Optoelectronică, structuri şi tehnologii

Curs 9

2014/2015

Capitolul 11

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

Lista subiecte

- Amplificatoare transimpedanţă
  - 4.1
  - 4.1.1
  - 4.2
  - 4.2.1
  - 4.3
  - 4.3.1
- Circuite pentru controlul emiţătoarelor optice
  - 10.3
  - 10.3.1
  - 10.4
  - 10.4.1

LED

Dioda electroluminescenta
Capitolul 8

Caracteristici LED

- Dezavantaje
  - Putere redusa (cuplata in fibra) ~ 100μW
  - Banda (viteza) reduse ~ 150MHz (300Mb/s)
  - Spectru larg ~ 0.05 λ
  - Lumina necoerenta si nedirectiva
- Avantaje
  - Structura interna mult mai simpla (fara suprafete reflective, straturi planare)
  - Cost (dispozitiv si circuit de comanda)
  - Durata de viata
  - Insenzitivitate la temperatura
  - Liniaritate (modulatie analogica)

Aplicatii majore LED

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

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 $E_g = h\nu; \quad \lambda = \frac{hc}{E_g}$
- Recombinare eficienta:
  - alegerea judicioasa a materialului
  - concentrarea purtatorilor in zona jonctiunii
- Lungimea de unda depinde de temperatura de functionare a dispozitivului: 0.6nm/°C

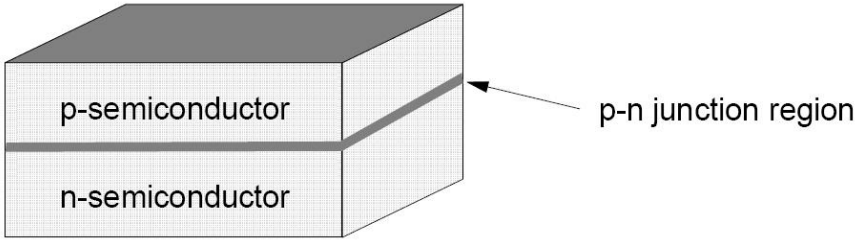
Lăţimea benzii interzise/lungime de undă pentru materialele uzuale

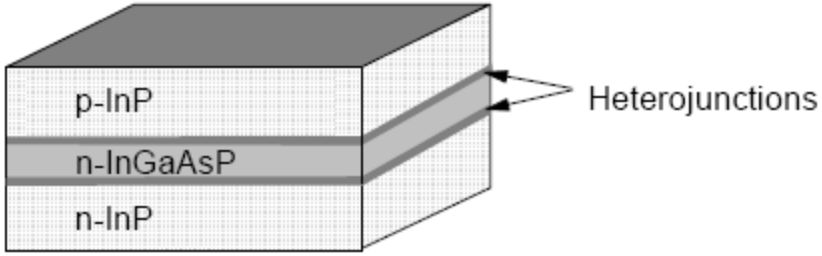
Material	Formula	Wavelength Range λ (μm)	Bandgap Energy W_g (eV)
Indium Phosphide	InP	0.92	1.35
Indium Arsenide	InAs	3.6	0.34
Gallium Phosphide	GaP	0.55	2.24
Gallium Arsenide	GaAs	0.87	1.42
Aluminium Arsenide	AlAs	0.59	2.09
Gallium Indium Phosphide	GaInP	0.64-0.68	1.82-1.94
Aluminium Gallium Arsenide	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

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

- h constanta lui Plank $6.62 \cdot 10^{-32}$ Ws^2
- c viteza luminii **in vid** $2.998 \cdot 10^8 m/s$
- benzi energetice: λ_0, **$\Delta\lambda$**

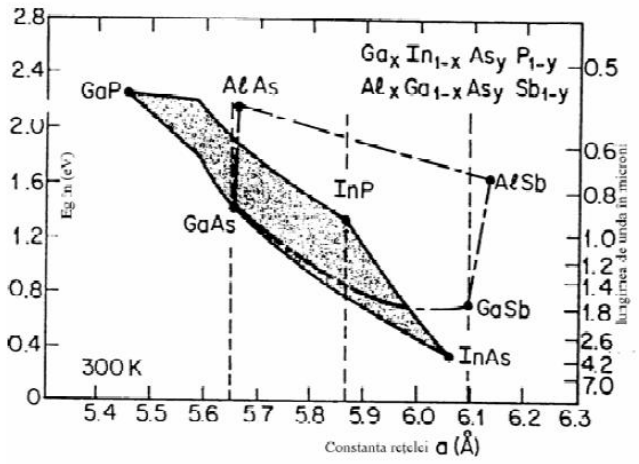
LED cu heterojuncţiuni – principiu

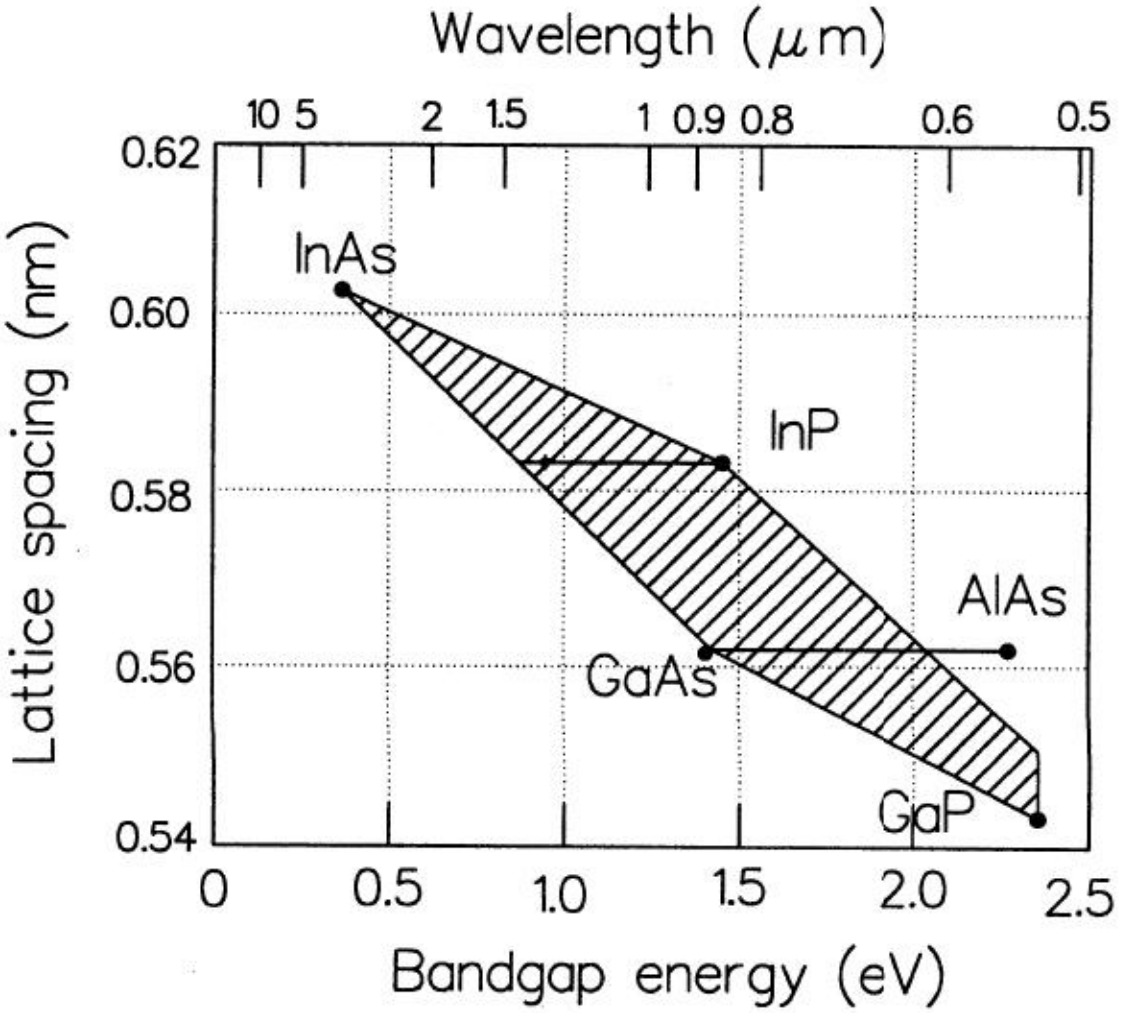




- **Orice** jonctiune p-n emite lumina
- O jonctiune p-n obisnuita este foarte subtire
  - volumul in care apar recombinari este foarte mic
  - eficienta luminoasa, redusa
- lumina este emisa in toate directiile
  - cantitatea de lumina utilizabila (intr-o anumita directie) este redusa

Dependenţa benzii interzise de constanta reţelei



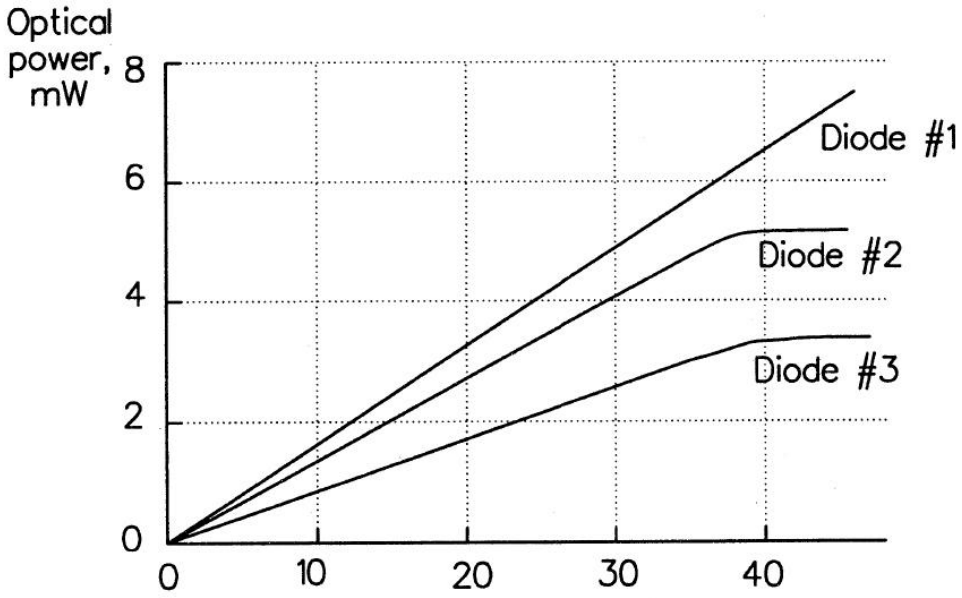


Caracteristica de raspuns a LED-urilor

- 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



Dioda Laser

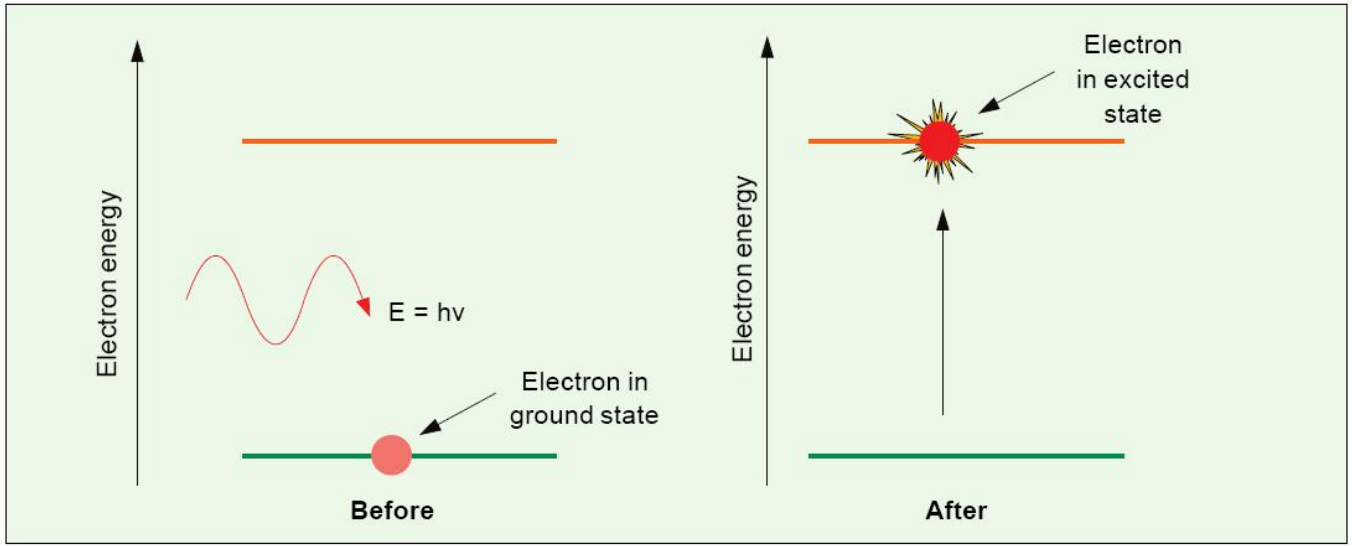
Capitolul 9

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

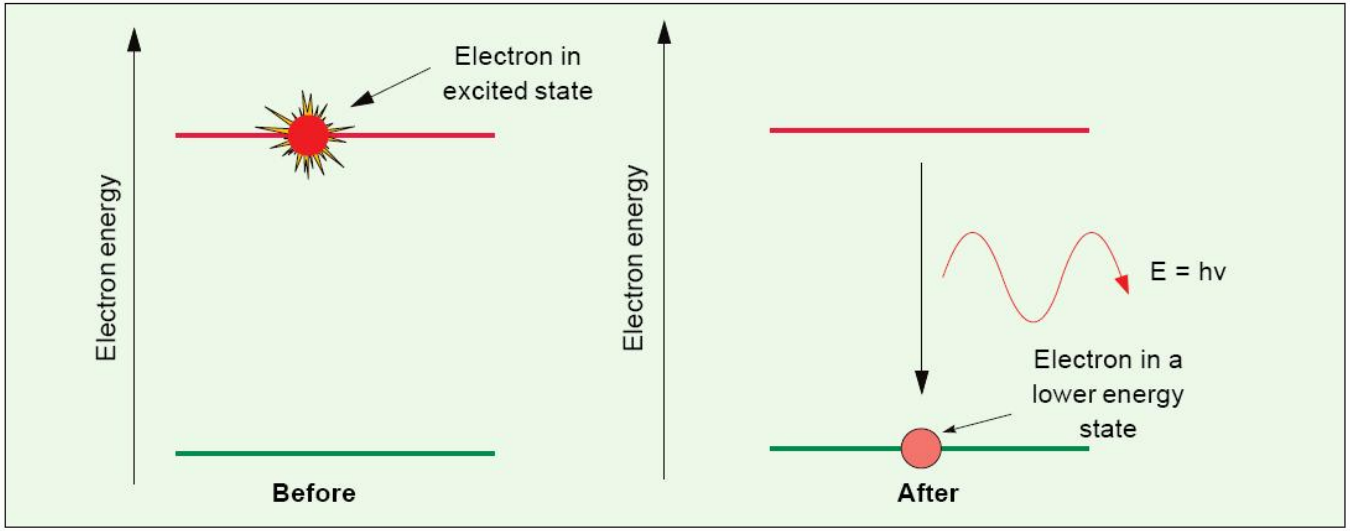
Dioda LASER – Principiu de operare

- LASER = Light Amplification by the Stimulated Emission of Radiation = Amplificarea Luminii prin Emisie Stimulata
- Un foton incident poate cauza prin absorbtie tranzitia unui electron pe un nivel energetic superior



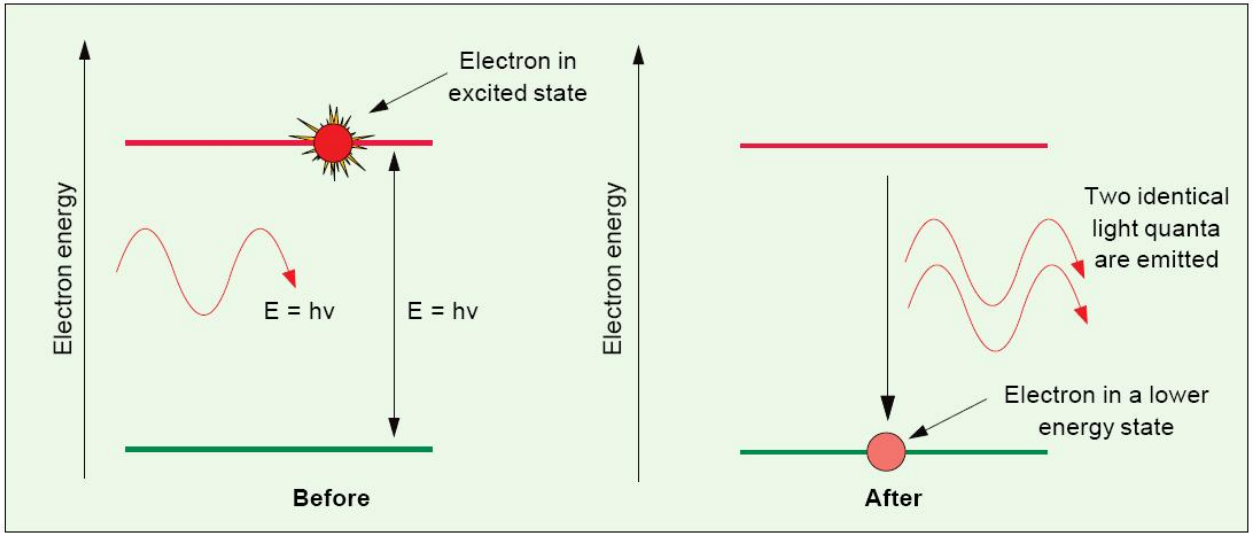
Dioda LASER – Principiu de operare

- Emisia spontana – electronul trece in starea energetica de echilibru emitand un foton
- Trecerea se realizeaza prin recombinarea unei perechi electron-gol
- Directia si faza radiatiei emise sunt aleatoare



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



Detalii constructive

- Recombinarea unei perechi electron-gol necesita conservarea impulsului
- In Si si Ge aceasta conditie presupune aparitia unui foton intermediar (tranzitie indirecta) a carui energie se transforma in caldura
- Se utilizeaza aliaje de Ga Al As sau In Ga As P
- 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

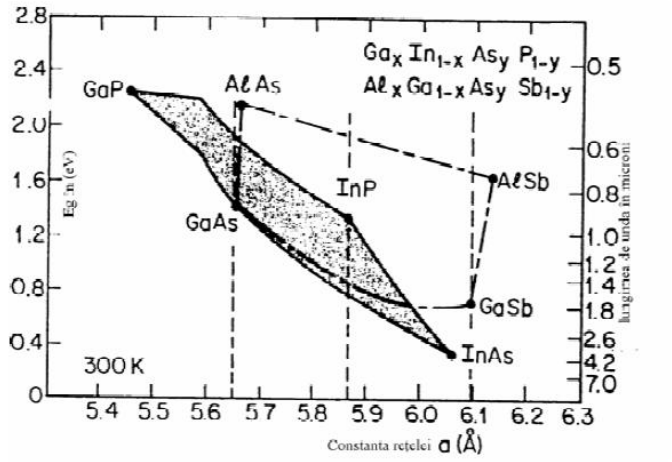
Lăţimea benzii interzise/lungime de undă pentru materialele uzuale

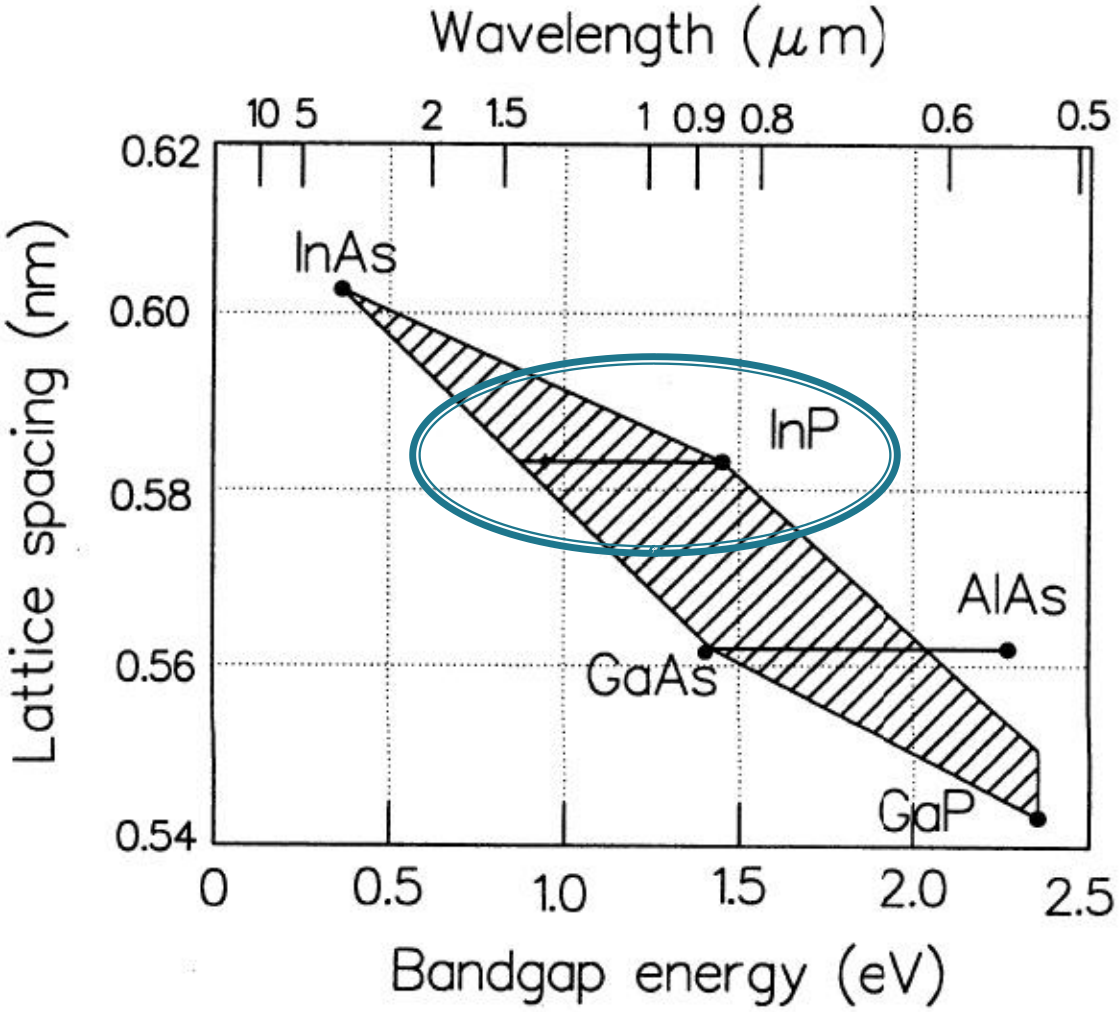
Material	Formula	Wavelength Range λ (μm)	Bandgap Energy W_g (eV)
Indium Phosphide	InP	0.92	1.35
Indium Arsenide	InAs	3.6	0.34
Gallium Phosphide	GaP	0.55	2.24
Gallium Arsenide	GaAs	0.87	1.42
Aluminium Arsenide	AlAs	0.59	2.09
Gallium Indium Phosphide	GaInP	0.64-0.68	1.82-1.94
Aluminium Gallium Arsenide	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

$$E_g = h\nu; \quad \lambda = \frac{hc}{E_g}$$

- h constanta lui Plank $6.62 \cdot 10^{-32}$ Ws^2
- c viteza luminii in vid $2.998 \cdot 10^8 m/s$

Dependenţa benzii interzise de constanta reţelei





Principii LASER

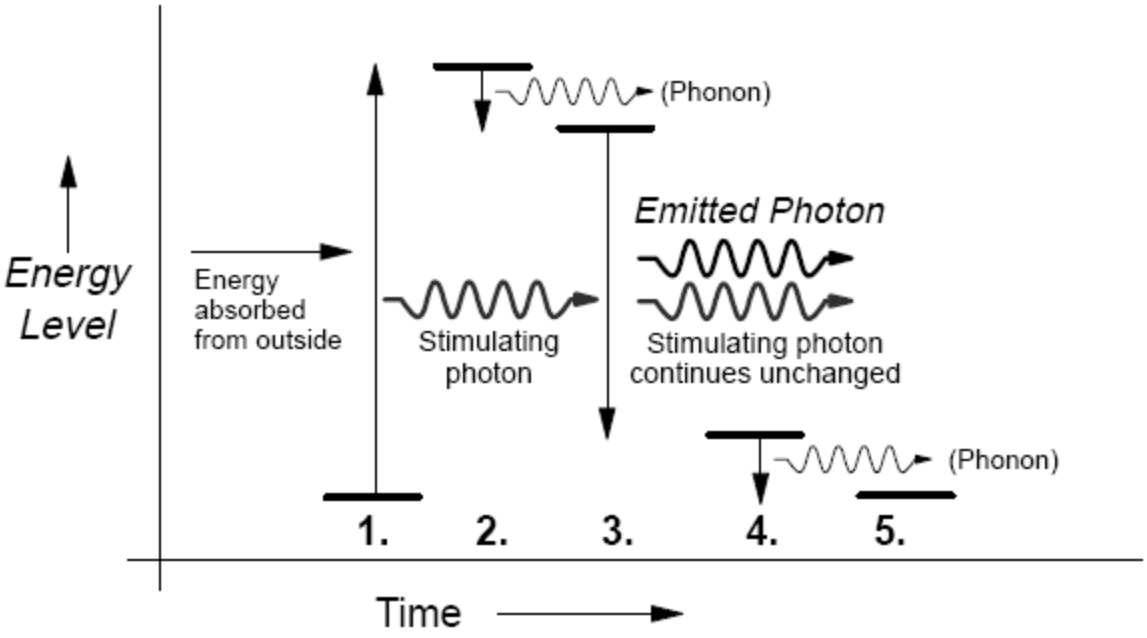
- Inversiune de populatie
  - necesara deoarece electronii au capabilitatea de a absorbi energie **la aceeasi frecventa** la care are loc emisia stimulata
  - se defineste probabilistic: probabilitatea de emisie stimulata sa fie mai mare decat probabilitatea de absorbtie

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

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

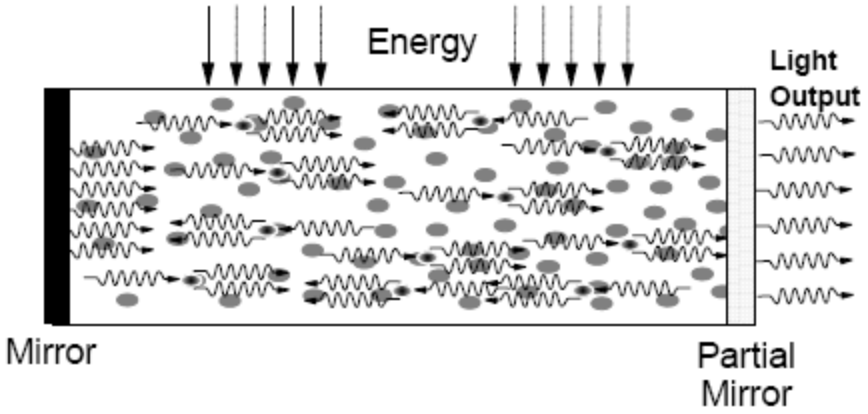
Materiale cu 4 nivele energetice

- 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



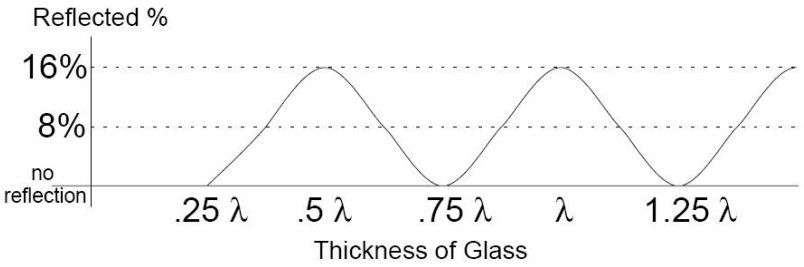
Dioda LASER – Principiu de realizare

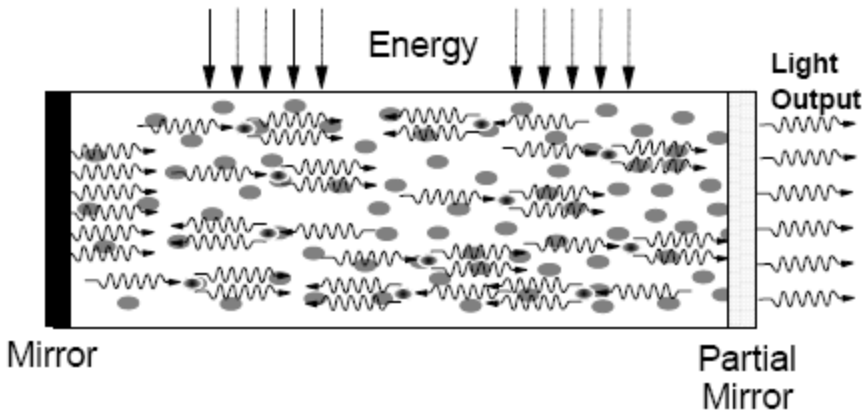
- Pentru ca emisia stimulata sa apara, fotonii emisi trebuie sa ramana in contact cu materialul o perioada mai mare de timp – 2 oglinzi necesare
- Pentru a permite extragerea radiatiei e necesar ca una din oglinzi sa fie partial reflectanta



Dioda LASER – Principiu de realizare

- Pentru diodele laser utilizate in comunicatii reflectivitatea oglinzilor nu trebuie sa fie foarte mare
- Interfata semiconductor aer ofera un coeficient de reflexie de ~6% dar poate ajunge la 36% pentru lungimea de unda de operare (vezi lamela dielectrica)





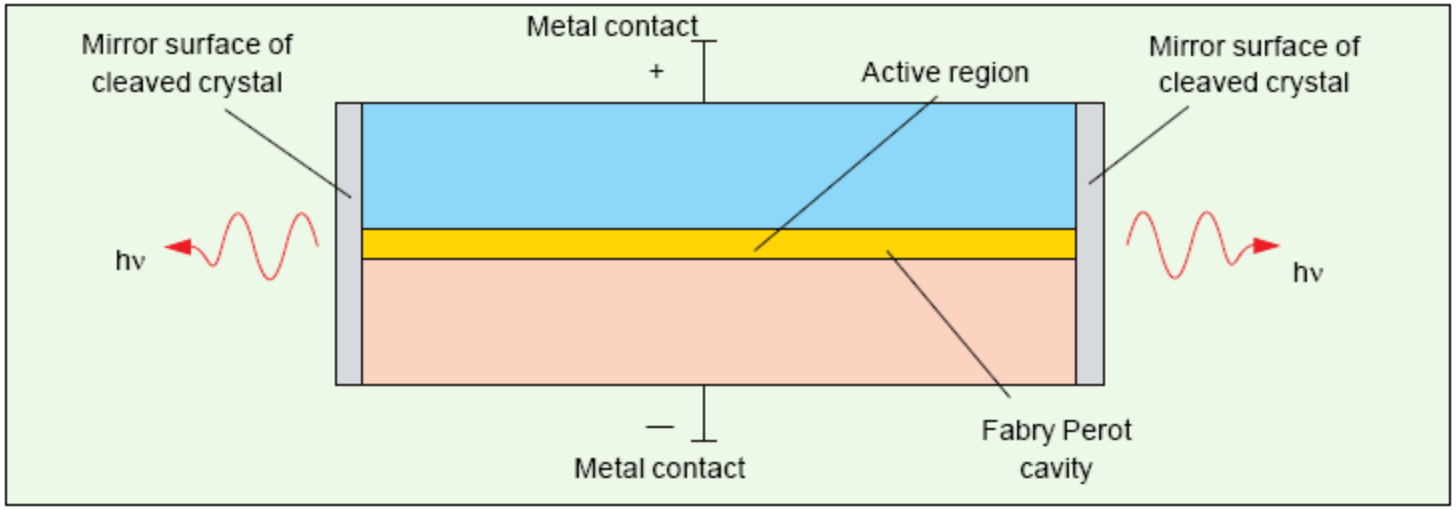
Dioda LASER – Principiu de realizare

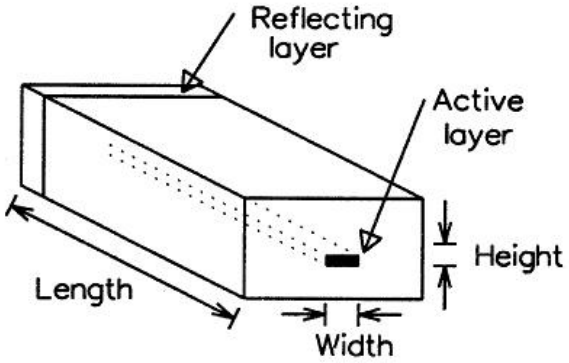
- Pentru a realiza
  - coerenta radiatiei
  - interferenta constructiva intre radiatiile incidente si reflectate de oglinzi,
- distanta intre oglinzi trebuie sa fie un multiplu a jumatate din lungimea de unda

$$L = k \cdot \frac{1}{2} \cdot \frac{\lambda_0}{n} \qquad L = k \cdot \frac{c_0}{2 \cdot n \cdot f}$$

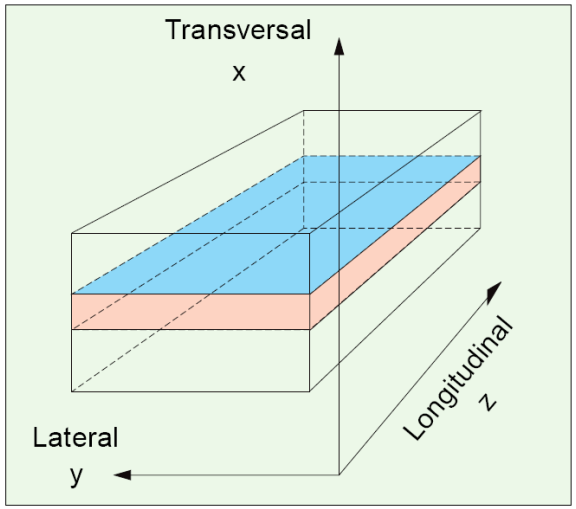
- Pentru eficientizarea pomparii de energie din exterior L=100÷200μm, k ≅ 400

Dioda LASER Fabry Perot



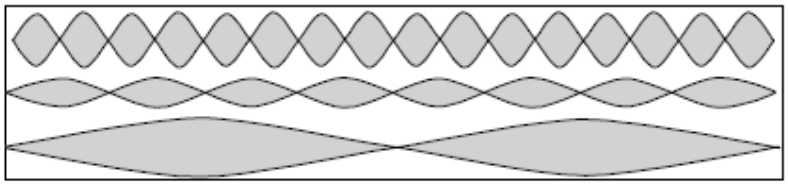


Height: 0.1 – 0.2 μm
Length: 250 – 500 μm
Width: 5 – 15 μm
Sides: rough–cut
Front: cleaved
Back: 100% reflector

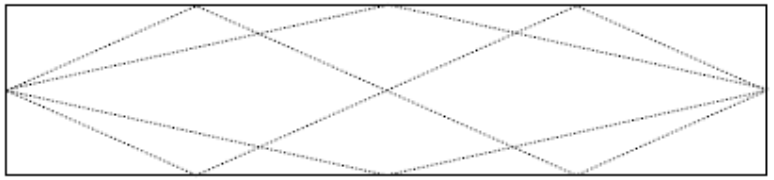


Definirea directiilor in dioda LASER

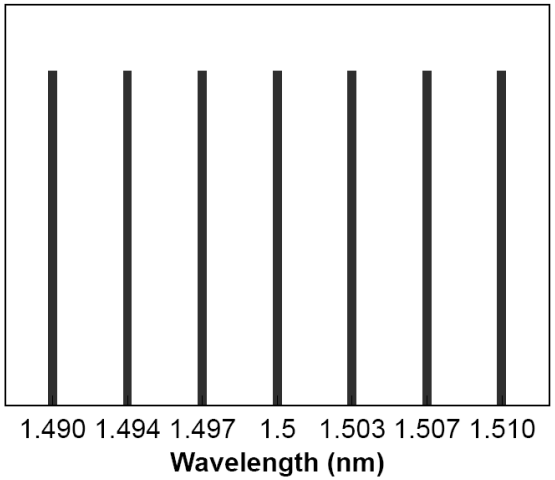
Spectrul diodei LASER



Longitudinal Modes



Lateral Modes

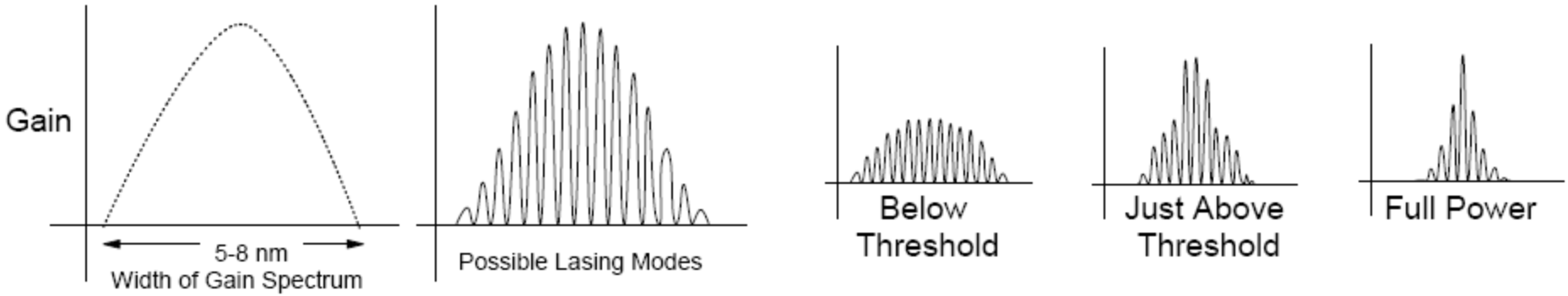


$$f_k = k \cdot \frac{c_0}{2 \cdot n \cdot L} \qquad \Delta f = \frac{c_0}{2 \cdot n \cdot L}$$

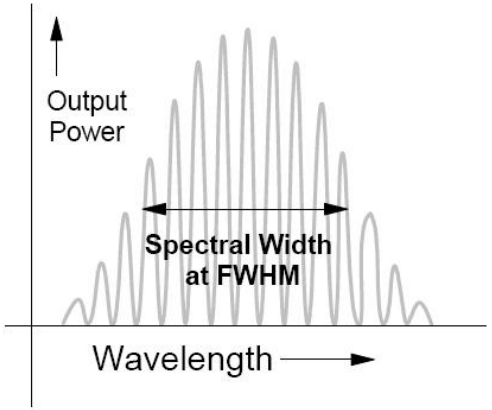
$$\Delta\lambda \cong \frac{\lambda_0^2}{2 \cdot n \cdot L}$$

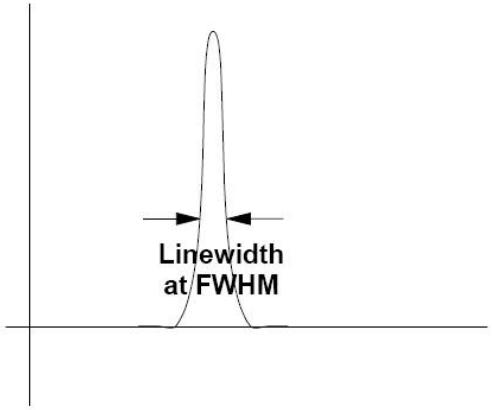
Spectrul diodei LASER

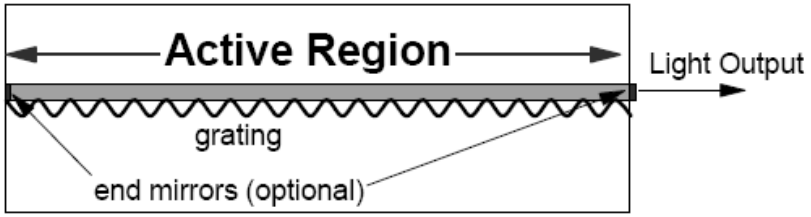
- Castigul diodei laser (eficacitatea aparitiei emisiei stimulate) depinde
  - de caracteristicile energetice ale materialului din care e realizata dioda
  - de energia pompata din exterior (curentul prin dioda)

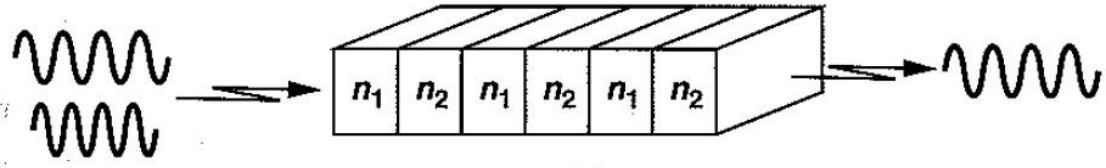


Distributed Feedback (DFB) Lasers

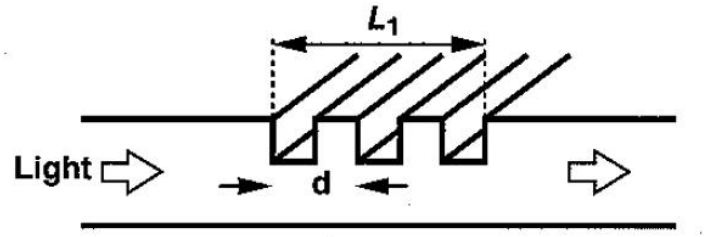








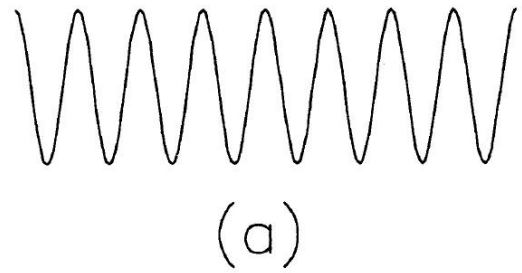
(a)

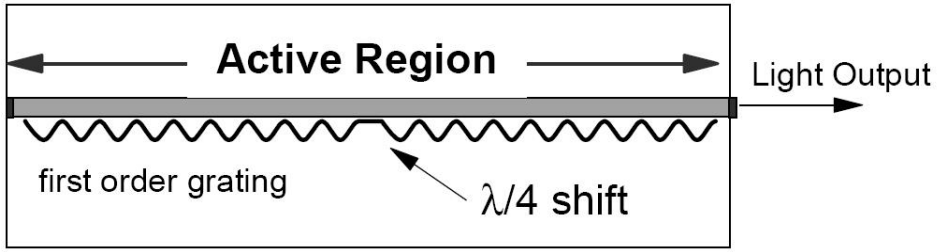


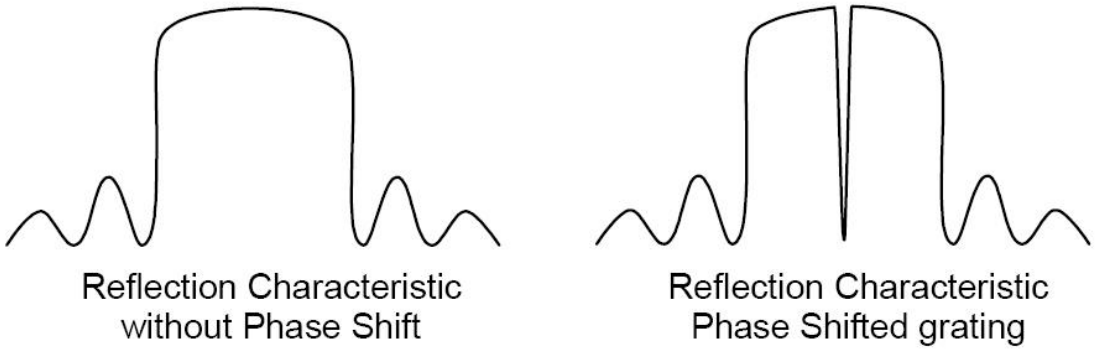
(b)

Distributed Feedback (DFB) Lasers

- Pentru operarea in impulsuri, un salt de λ/4 ingusteaza suplimentar spectrul diodei laser

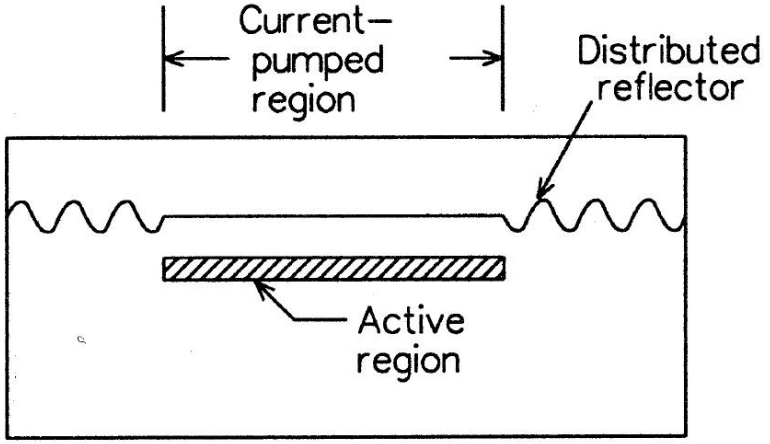


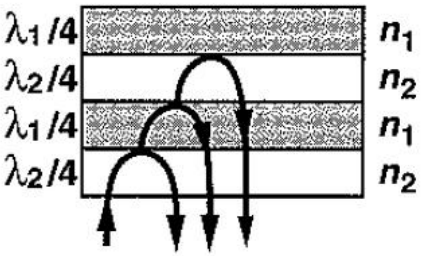


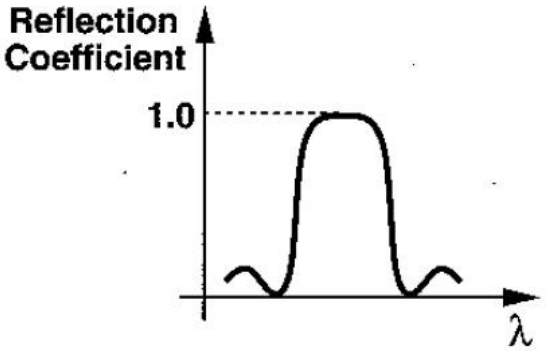


Distributed Bragg Reflector (DBR) Lasers

- Se utilizeaza suprafete reflective selective pentru filtrare optica





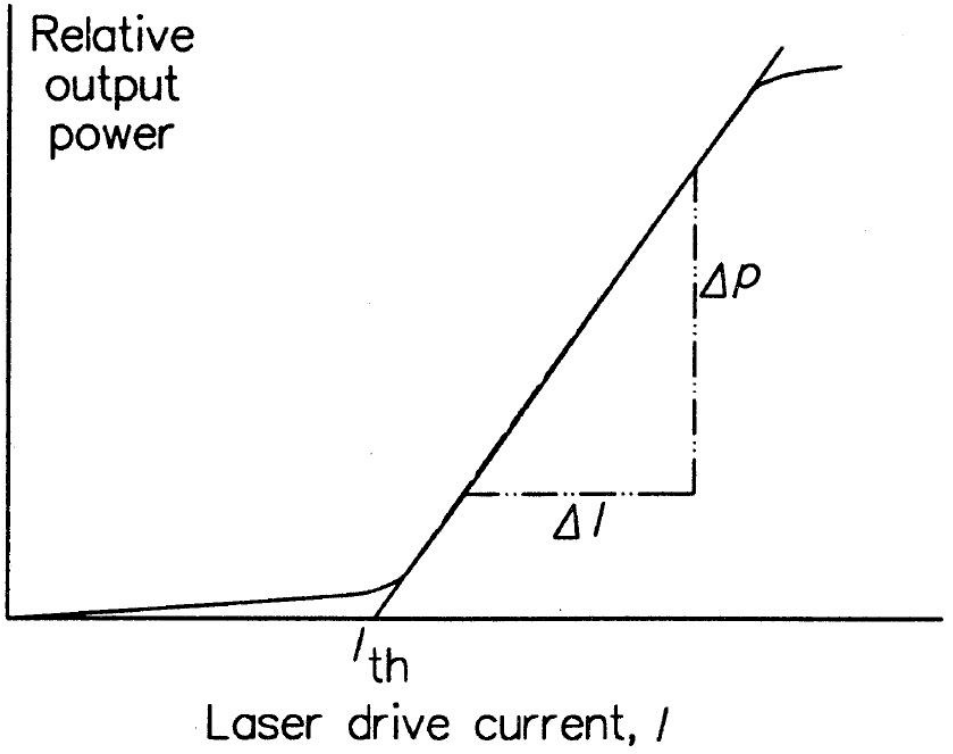


Caracteristici curent tensiune

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

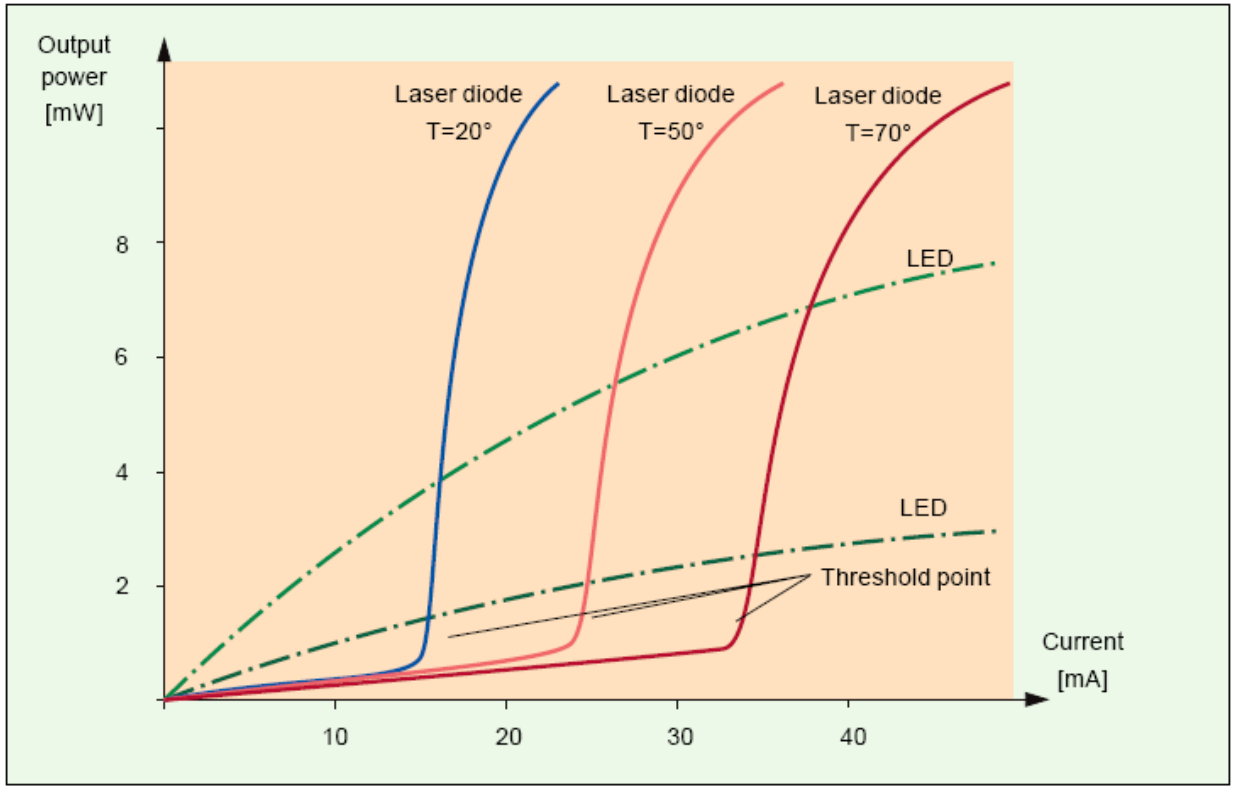
$$I > I_{th}$$

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



Temperatura si îmbatrânire

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

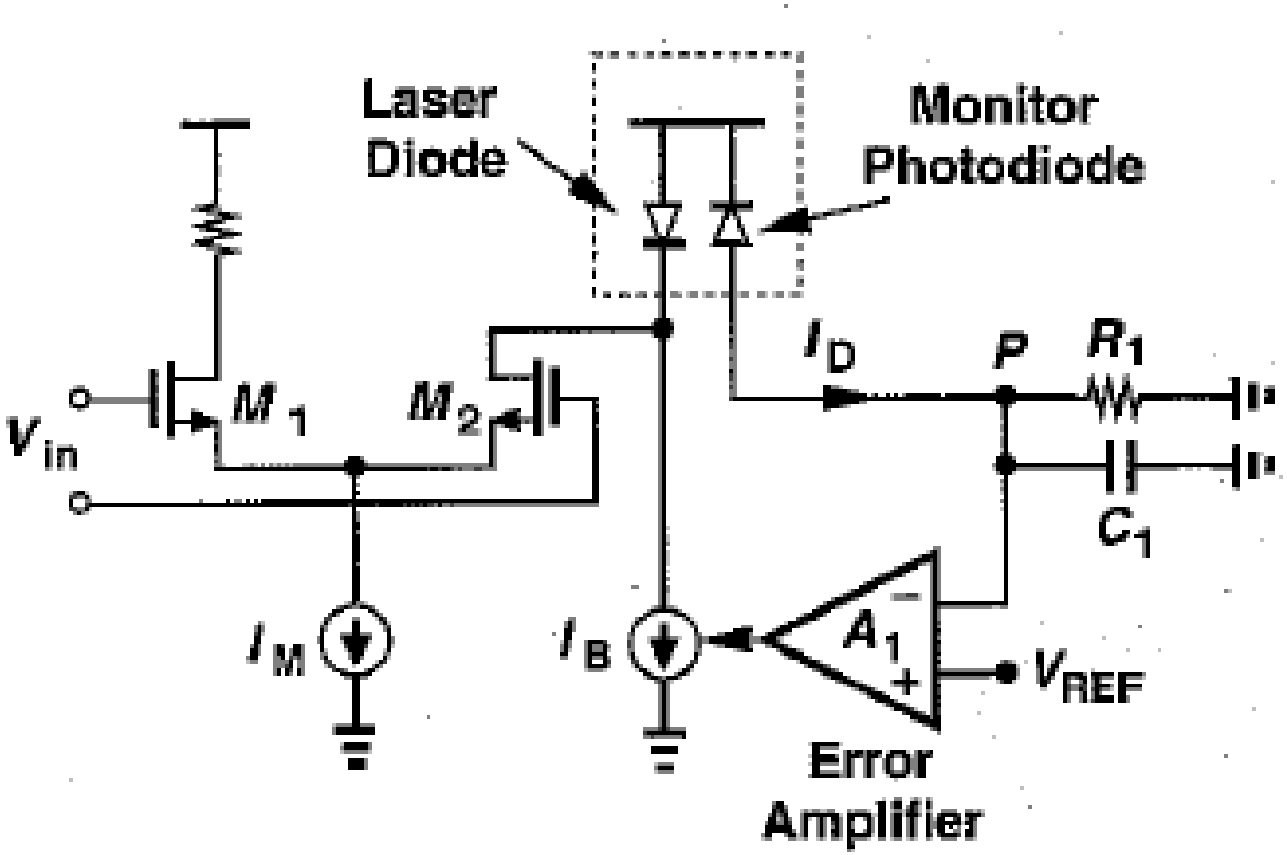


Dependenta de temperatura

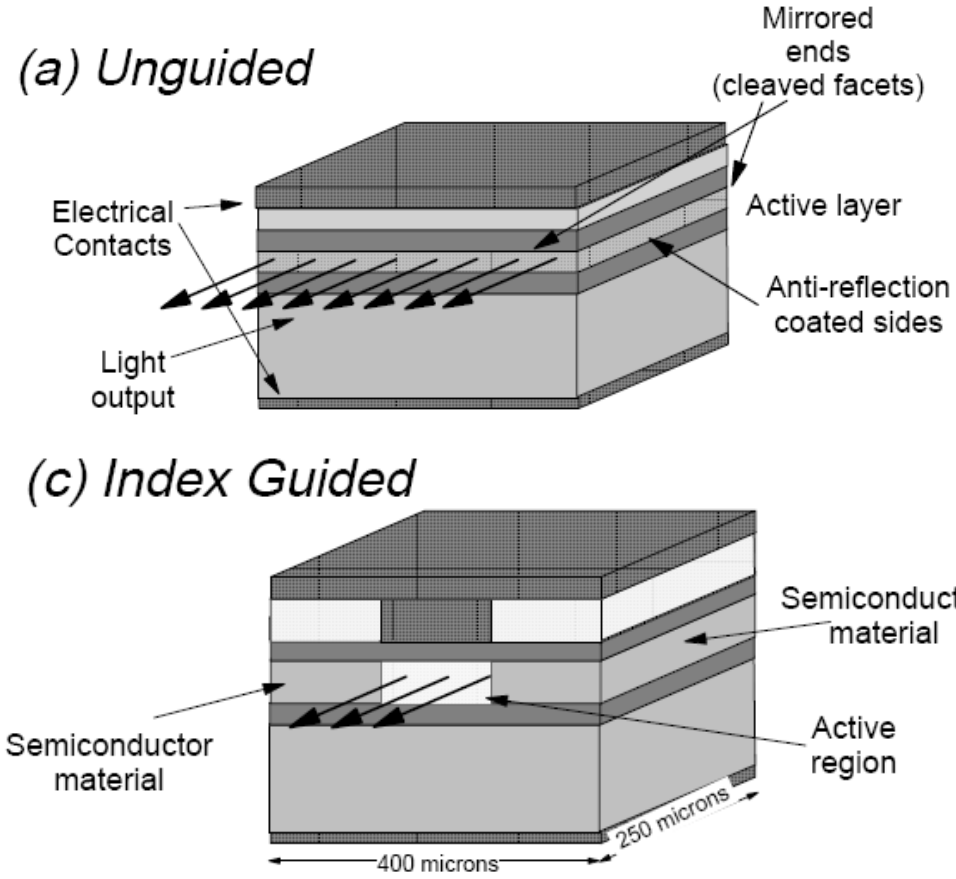
- Dependenta de temperatura a curentului de prag este exponentiala
- $$I_{th} = I_0 \cdot e^{T/T_0}$$
- I_0 e o constanta determinata la temperatura de referinta

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

Monitorizarea radiaţiei de spate

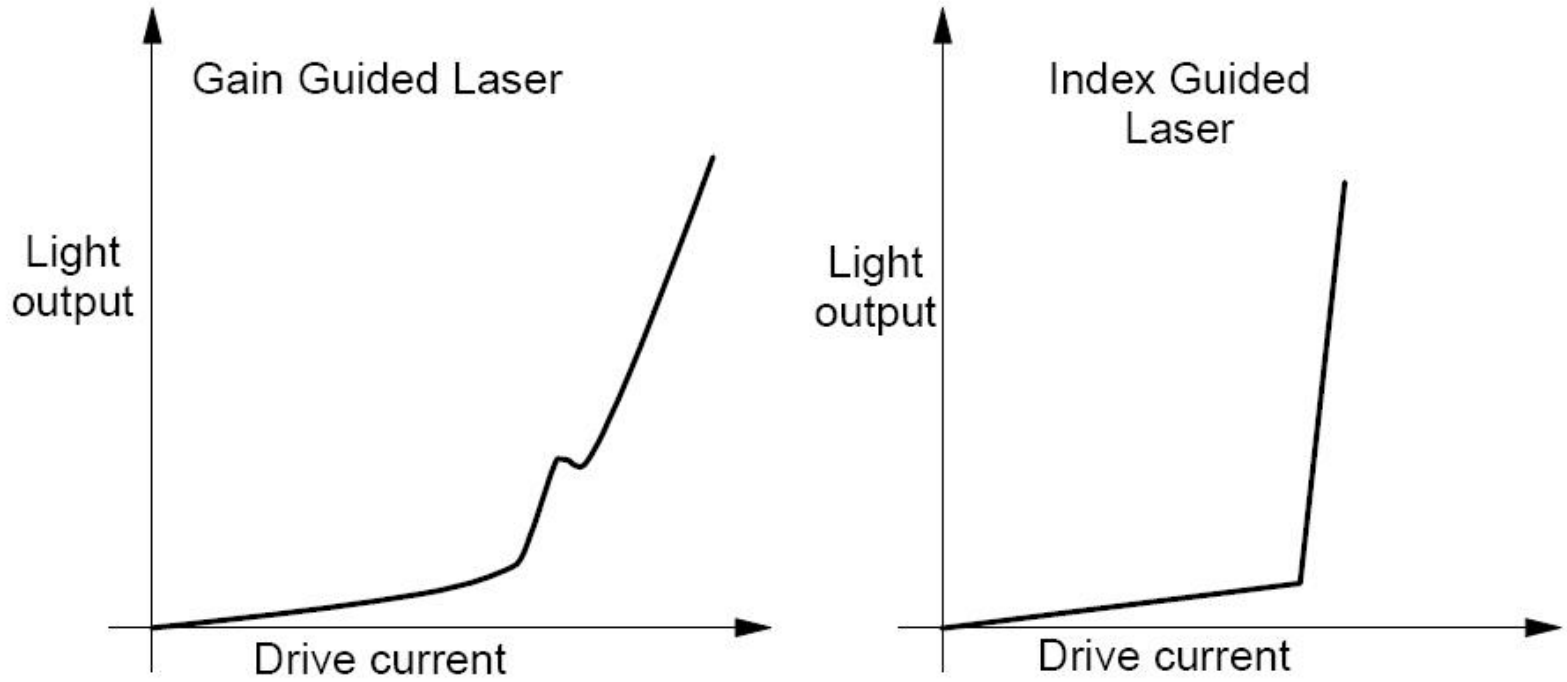


Direcţionarea luminii în laser-ul Fabry Perot

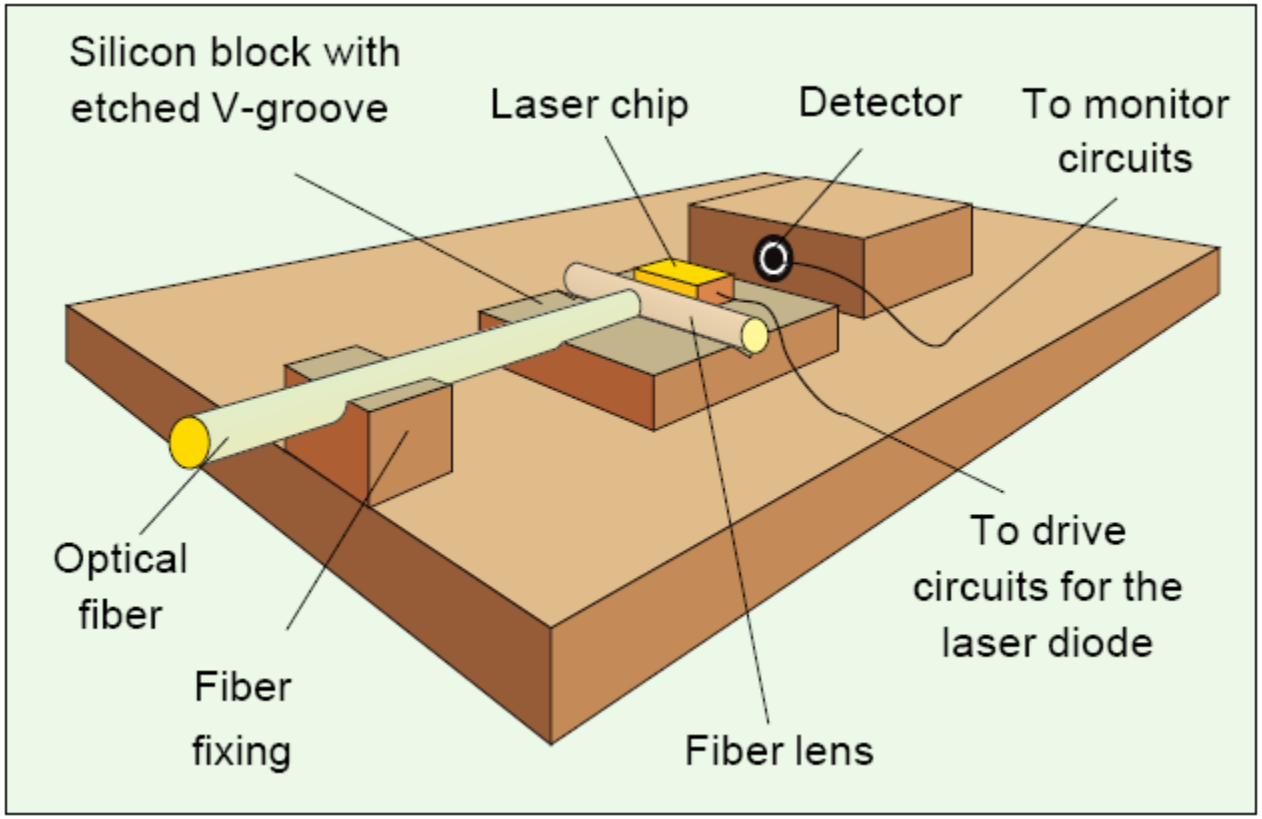


Efectul ghidarii

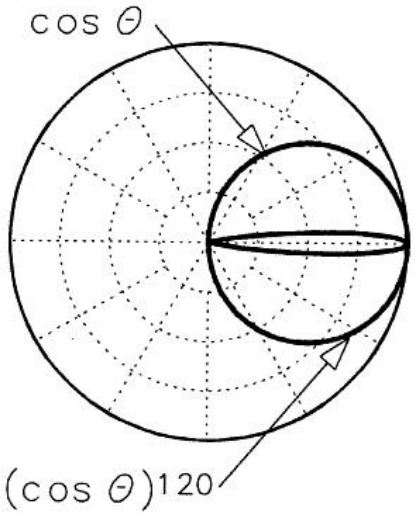
- Gain guided – 8÷20 linii spectrale (5÷8 nm)
- Index guided – 1÷5 linii spectrale (1÷3 nm)



Cuplarea luminii în fibră



Directivitatea radiatiei exterioare



- Sursa lambertiana

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

  - Eficienta cuplarii in fibra

$$\eta = \frac{P_f}{P_s} = NA^2 \qquad / \cdot \left(\frac{a}{r_s}\right)^2$$

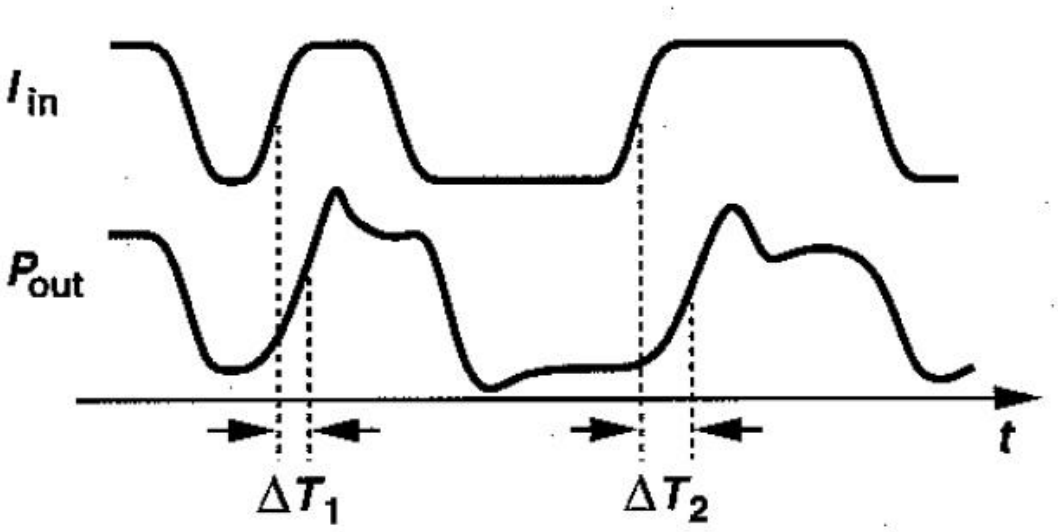
$$\eta = \frac{P_f}{P_s} = NA^2 \cdot \left(\frac{a}{r_s}\right)^2 \cdot \left(\frac{g}{g+2}\right)$$

- Aproximatie Lambertiana pentru surse cu directivitate crescuta

$$P(\theta) = P_0 \cdot \cos^m \theta \qquad \eta = \frac{P_f}{P_s} = \left(\frac{m+1}{2}\right) \cdot NA^2$$

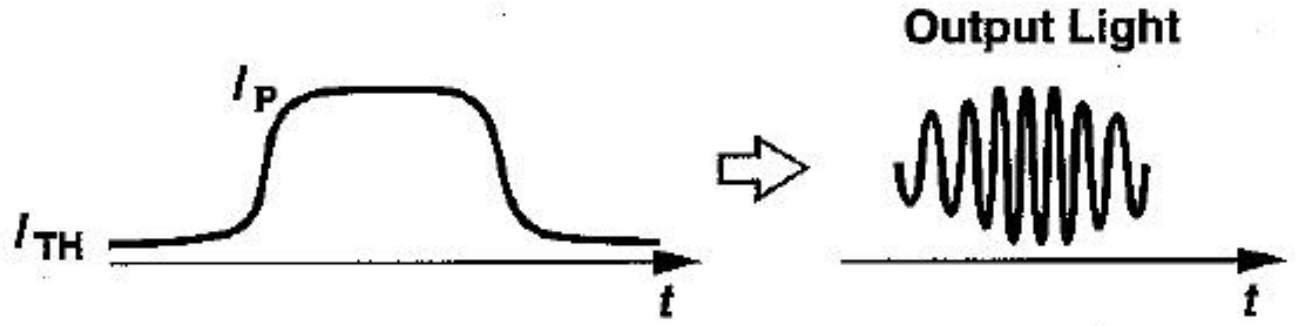
Turn-on delay

- La alimentarea cu curent a diodei laser emisia este initial spontana, devenind stimulata dupa amorsarea acesteia
- emisia spontana este un fenomen intrinsec aleator
- Intarzierea este variabila – jitter



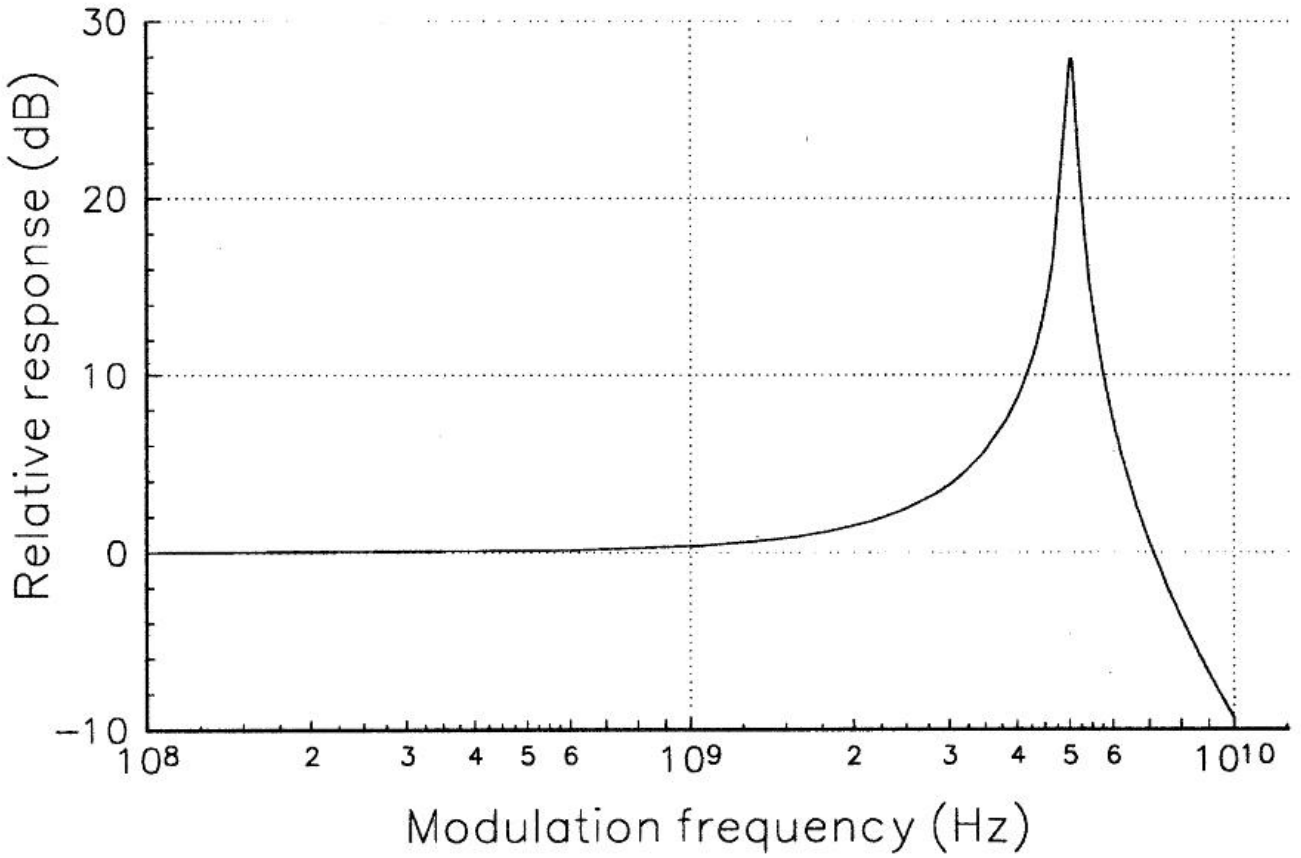
Chirping

- Frecventa de oscilatie depinde de indicele de refractie al materialului
- Indicele de refractie depinde de concentratia de purtatori
- Cand curentul este modulat in impuls apare o modulatie a frecventei luminii cu efectul cresterii latimii spectrale a diodei (un ordin de magnitudine)



Raspunsul unei diode laser

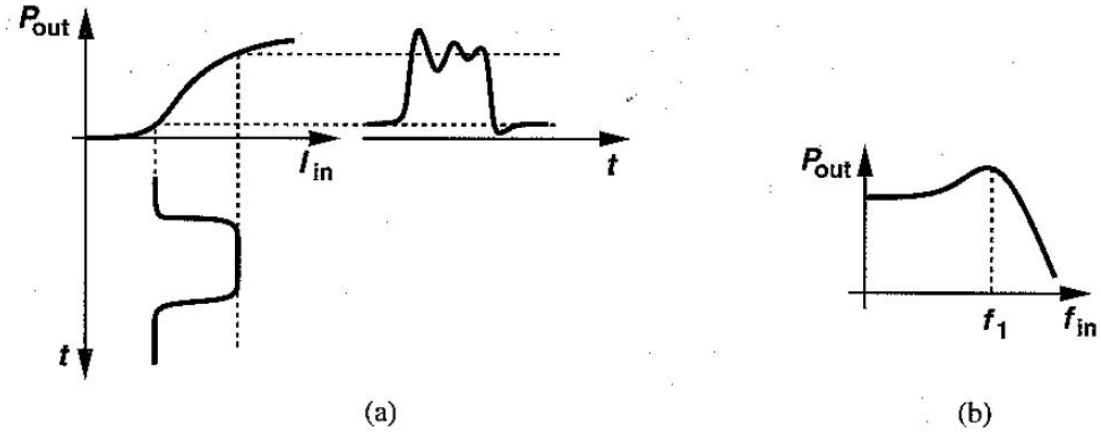
- oscilatii de relaxare – x GHz



Oscilatii de relaxare

- Generate de schimbul de energie intre electroni si fotoni
- Amorsarea emisiei stimulate duce la descresterea numarului de electroni in starea excitata, ceea ce duce la micsorarea emisiei de fotoni
- Acumularea din nou a electronilor in starea excitata duce din nou la cresterea puterii

- $f_1 = 1 \div 4$ GHz



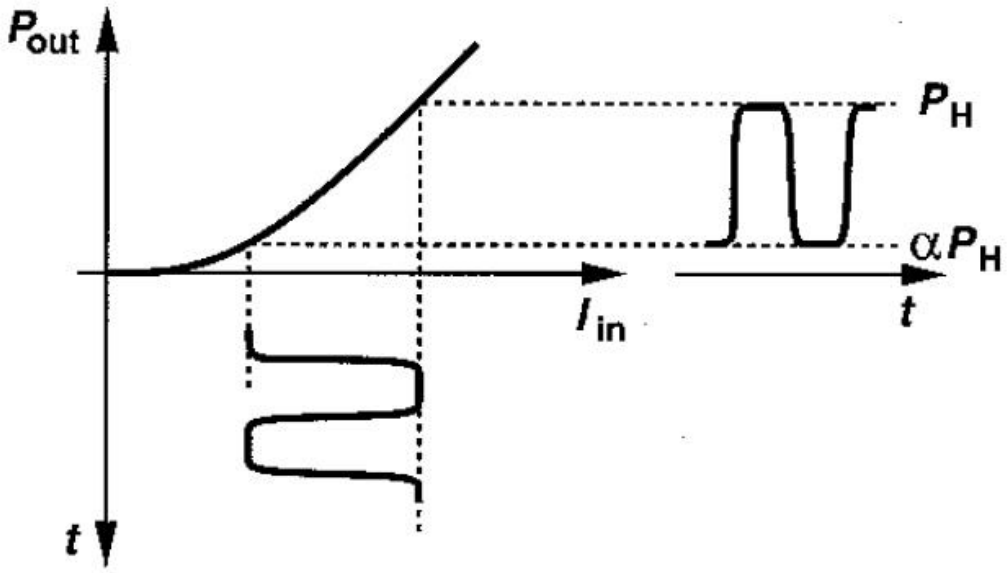
Oscilatii de relaxare

- Cresterea vitezei si minimizarea erorilor date de oscilatiile de relaxare si variatiile timpului de amorsare dioda este **partial** stinsa in timpul transmisiei unui nivel 0 logic

- Raport de stingere

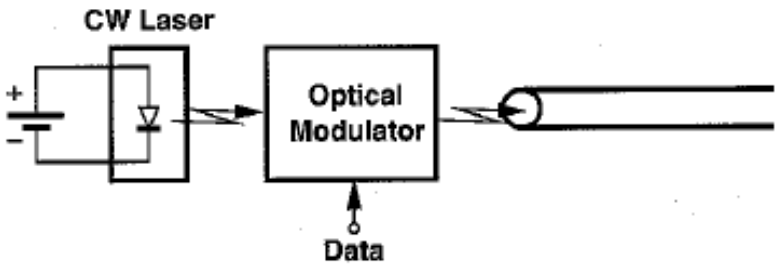
$$ER = \frac{P_H}{\alpha \cdot P_H} = \frac{1}{\alpha}$$

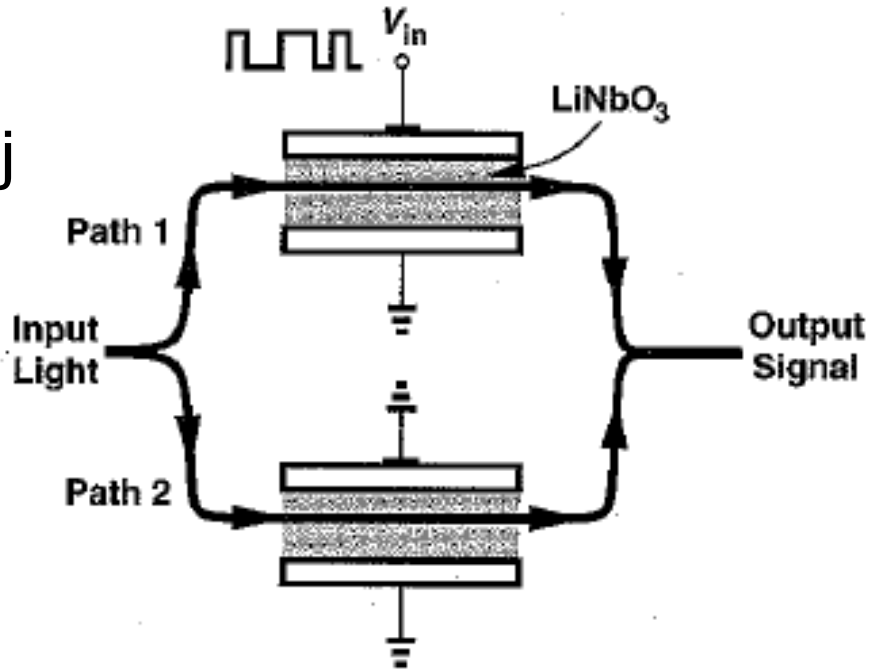
- Raportul semnal zgomot scade cu $(1-\alpha)$
- Tipic ER $= 10 \div 15\text{dB}$



Modulaţie optică

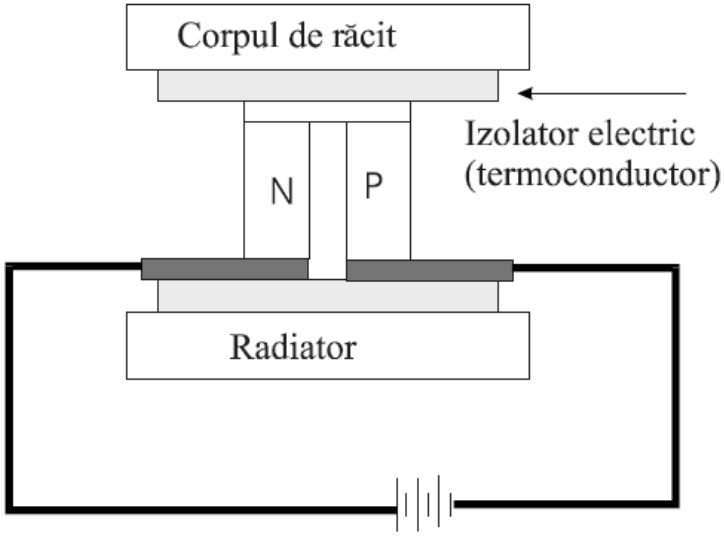
- Pentru viteze mari se prefera utilizarea emisiei continue si modularea optica a radiatiei
- In $LiNbO_3$ viteza luminii depinde de campul electric, ceea ce permite introducerea unui defazaj egal π
- Creste complexitatea circuitului de control
- Tensiuni de 4÷6 V necesare





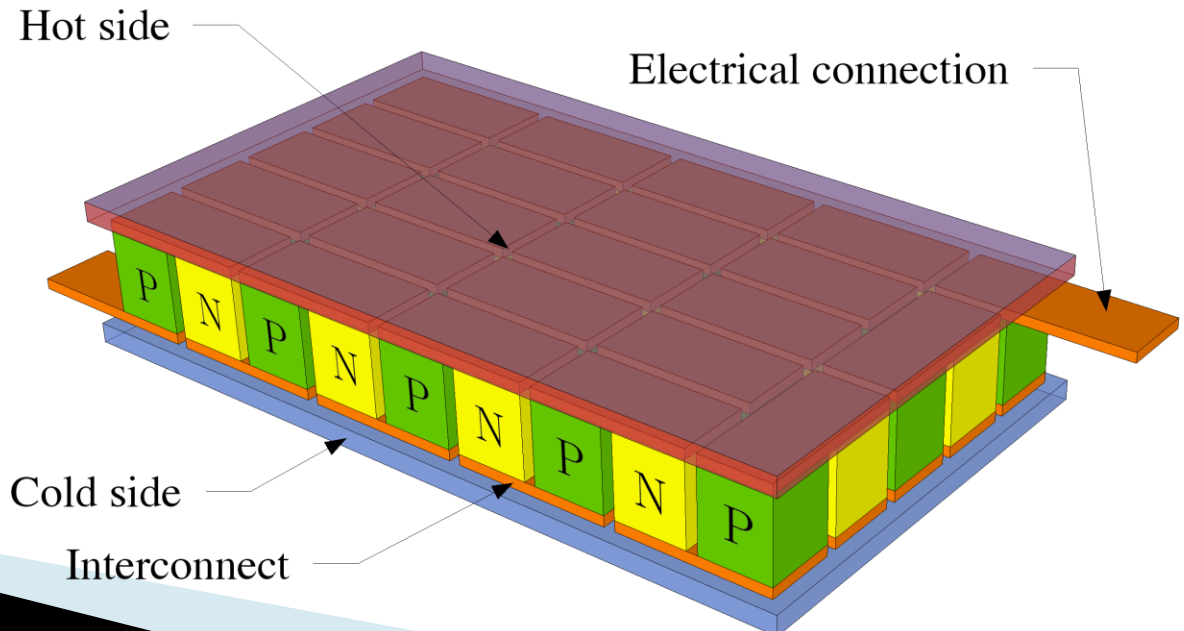
Dispozitiv termoelectric (Peltier)

- Jonctiunea intre doua materiale conductoare diferite poate genera sau absorbi caldura in functie de sensul curentului
- Tipic se utilizeaza doua regiuni semiconductoare puternic dopate (tipic telurit de bismut) conectate electric in serie iar termic in paralel

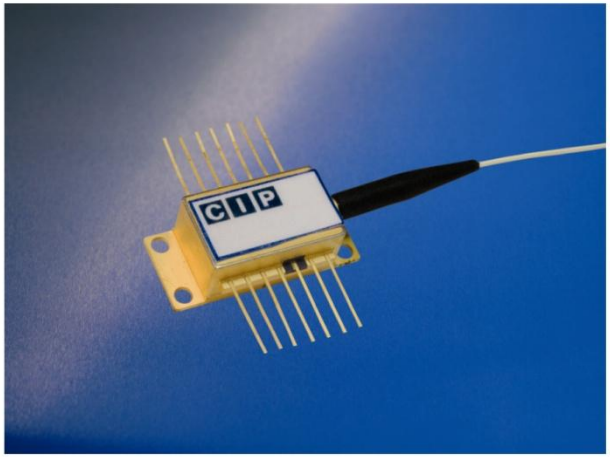


Dispozitiv termoelectric (Peltier)

- Poate produce o diferenta maxima de temperatura de 70°C
- Lucreaza la nivele mici de caldura disipata
- Devine cu atat mai ineficient cu cat fluxul termic disipat e mai mare
- De 4 ori mai putin eficiente decat sistemele cu compresie de vapori

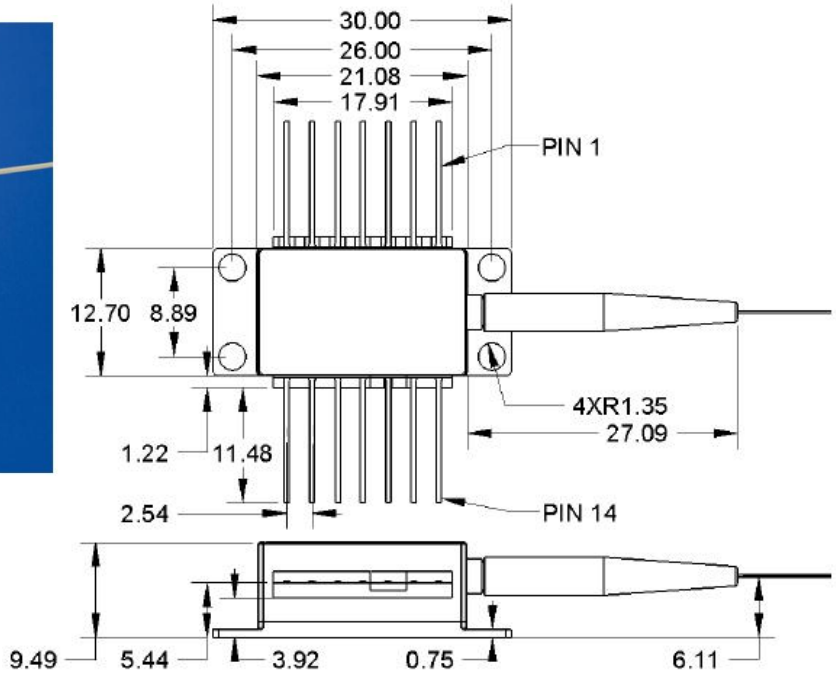


1550nm DFB Laser



Mechanical Drawing

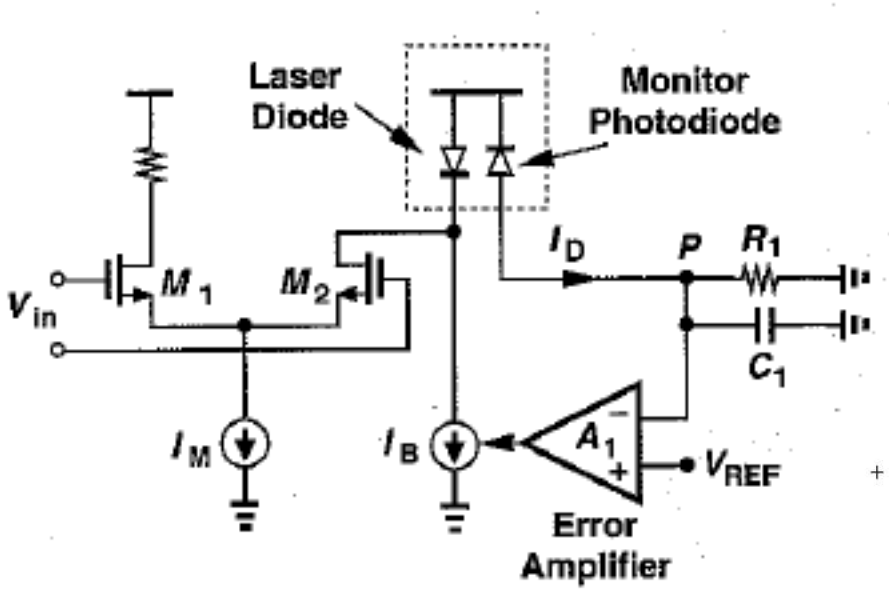
All units in mm

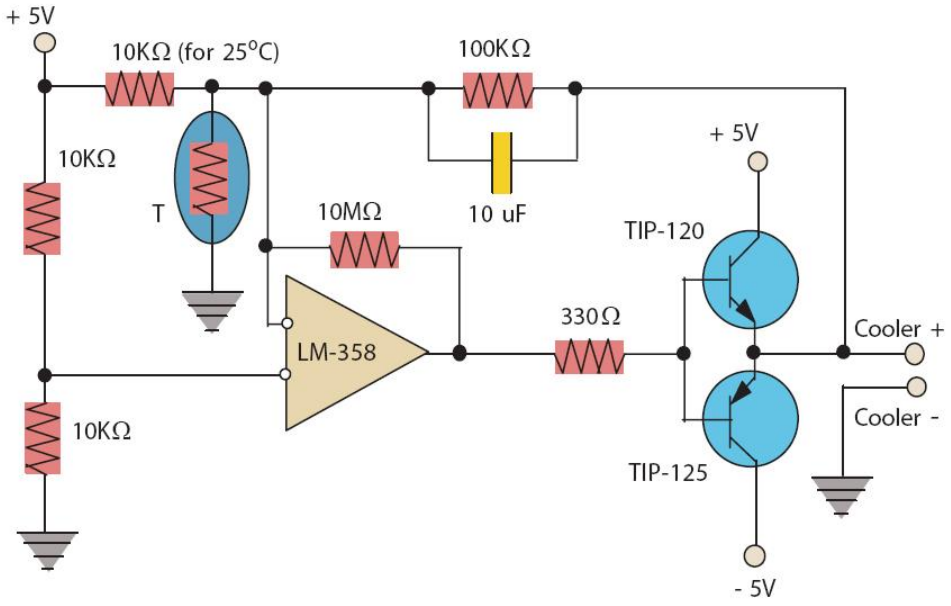


Pin out

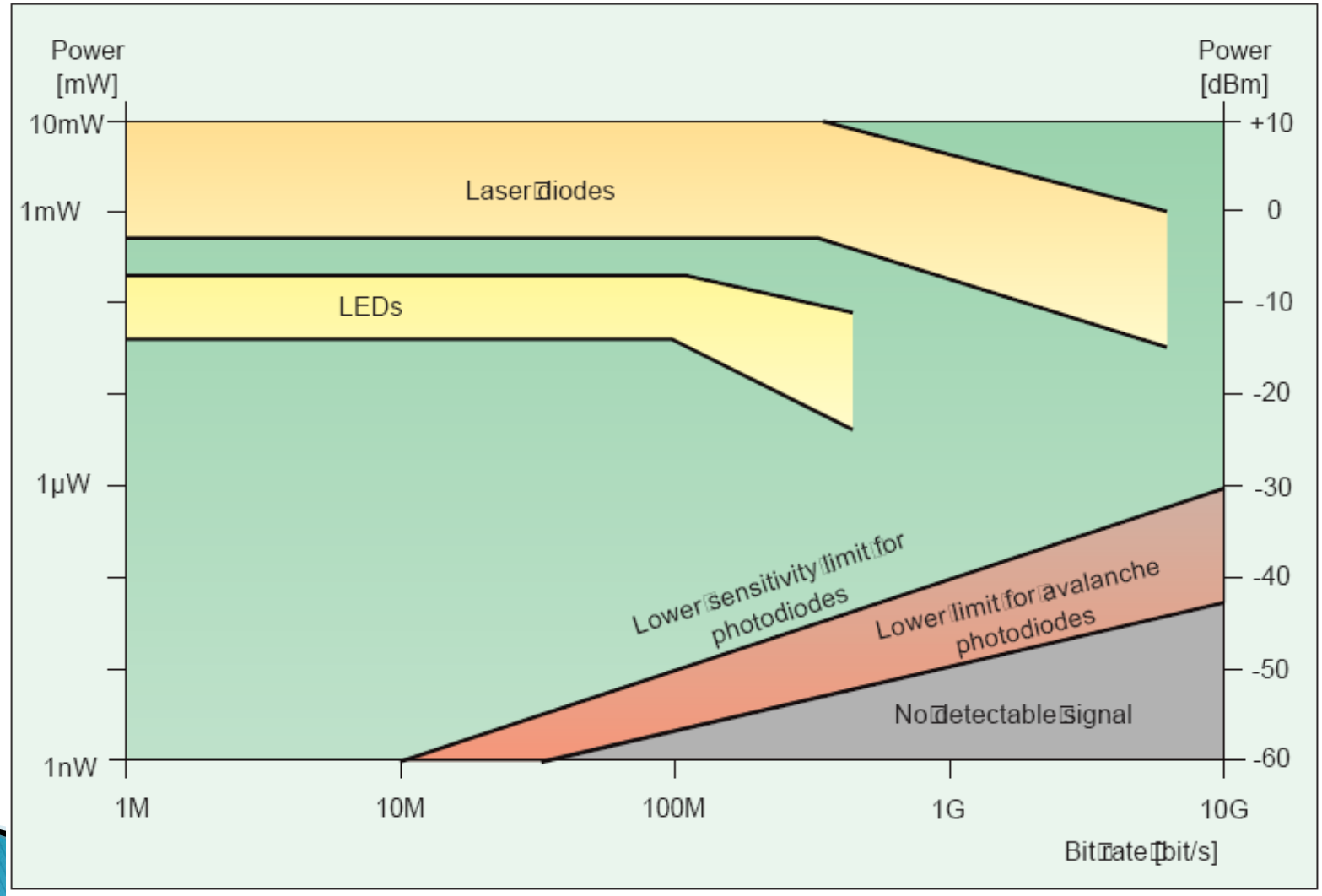
Pin	Description
1	Thermistor
2	Thermistor
3	Laser Cathode (Bias)
4	Monitor PD Anode
5	Monitor PD Cathode
6	TEC +
7	TEC -
8	Case GND, Laser Anode
9	Case GND, Laser Anode
10	Case GND, Laser Anode
11	Case GND, Laser Anode
12	Laser Cathode (modulation)
13	Case GND, Laser Anode
14	Case GND, Laser Anode

Control dioda LASER





Limite putere/bandă a dispozitivelor optoelectronice



Contact

- Laboratorul de microunde si optoelectronica
- http://rf-opto.etti.tuiasi.ro
- rdamian@etti.tuiasi.ro