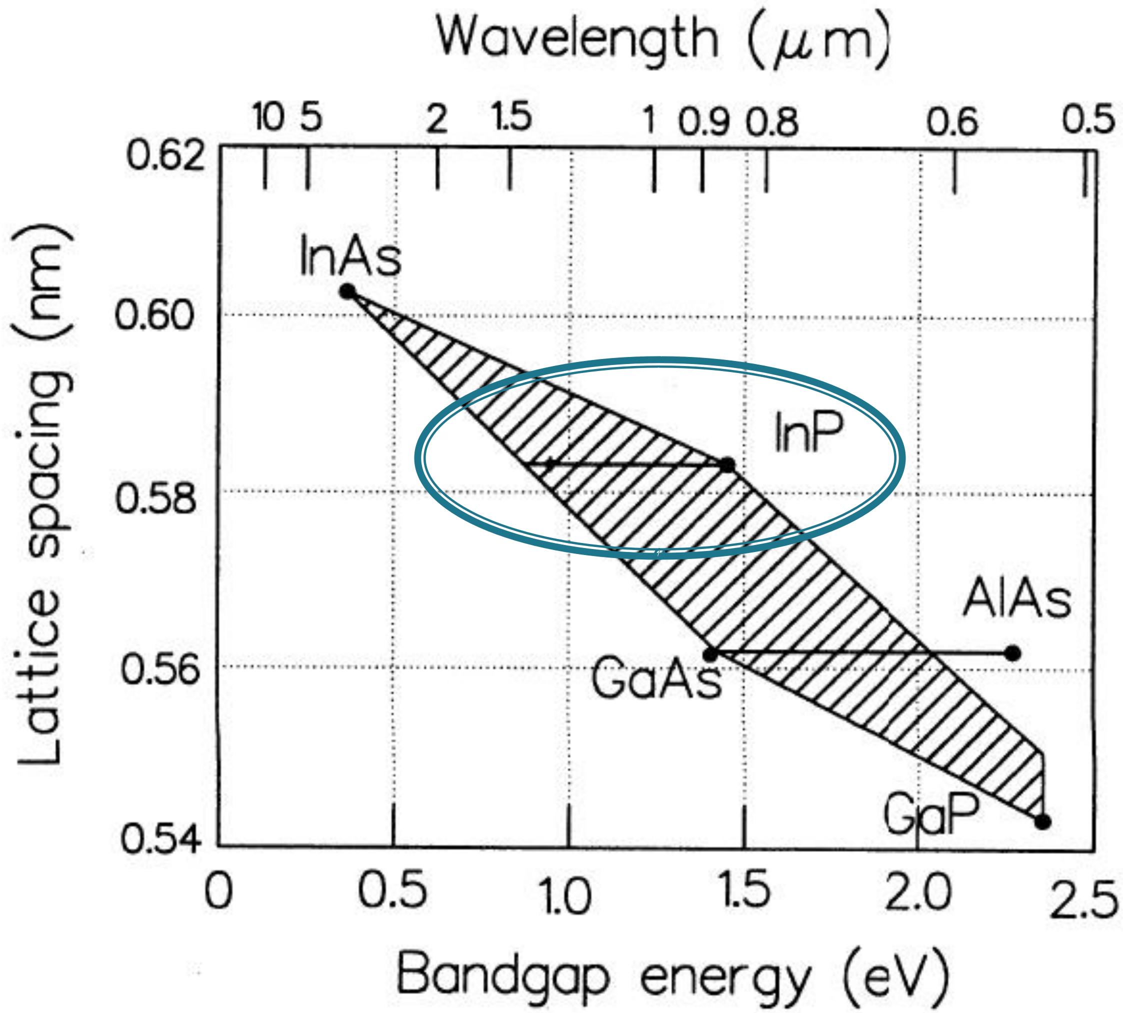
Dioda LASER – Principiu de operare

- Emisia stimulata – un foton incident cu energie corespunzatoare poate stimula emisia unui al doilea foton fara a fi absorbit
- Noul foton are aceeasi directie si faza cu fotonul incident, Lumina rezultata e coerenta



Dependenţa benzii interzise de constanta reţelei





Principii LASER

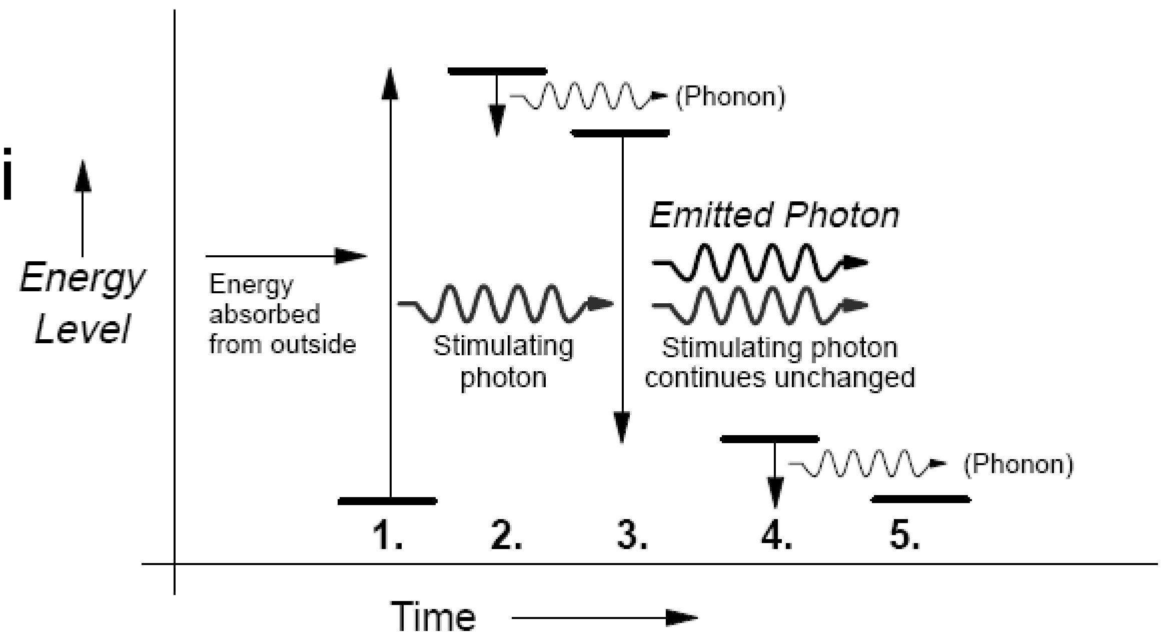
- Inversiune de populatie
  - necesara deoarece electronii au capabilitatea de a absorbi energie la aceeasi frecventa la care are loc emisia stimulata
  - se defineste probabilistic: probabilitatea de emisie stimulata sa fie mai mare decat probabilitatea de absorbtie

$$n_c \cdot p_e > n_v \cdot p_a$$

- Materialele capabile sa genereze inversiune de populatie au starea excitata metastabila

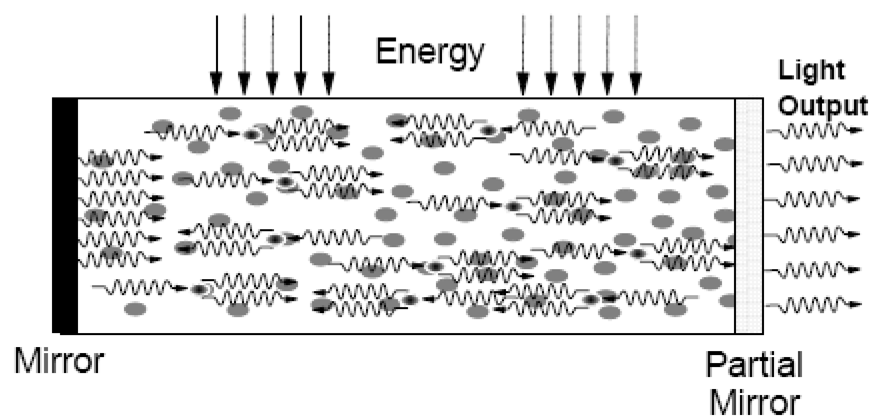
Materiale cu 4 nivele energetice

- La un material cu 4 nivele energetice tranzitia radianta a electronului (3) se termina intr-o stare instabila, starea de echilibru obtinandu-se prin emisia unui fonon
- Inversiunea de populatie se obtine mult mai usor datorita electronilor din starea intermediara

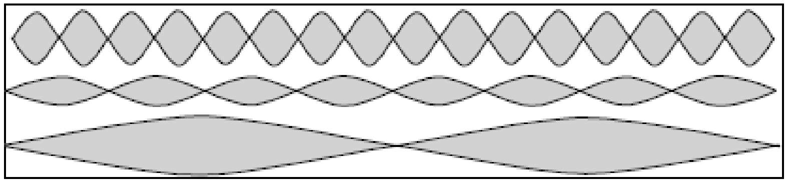


Dioda LASER – Principiu de realizare

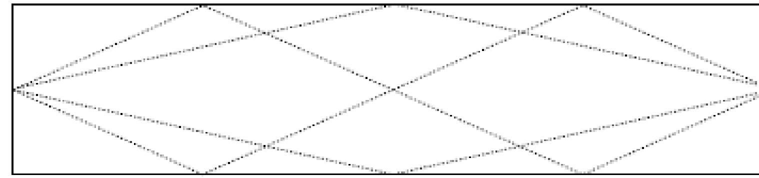
- Pentru ca emisia stimulata sa apara, fotonii emisi trebuie sa ramana in contact cu materialul o perioada mai mare de timp – 2 oglinzi necesare
- Pentru a permite extragerea radiatiei e necesar ca una din oglinzi sa fie partial reflectanta



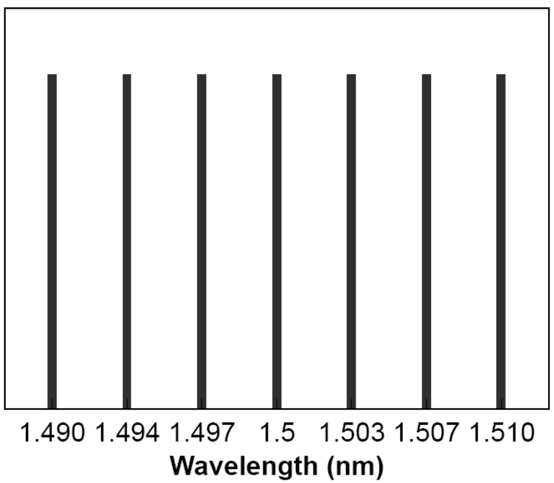
Spectrul diodei LASER



Longitudinal Modes



Lateral Modes

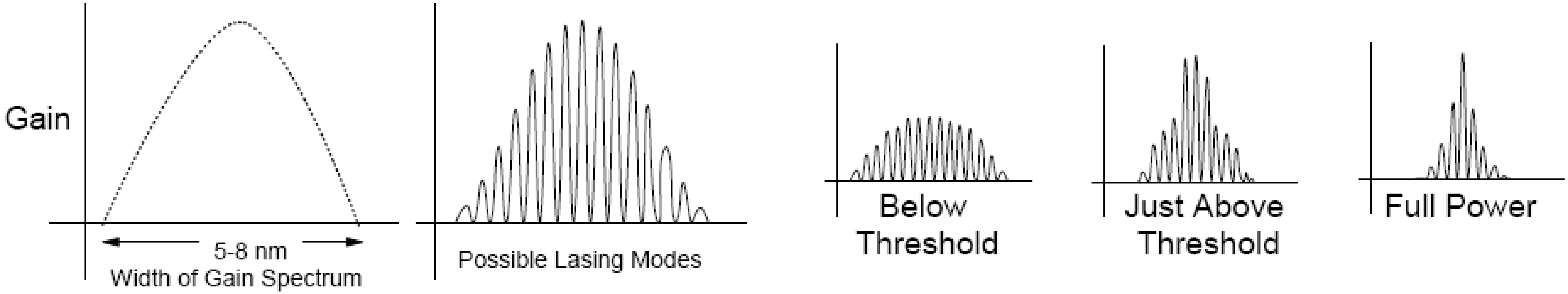


$$f_k = k \cdot \frac{c_0}{2 \cdot n \cdot L} \qquad \Delta f = \frac{c_0}{2 \cdot n \cdot L}$$

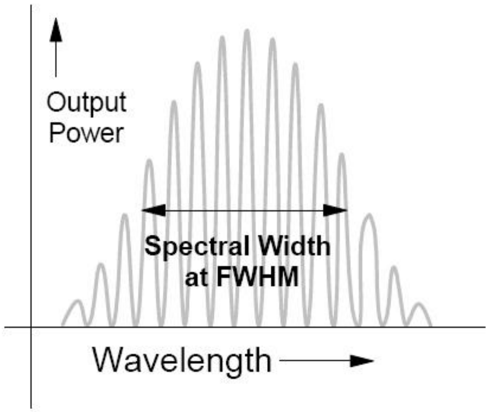
$$\Delta\lambda \cong \frac{\lambda_0^2}{2 \cdot n \cdot L}$$

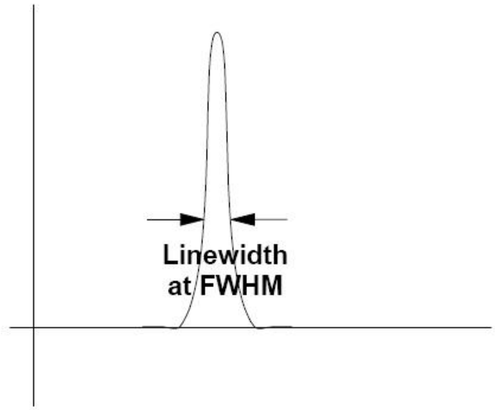
Spectrul diodei LASER

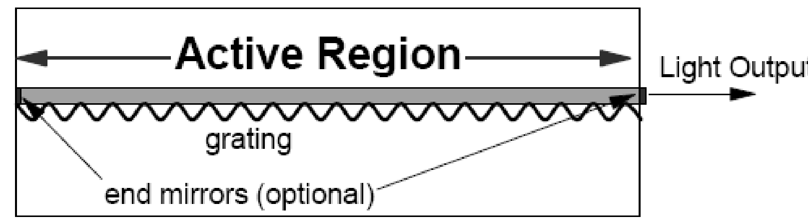
- Castigul diodei laser (eficacitatea aparitiei emisiei stimulate) depinde
  - de caracteristicile energetice ale materialului din care e realizata dioda
  - de energia pompata din exterior (curentul prin dioda)

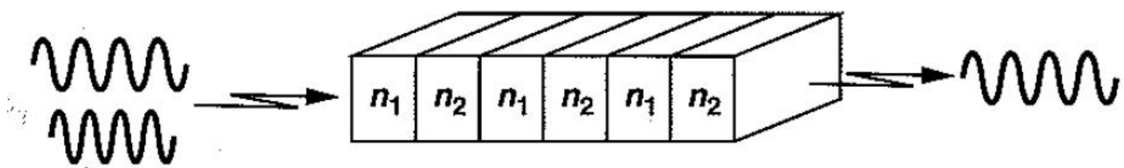


Distributed Feedback (DFB) Lasers

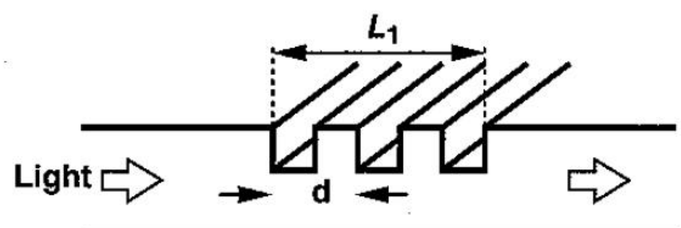








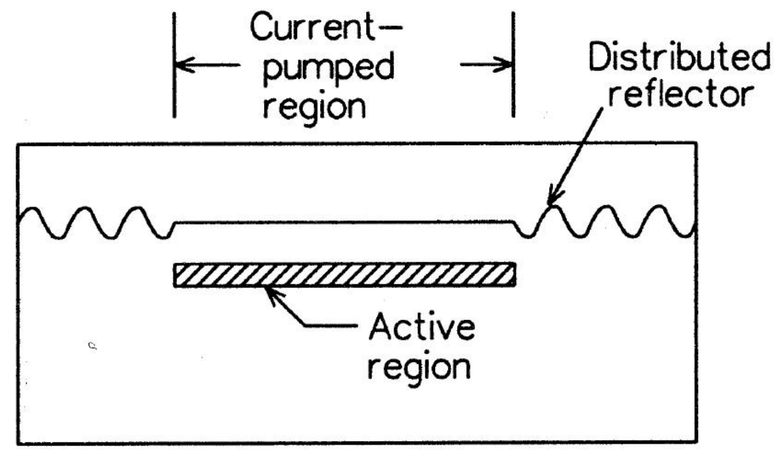
(a)

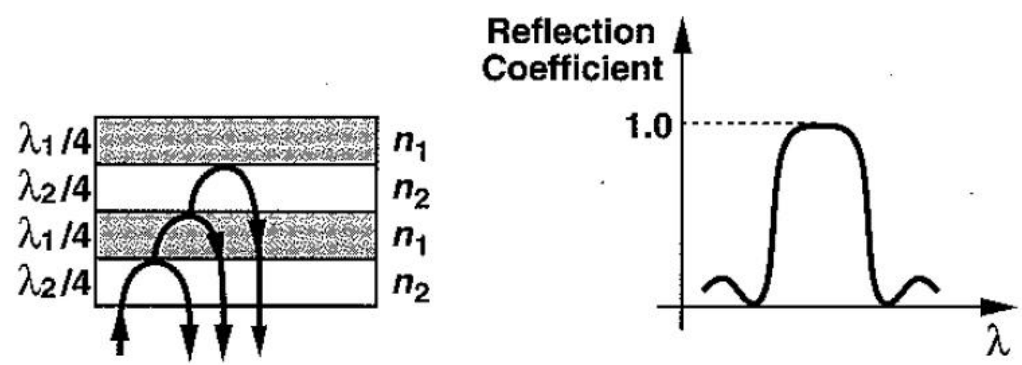


(b)

Distributed Bragg Reflector (DBR) Lasers

- Se utilizeaza suprafete reflective selective pentru filtrare optica



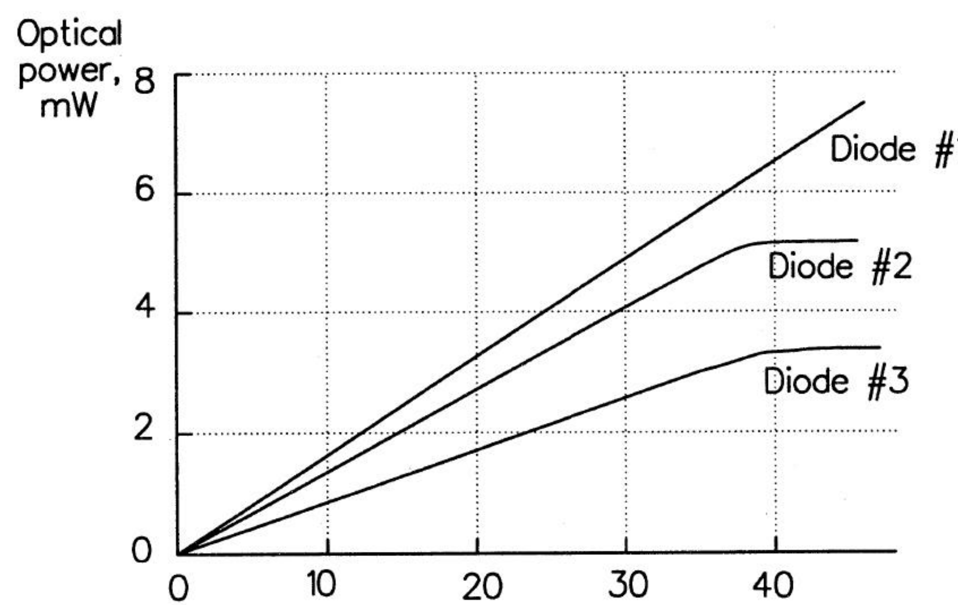


Caracteristica de raspuns a LED-urilor

- 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

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

- Tipic r=50μW/mA



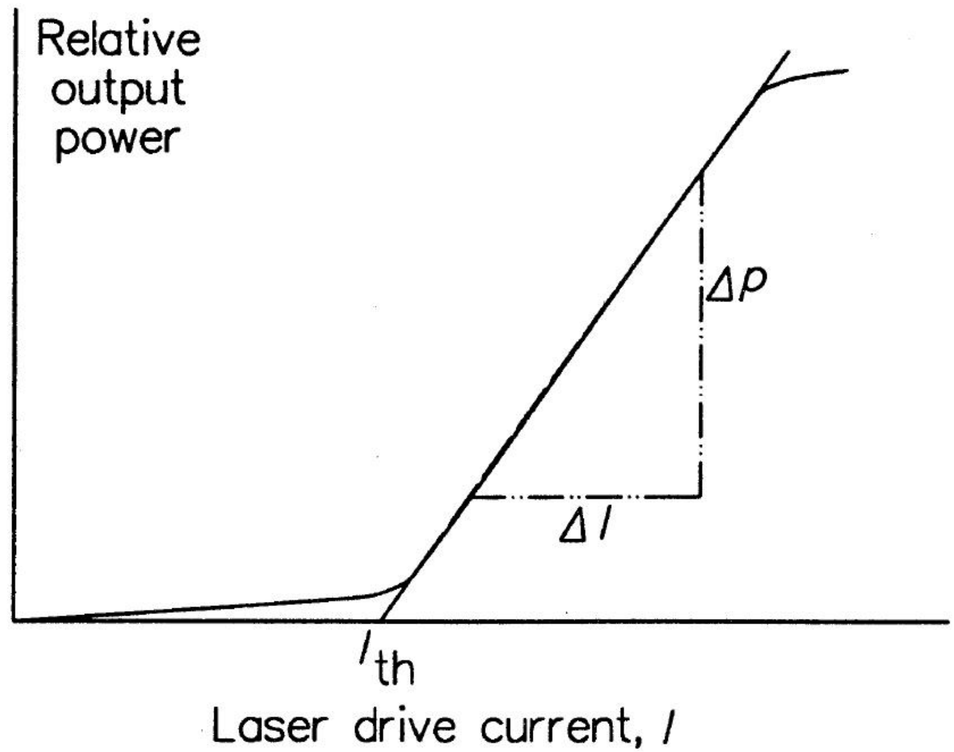
Caracteristici curent tensiune

- Amorsarea emisiei stimulate necesita pomparea unei anumite cantitati de energie – curent de prag

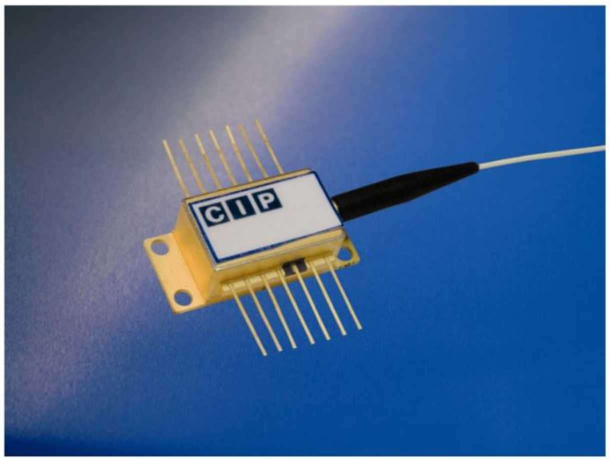
$$r = \frac{\Delta P_o}{\Delta I} \quad \left[\frac{W}{A}\right]$$

$$I > I_{th}$$

$$P_o = r \cdot \left(I - T_{th}\right)$$

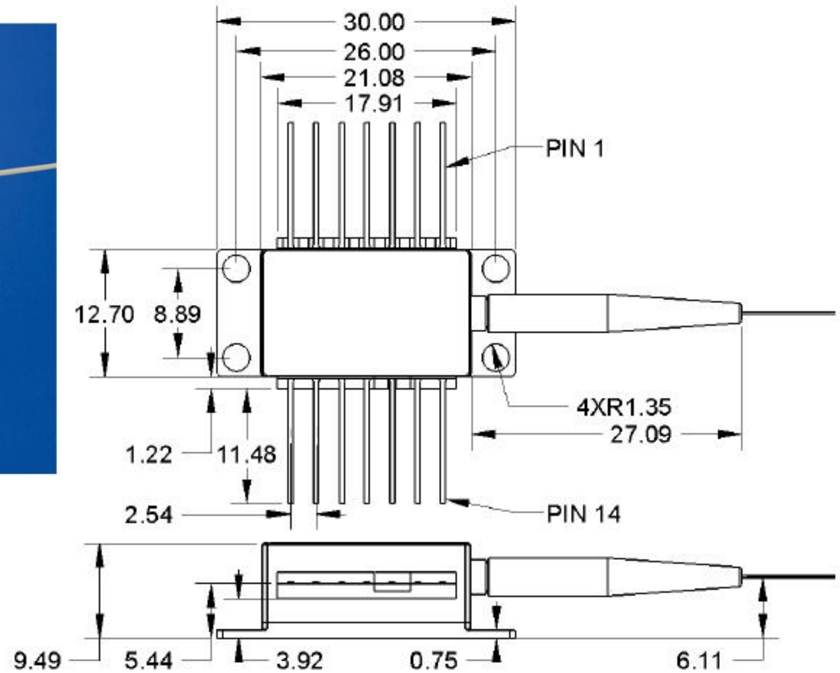


1550nm DFB Laser



Mechanical Drawing

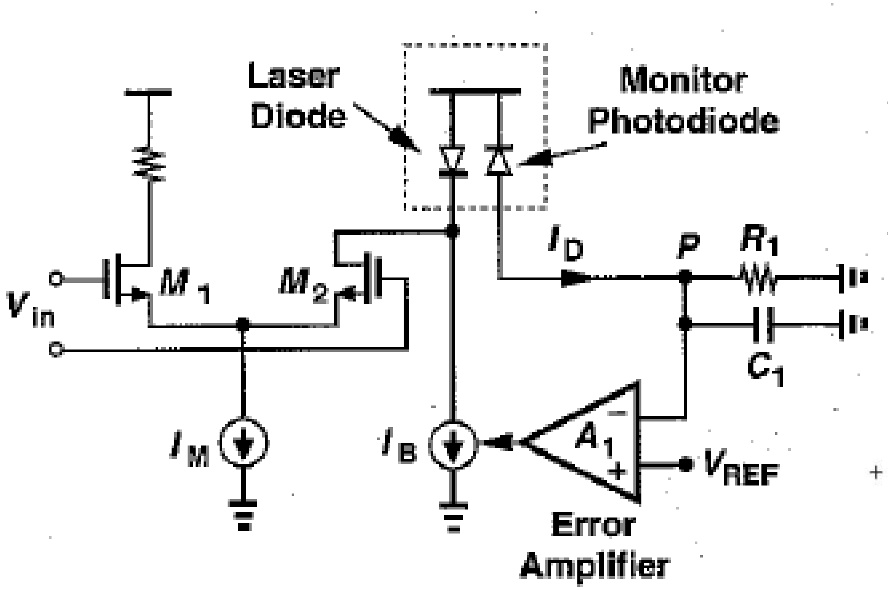
All units in mm



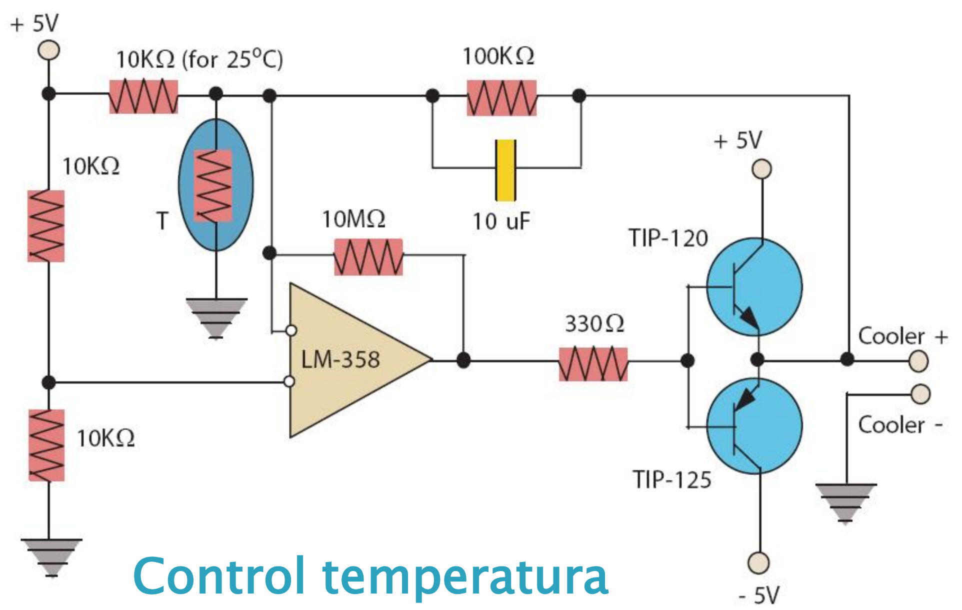
Pin out

Pin	Description
1	Thermistor
2	Thermistor
3	Laser Cathode (Bias)
4	Monitor PD Anode
5	Monitor PD Cathode
6	TEC +
7	TEC -
8	Case GND, Laser Anode
9	Case GND, Laser Anode
10	Case GND, Laser Anode
11	Case GND, Laser Anode
12	Laser Cathode (modulation)
13	Case GND, Laser Anode
14	Case GND, Laser Anode

Control dioda LASER



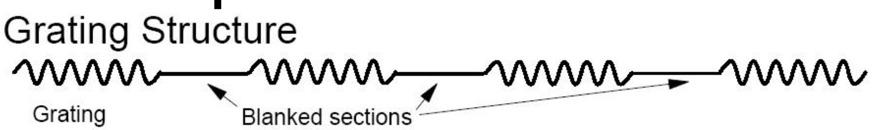
Control putere optica



Control temperatura

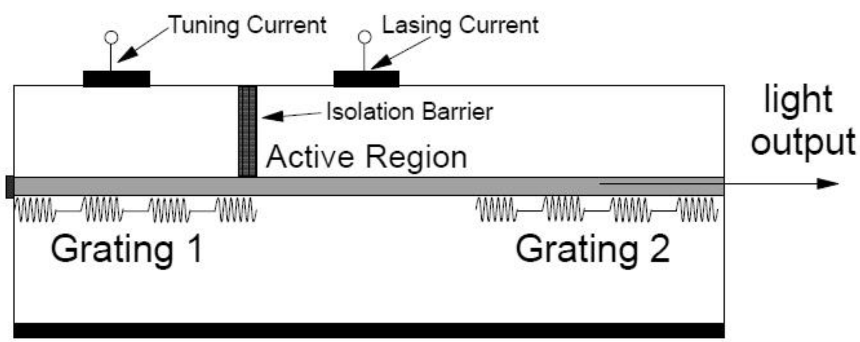
Diode laser reglabile

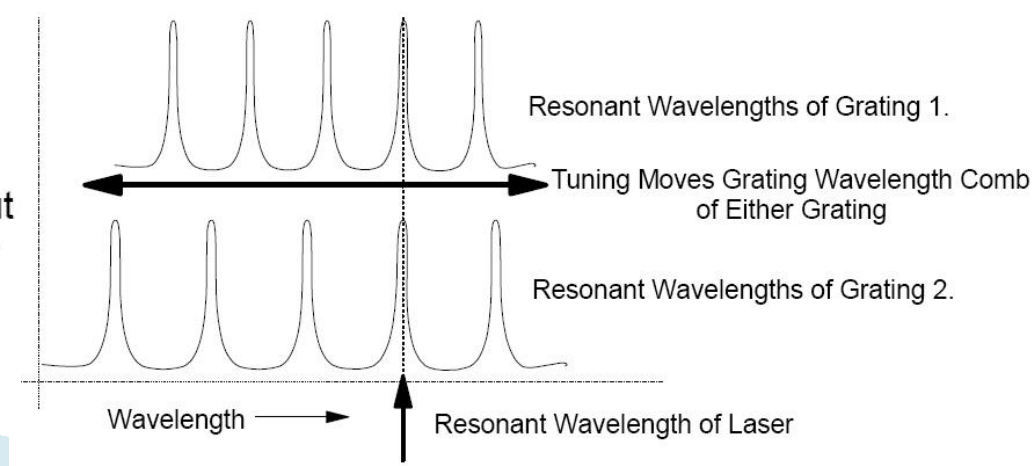
- Dezavantajul metodelor anterioare e dat de limita redusa a reglajului (~10nm)
- Reflectorul Bragg esantionat (periodic) produce spectru de filtrare discret



Dezavantaj : reglajul e discret

- Regland unul din reflectori se obtine rezonanta la suprapunerea celor doua spectre

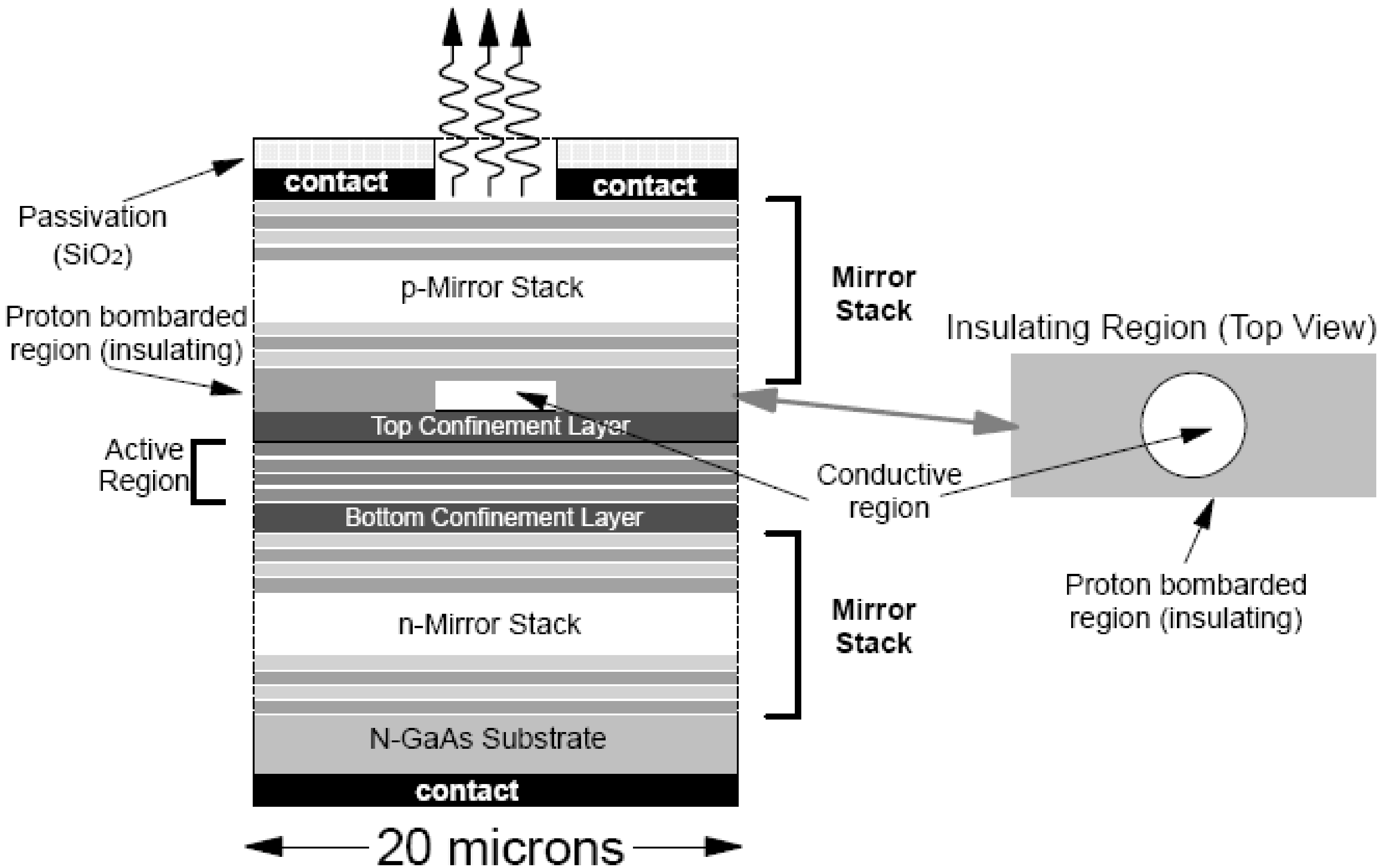




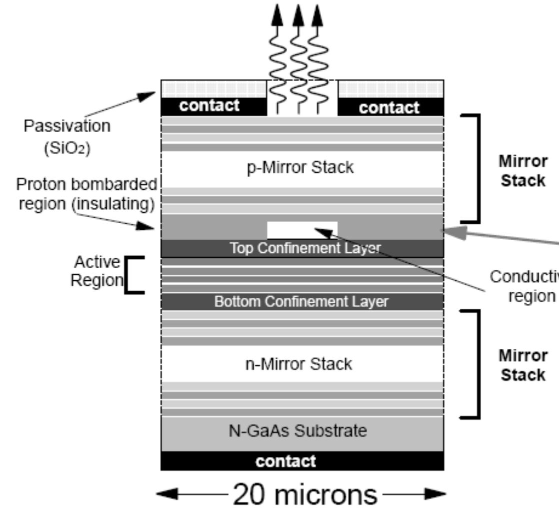
Continuare

Curs 10

Vertical Cavity Surface Emitting Lasers (VCSEL)



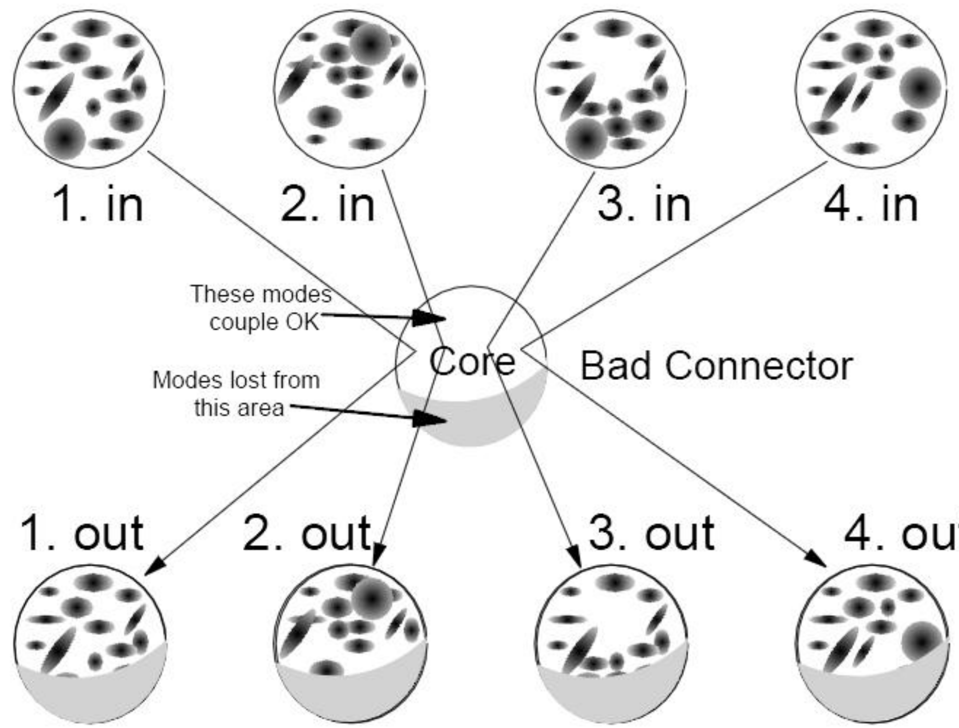
Vertical Cavity Surface Emitting Lasers (VCSEL)



- Oglinzile pot fi realizate din straturi succesive din semiconductori cu indici de refractie diferiti – reflector Bragg
- Prelucrarea laterala se rezuma la taierea materialului
    - Caracteristici
        - puteri de ordinul 1mW
        - lungimi de unda 850 si 980 nm
        - radiatie de iesire circulara cu divergenta redusa
        - Curenti de prag foarte mici (5mA) si putere disipata redusa
        - circuite de control speciale nu sunt necesare
        - Banda de modulatie mare (2.4GHz)
        - Stabilitate mare cu temperatura si durata de viata

VCSEL

- Caracteristici
  - VCSEL produce mai multe moduri transversale
    - insensibila la pierderile selective la mod din fibrele multimod (principala limitare in utilizarea diodelor laser in fibrele multimod)



Parametri dioda LASER

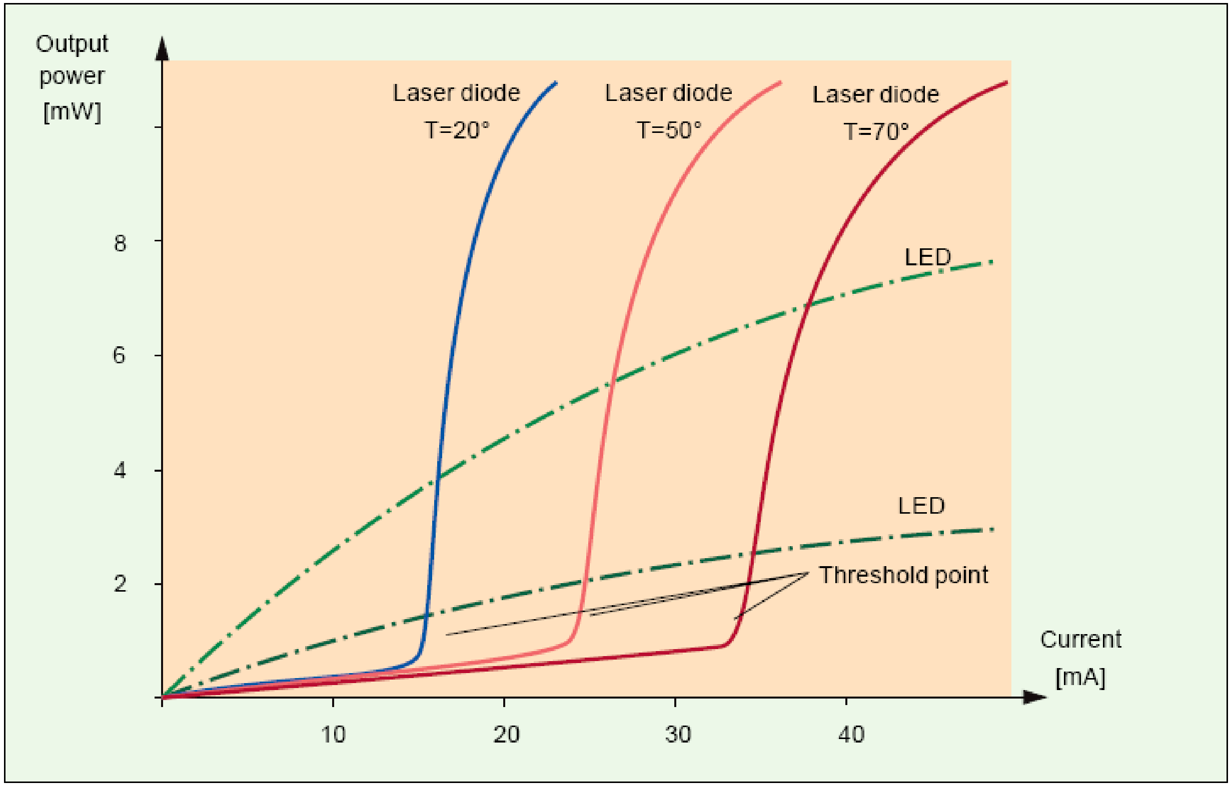
Dependenta de temperatura

- Dependenta de temperatura a curentului de prag este exponentiala
- $$I_{th} = I_0 \cdot e^{T/T_0}$$
- I_0 e o constanta determinata la temperatura de referinta

Material	Lungime de unda	T_0
InGaAsP	1300 nm	60÷70 K
InGaAsP	1500 nm	50÷70 K
GaAlAs	850 nm	110÷140 K

Temperatura si îmbatrânire

- Curentul de prag variaza cu temperatura si cu timpul
- Variatia tipica 1-2%/°C



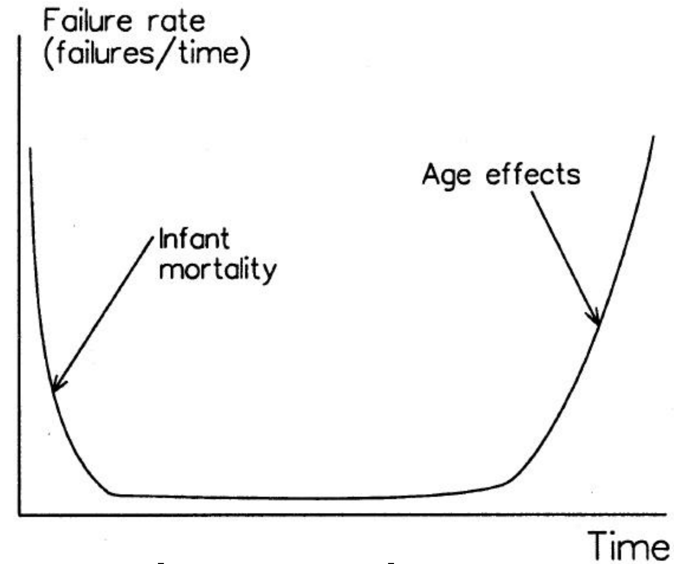
Degradare in timp

- Puterea scade in timp exponential

$$P(t) = P_0 \cdot e^{-t/\tau_m}$$

- τ_m – timpul de viata
- Diodele laser sunt supuse la conditii extreme de lucru
  - densitati de curent in zona activa $2000 \div 5000 A/cm^2$
  - densitati de putere optica: $10^5 \div 10^6 W/cm^3$
- Diverse definitii ale timpului de viata fac comparatiile dificile

Degradare in timp



- Cresterea curentului duce la scaderea duratei de viata

$$\tau_m \sim J^{-n}$$

  - n = 1.5÷2 (empiric)
  - dublarea curentului duce la scaderea de 3-4 ori a duratei de viata
- Cresterea temperaturii duce la scaderea duratei de viata

$$\tau_m \sim e^{E/kT}$$

  - E = 0.3÷0.95eV (valoarea tipica in teste 0.7eV)
  - cresterea temperaturii cu 10 grade injumatateste durata de viata

Parametri

- Coerenta radiatiei emise
  - LED: $t_c \approx 0.5ps$, $L_c \approx 15\mu m$
  - LASER : $t_c \approx 0.5ns$, $L_c \approx 15cm$

$$L_c = c \cdot t_c = \frac{\lambda_0^2}{\Delta\lambda}$$

- Stabilitatea frecventei
  - detectie necoerenta (modulatie in amplitudine)
  - mai ales in sistemele multicanal
- Timpul de raspuns
- Viteza, interval de reglaj

Caracteristici curent tensiune

- Amorsarea emisiei stimulate necesita pomparea unei anumite cantitati de energie – curent de prag

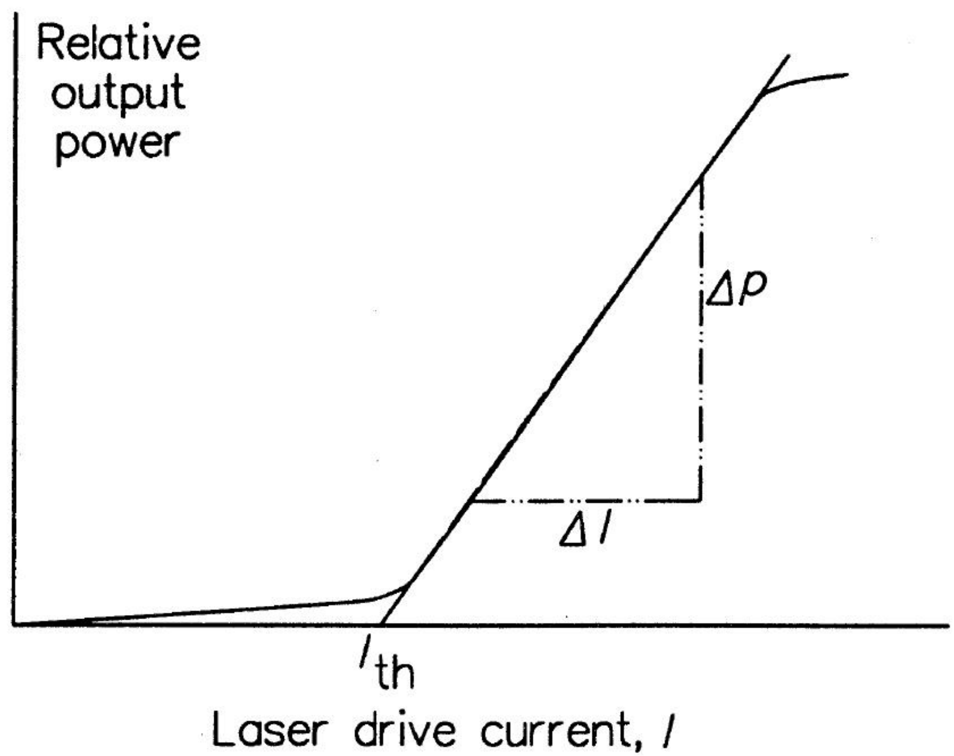
$I < I_{th}$ regim LED

ineficient!

$I > I_{th}$ regim LASER

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

Apare saturare la nivele mari de curent



Eficienta

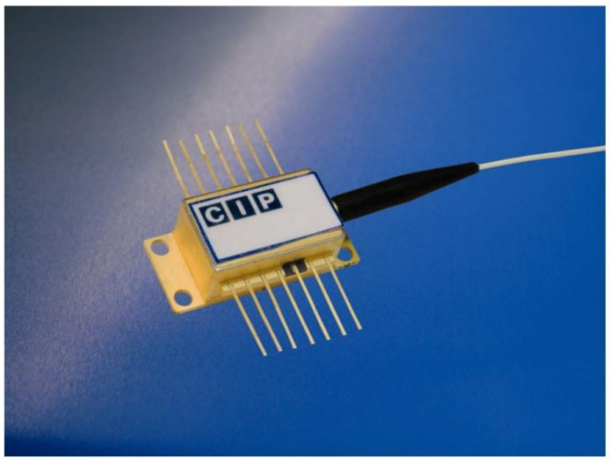
- eficienta de conversie electro-optic (randament)

$$\eta = \frac{P_{out}(optic)}{P_{in}(electric)} = \frac{P_o}{V_f \cdot I_f} \approx \frac{r \cdot (I_f - I_{th})}{V_f \cdot I_f}$$

- tipic, randamente sub 10% sunt intalnite
- eficienta cuantica
  - interna
  - externa

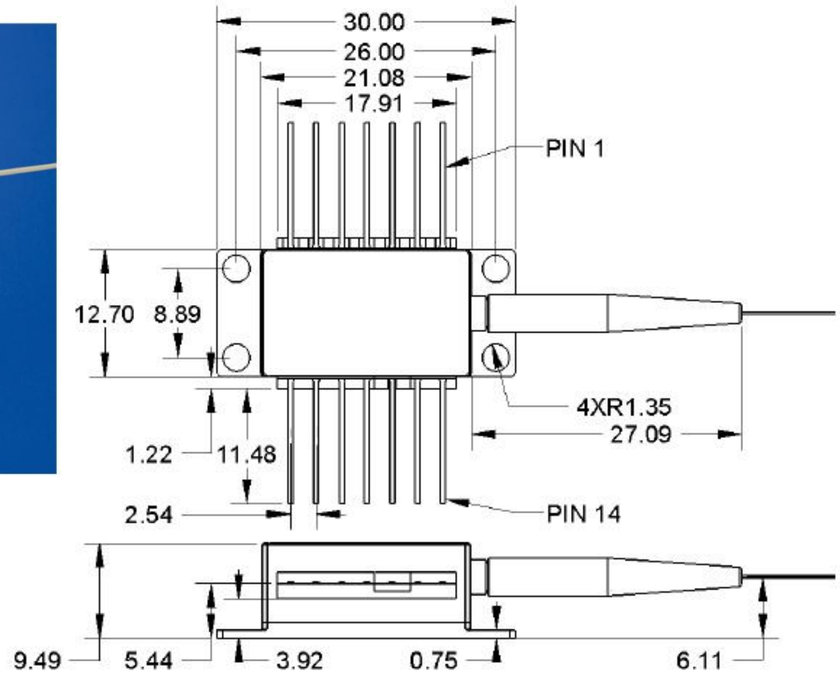
$$\eta = \frac{n_f}{n_e} \qquad \eta = \frac{\Delta P / h\nu}{\Delta I / e} = r \cdot \frac{e}{h\nu}$$

1550nm DFB Laser



Mechanical Drawing

All units in mm



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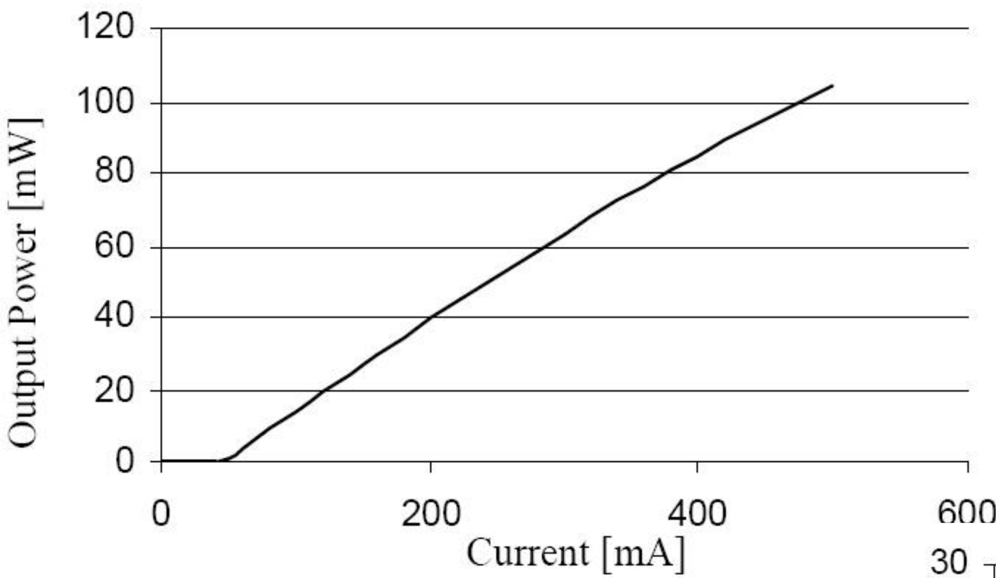
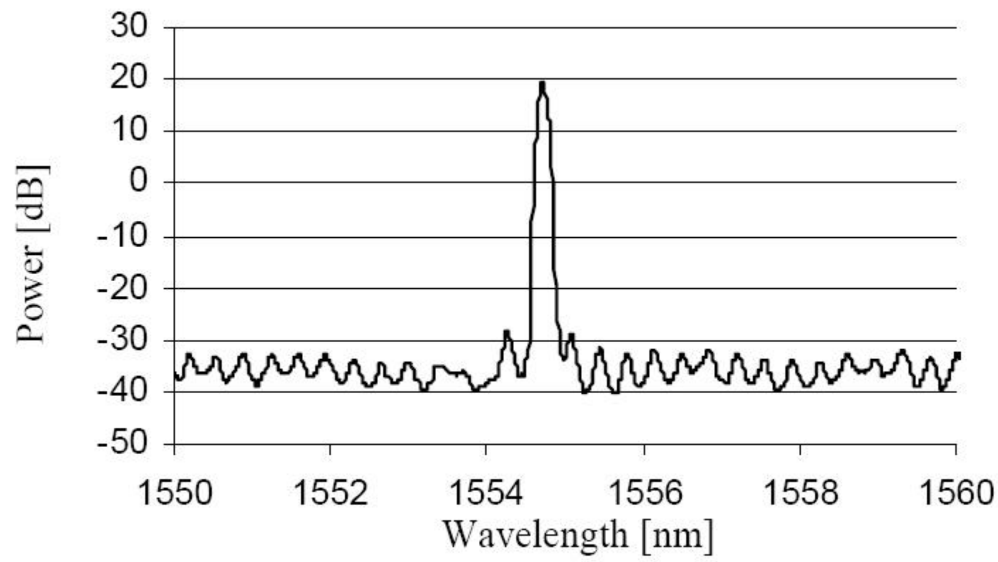
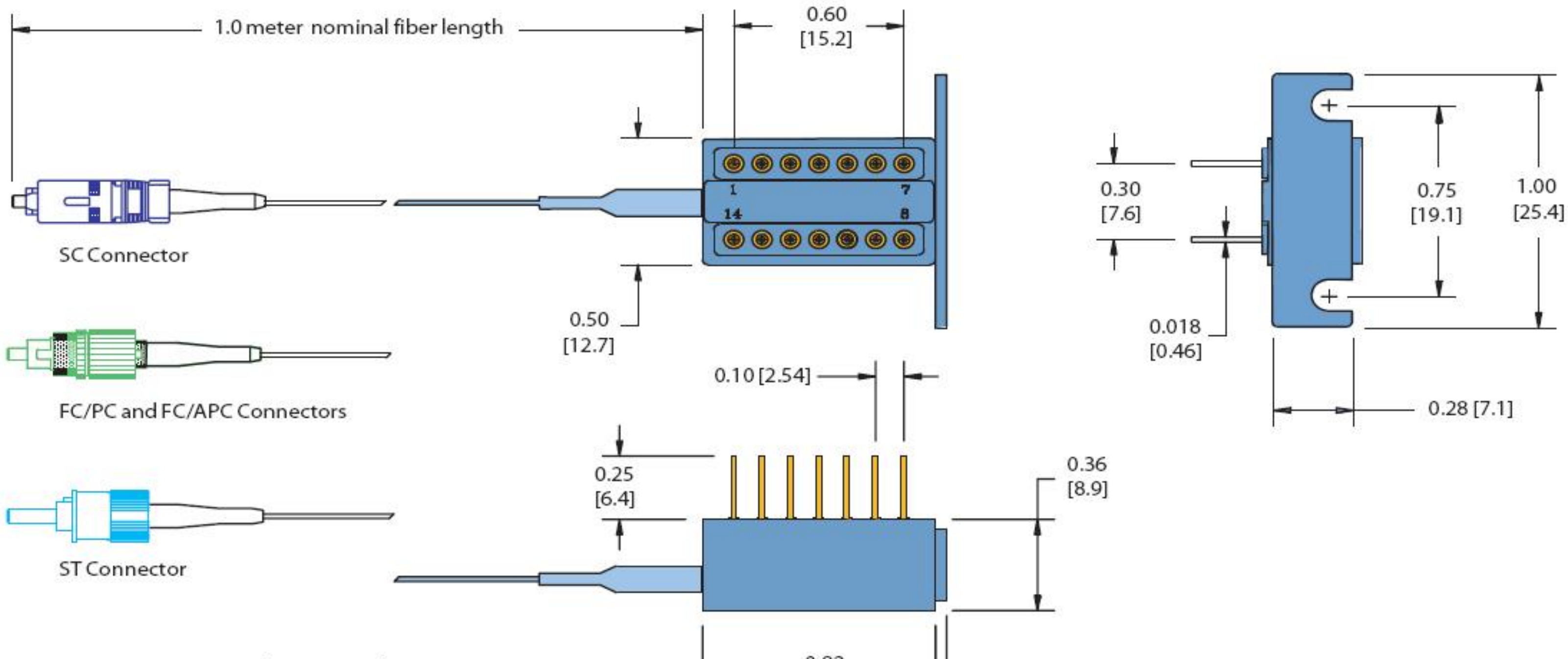
1550nm DFB Laser

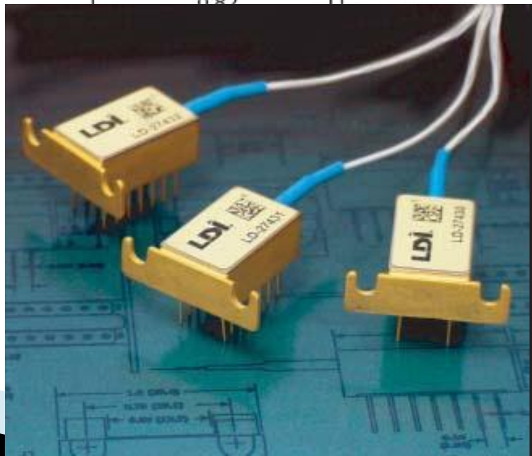


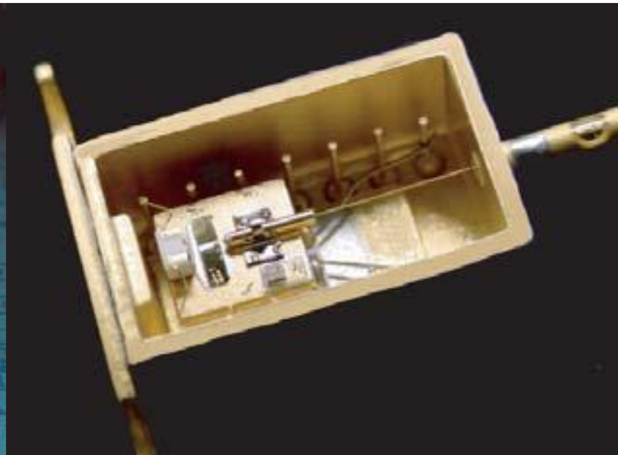


1550nm MQW Laser

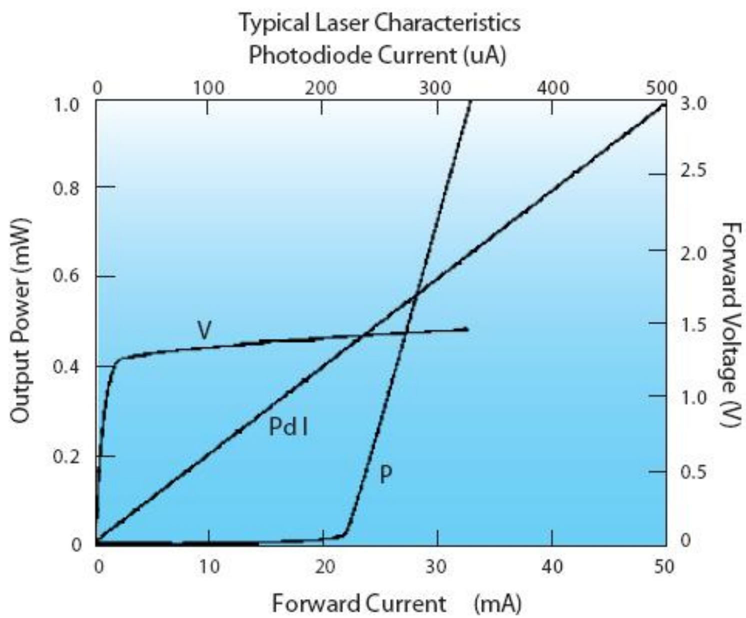


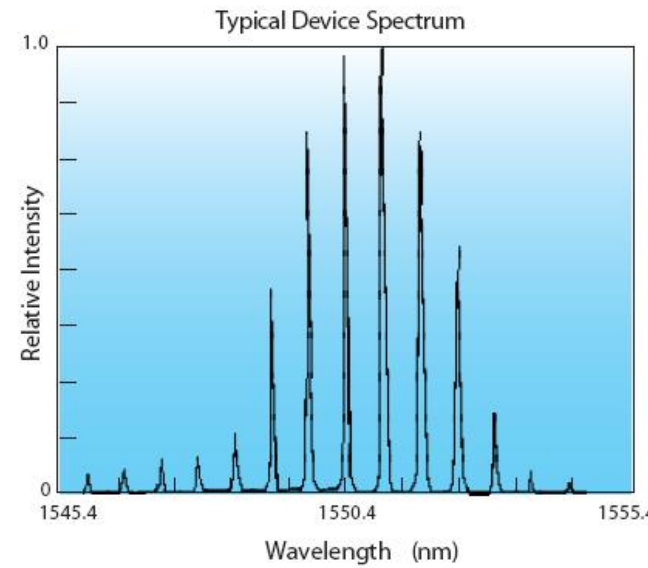
Note: Connectors are not drawn to scale.





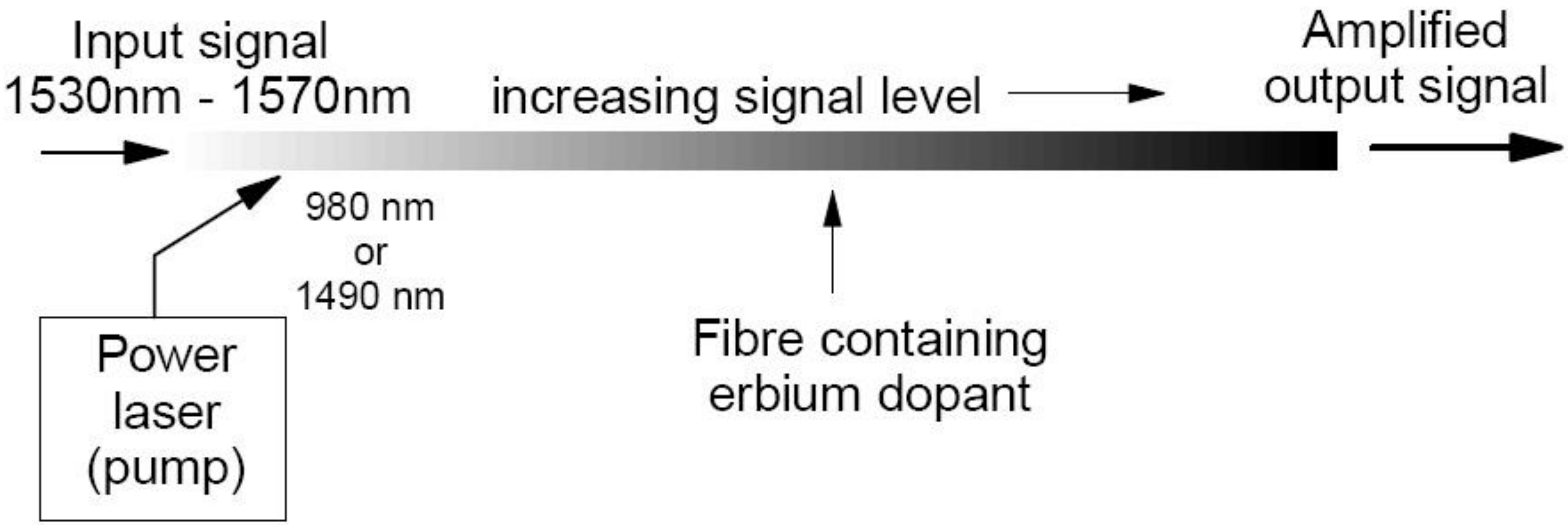
1550nm MQW Laser



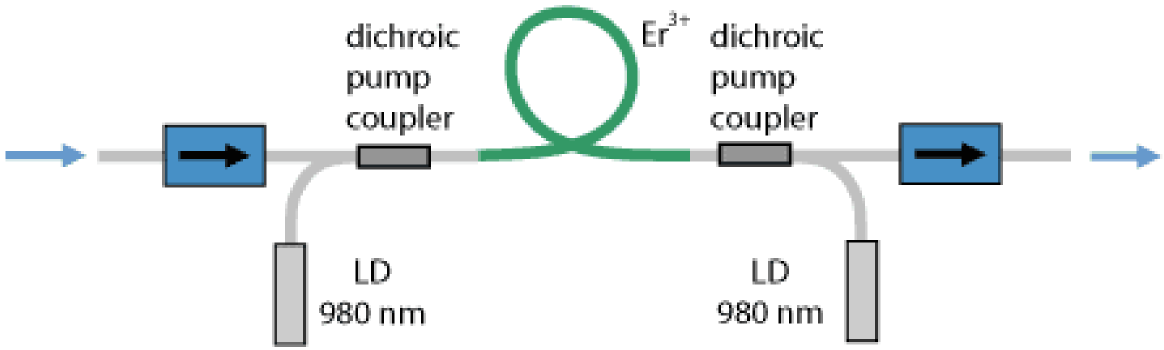


EDFA

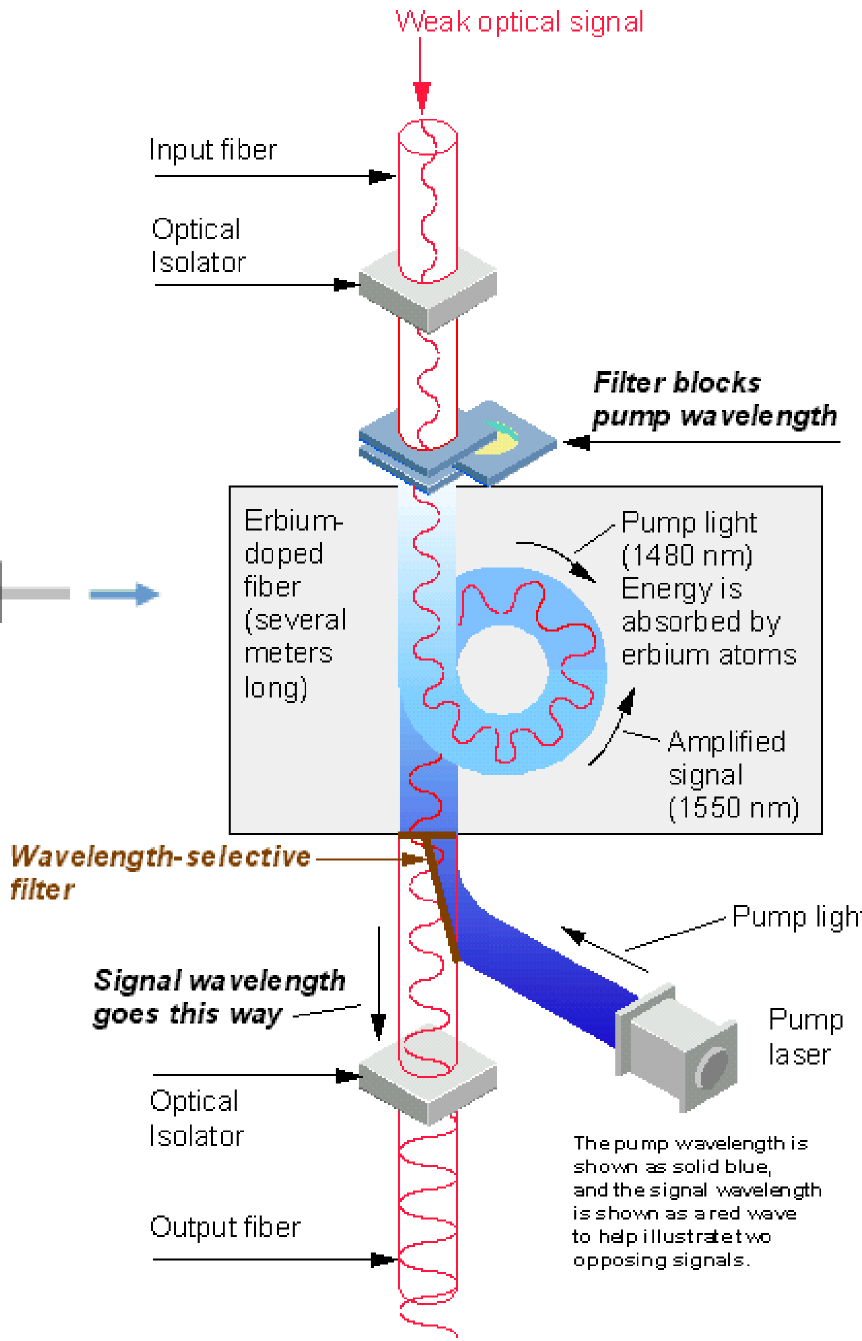
- Erbidium Dopped Fiber Amplifier



EDFA

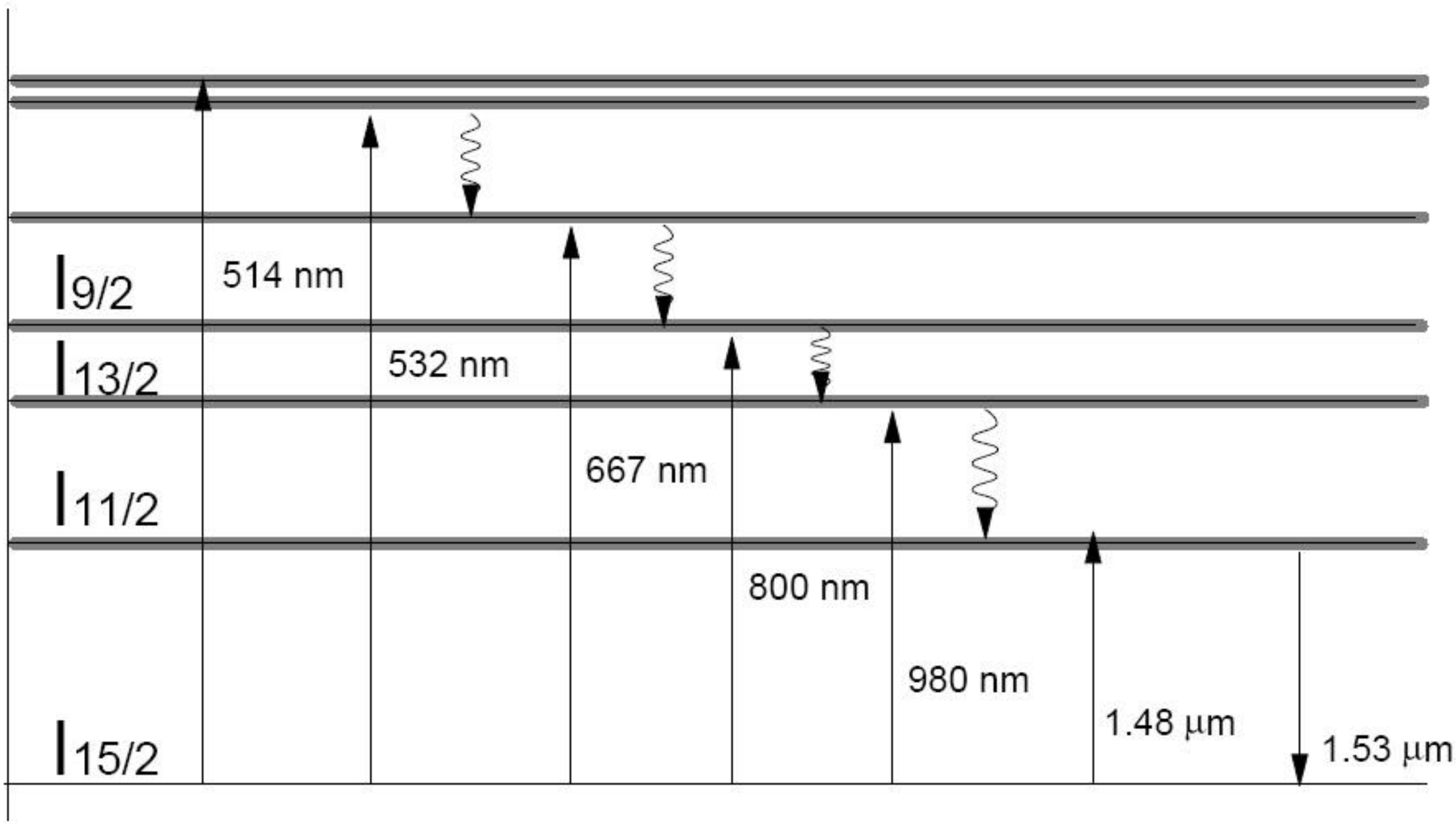


dichroic pump coupler
Er3+
dichroic pump coupler
LD 980 nm
LD 980 nm



Weak optical signal
Input fiber
Optical Isolator
Filter blocks pump wavelength
Erbium-doped fiber (several meters long)
Pump light (1480 nm) Energy is absorbed by erbium atoms
Amplified signal (1550 nm)
Wavelength-selective filter
Pump light
Signal wavelength goes this way
Pump laser
Optical Isolator
Output fiber
The pump wavelength is shown as solid blue, and the signal wavelength is shown as a red wave to help illustrate two opposing signals.

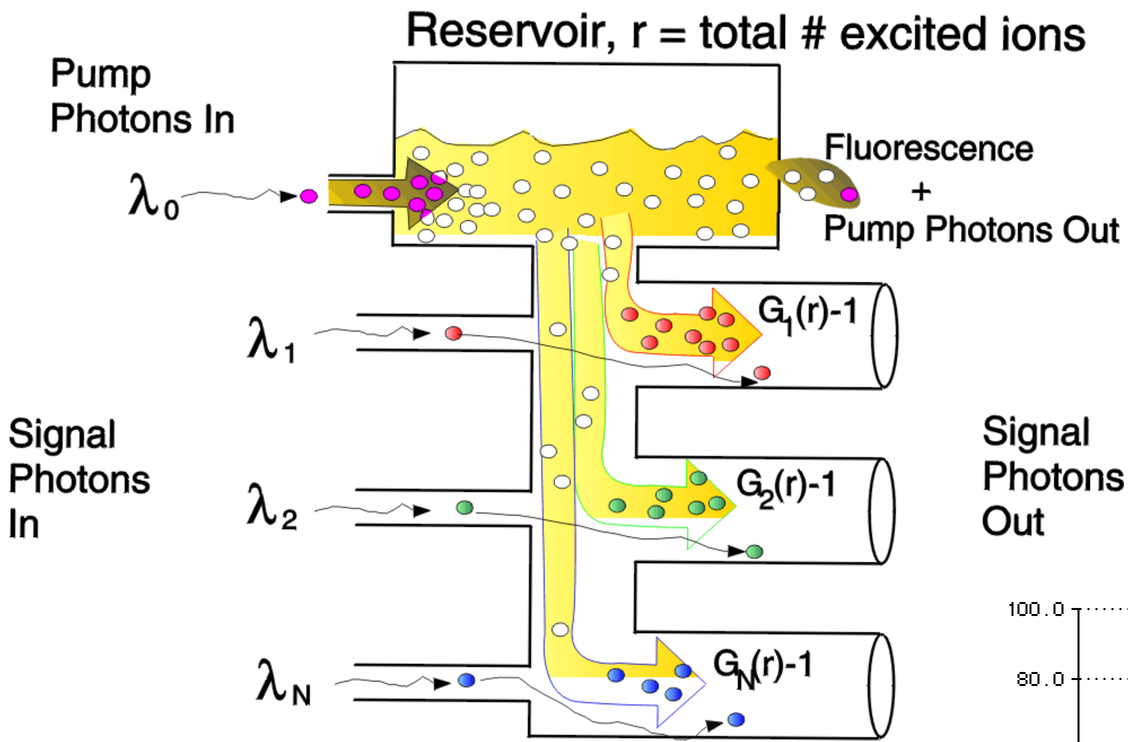
EDFA

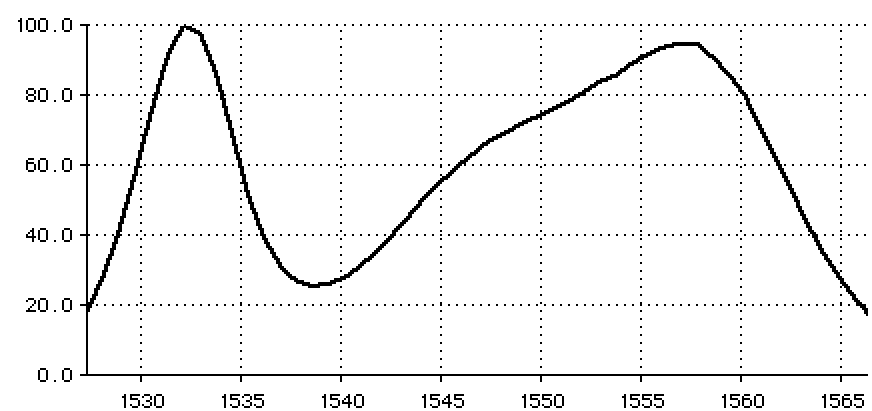


I9/2
I13/2
I11/2
I15/2
514 nm
532 nm
667 nm
800 nm
980 nm
1.48 μm
1.53 μm

EDFA

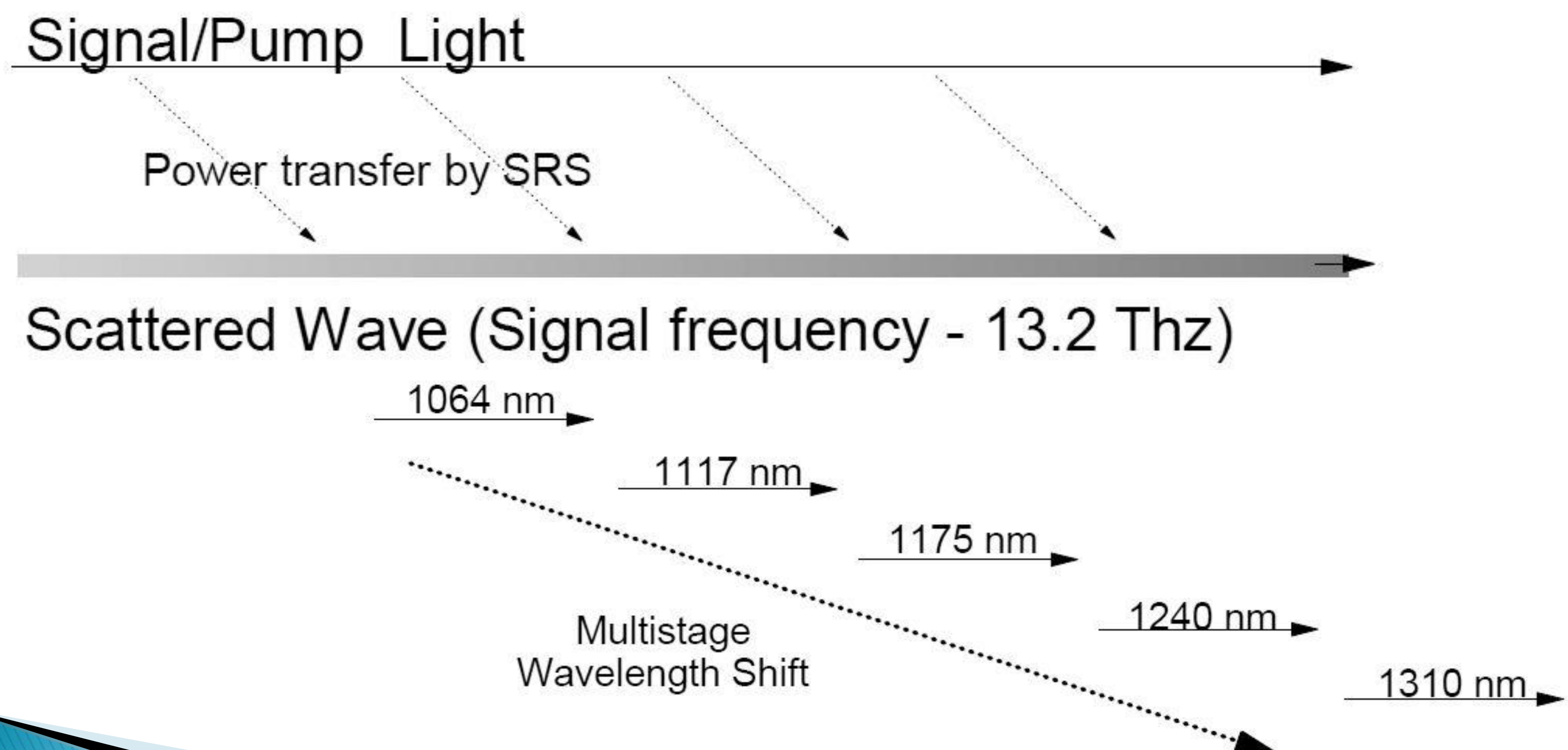
How to think of an EDFA



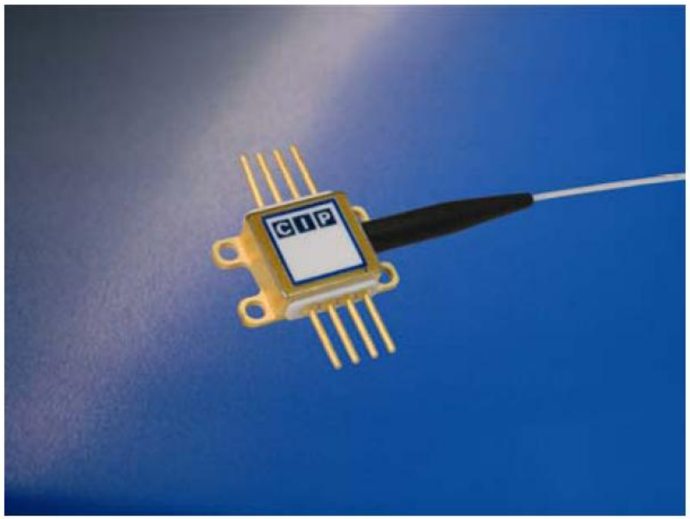


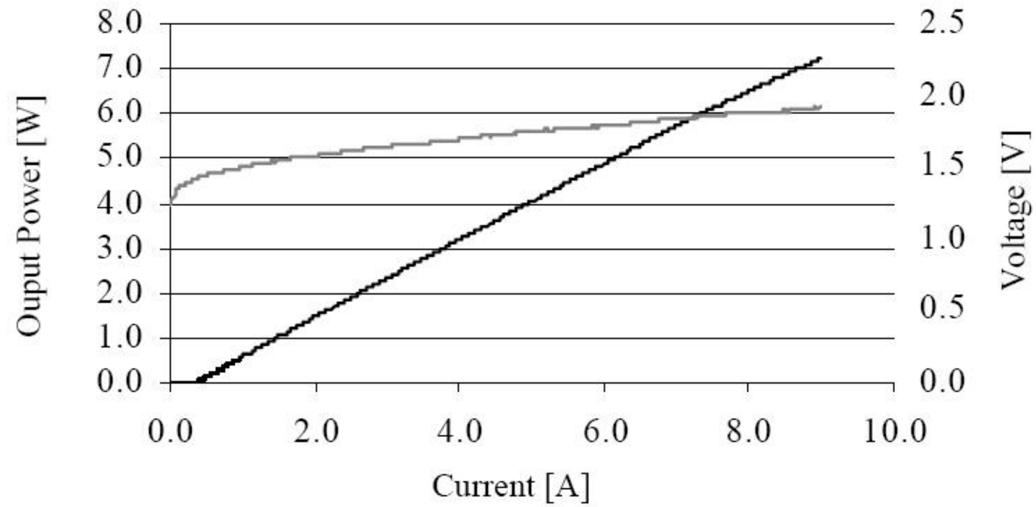
Amplificator cu efect Raman

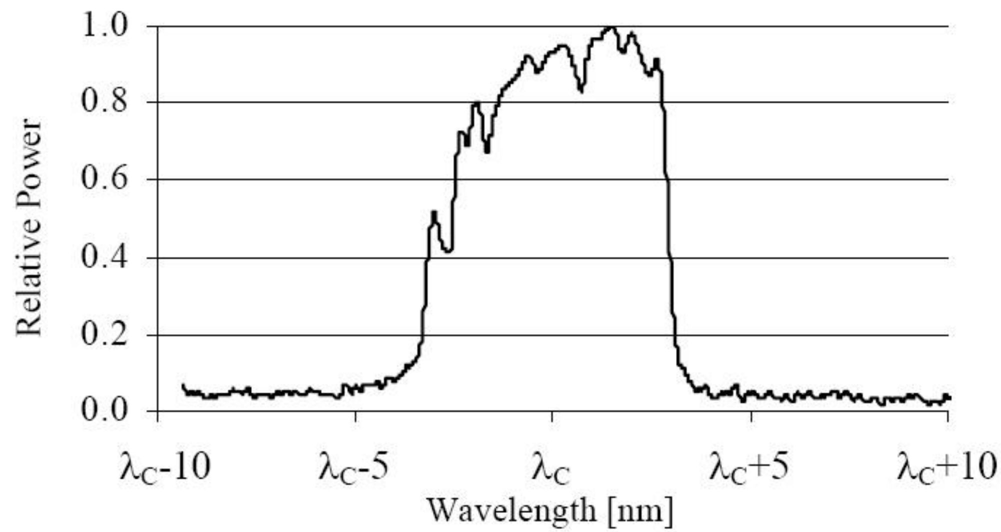
- Bazat pe efect Raman



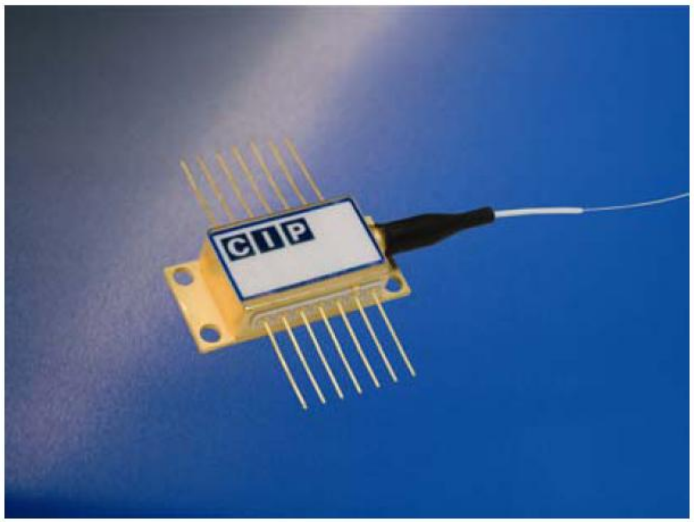
7W 980 nm Multimode Pump Laser

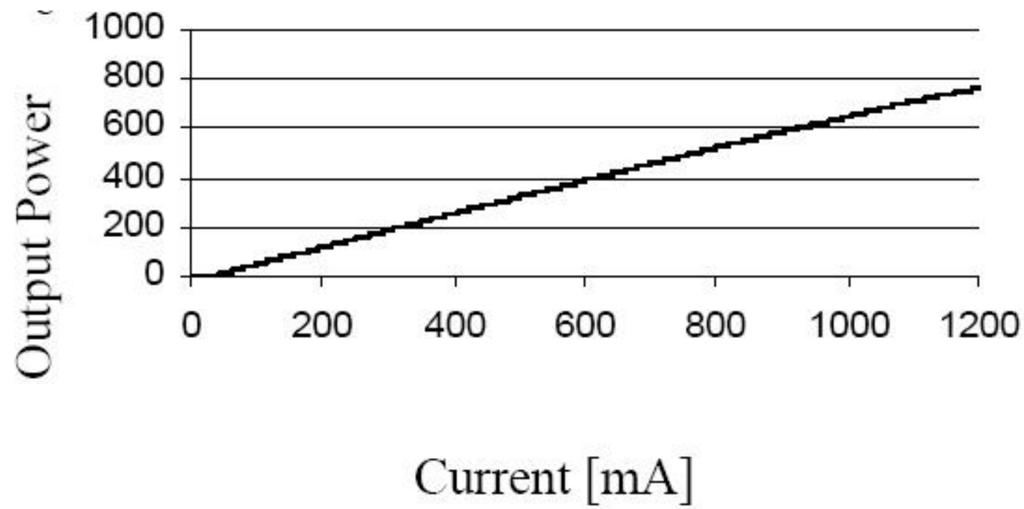


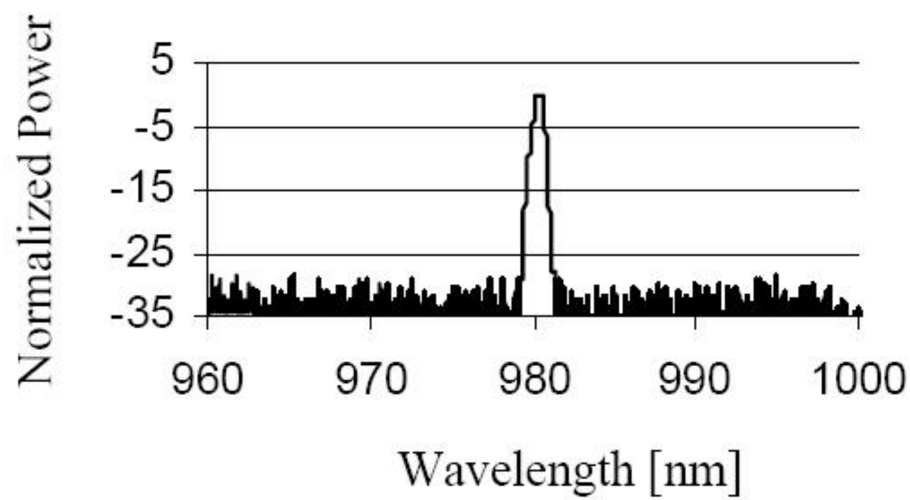




600mW 980 nm Singlemode Pump Laser

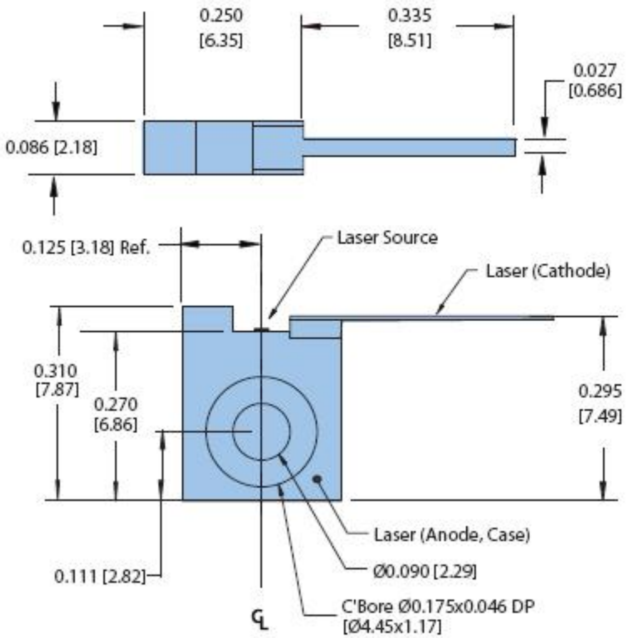




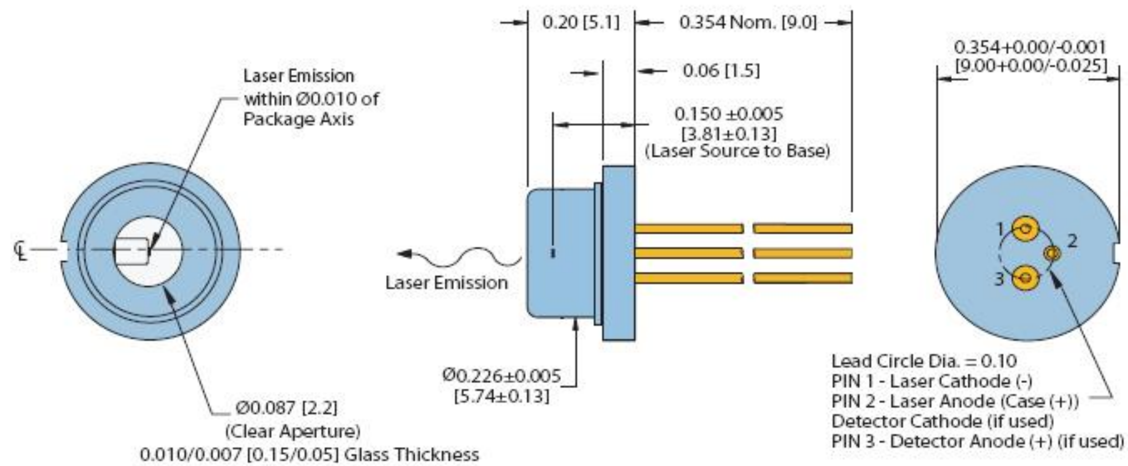


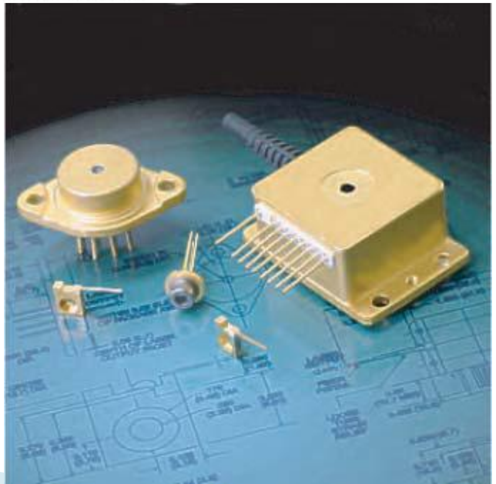
6 W, CW, 800nm

C-Mount Package



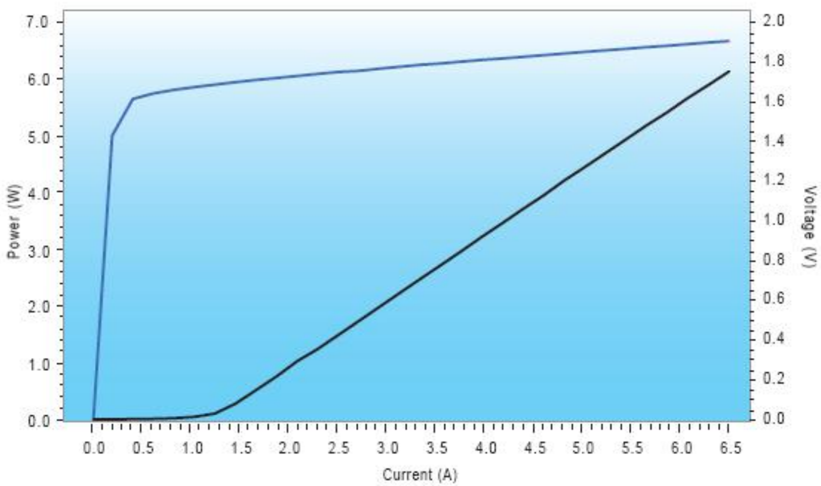
9mm Package



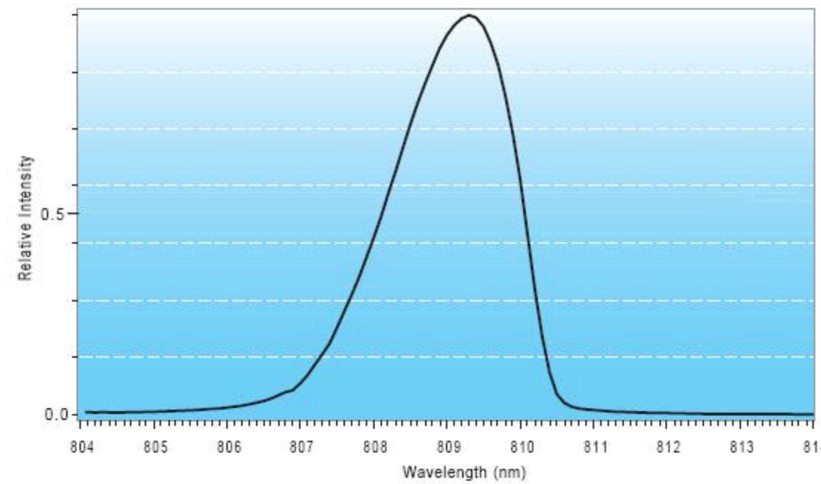


6 W, CW, 800nm

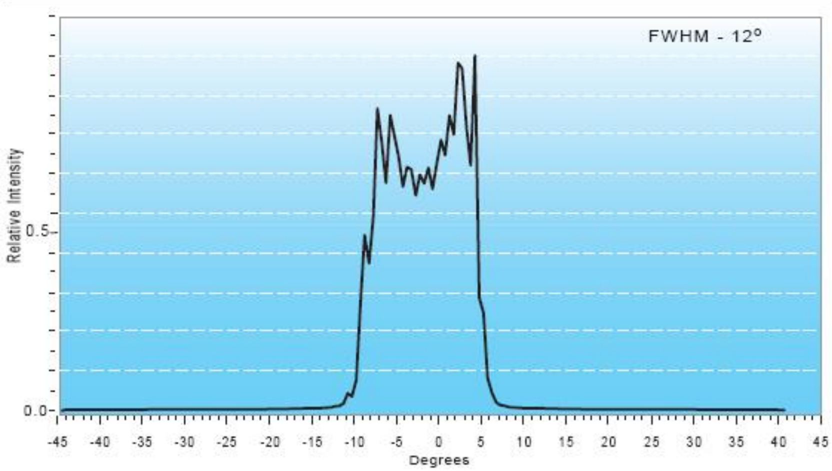
Typical L/I, V/I Graph



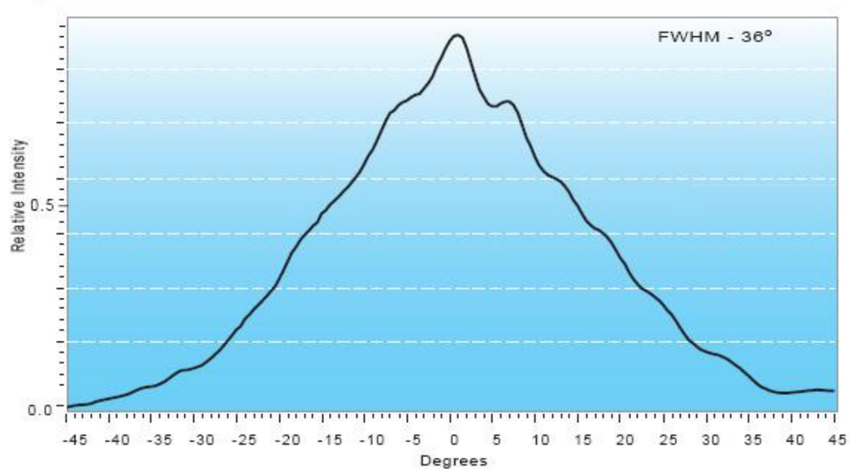
Wavelength Distribution



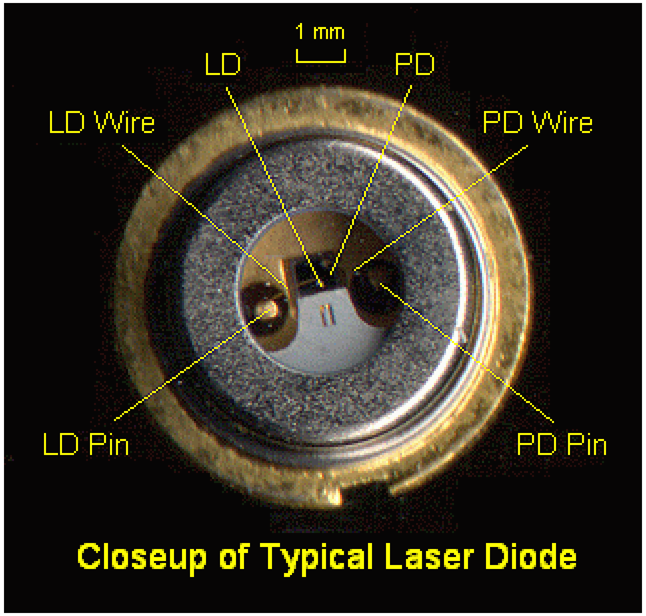
Typical Beam Divergence **Parallel**

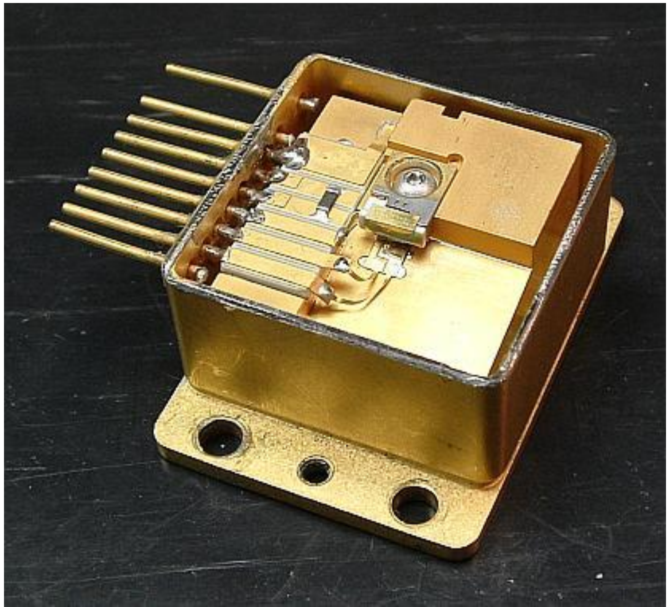


Typical Beam Divergence **Perpendicular**

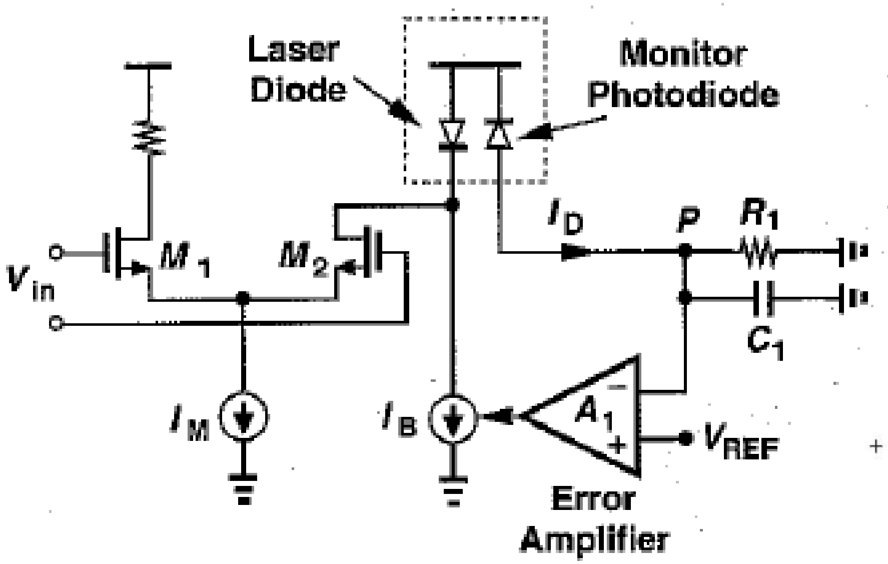


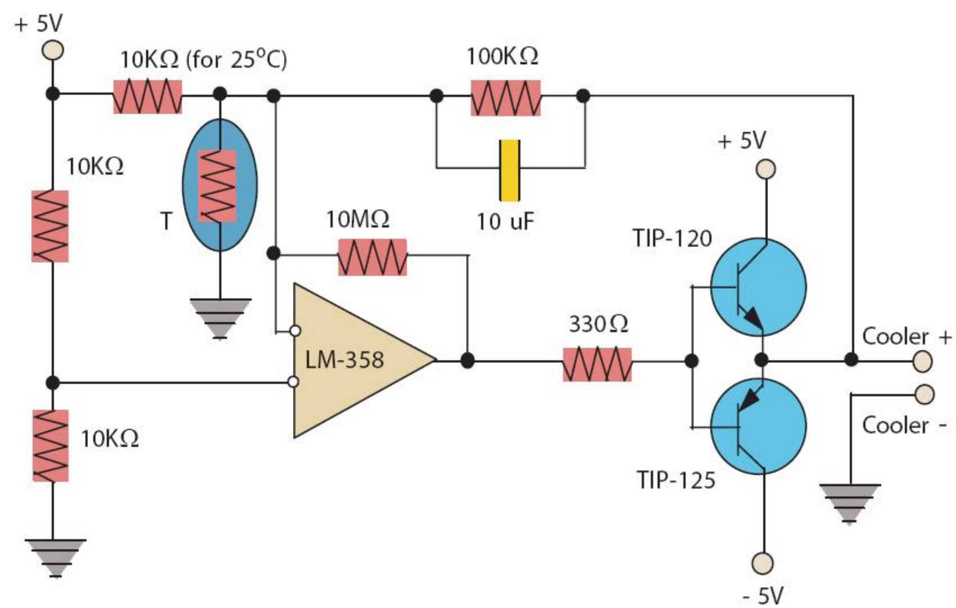
CW Laser, 650 nm





Control dioda LASER





Fotodioda

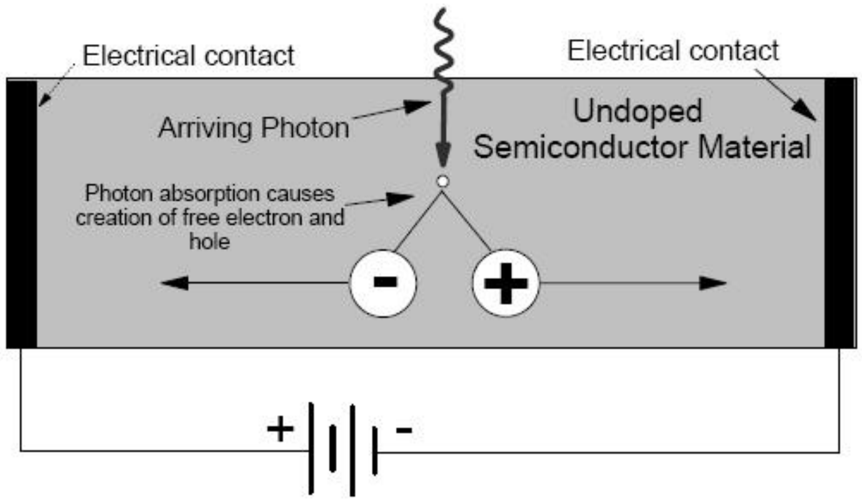
Capitolul 10

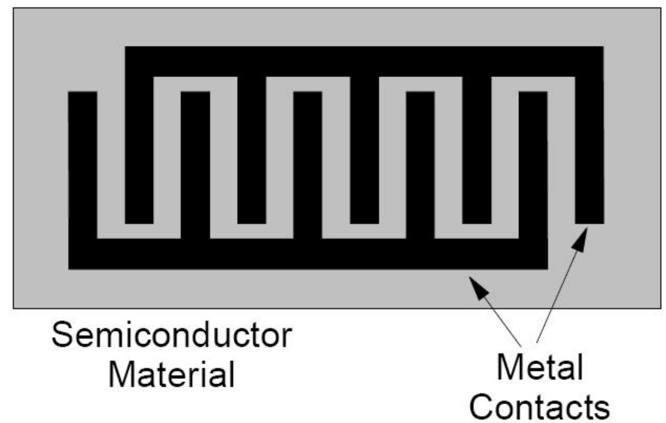
Detectori optici

- Cerinte
  - eficienta crescuta a conversiei optic/electric
  - zgomot redus
  - raspuns uniform la diferite lungimi de unda
  - viteza de raspuns ridicata
  - liniaritate
- Principii de operare
  - fotoconductori $R = R(P_o)$
  - fototranzistori $I_B = I_B(P_o)$
  - fotodiode $I = I(P_o)$
    - pn
    - pin
    - pin cu multiplicare in avalansa
    - Schottky

Fotoconductori

- Principiu

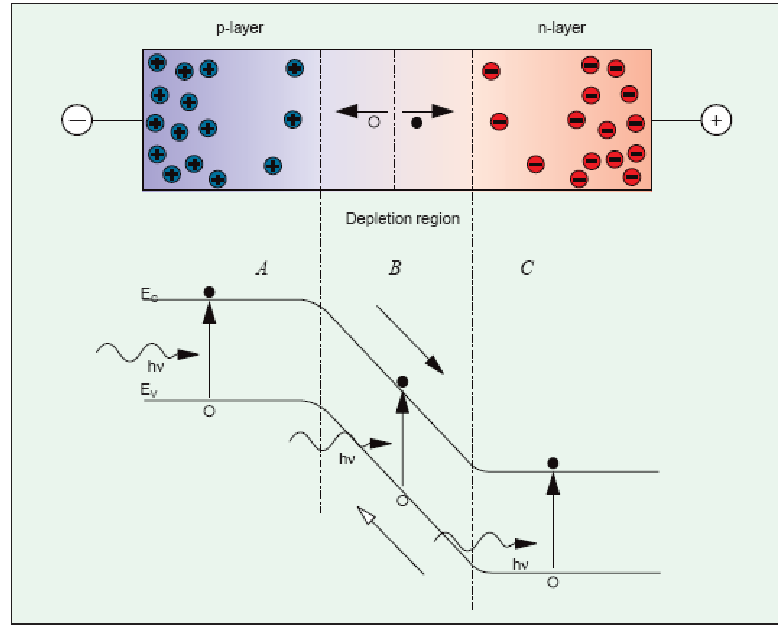


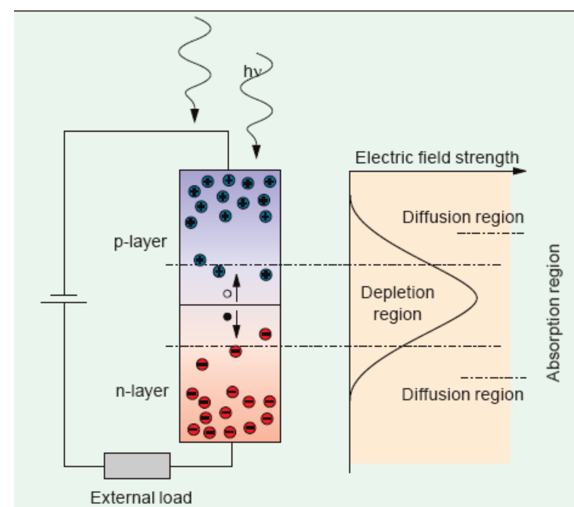


- Recent dispozitive Metal Semiconductor Metal (filtru interdigital) au inceput sa fie utilizate pentru usurinta de fabricare si integrare in aplicatii mai putin pretentioase

Fotodioda – Principiul de operare

- Jonctiunea pn este polarizata invers
- Lumina este absorbita in regiunea golita de purtatori, un foton absorbit generand o pereche electron-gol
- Sarcinile sunt separate de campul electric existent in regiunea golita si genereaza un curent in circuitul exterior





Fotodioda – Principiul de operare

- Energia necesara pentru eliberarea unei perechi electron gol

$$h\nu = \frac{hc}{\lambda} \geq E_g$$

- Lungime de unda de taiere

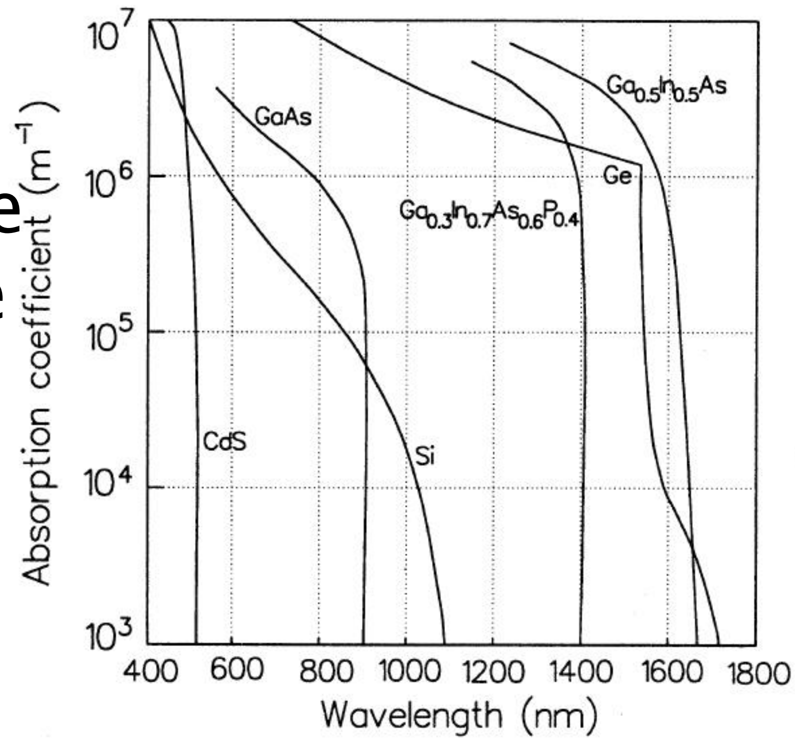
$$\lambda_{\max} = \frac{hc}{E_g}$$

- Puterea optica absorbita in zona golita de purtatori (w) aflata la o adincime d in interiorul dispozitivului

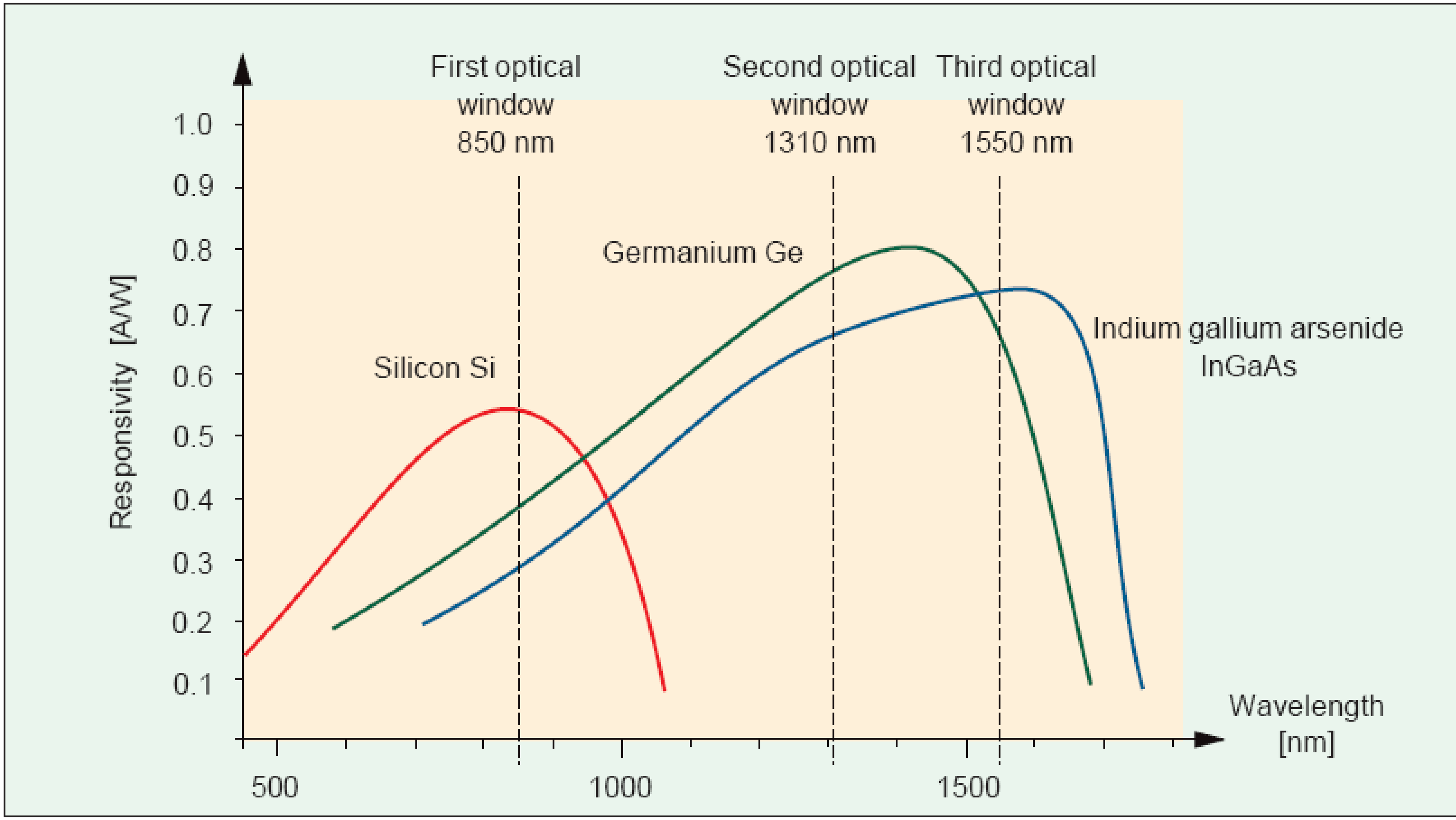
$$P(w) = P_i \cdot e^{-\alpha \cdot d} \cdot \left(1 - e^{-\alpha \cdot w}\right) \cdot \left(1 - R_f\right)$$

Fotodioda – Principiul de operare

- Coeficientul de absorbtie pentru materialele uzuale
- Valoarea mare a coeficientului de absorbtie la lungimi de unda reduse implica scaderea responzivitatii
- Ca urmare comportarea **tuturor** materialelor este de tip trece banda



Materiale utilizate pentru fotodiode



Fotodioda – Marimi caracteristice

- Eficienta cuantica – raportul dintre numărul de perechi electron–gol generate şi numărul de fotoni incidenţi

$$\eta = \frac{n_e}{n_f}$$

- In unitatea de timp numarul de fotoni depinde de puterea optica, iar numarul de electroni impune curentul generat

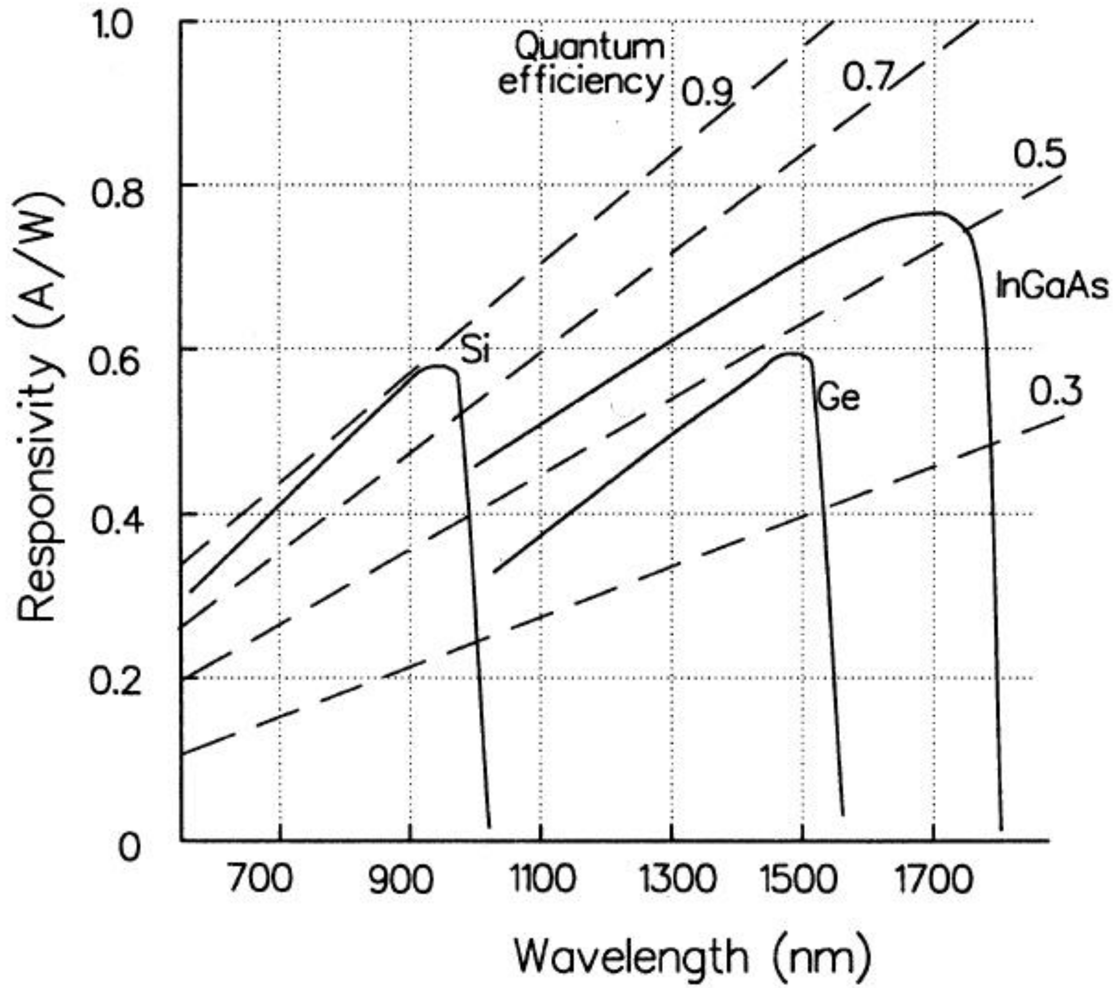
$$\eta = \frac{I/e}{P/h\nu}$$

- Responzivitatea

$$R = \frac{I}{P_o} = \frac{\eta \cdot e \cdot \lambda}{hc} \qquad R = 0.8 \cdot \eta \cdot \lambda[\mu m] \qquad \left[\frac{A}{W}\right]$$

Fotodiode – marimi caracteristice

$$R = \frac{I}{P_o} = \eta \cdot \frac{e}{hc} \cdot \lambda$$



Materiale utilizate pentru fotodiode

Material	λ [μm]	Responsivitate [A/W]	Viteza [ns]	Curent de intuneric
Si	0.85	0.55	3	1
Si	0.65	0.4	3	1
InGaAs	1.3-1.6	0.95	0.2	3
Ge	1.55	0.9	3	66

- Dezavantajul major pentru Ge este curentul de intuneric mare

Material	Eg (eV)
GaAs	1.43
GaSb	0.73
$GaAs_{0.88}Sb_{0.12}$	1.15
Ge	0.67
InAs	0.35
InP	1.35
$In_{0.53}Ga_{0.47}As$	0.75
$In_{0.14}Ga_{0.86}As$	1.15
Si	1.14

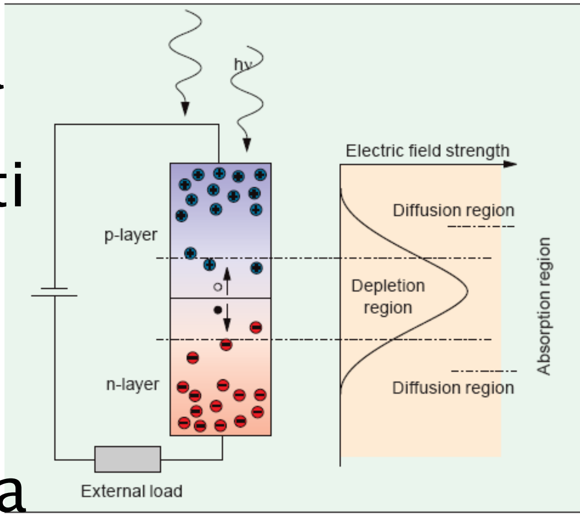
Curent de intuneric

- Curentul invers al jonctiunii p-n, datorat agitatiei termice, prezent in absenta iluminarii
- Constituie o importanta sursa de zgomot (limiteaza aplicatiile Ge)

$$I_D = I_S \approx \frac{\beta \cdot kT}{eR_0}$$

  - β – coeficient de idealitate $\beta = 1 \div 2$
  - R_0 – rezistenta la intuneric a diodei (invers proportionala cu aria diodei)

Fotodioda PIN



- Existenta campului electric in regiunea golita de purtatori face ca eventualii purtatori generati optic sa fie accelerati spre terminale pentru constituirea fotocurentului
- Problemele utilizarii diodei pn polarizate invers ca fotodetector sunt generate de adancimea extrem de mica a zonei golite (w)
- Puterea optica absorbita in interiorul acestei zone e in consecinta redusa
- Purtatorii generati inafara zonei de golire ajung eventual in zona golita si vor fi accelerati spre terminale, dar viteza fenomenului este prea redusa pentru aplicatii in comunicatii

Contact

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