

Optoelectronică

Curs 8

2017/2018

Disciplina 2017/2018

- ▶ 2C/1L Optoelectronică **OPTO**
- ▶ **Minim 7** prezente curs + laborator
- ▶ Curs – **conf. Radu Damian**
 - an IV μ E
 - Vineri 8–11, P5
 - E – 70% din nota
 - **20% test la curs**, saptamana 4–5?
 - probleme + (? 1 subiect teorie) + (2p prez. curs)
 - toate materialele permise
- ▶ Laborator – **sl. Daniel Matasaru**
 - an IV μ E, an IV Tc
 - Joi 14-16 par/impar
 - L – 15% din nota
 - C – 15% din nota

Orar 2017/2018

▶ Curs

- Vineri 8–11, P5
- **2C ⇒ 3C**
 - $14 * 2/3 \approx 9.33$
 - $9 \div 10$ C

Recapitulare

Reprezentare logaritmică!!!

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

LED

Dioda electroluminescenta

Capitolul 7

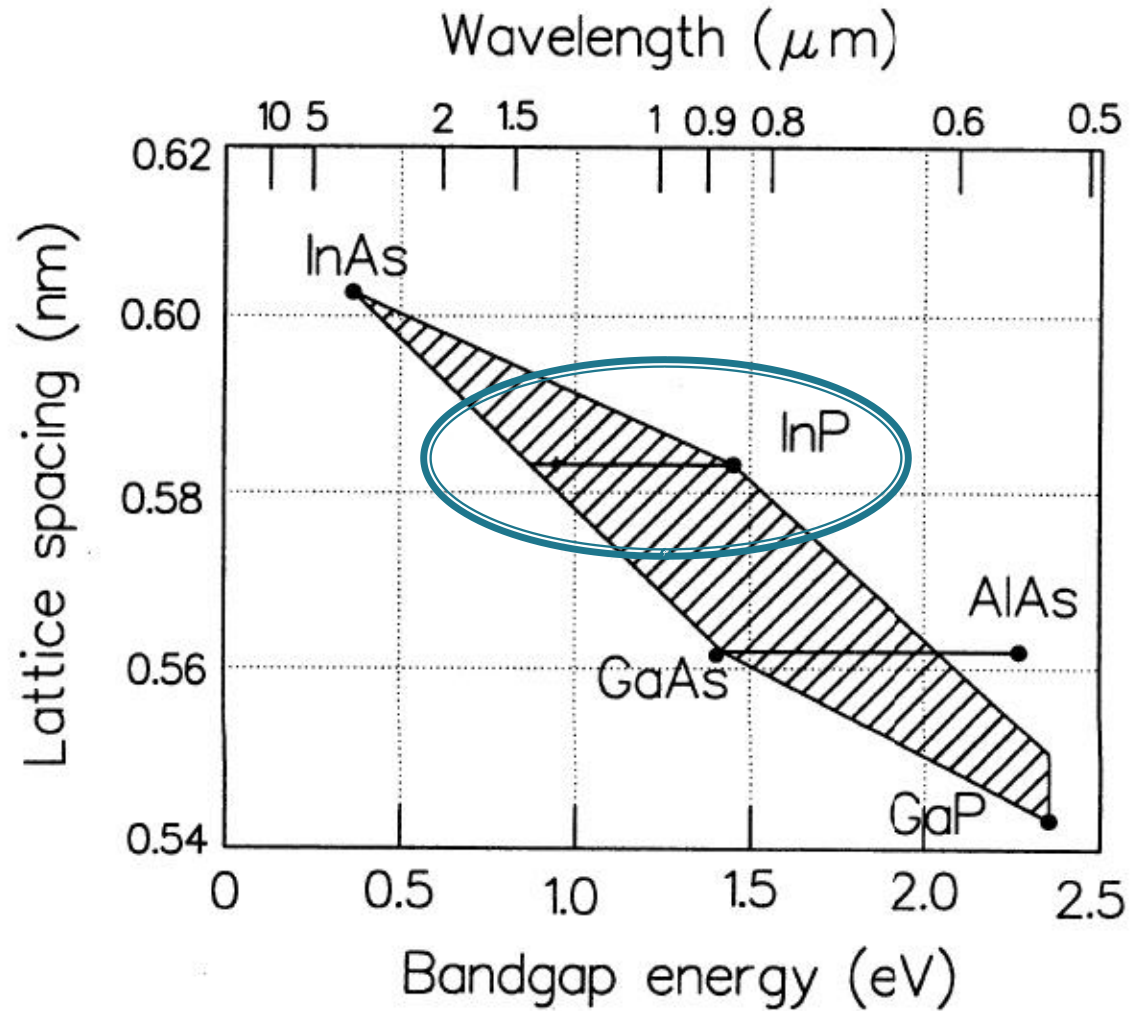
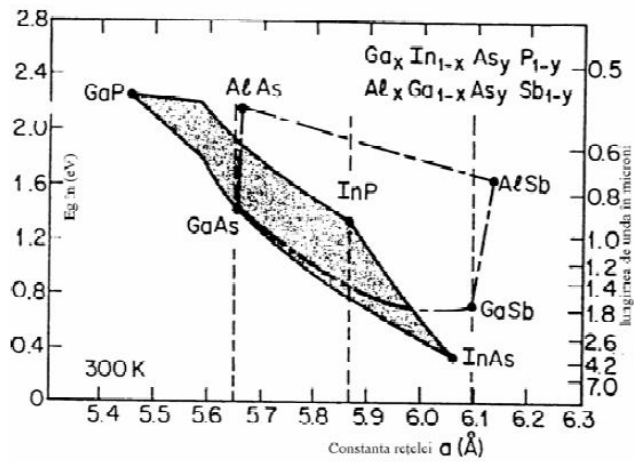
Lățimea benzii interzise/lungime de undă pentru materialele uzuale

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

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

- ▶ h constanta lui Plank
 $6.6261 \cdot 10^{-34} \text{ W s}^2$
- ▶ c viteza luminii **in vid**
 $2.998 \cdot 10^8 \text{ m/s}$
- ▶ e sarcina electronului
 $1.6 \cdot 10^{-19} \text{ C}$
- ▶ benzi energetice: λ_0 , $\Delta\lambda$

Dependența benzii interzise de constanta rețelei



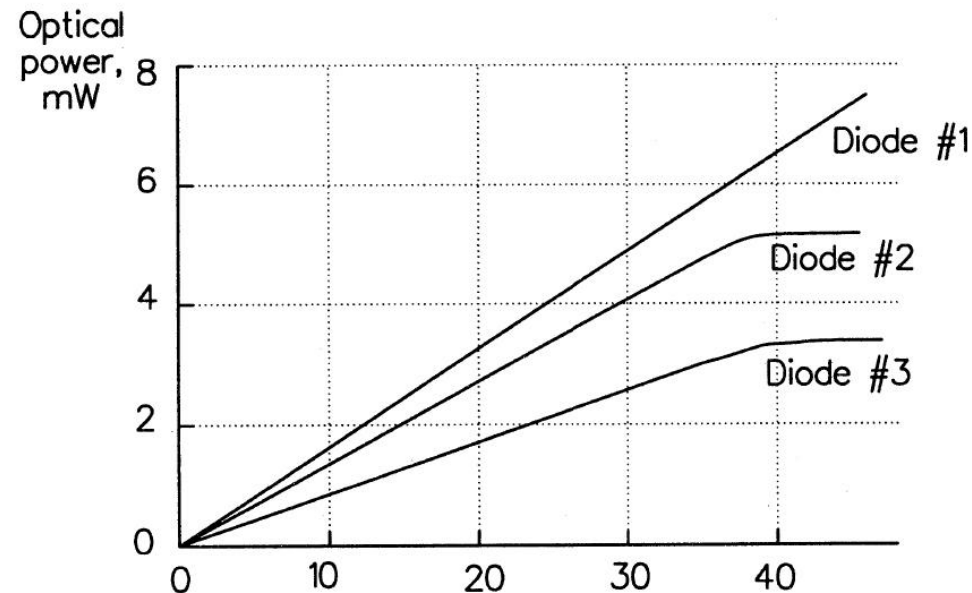
Caracteristica de raspuns a LED-urilor

- ▶ 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 $r = 50 \mu\text{W}/\text{mA}$



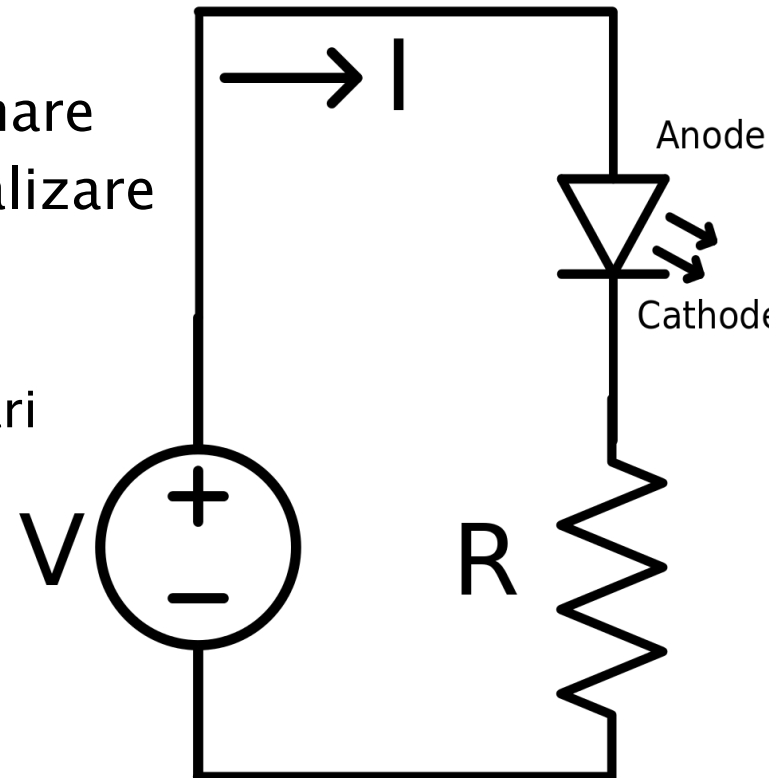
Control static LED

▶ Cea mai simpla schema de control: un rezistor in serie cu LED

- **Atentie!** Tensiunea directa poate varia semnificativ ($\gg 0.7V$) si trebuie preluata din catalog
 - mai ales la intensitate luminoasa mare
 - datorita materialelor diferite de realizare a LED-urilor
 - dependenta de lungimea de unda
 - mai mica la lungimi de unda mai mari

$$I_v = f(I_F [\text{mA}]) \quad [\text{cd/mcd}]$$

$$I_F = \frac{V_{cc} - V_F}{R}$$

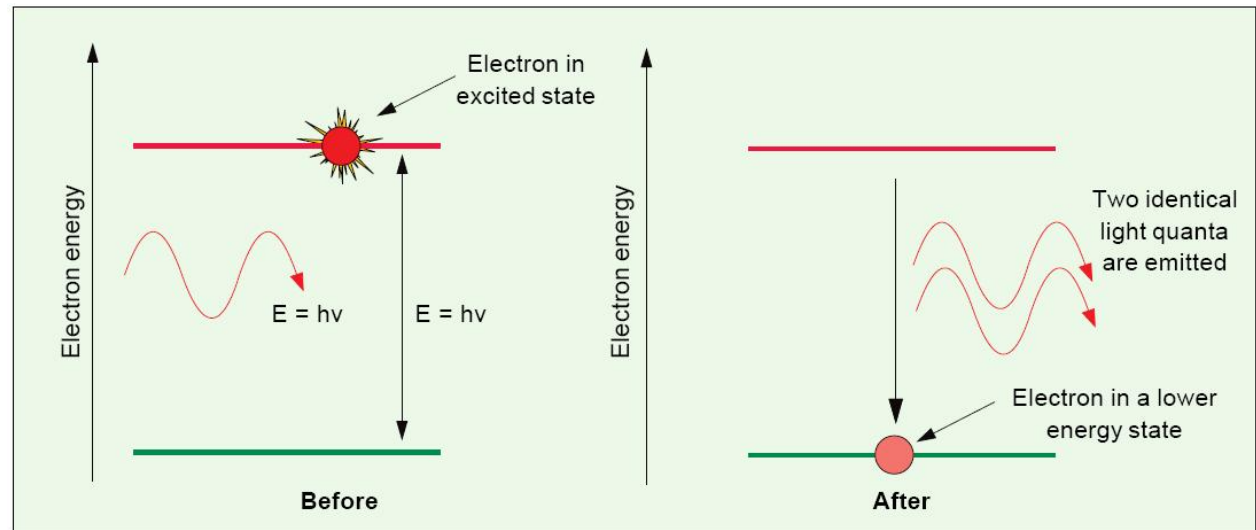


Dioda Laser

Capitolul 8

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



Principii LASER

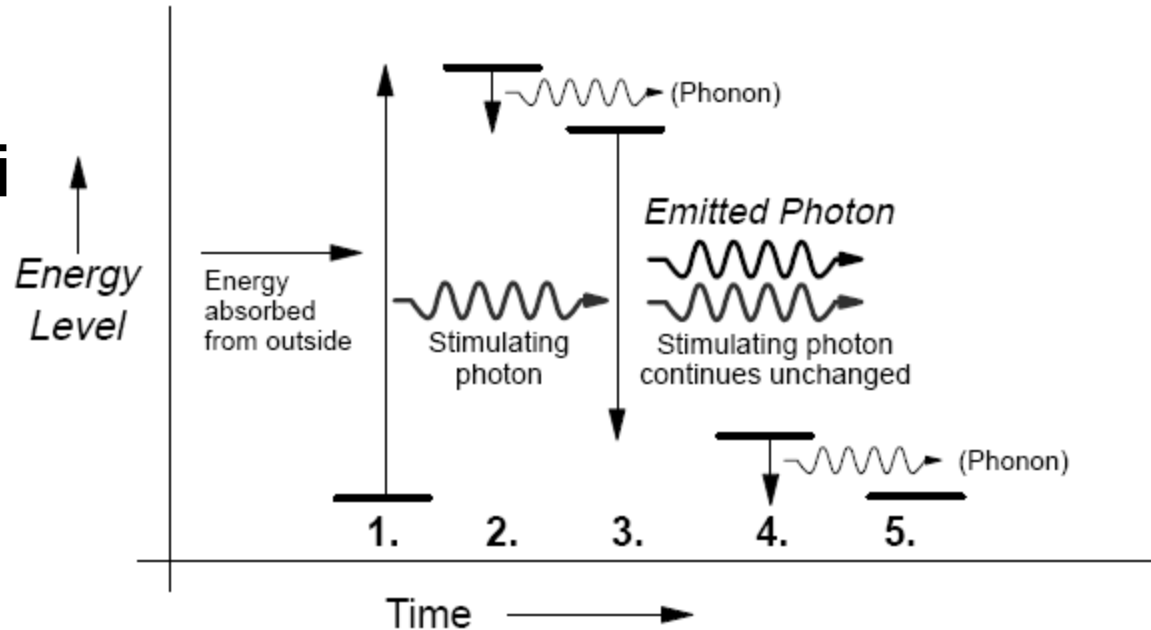
- ▶ Inversiune de populatie
 - necesara deoarece electronii au capabilitatea de a absorbi energie **la aceeasi frecventa** la care are loc emisia stimulata
 - se defineste probabilistic: probabilitatea de emisie stimulata sa fie mai mare decat probabilitatea de absorbtie

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

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

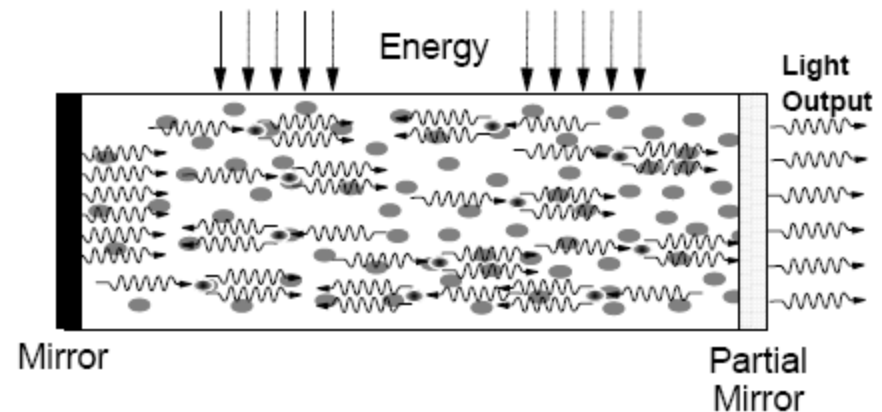
Materialie cu 4 nivele energetice

- ▶ 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

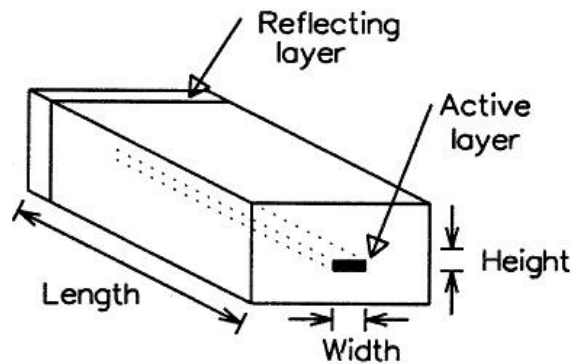
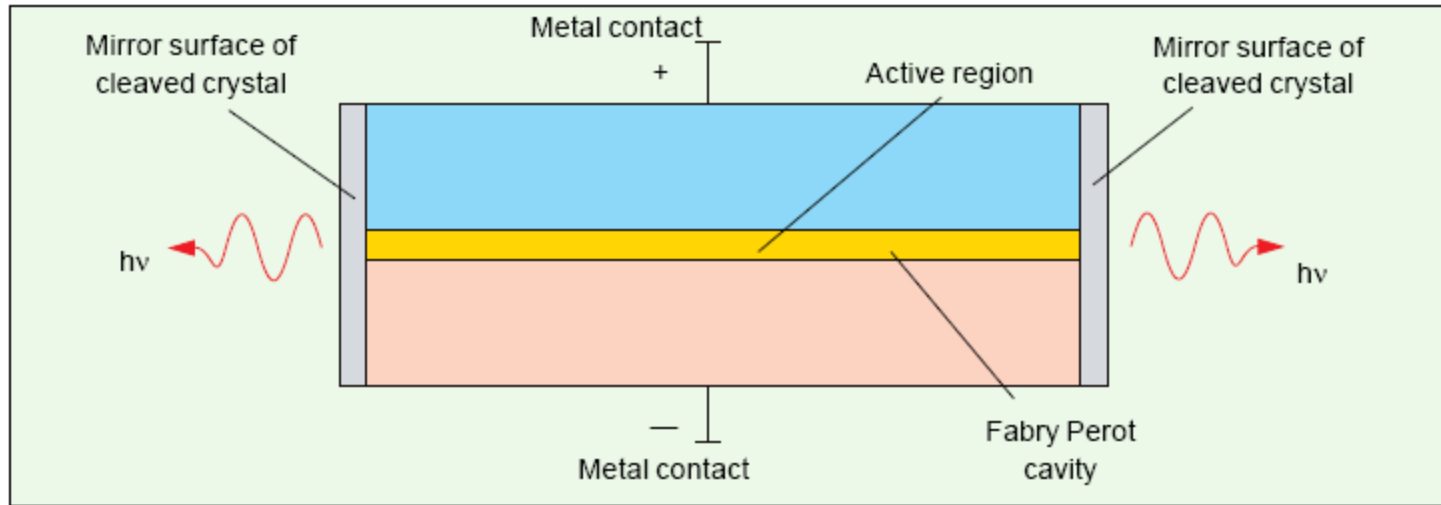


Dioda LASER – Principiu de realizare

- ▶ 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

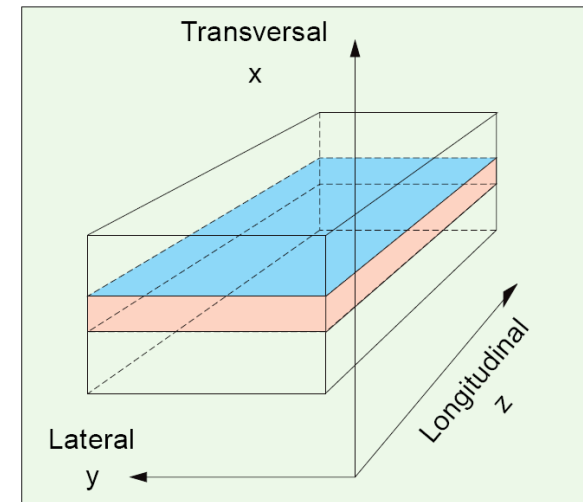


Dioda LASER Fabry Perot

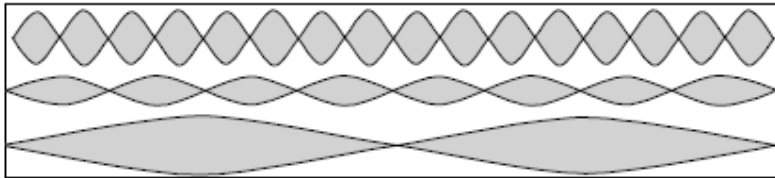


Height: $0.1 - 0.2 \mu\text{m}$
Length: $250 - 500 \mu\text{m}$
Width: $5 - 15 \mu\text{m}$
Sides: rough-cut
Front: cleaved
Back: 100% reflector

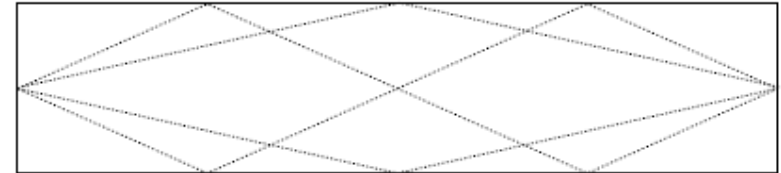
Definirea directiilor in dioda LASER



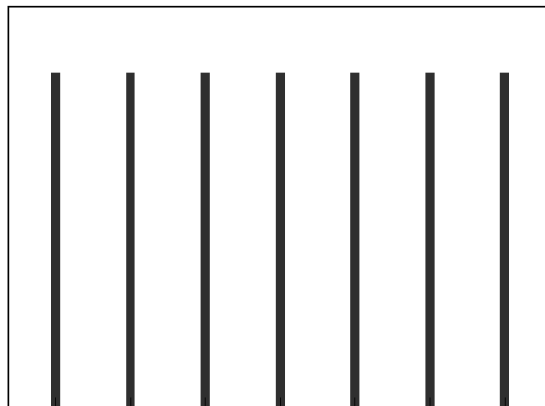
Spectrul diodei LASER



Longitudinal Modes



Lateral Modes



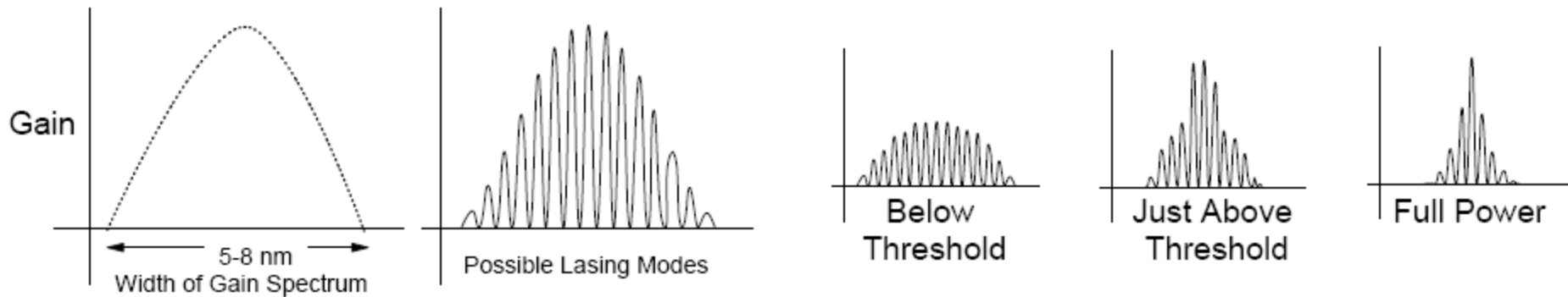
1.490 1.494 1.497 1.5 1.503 1.507 1.510
Wavelength (nm)

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

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

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)

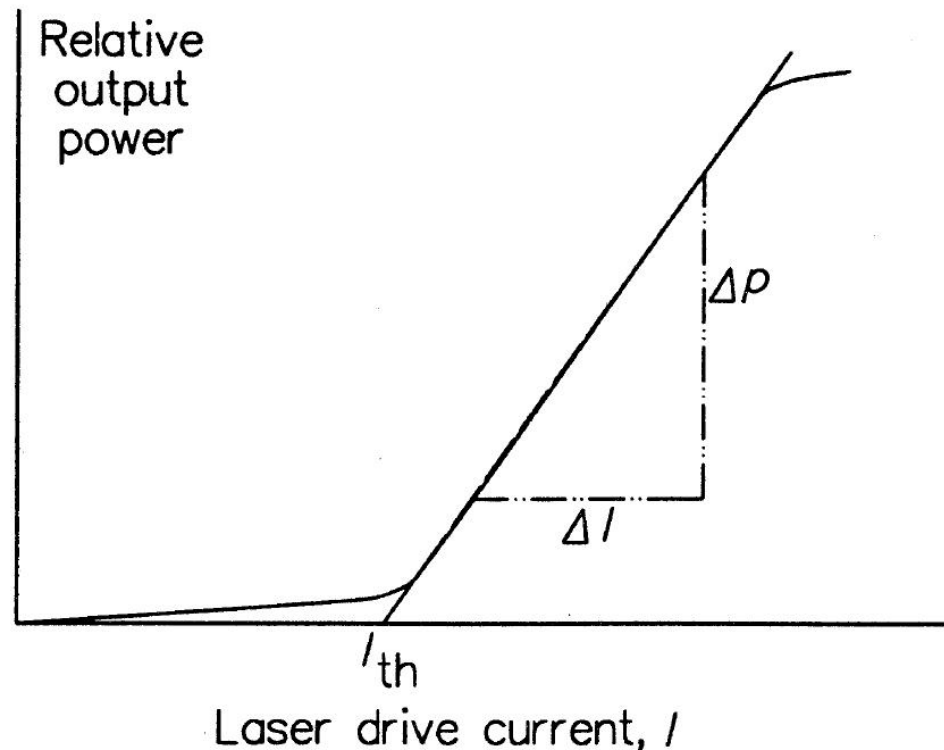


Caracteristici curent tensiune

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

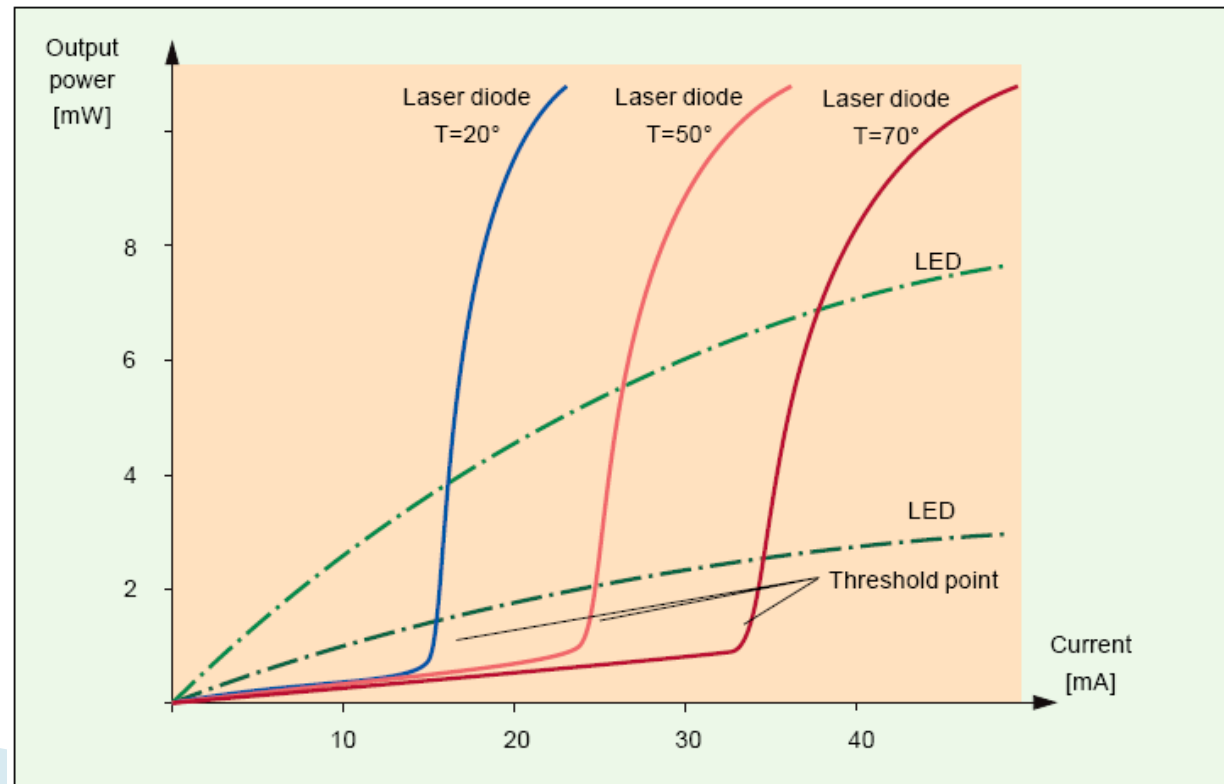
$$I > I_{th}$$

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

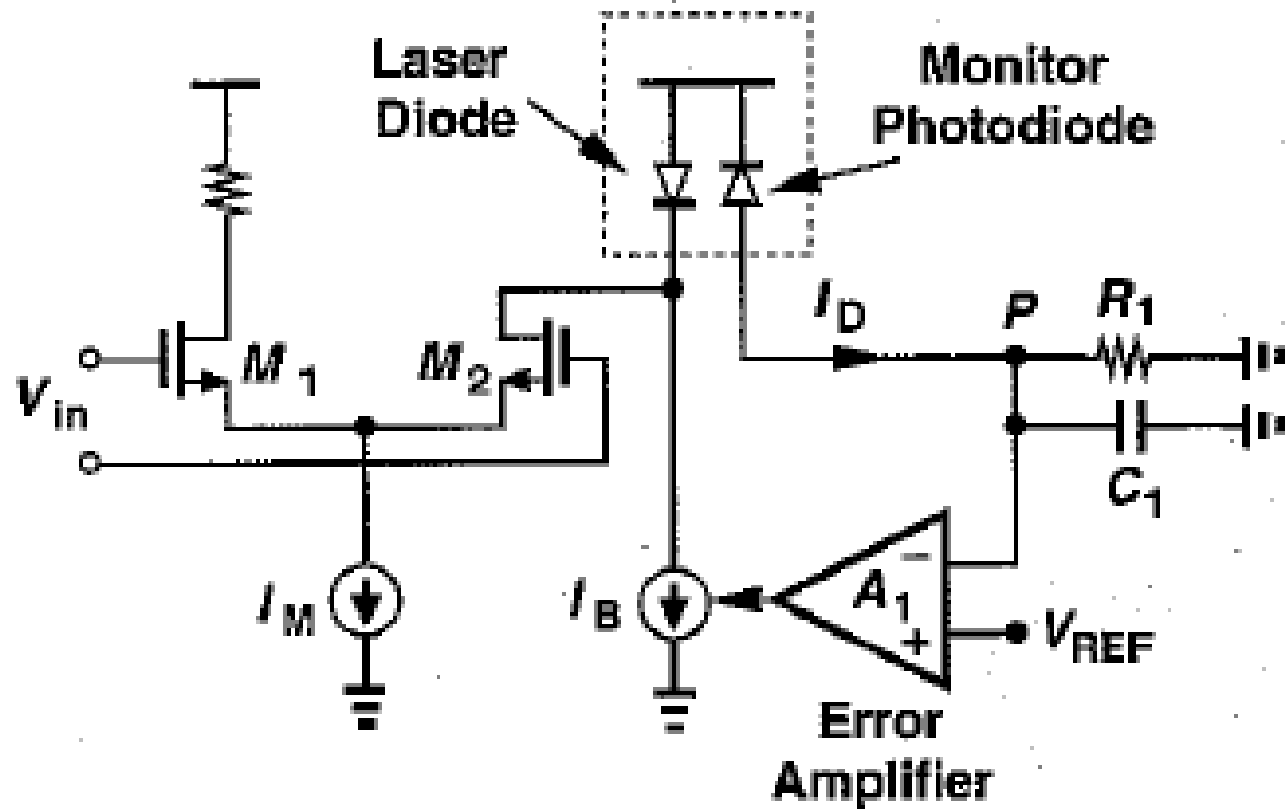


Temperatura si îmbatrânire

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

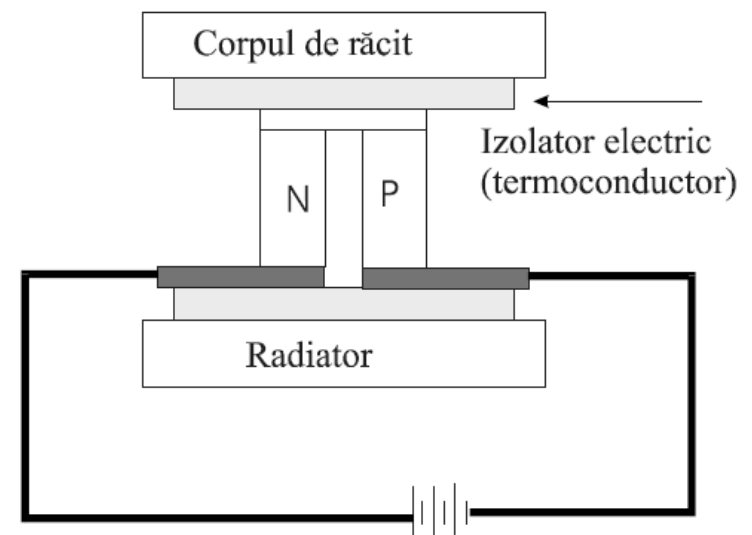


Monitorizarea radiației de spate



Dispozitiv termoelectric (Peltier)

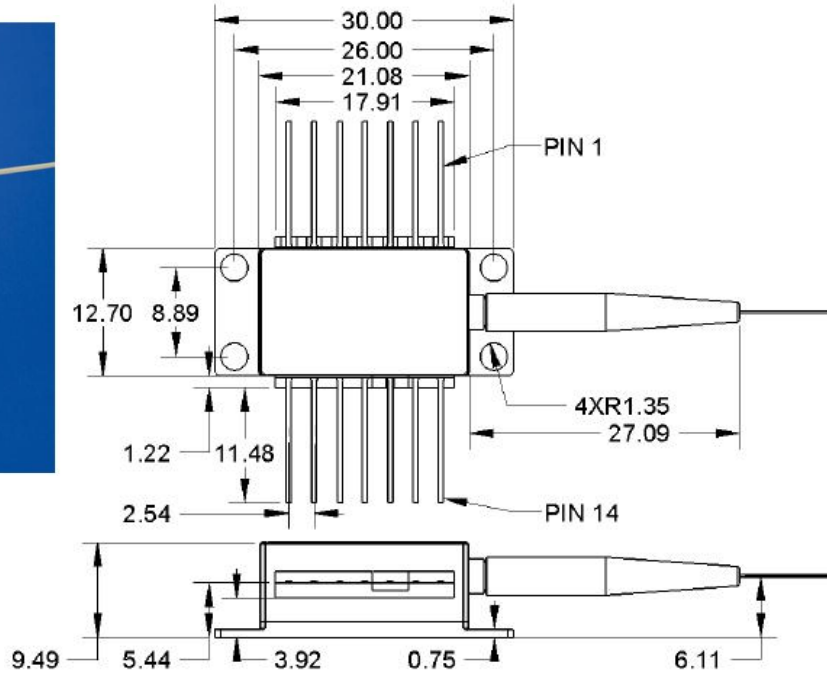
- ▶ Jonctiunea intre doua materiale conductoare diferite poate genera sau absorbi caldura in functie de sensul curentului
- ▶ Tipic se utilizeaza doua regiuni semiconductoare puternic dopate (tipic telurit de bismut) conectate electric in serie iar termic in paralel



1550nm DFB Laser

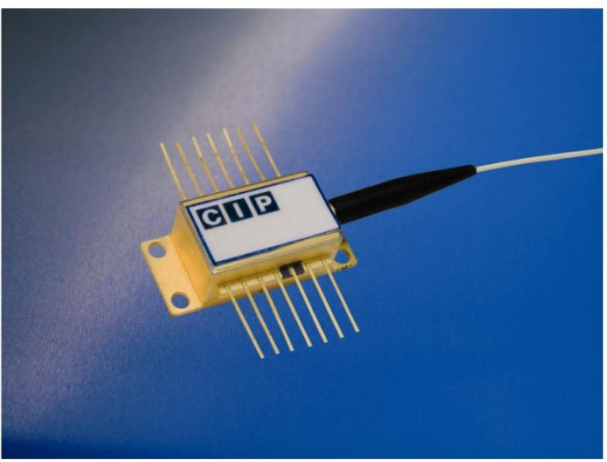
Mechanical Drawing

All units in mm

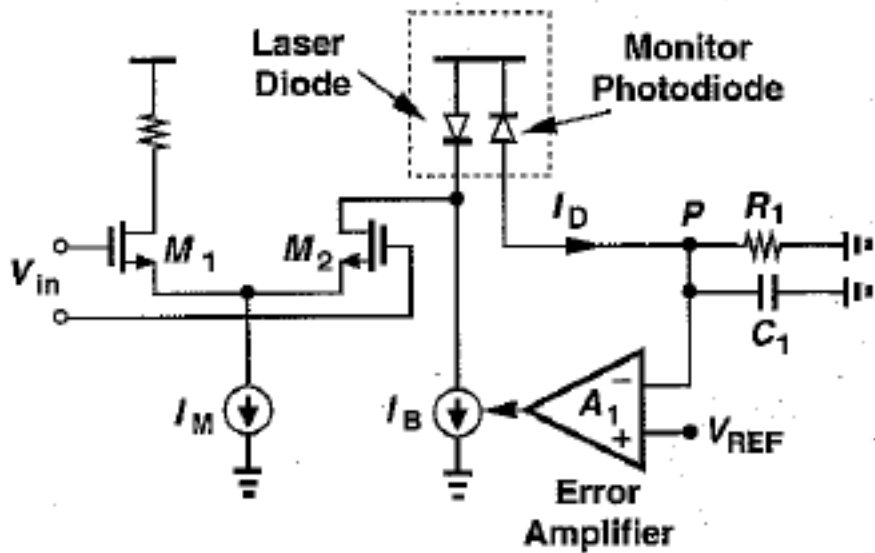


Pin out

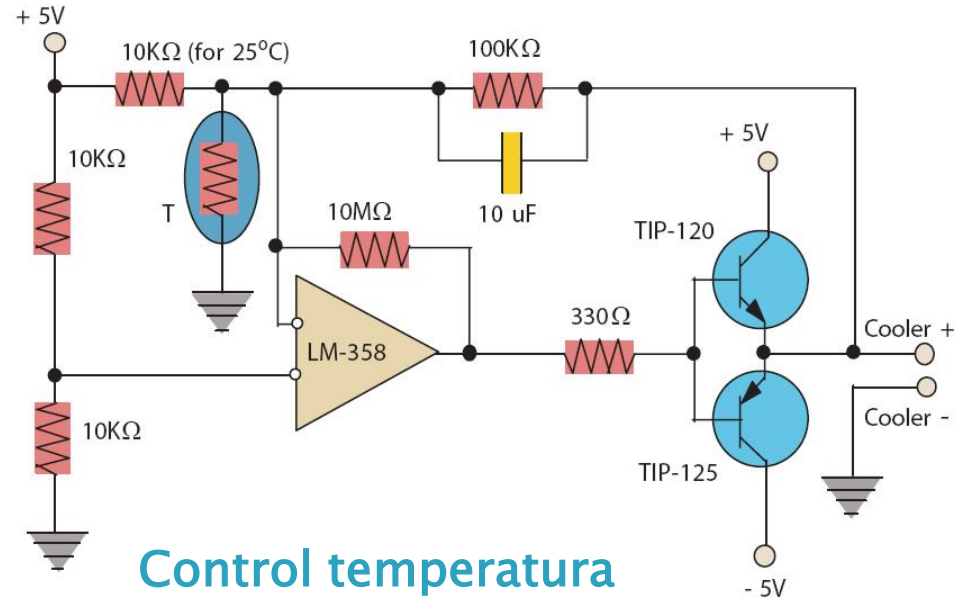
Pin	Description
1	Thermistor
2	Thermistor
3	Laser Cathode (Bias)
4	Monitor PD Anode
5	Monitor PD Cathode
6	TEC +
7	TEC -
8	Case GND, Laser Anode
9	Case GND, Laser Anode
10	Case GND, Laser Anode
11	Case GND, Laser Anode
12	Laser Cathode (modulation)
13	Case GND, Laser Anode
14	Case GND, Laser Anode



Control dioda LASER



Control putere optica

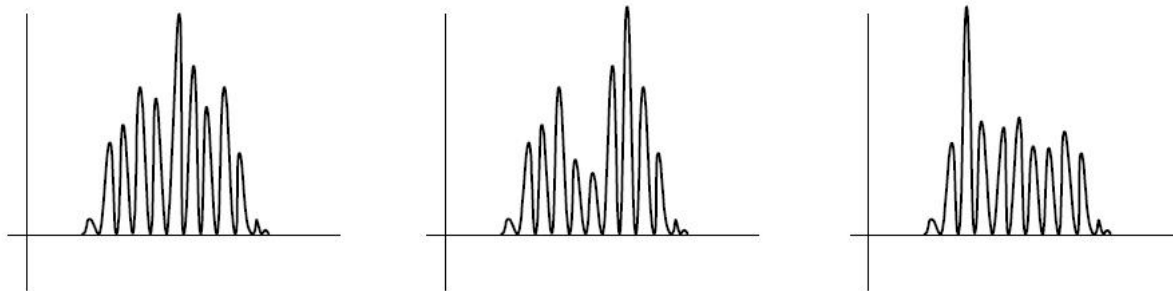


Control temperatura

Continuare

Alte caracteristici DL

- ▶ Mode hopping – salt de mod (hole burning)

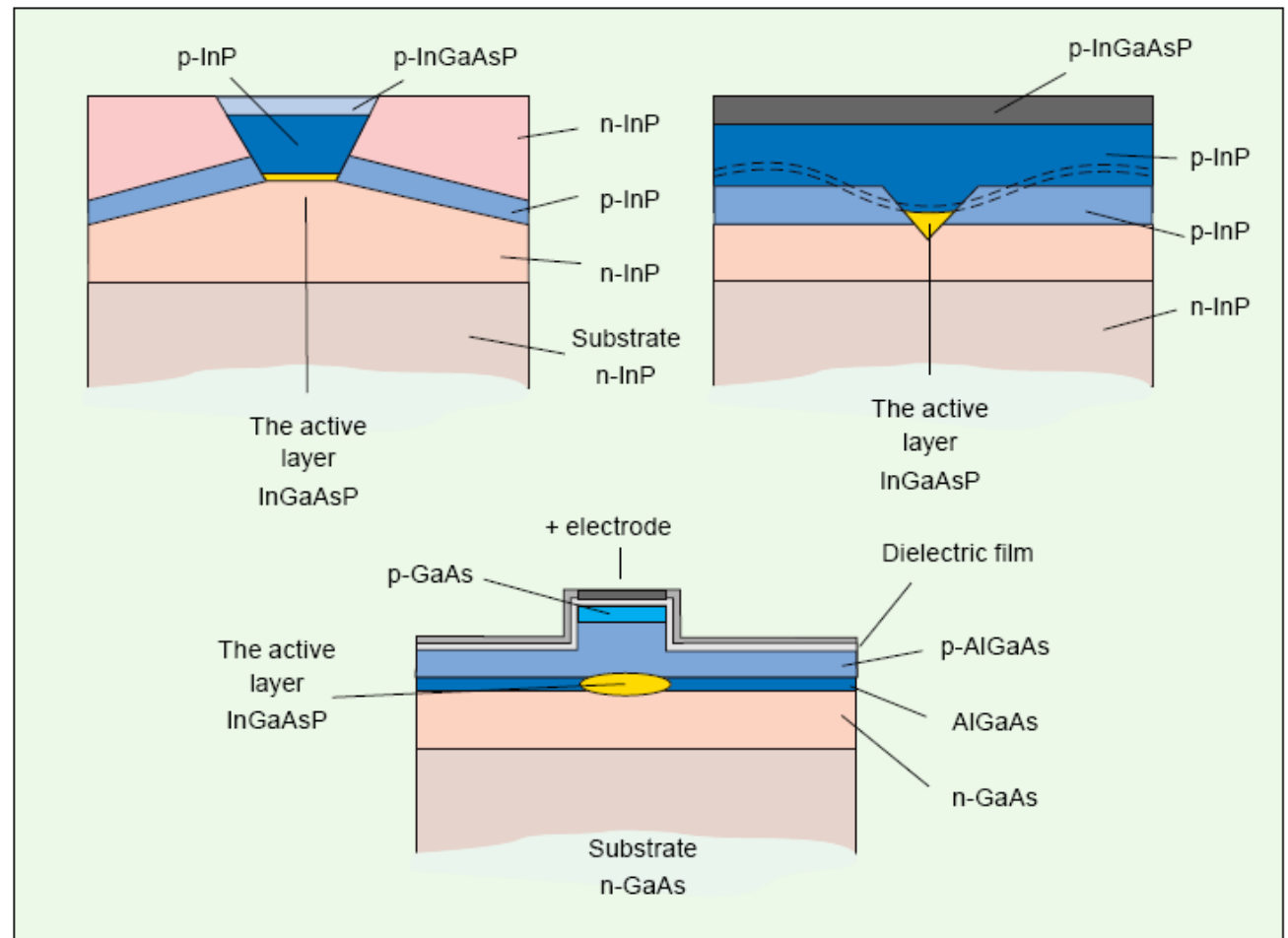


- ▶ RIN – Relative Intensity Noise (generat de emisia spontana)
- ▶ Zgomot de faza (idem) – necesitatea modulatiei in amplitudine
- ▶ Zgomot intercavitati (reflexiile din exterior in zona activa)
- ▶ Drift – variatia parametrilor cu varsta si temperatura (in special distanta intre oglinzi)

Diode LASER cu heterojunțione

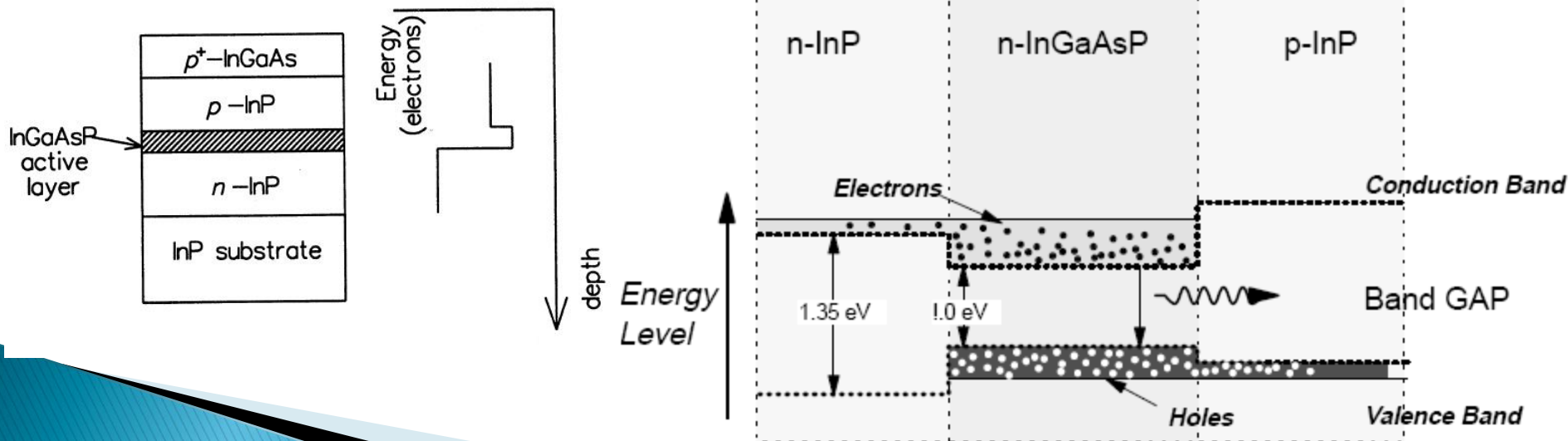
Heterojunțione
ingropata

Heterojunțione
muchie (ridge)



Heterojunții – 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

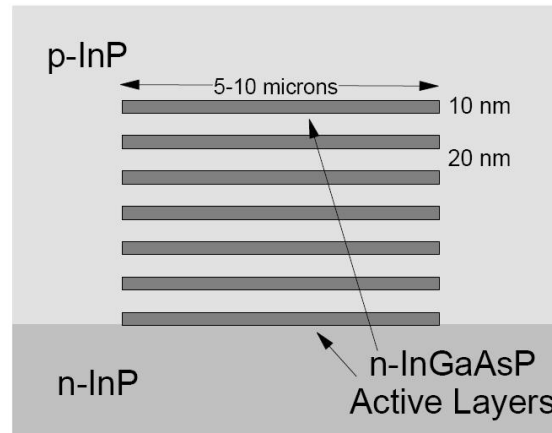


Quantum Well Laser

- ▶ Cand lumina e pastrata in cavitati mai mici decat lungimea de unda nu mai poate fi modelata prin unda, modelul devine cuantic
- ▶ Daca inaltimea zonei active scade la 5–20 nm comportarea diodei laser se schimba
 - energia necesara pentru inversarea de populatie se reduce, deci curentul de prag scade
 - dimensiunea redusa a zonei active duce la scaderea puterii maxime

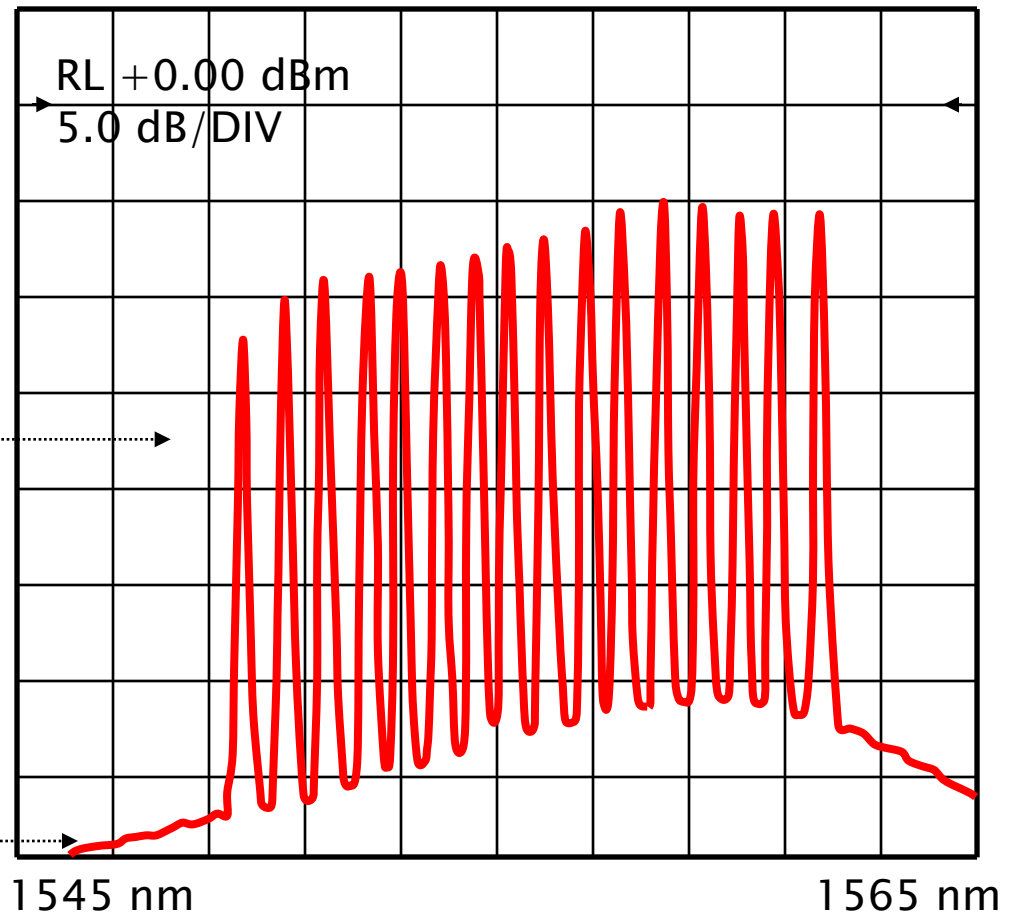
Quantum Well Laser

- ▶ multiple straturi subtiri suprapuse – Multiple Quantum Well



- ▶ Avantaje
 - curent de prag redus
 - stabilitate crescuta a frecventei la functionarea in impuls
 - latime mica a liniilor spectrale
 - zgomot redus

Spectrul WDM – Wavelength Division Multiplexing

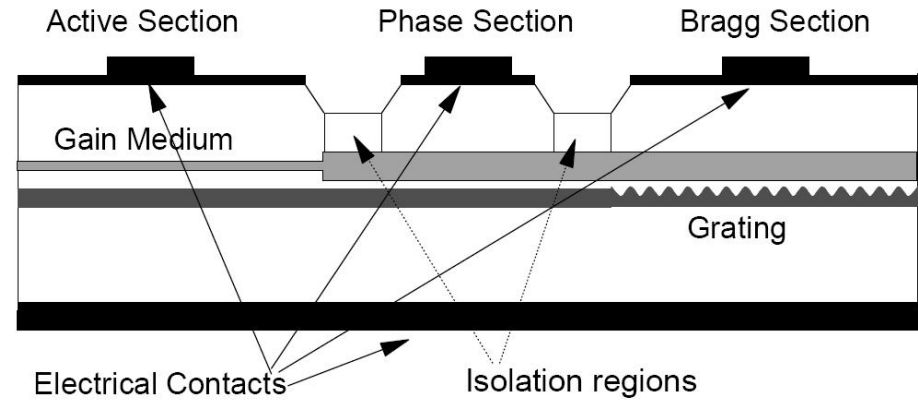
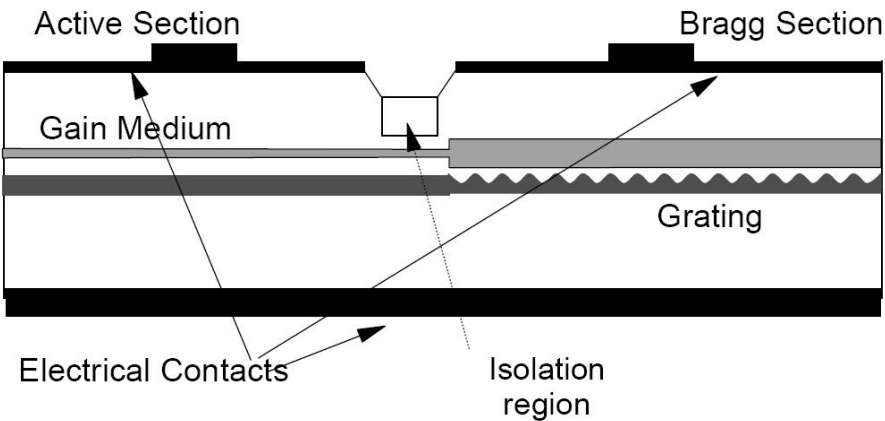


Diode laser reglabile

▶ Necesitate

- In sistemele WDM exista necesitatea (in propuneri pentru arhitecturi viitoare de retele) pentru reglaj foarte rapid al lungimii de unda pe un anume canal – zeci de ns
- In aceleasi sisteme intervine necesitatea rutarii prin lungime de unda – timp de reglaj necesar de ordinul secundelor)
- realizarea cererilor de date – timp de reglaj de ordinul sute de μ s
- reglarea emitatorilor individuali in sistemele WDM
 - lipsa necesitatii controlului strict la productia diodelor
 - degradarea lungimii de unda in timp

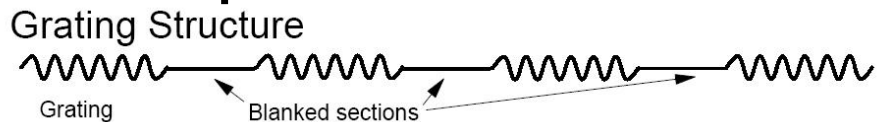
Diode laser reglabile



- ▶ Curentul trece prin zona activa ducand la amplificarea luminii
- ▶ curentul ce parcurge zona corespunzatoare reflectorului Bragg modifica indicele de refractie al acestei zone deci lungimea de unda
- ▶ zona centrala suplimentara permite reglaj fin suplimentar in jurul valorii impuse de reflectorul Bragg

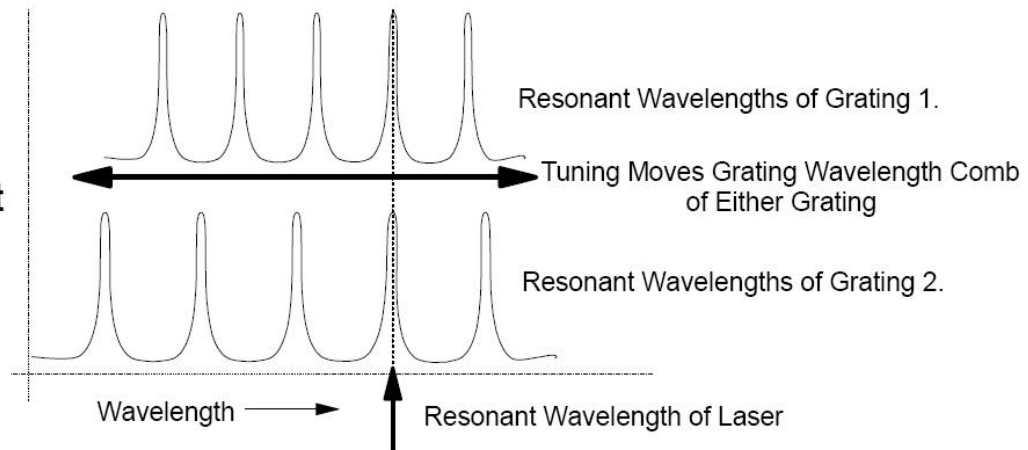
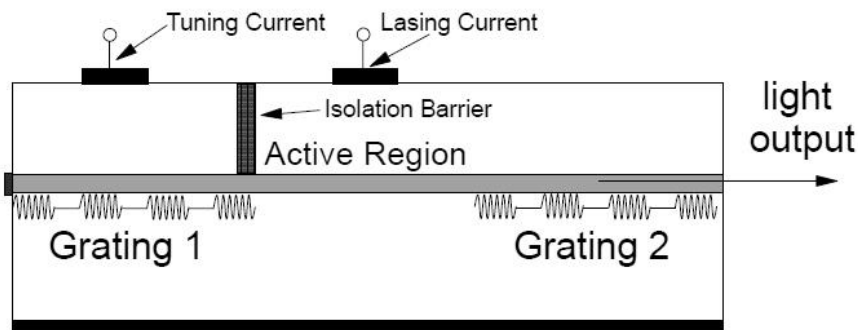
Diode laser reglabile

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

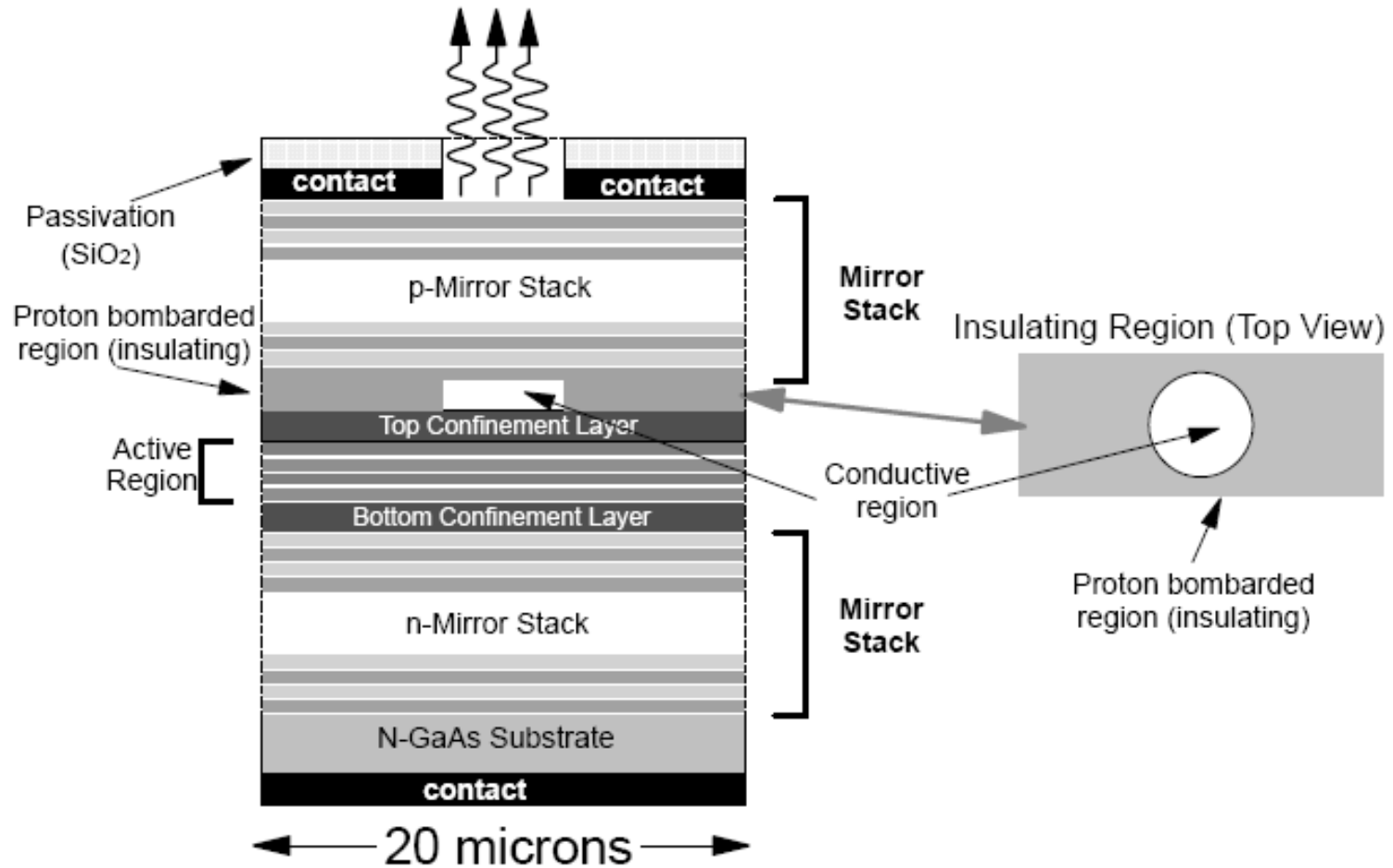


Dezavantaj :
reglajul e discret

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

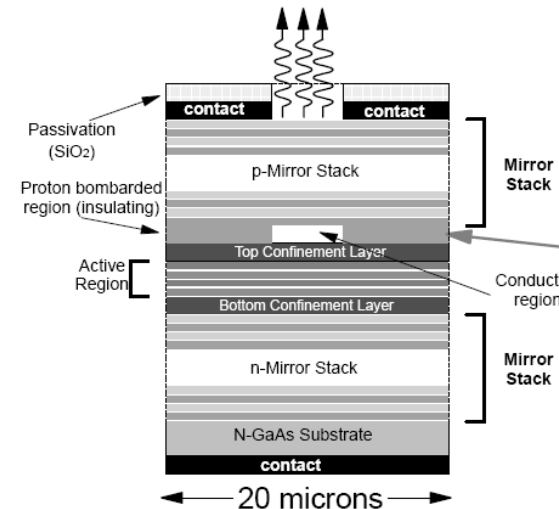


Vertical Cavity Surface Emitting Lasers (VCSEL)



Vertical Cavity Surface Emitting Lasers (VCSEL)

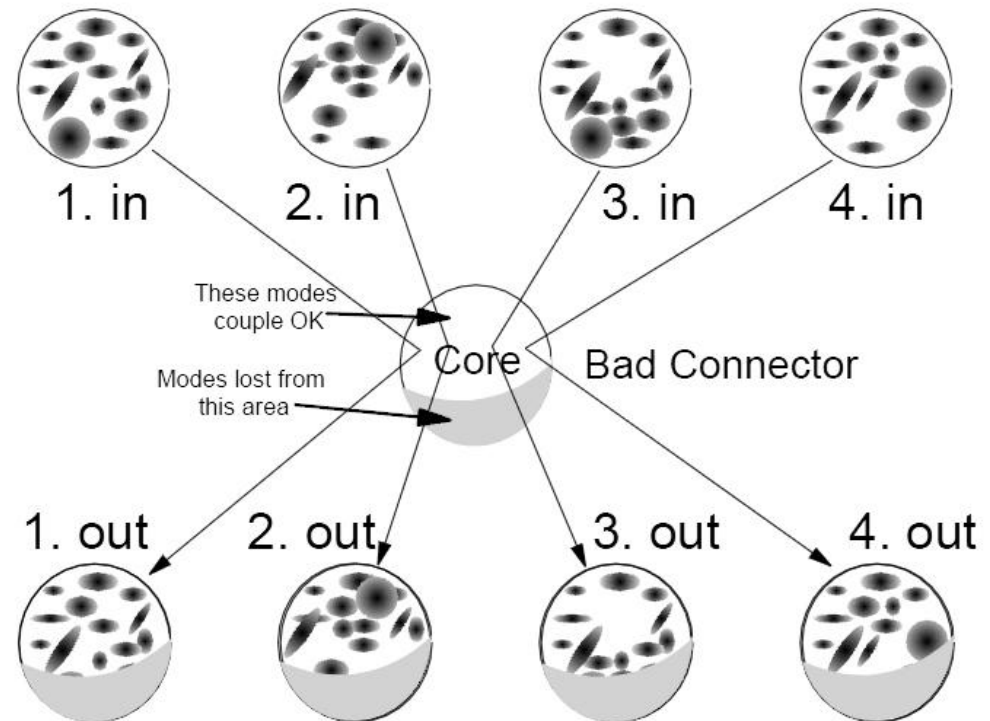
- ▶ Oglinzile pot fi realizate din straturi succesive din semiconductori cu indici de refractie diferiti - reflector Bragg
- ▶ Prelucrarea laterala se rezuma la taierea materialului
 - ▶ Caracteristici
 - ▶ puteri de ordinul 1mW
 - ▶ lungimi de unda 850 si 980 nm
 - ▶ radiatie de iesire circulara cu 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

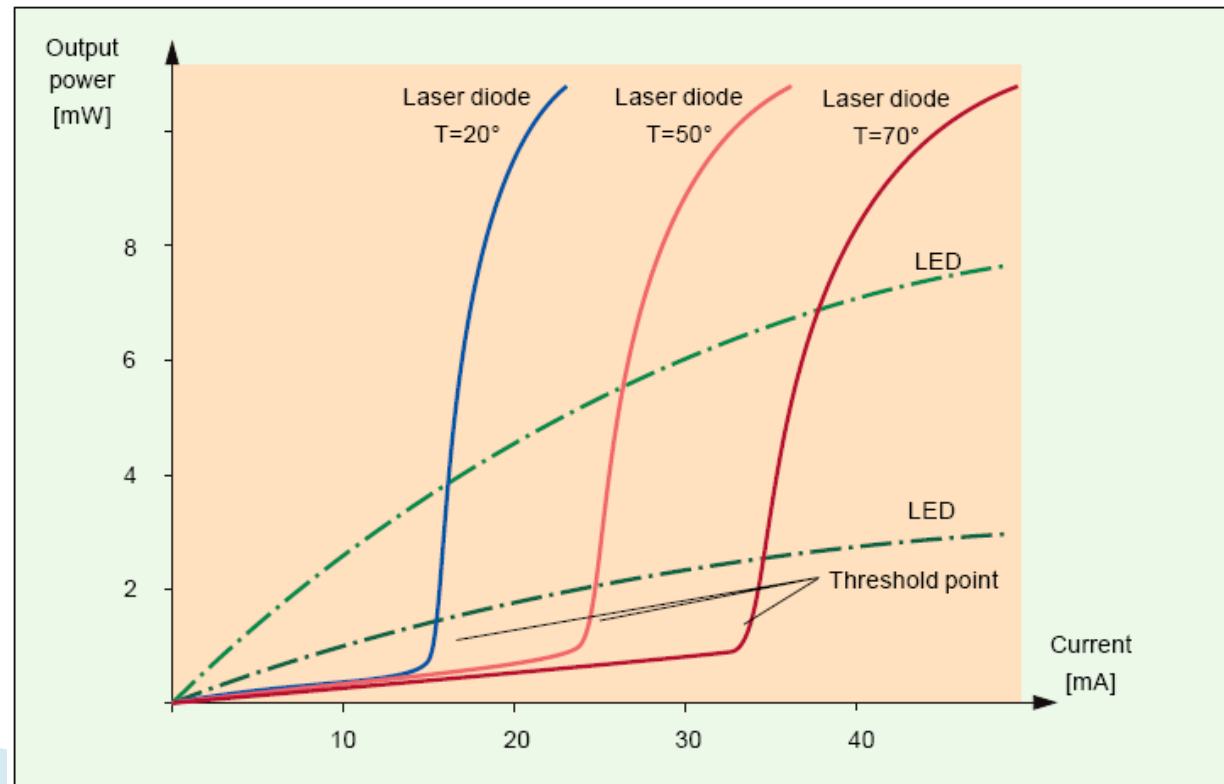
- VCSEL produce mai multe moduri transversale
 - insensibila la pierderile selective la mod din fibrele multimod (principala limitare in utilizarea diodelor laser in fibrele multimod)



Parametri dioda LASER

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

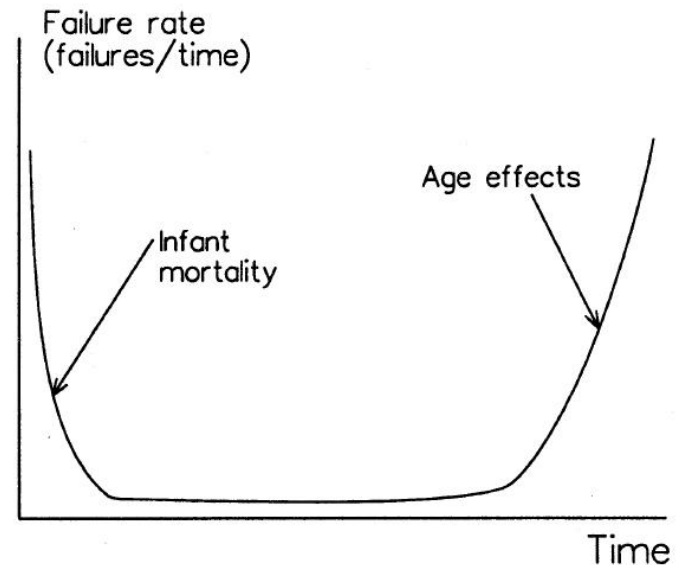
Degradare in timp

- ▶ 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 $2000 \div 5000 \text{ A/cm}^2$
 - densitati de putere optica: $10^5 \div 10^6 \text{ W/cm}^2$
- ▶ Diverse definitii ale timpului de viata fac comparatiile dificile

Degradare in timp



- ▶ Cresterea curentului duce la scaderea duratei de viata

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

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

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

- $E = 0.3 \div 0.95 \text{ eV}$ (valoarea tipica in teste 0.7 eV)
- cresterea temperaturii cu 10 grade injumatateste durata de viata

Parametri

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

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

- ▶ 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

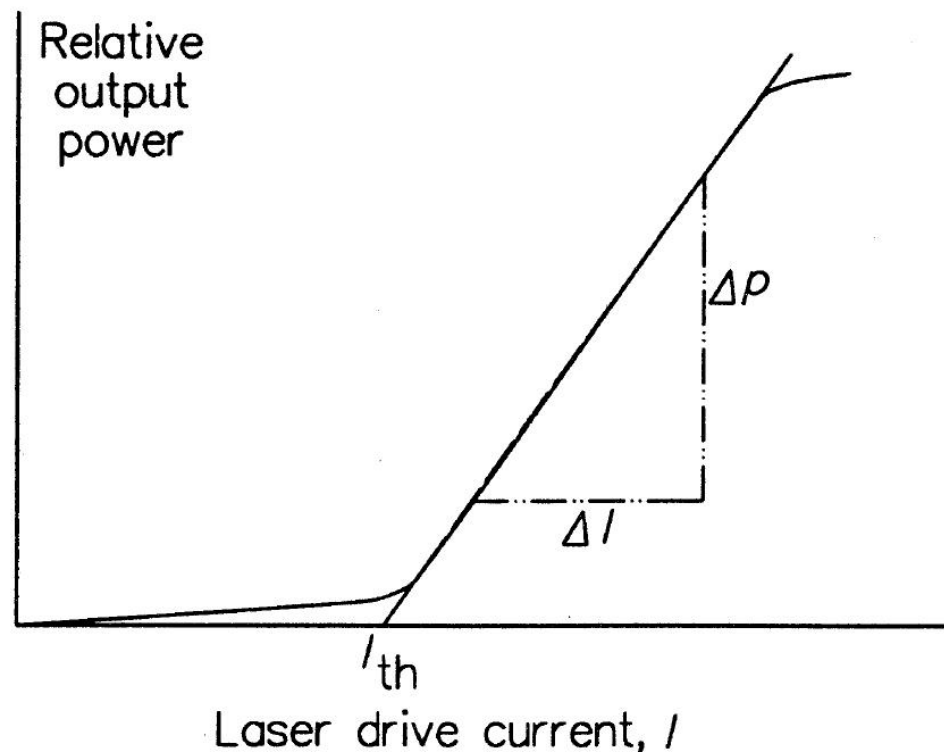
$I < I_{th}$ regim LED
ineficient!, $P_o \cong 0$

$I > I_{th}$ regim LASER

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

$$P_o = r \cdot (I - I_{th})$$

Apare saturare la nivele mari de curent



Eficienta

- ▶ eficienta de conversie electro-optic (randament)

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

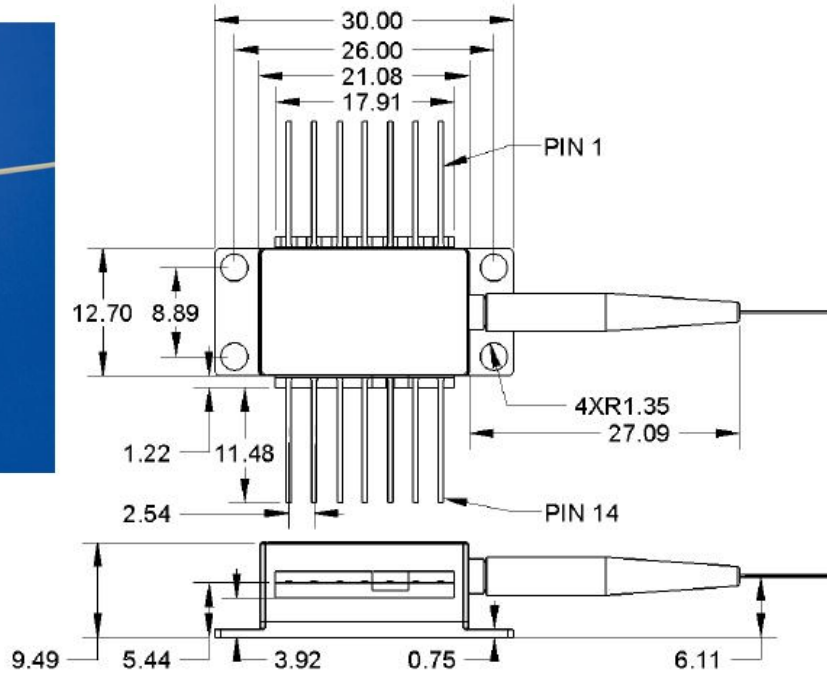
- ▶ tipic, randamente sub 10% sunt intalnite
- ▶ eficienta cuantica
 - interna
 - externa

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

1550nm DFB Laser

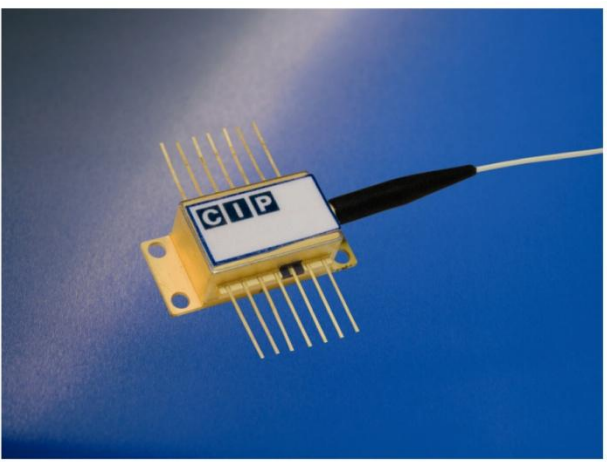
Mechanical Drawing

All units in mm

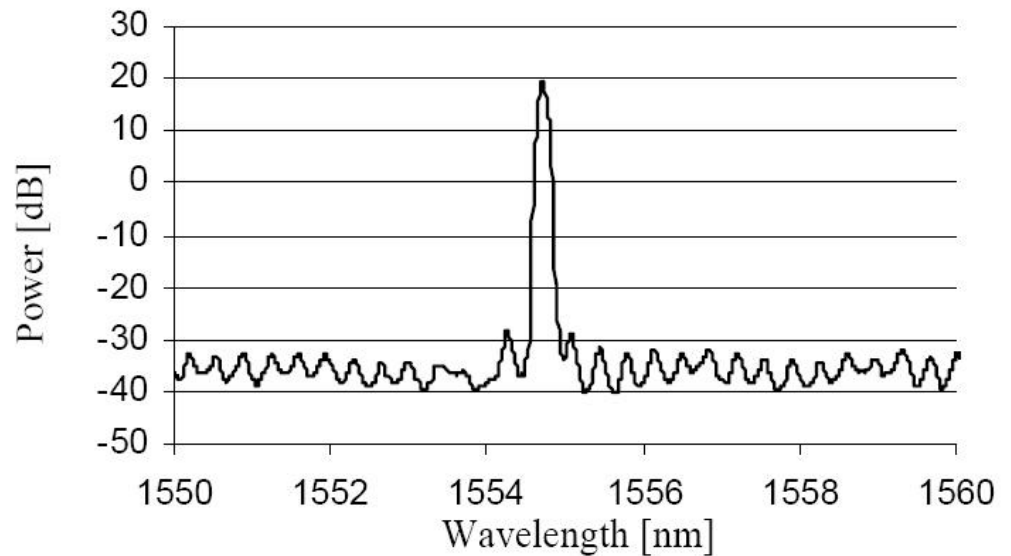
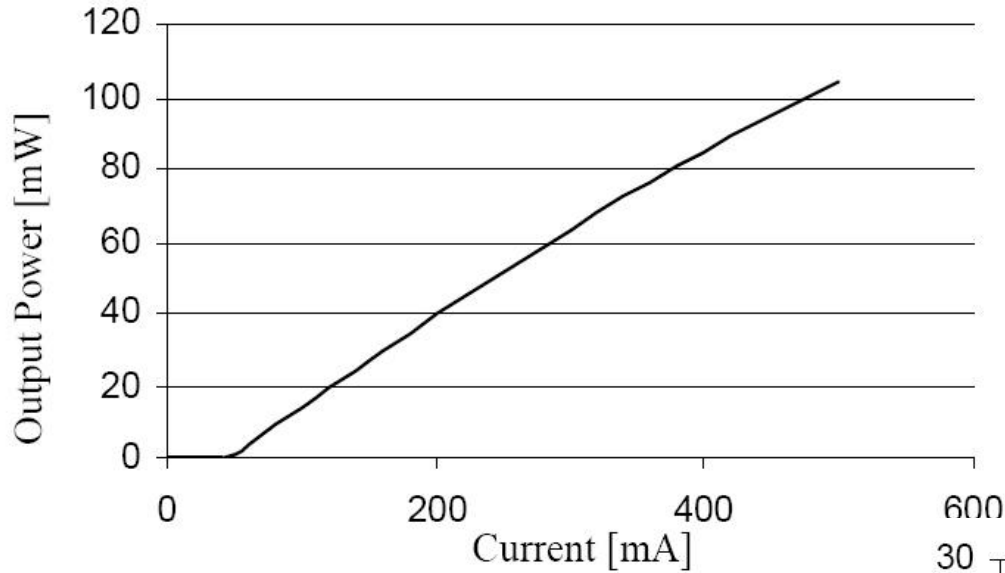


Pin out

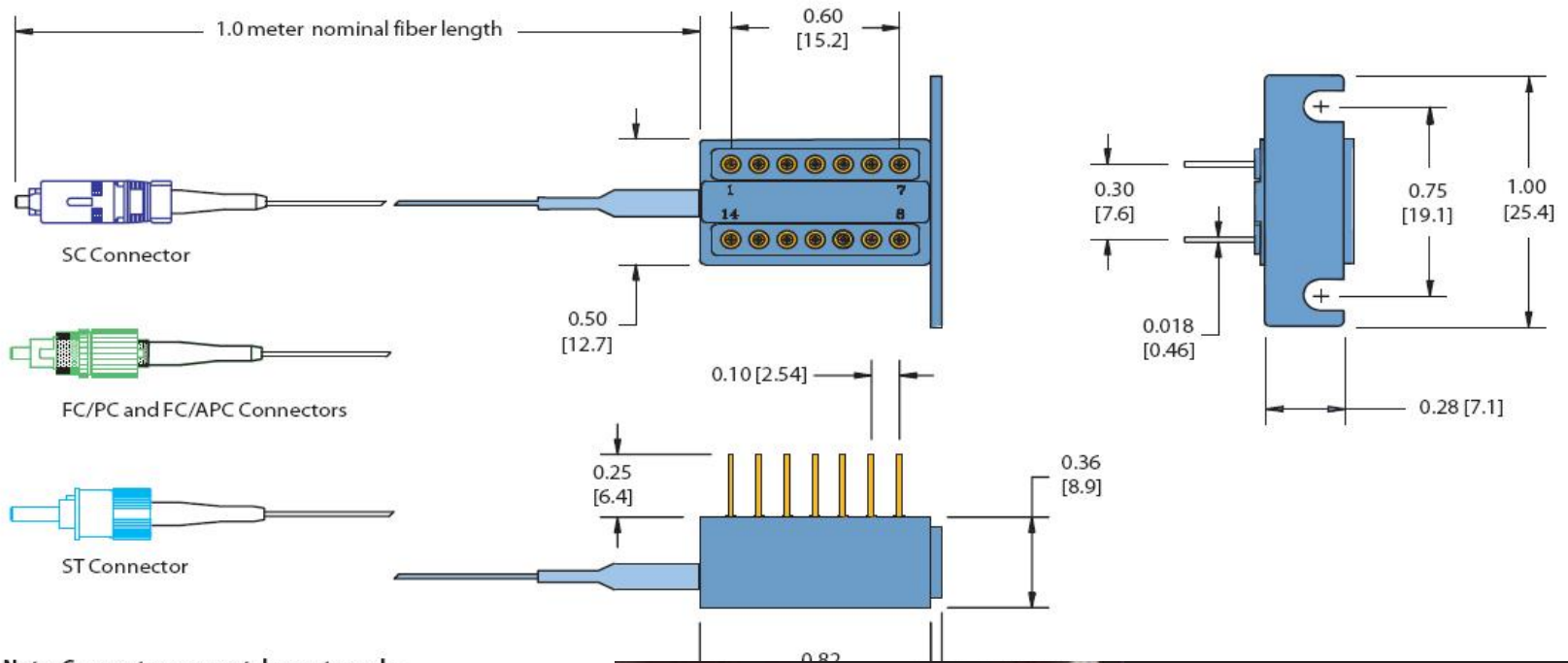
Pin	Description
1	Thermistor
2	Thermistor
3	Laser Cathode (Bias)
4	Monitor PD Anode
5	Monitor PD Cathode
6	TEC +
7	TEC -
8	Case GND, Laser Anode
9	Case GND, Laser Anode
10	Case GND, Laser Anode
11	Case GND, Laser Anode
12	Laser Cathode (modulation)
13	Case GND, Laser Anode
14	Case GND, Laser Anode



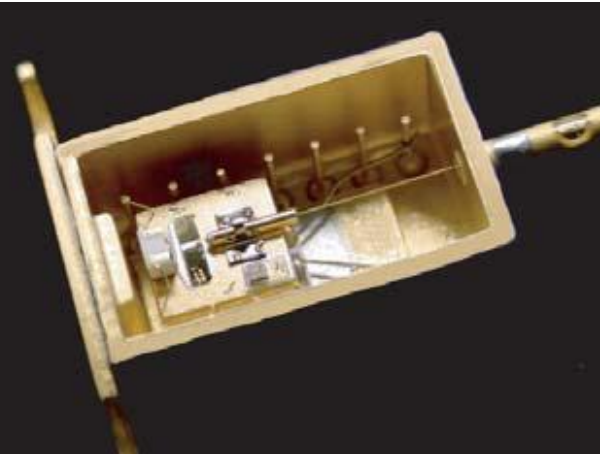
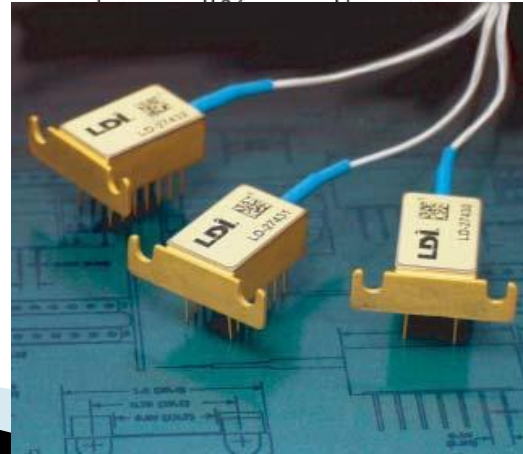
1550nm DFB Laser



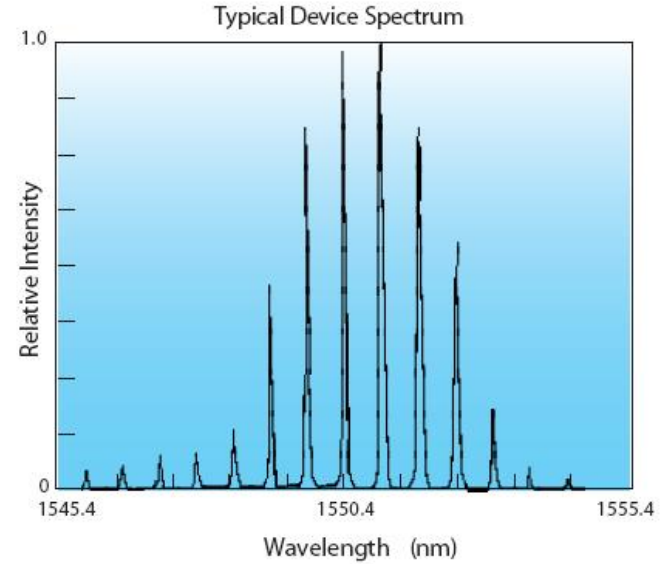
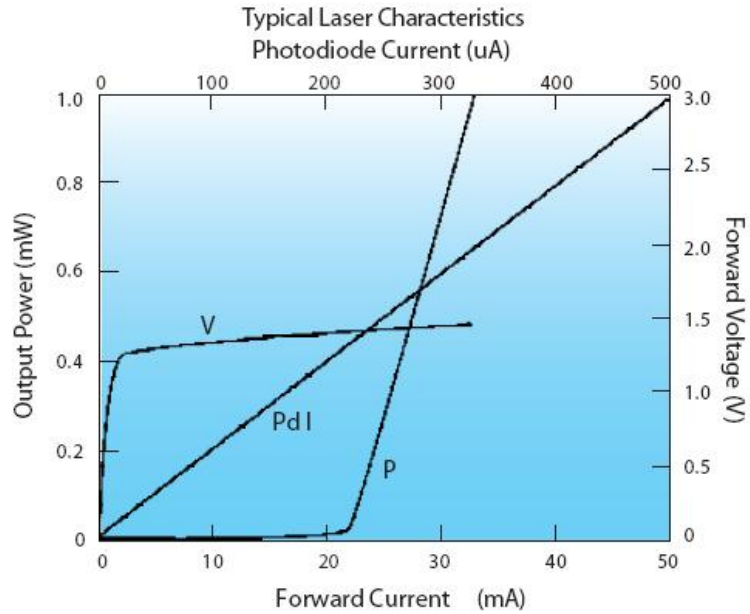
1550nm MQW Laser



Note: Connectors are not drawn to scale.

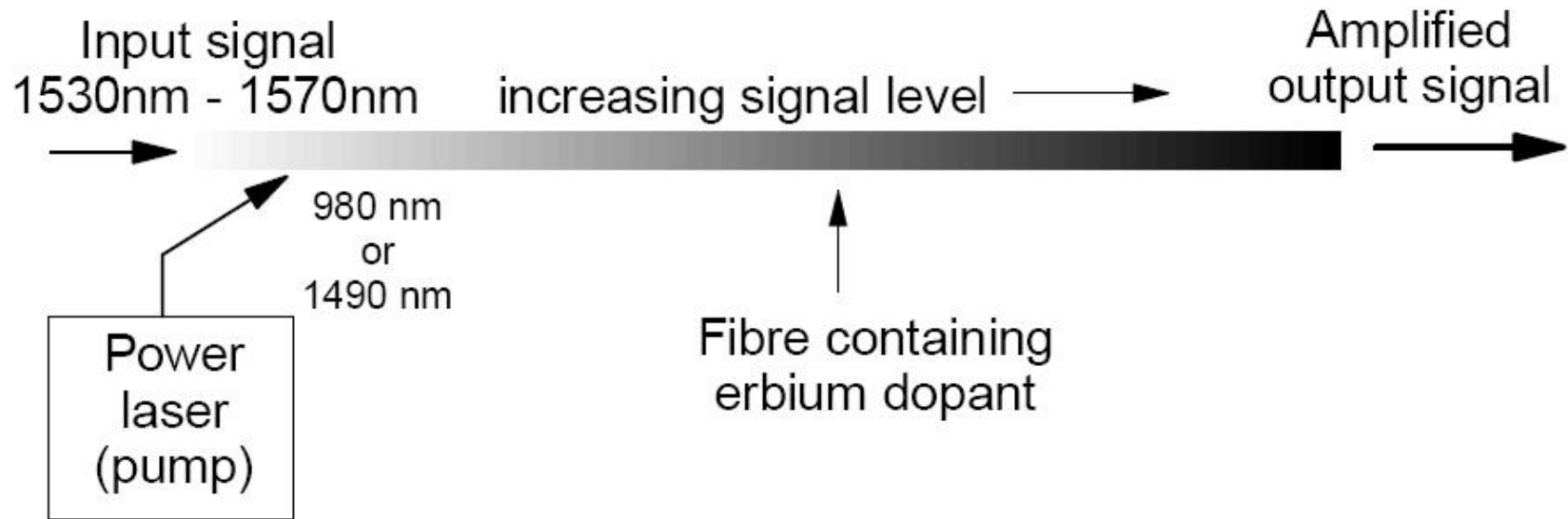


1550nm MQW Laser

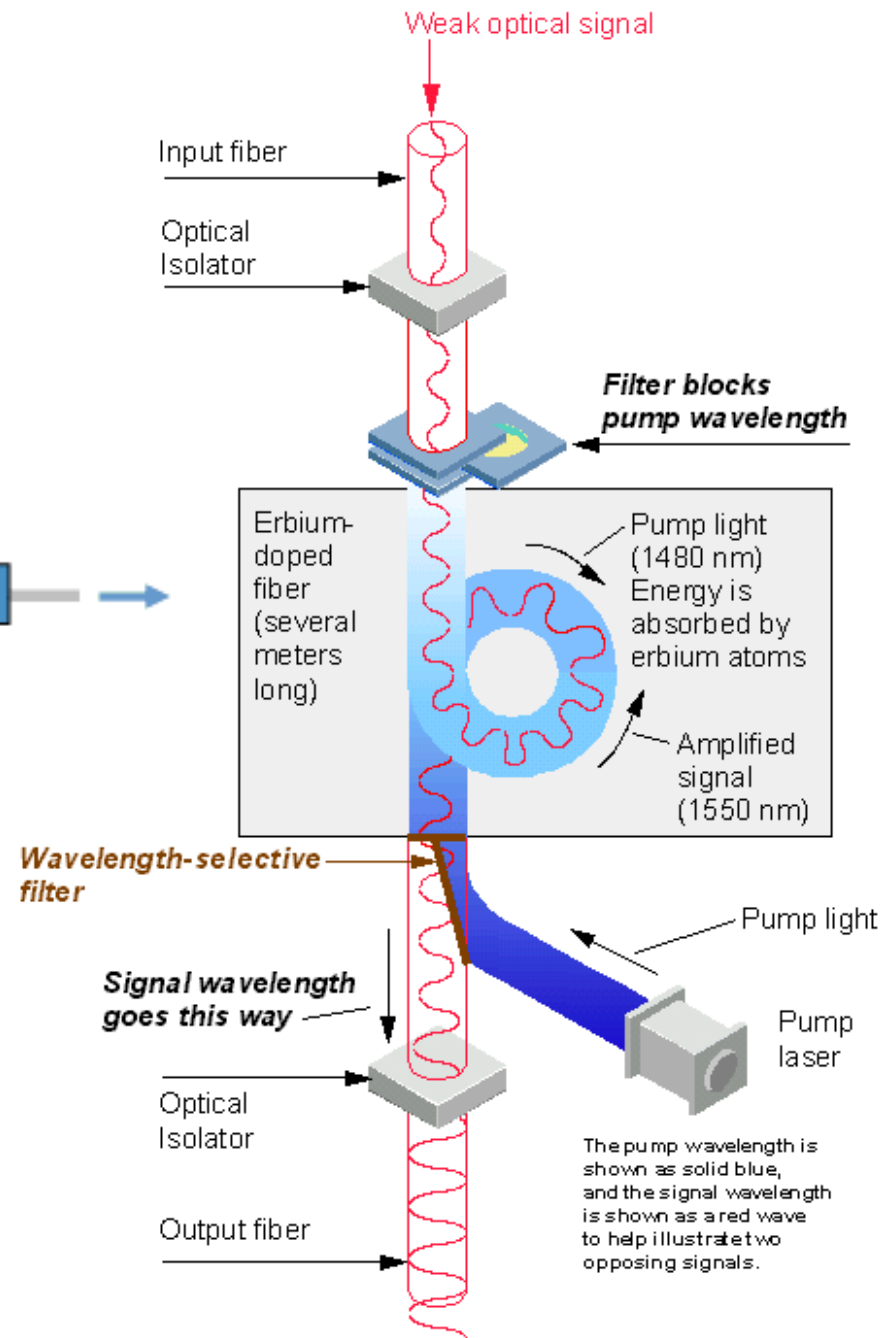
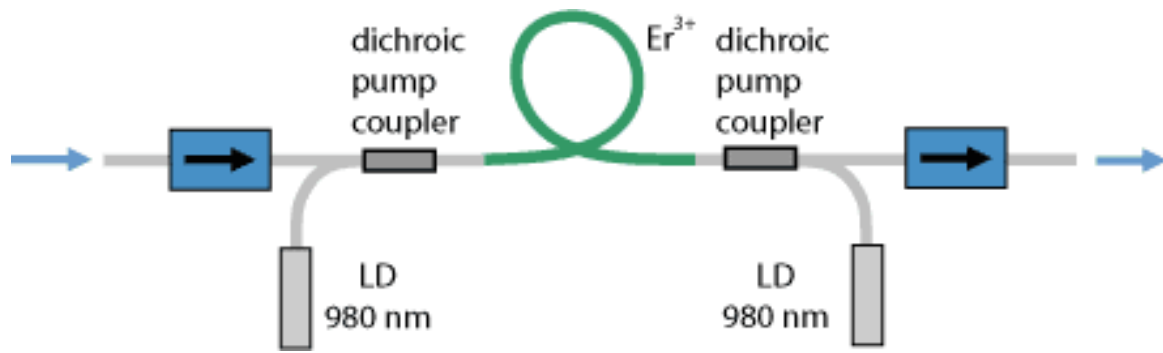


EDFA

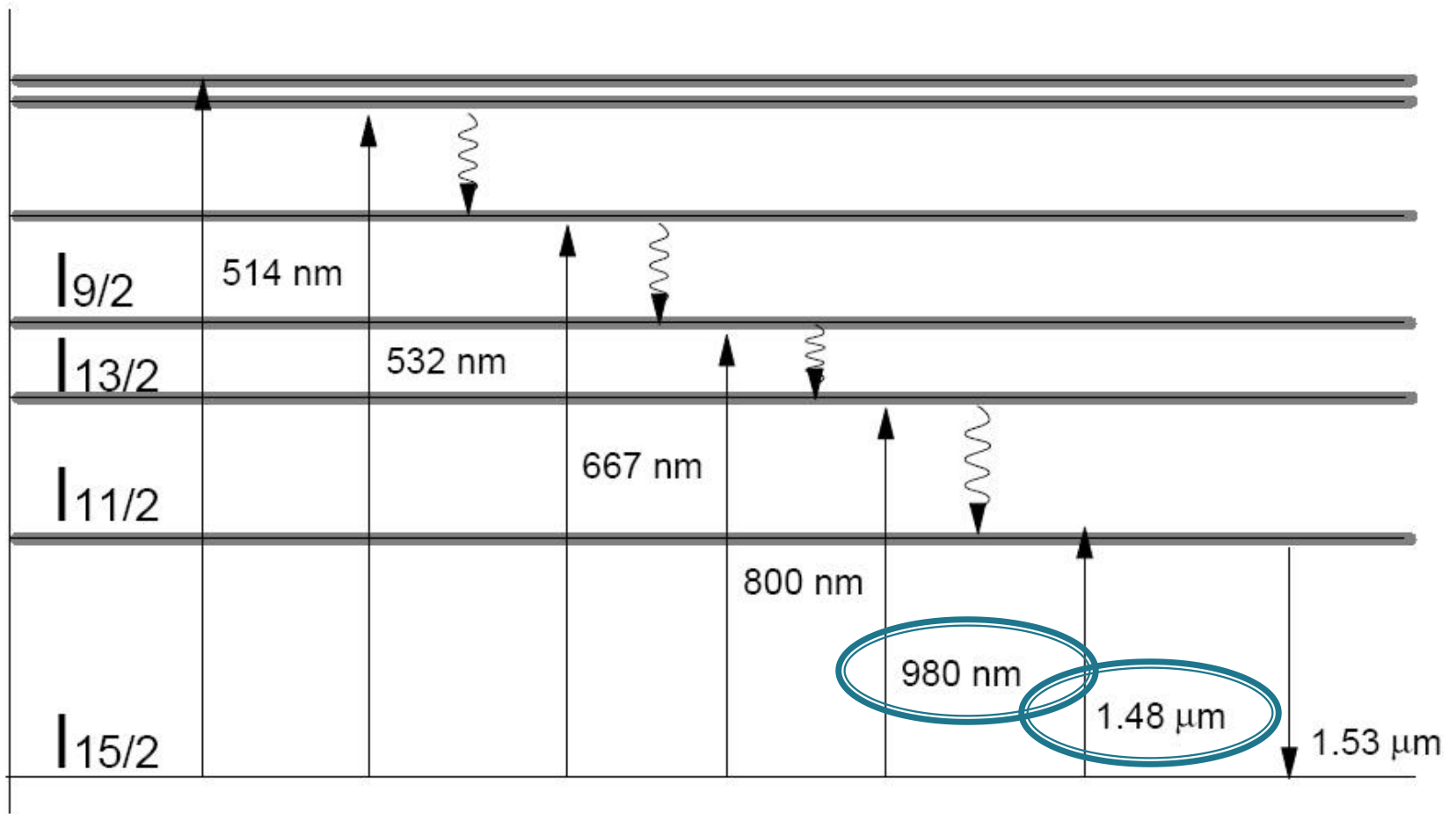
▶ Erbium Doped Fiber Amplifier



EDFA

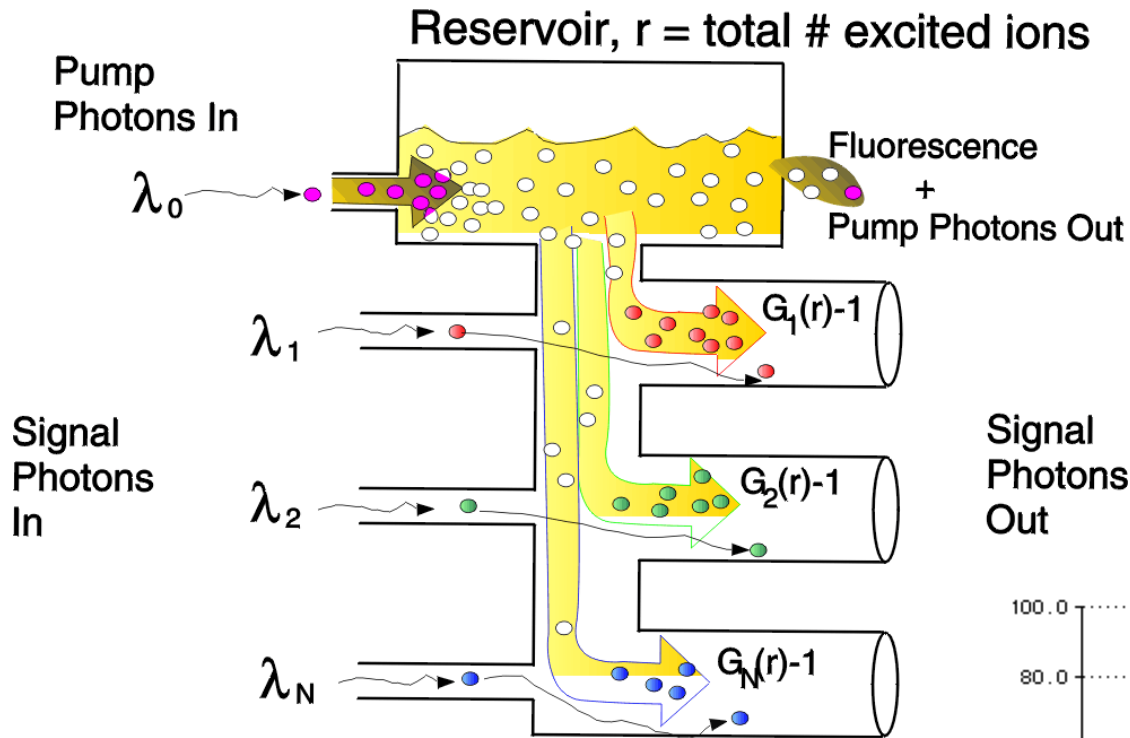


EDFA

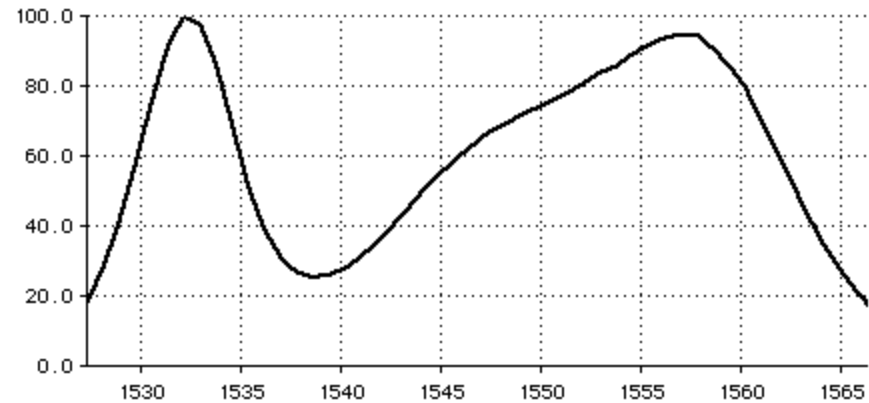


EDFA

How to think of an EDFA

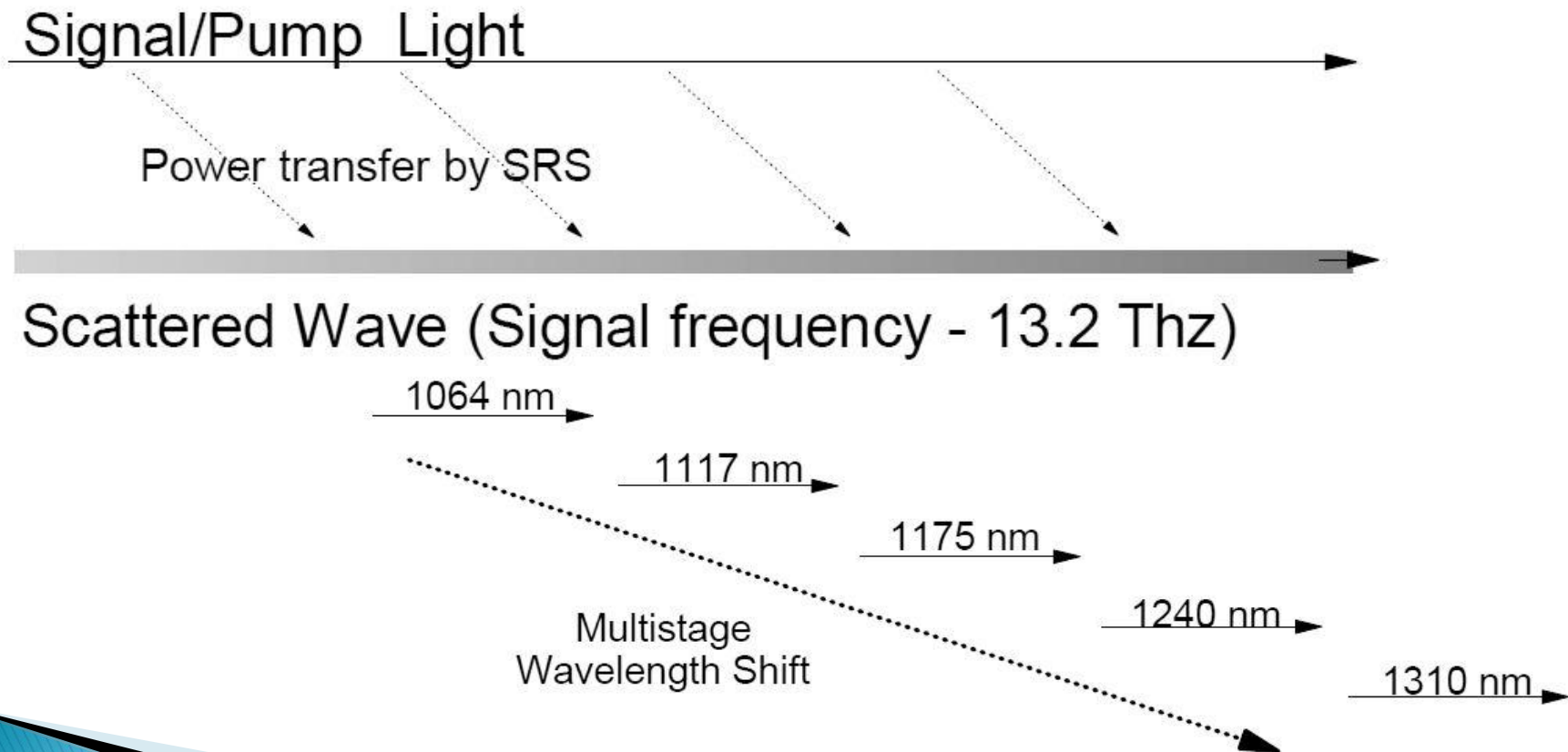


Signal Photons Out

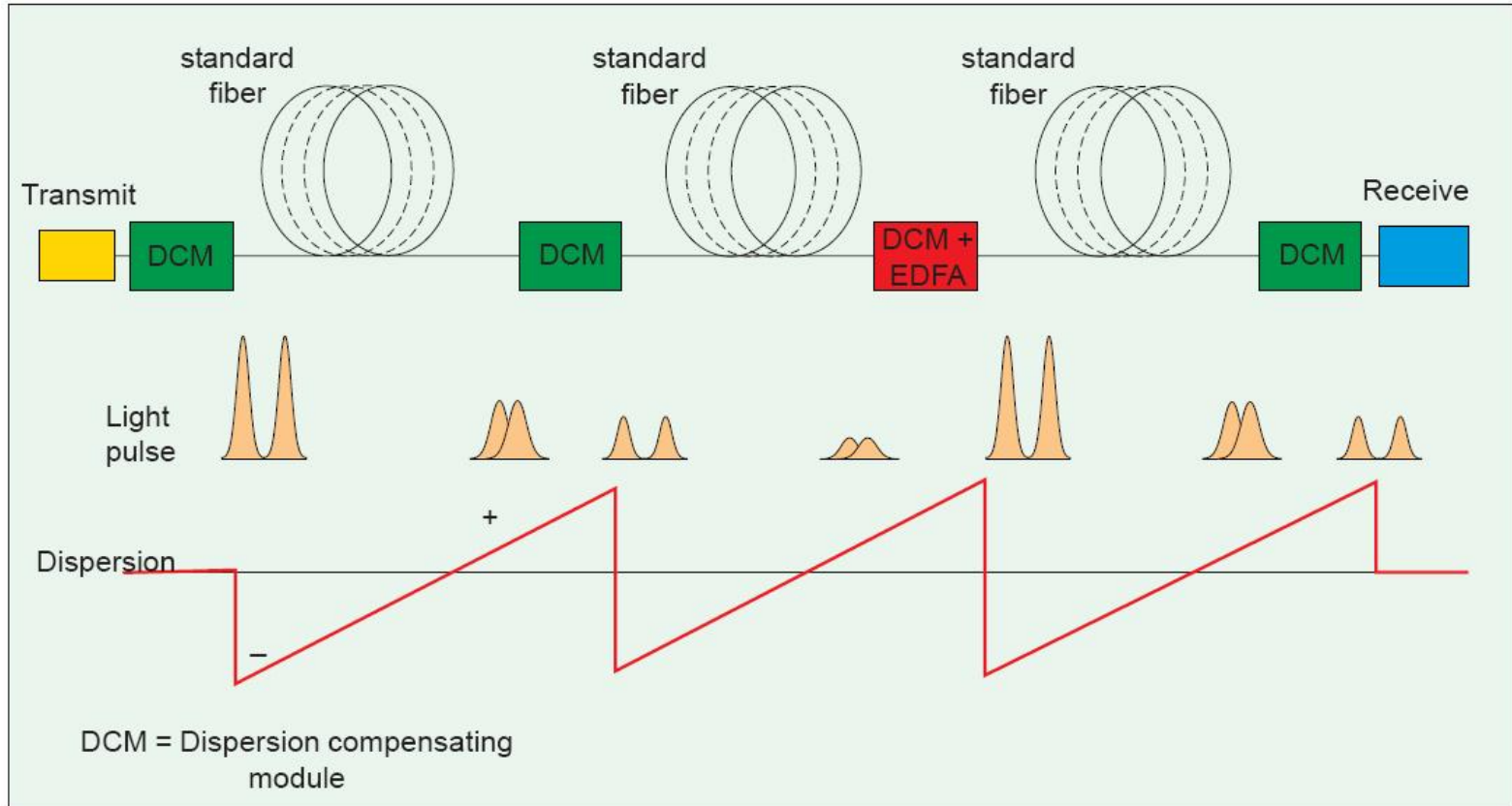


Amplificator cu efect Raman

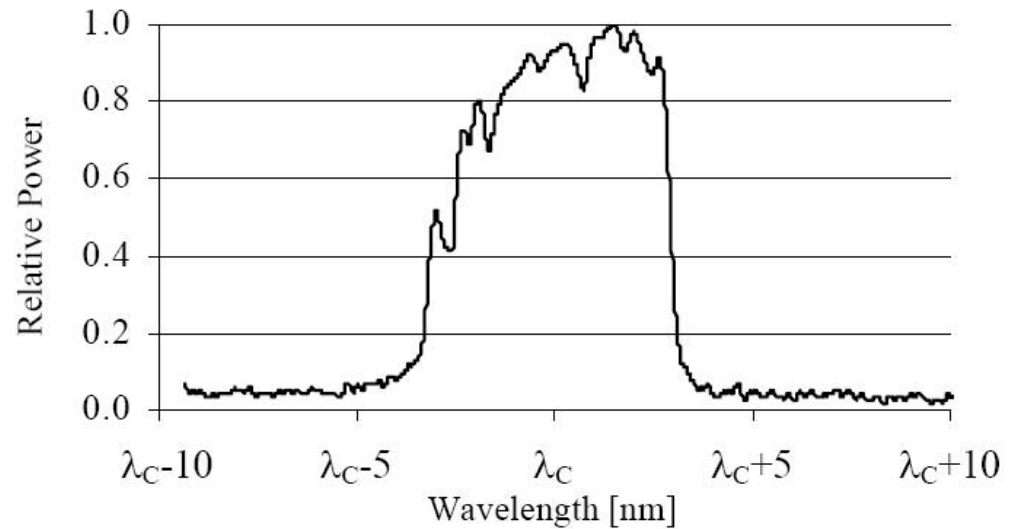
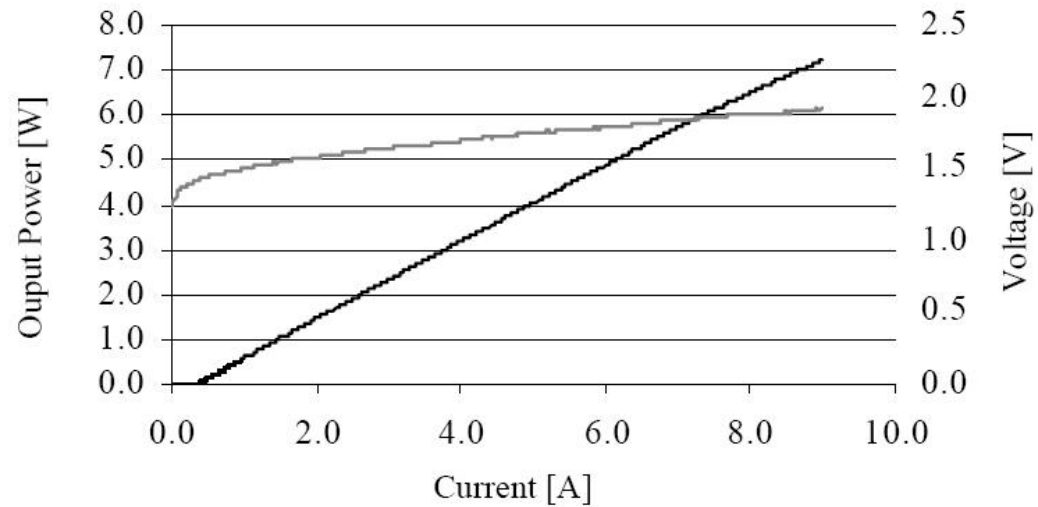
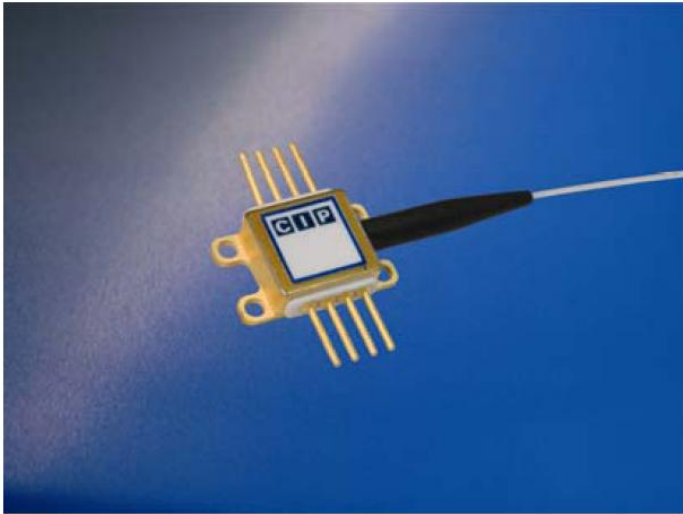
- ▶ Bazat pe efect Raman



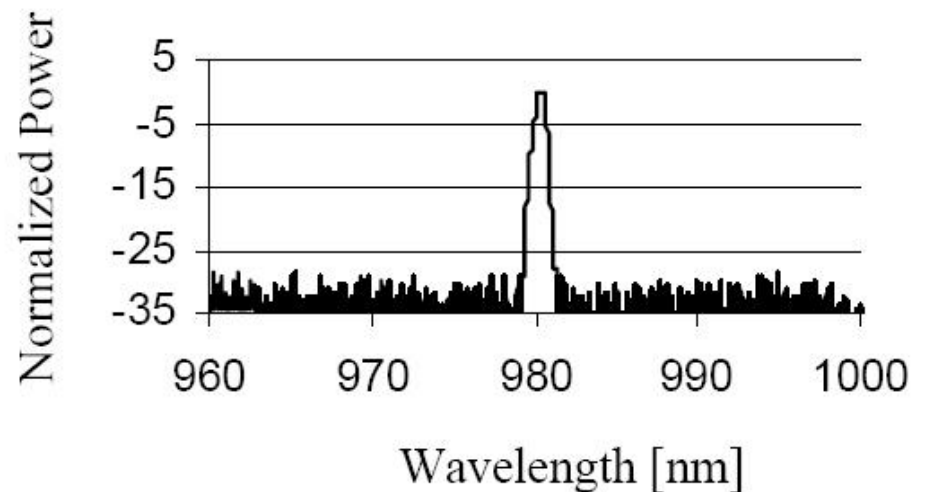
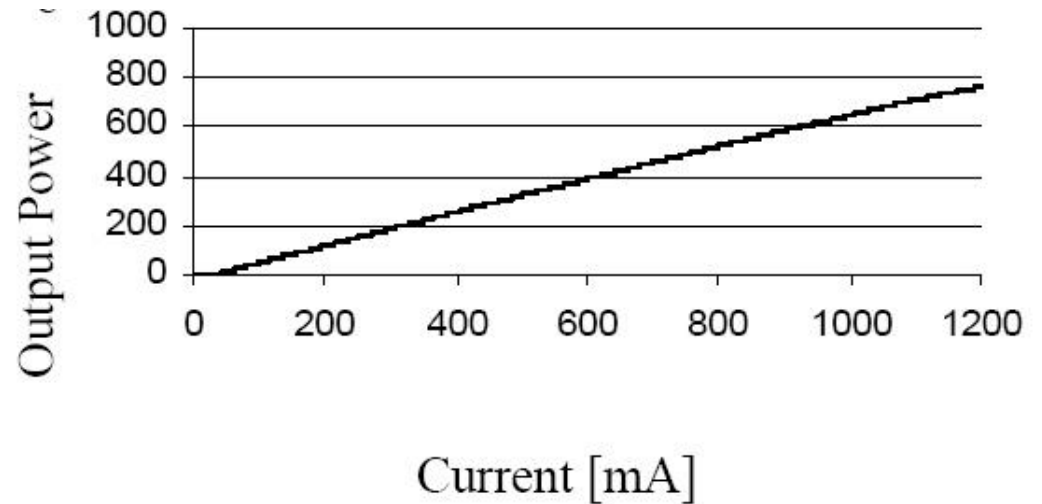
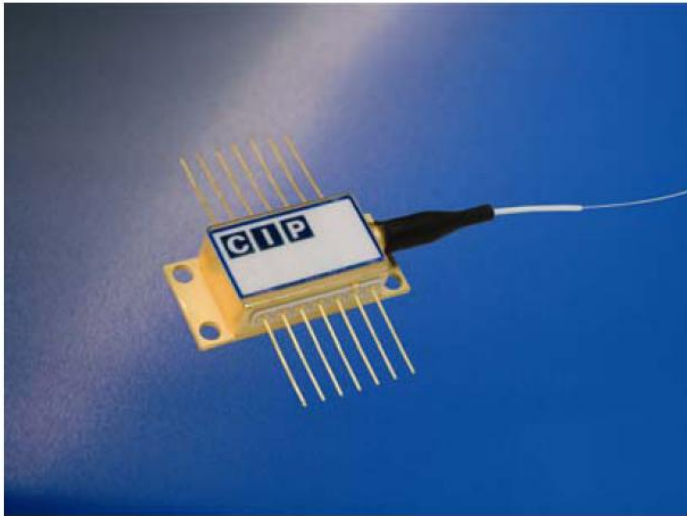
Utilizare amplificatoare optice



7W 980 nm Multimode Pump Laser

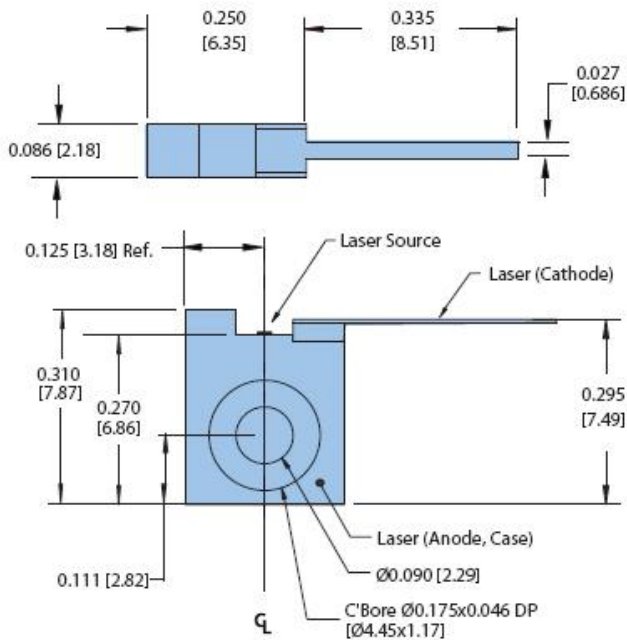


600mW 980 nm Singlemode Pump Laser

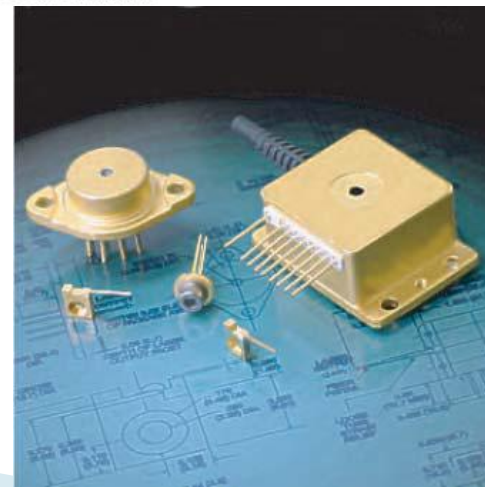
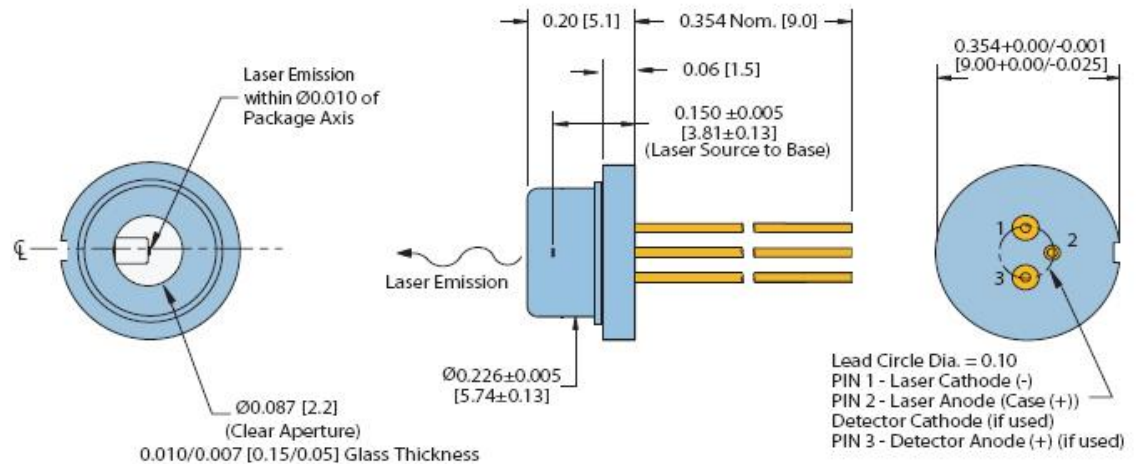


6 W, CW, 800nm

C-Mount Package

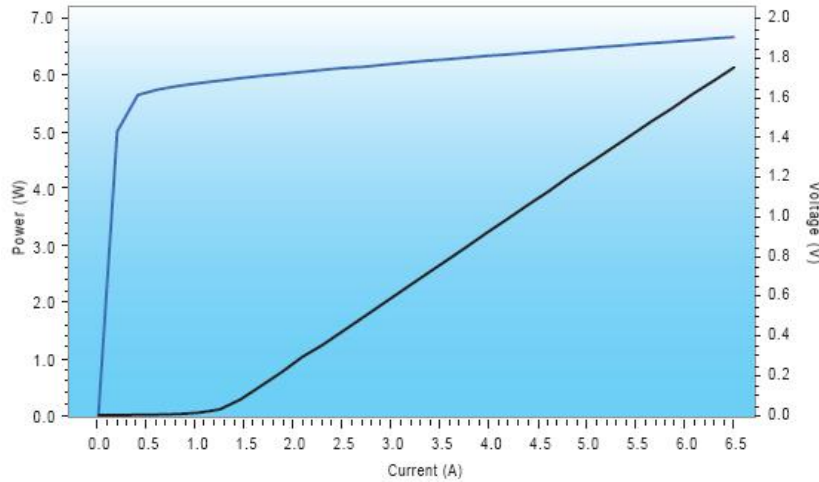


9mm Package

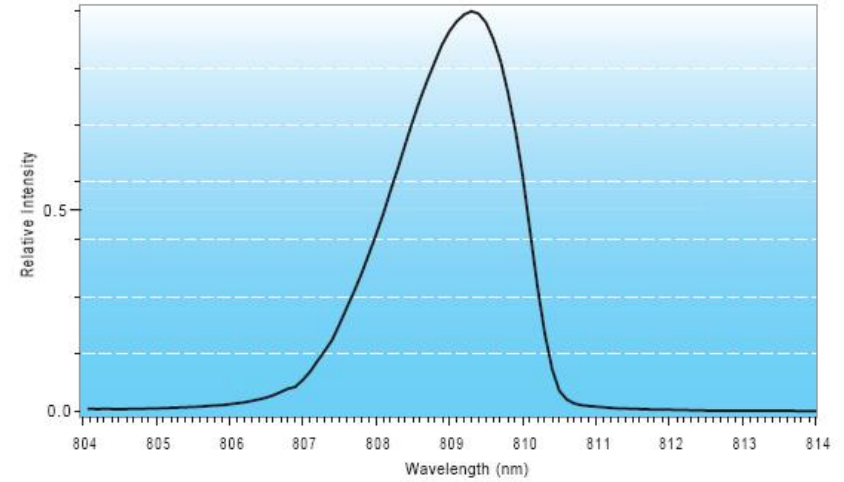


6 W, CW, 800nm

Typical L/I, V/I Graph

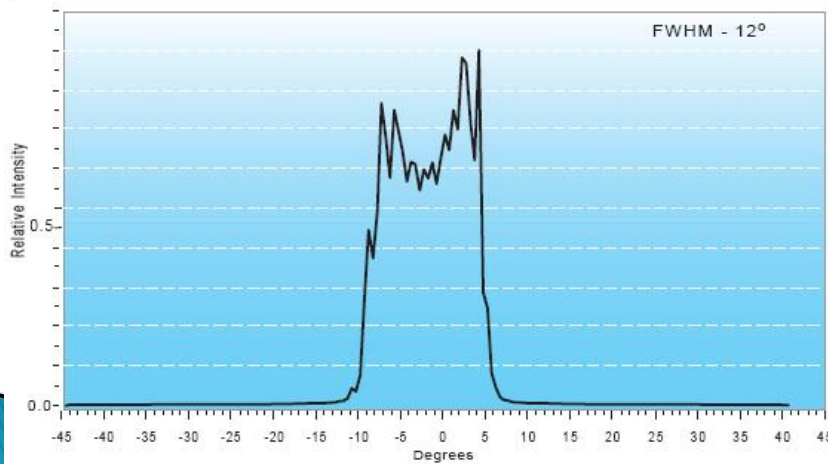


Wavelength Distribution



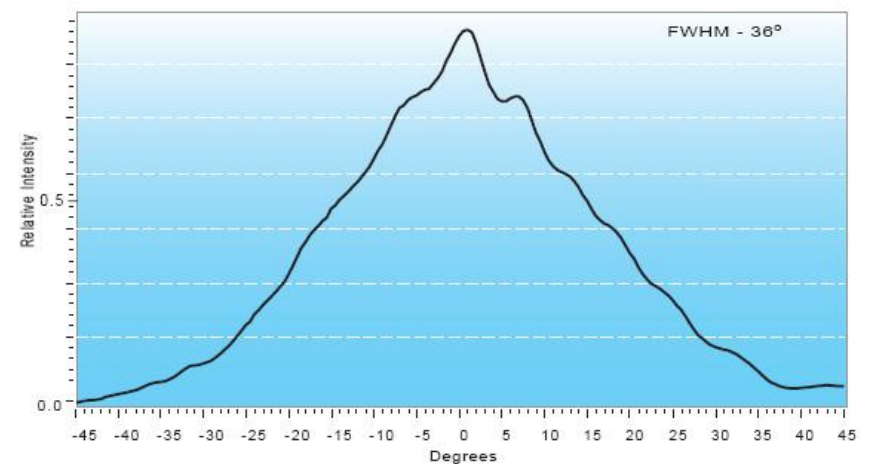
Typical Beam Divergence

Parallel

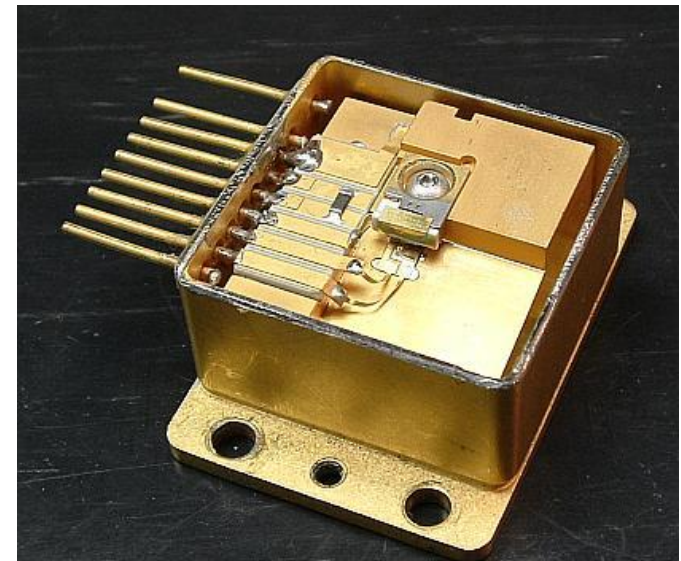
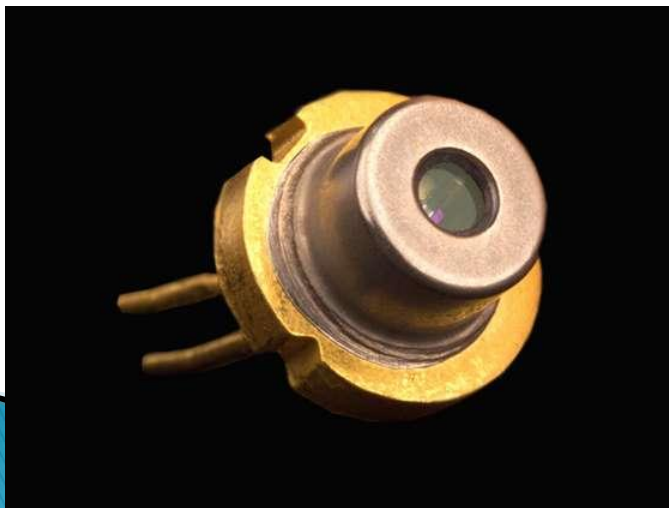
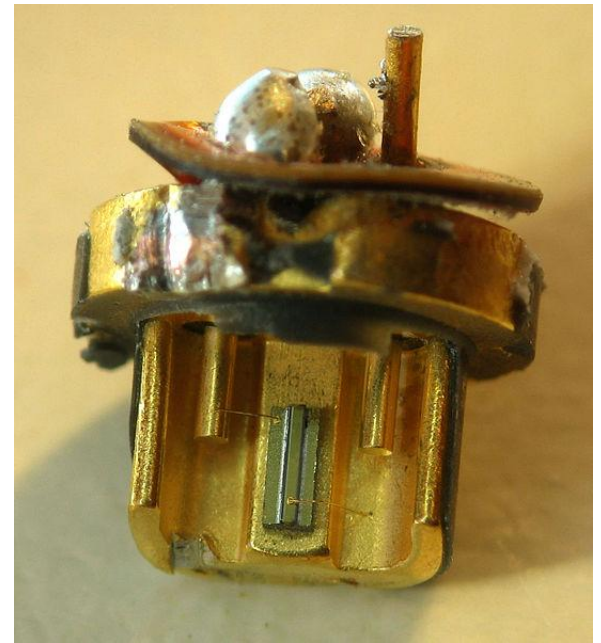
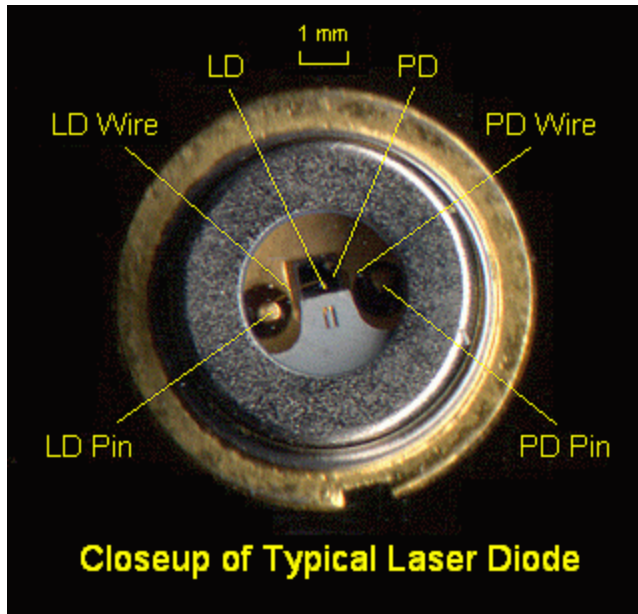


Typical Beam Divergence

Perpendicular



CW Laser, 650 nm



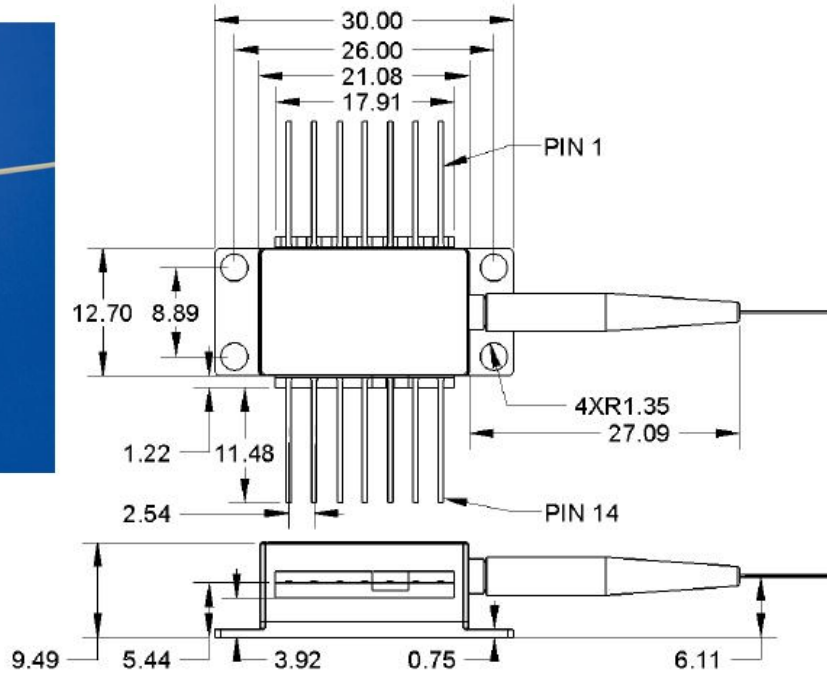
Lungimi de unda

- ▶ **405 nm** – InGaN blue-violet laser, in Blu-ray Disc and HD DVD drives
- ▶ **445–465 nm** – InGaN blue laser multimode diode recently introduced (2010) for use in mercury-free high-brightness data projectors
- ▶ **510–525 nm** – Green diodes recently (2010) developed by Nichia and OSRAM for laser projectors.
- ▶ **635 nm** – AlGaInP better red laser pointers, same power subjectively twice as bright as 650 nm
- ▶ **650–660 nm** – GaInP/AlGaInP CDDVD, cheap red laser pointers
- ▶ **670 nm** – AlGaInP bar code readers, first diode laser pointers (now obsolete, replaced by brighter 650 nm and 671 nm DPSS)
- ▶ **760 nm** – AlGaInP gas sensing: O₂
- ▶ **785 nm** – GaAlAs Compact Disc drives
- ▶ **808 nm** – GaAlAs pumps in DPSS Nd:YAG lasers (e.g., in green laser pointers or as arrays in higher-powered lasers)
- ▶ **848 nm** – laser mice
- ▶ **980 nm** – InGaAs pump for optical amplifiers, for Yb:YAG DPSS lasers
- ▶ **1,064 nm** – AlGaAs fiber-optic communication, DPSS laser pump frequency
- ▶ **1,310 nm** – InGaAsP, InGaAsN fiber-optic communication
- ▶ **1,480 nm** – InGaAsP pump for optical amplifiers
- ▶ **1,512 nm** – InGaAsP gas sensing: NH₃
- ▶ **1,550 nm** – InGaAsP, InGaAsNSb fiber-optic communication
- ▶ **1,625 nm** – InGaAsP fiber-optic communication, service channel
- ▶ **1,654 nm** – InGaAsP gas sensing: CH₄
- ▶ **1,877 nm** – GaInAsSb gas sensing: H₂O
- ▶ **2,004 nm** – GaInAsSb gas sensing: CO₂
- ▶ **2,330 nm** – GaInAsSb gas sensing: CO
- ▶ **2,680 nm** – GaInAsSb gas sensing: CO₂
- ▶ **3,030 nm** – GaInAsSb gas sensing: C₂H₂
- ▶ **3,330 nm** – GaInAsSb gas sensing: CH₄

1550nm DFB Laser

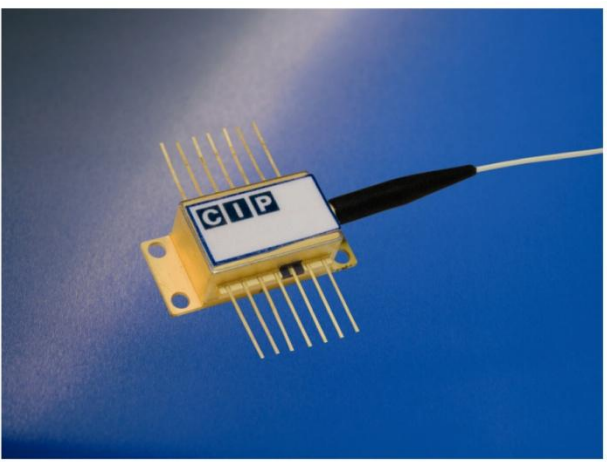
Mechanical Drawing

All units in mm

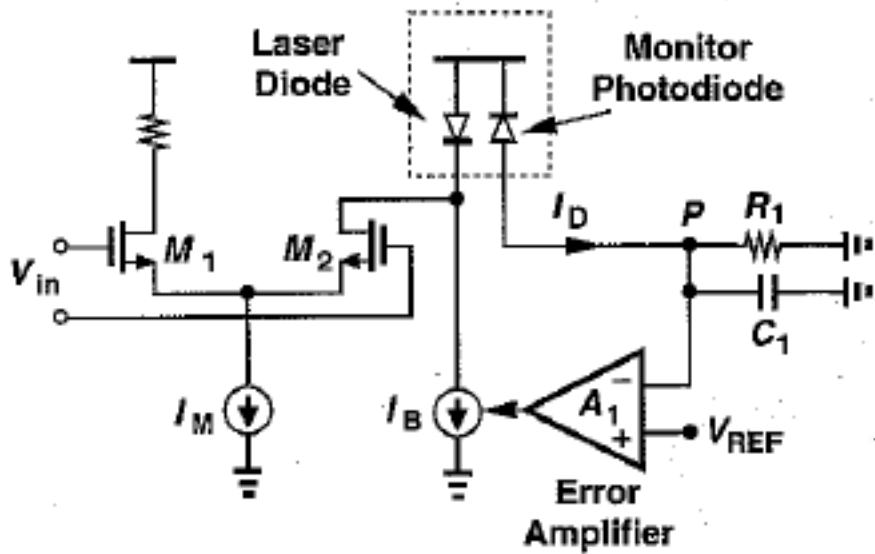


Pin out

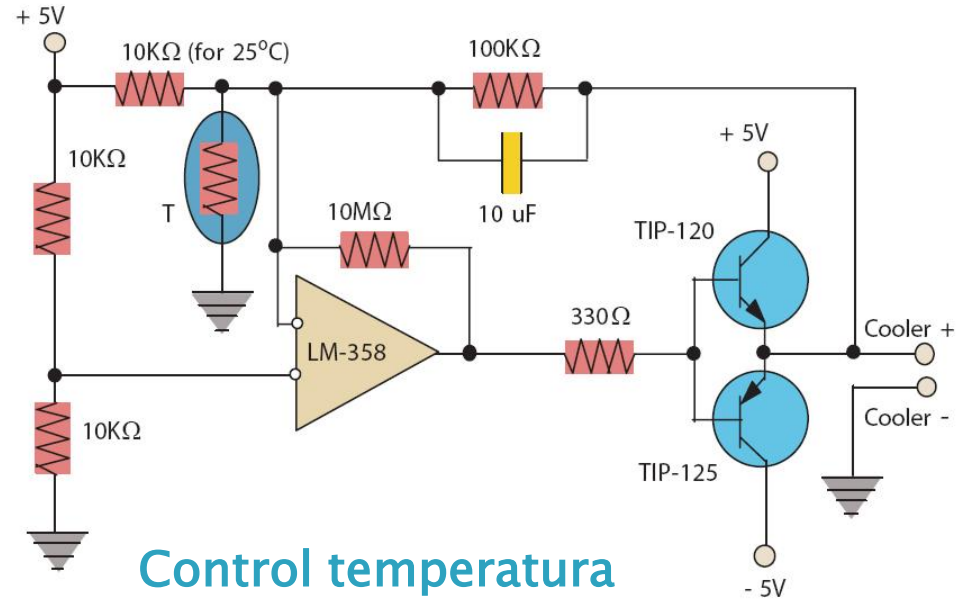
Pin	Description
1	Thermistor
2	Thermistor
3	Laser Cathode (Bias)
4	Monitor PD Anode
5	Monitor PD Cathode
6	TEC +
7	TEC -
8	Case GND, Laser Anode
9	Case GND, Laser Anode
10	Case GND, Laser Anode
11	Case GND, Laser Anode
12	Laser Cathode (modulation)
13	Case GND, Laser Anode
14	Case GND, Laser Anode



Control dioda LASER



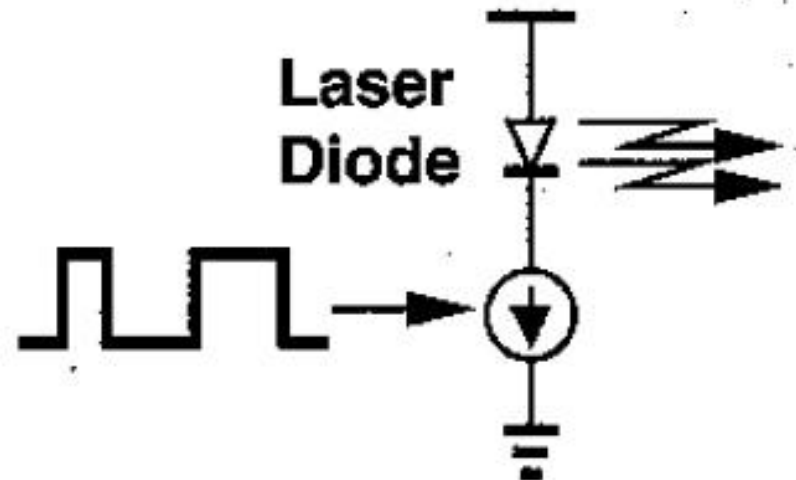
Control putere optica



Control temperatura

Dioda LASER

- ▶ Ca și în cazul LED, pentru DL intensitatea luminoasă emisă este o funcție de curentul prin dioda
 - aproape exclusiv, DL sunt controlate în curent
 - controlul în curent are avantajul unei viteze mai mari de lucru



Dioda LASER

- ▶ Cerinte pentru driver-ele de diode laser
 - viteza mare de basculare pentru minimizarea interferentei intersimbol
 - curent mare de iesire
 - capacitatea de a rezista la variatiile de tensiune pe dioda Laser
- ▶ Cerintele sunt dificil de respectat deoarece sunt contradictorii
 - viteza mare presupune micșorarea dimensiunii componentelor
 - micșorarea dimensiunii
 - scade tensiunea de strapungere
 - scade capabilitatea de curent/putere disipata

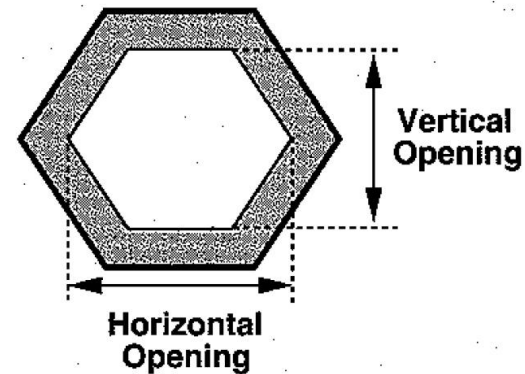
Caracteristici driver-e DL

▶ Viteza

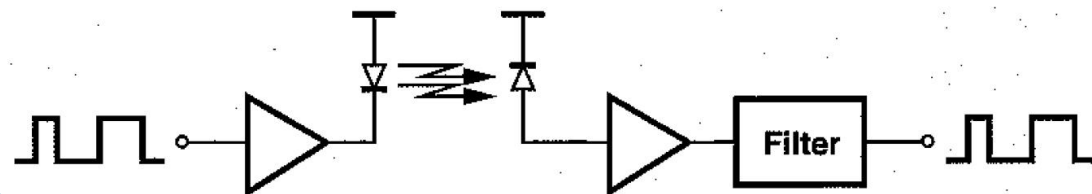
- caracterizata de timpii de crestere si de cadere
- suma acestora trebuie sa fie mult mai mica decat perioada de bit la viteza nominala de lucru

▶ Testarea vitezei de lucru

- standardizata
- “eye diagram”



(a)

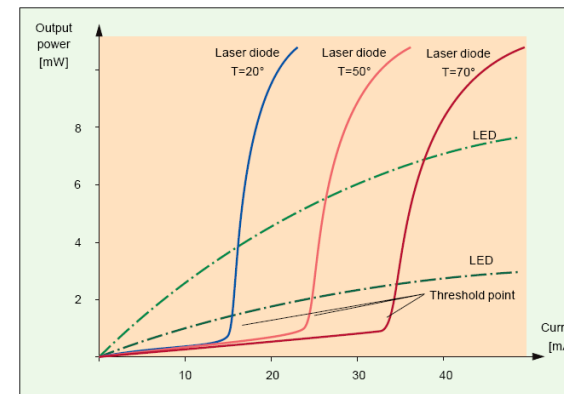


(b)

Caracteristici driver-e DL

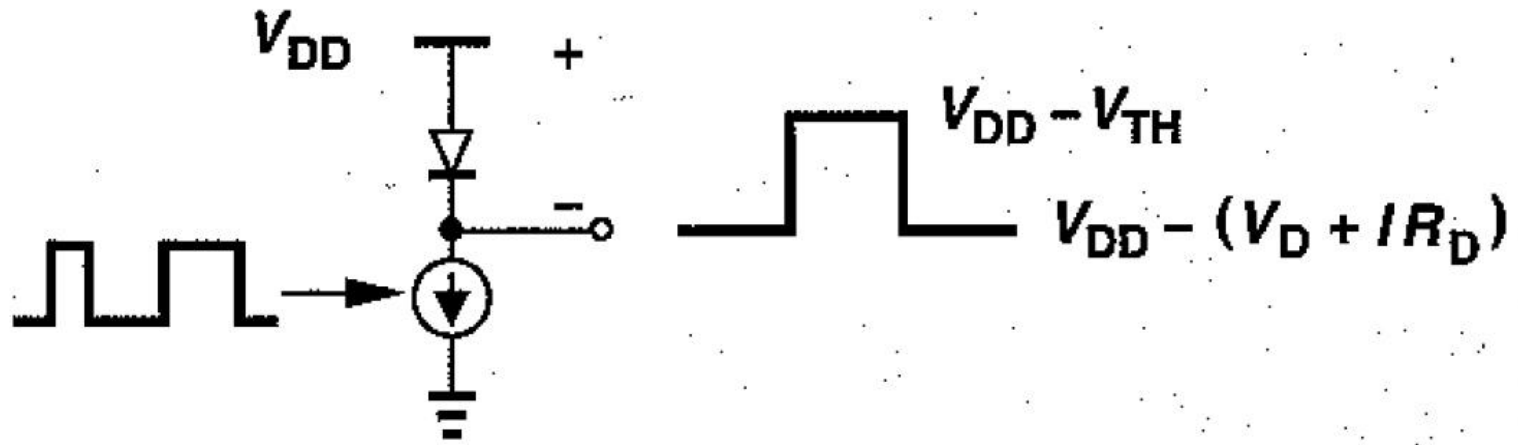
▶ Curent de iesire

- laserele trebuie polarizate in vecinatatea pragului, astfel incat o mica variatie de curent sa poata deschide dioda
- driver-ele de DL trebuie sa poata furniza:
 - un curent de “polarizare”
 - un curent de “modulatie”
- Curentul de “polarizare” (~ de prag) variaza cu temperatura si varsta diodei extrem de mult
- Curentul de “modulatie” (semnal) nu depinde de aceste elemente deoarece pentru DL
 - pragul depinde de temperatura si varsta
 - panta este aproximativ constanta



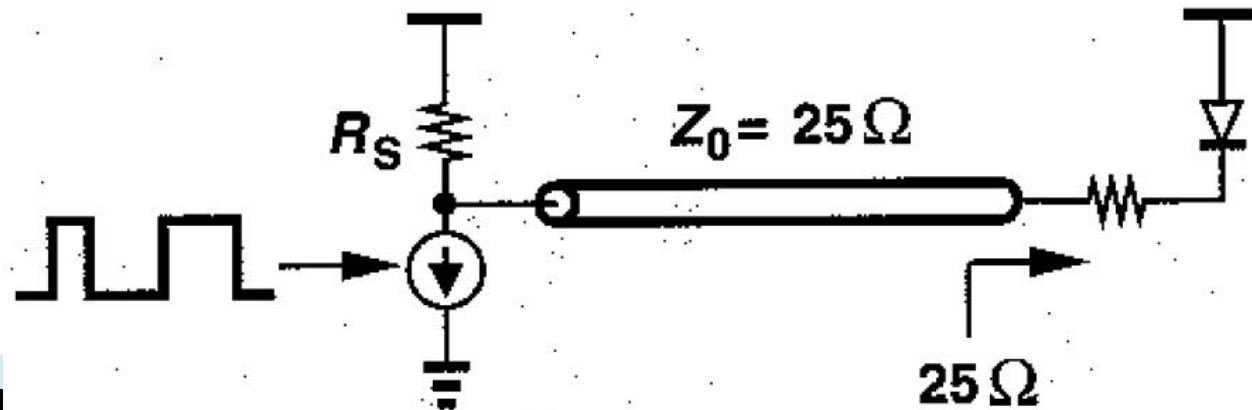
Caracteristici driver-e DL

- ▶ Variatii de tensiune pe dioda LASER
 - generate de variatiile mari de curent si rezistenta interna a diodei



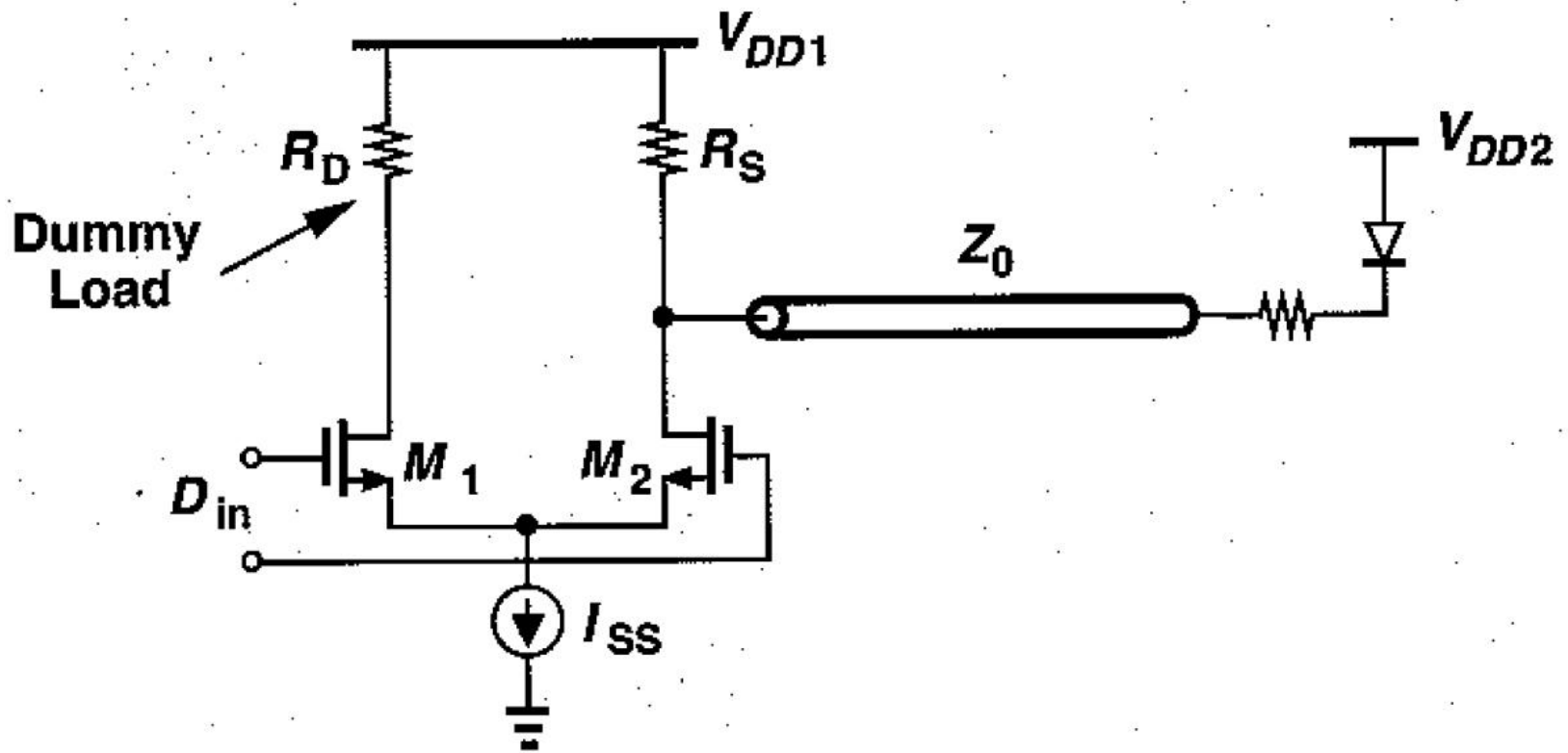
Caracteristici driver-e DL

- ▶ Impedante de intrare si iesire
- ▶ Se lucreaza la viteze mari (1 Gb/s, 10 GB/s)
 - se aplica considerente de proiectare a circuitelor de microunde
 - Intrarea in amplificator are tipic o impedanta de 50Ω
 - Iesirea trebuie adaptata la impedanta diodei Laser
 - daca aceasta impedanta e prea mica, se creste la valori adecvate ($\sim 25\Omega$) prin introducerea unui rezistor in serie



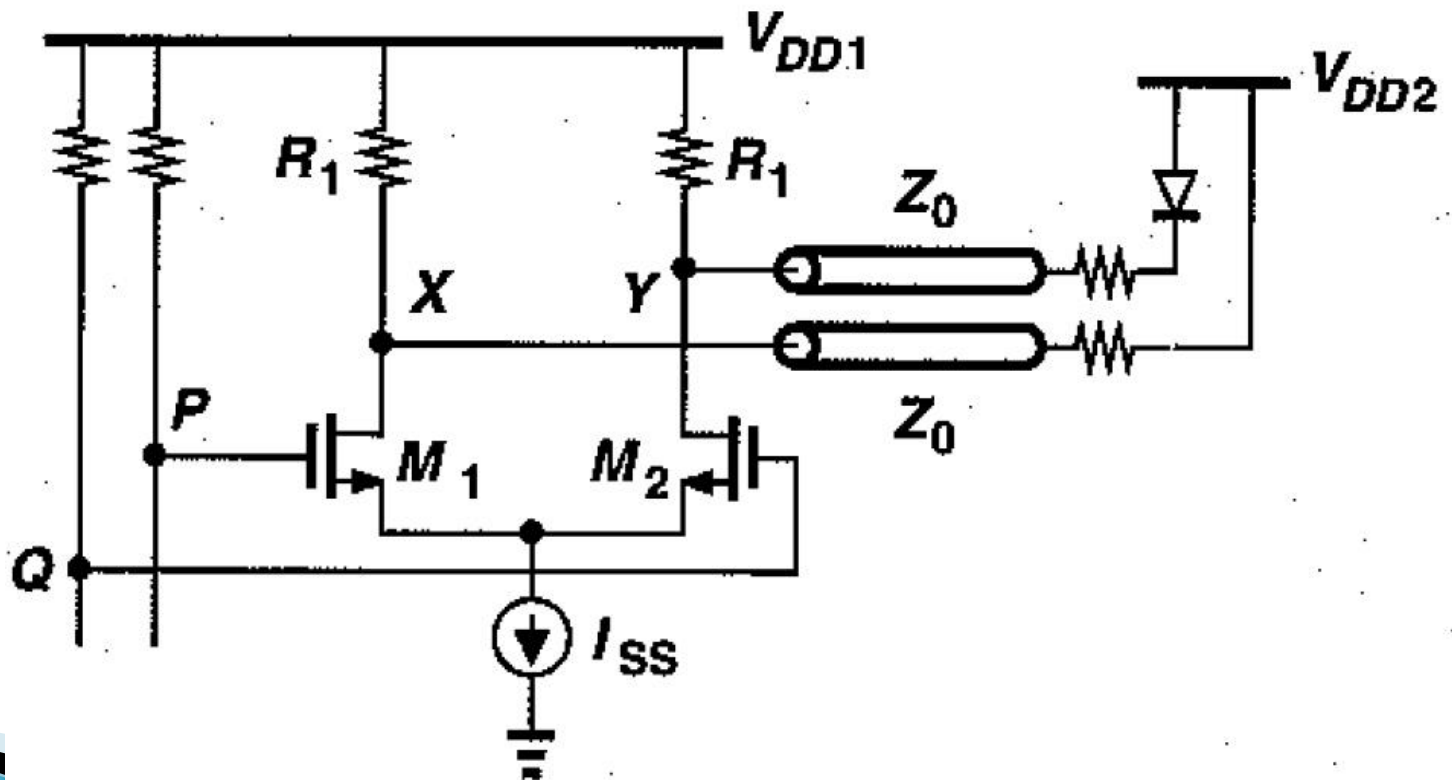
Principii de proiectare

- ▶ Tipic etajul de iesire se realizeaza diferential



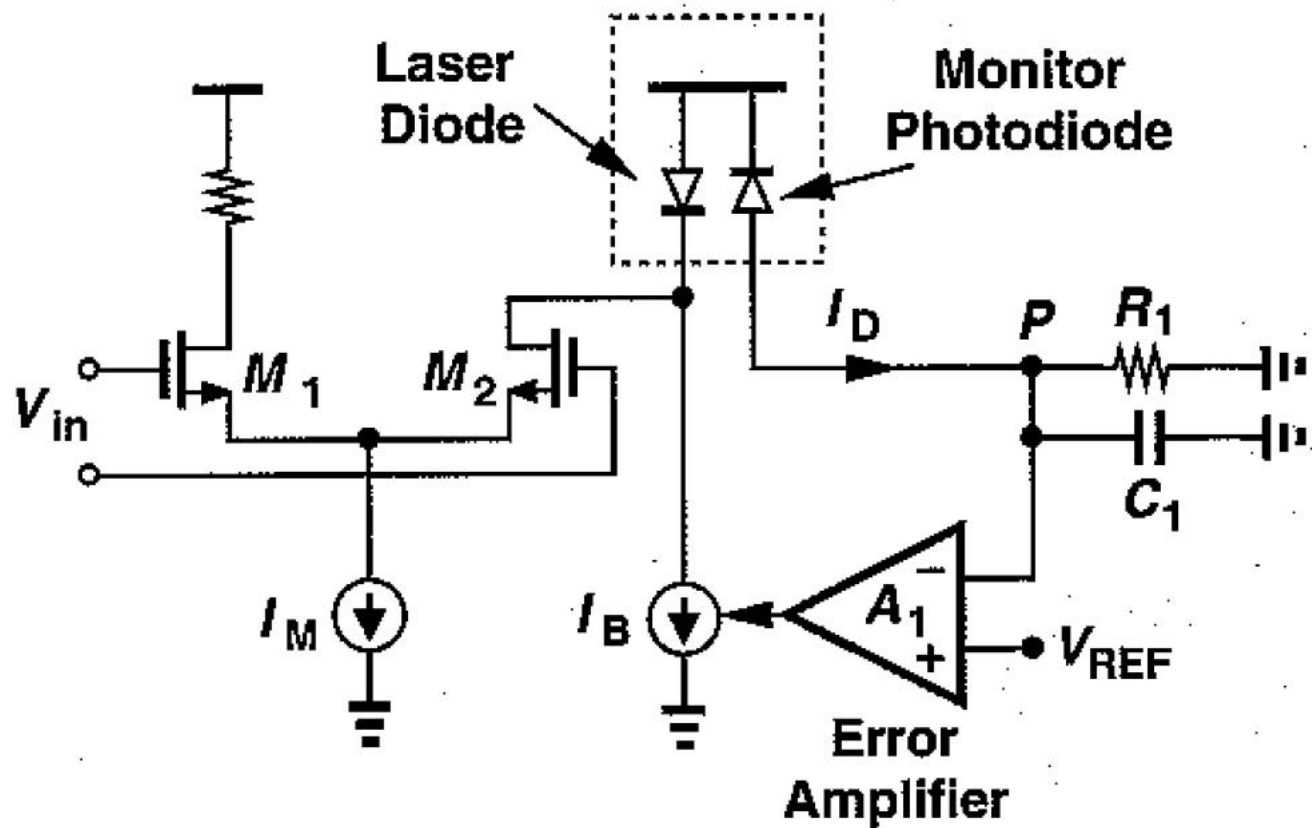
Principii de proiectare

- ▶ La viteze mari se utilizeaza tipic tranzistoare unipolare si etajul diferential se realizeaza simetric



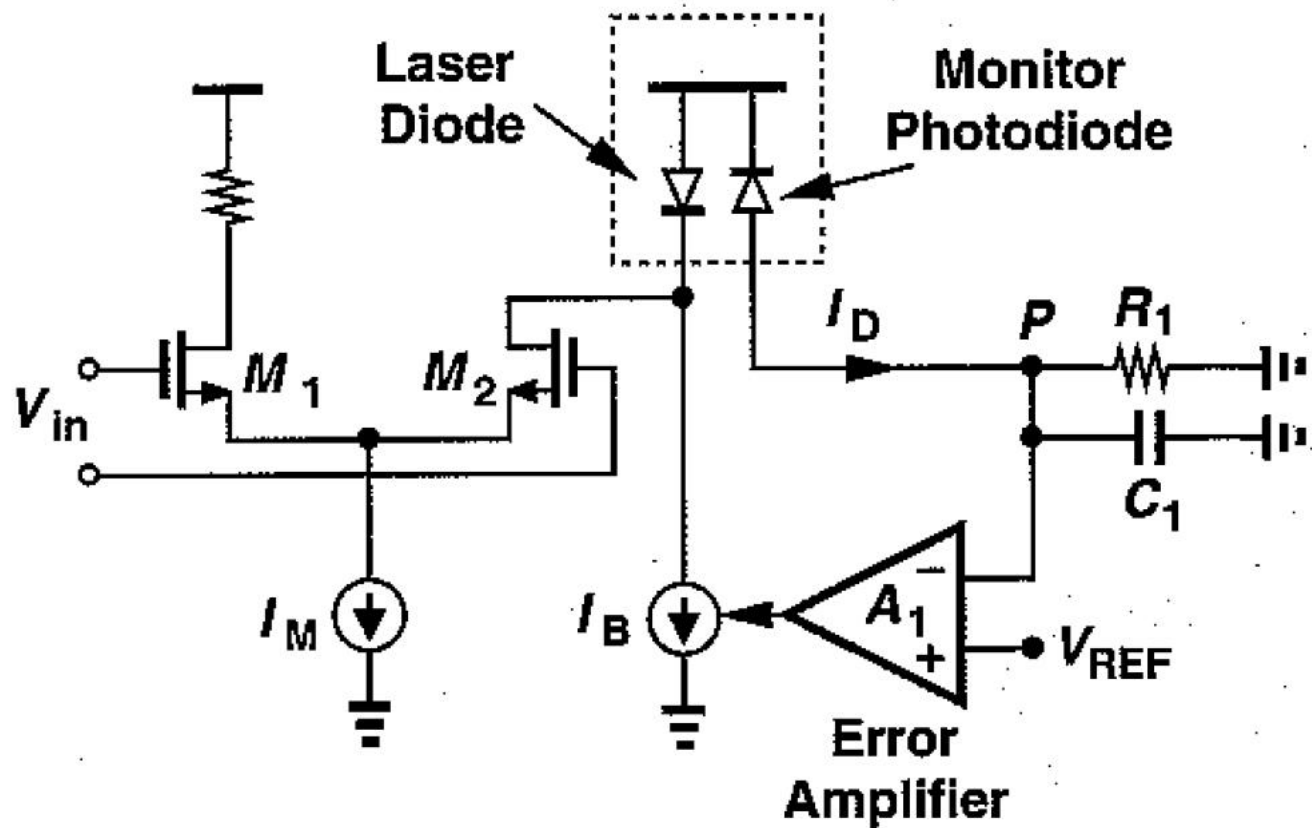
Controlul puterii in DL

- ▶ Necesara datorita variatiei curentului de “polarizare”



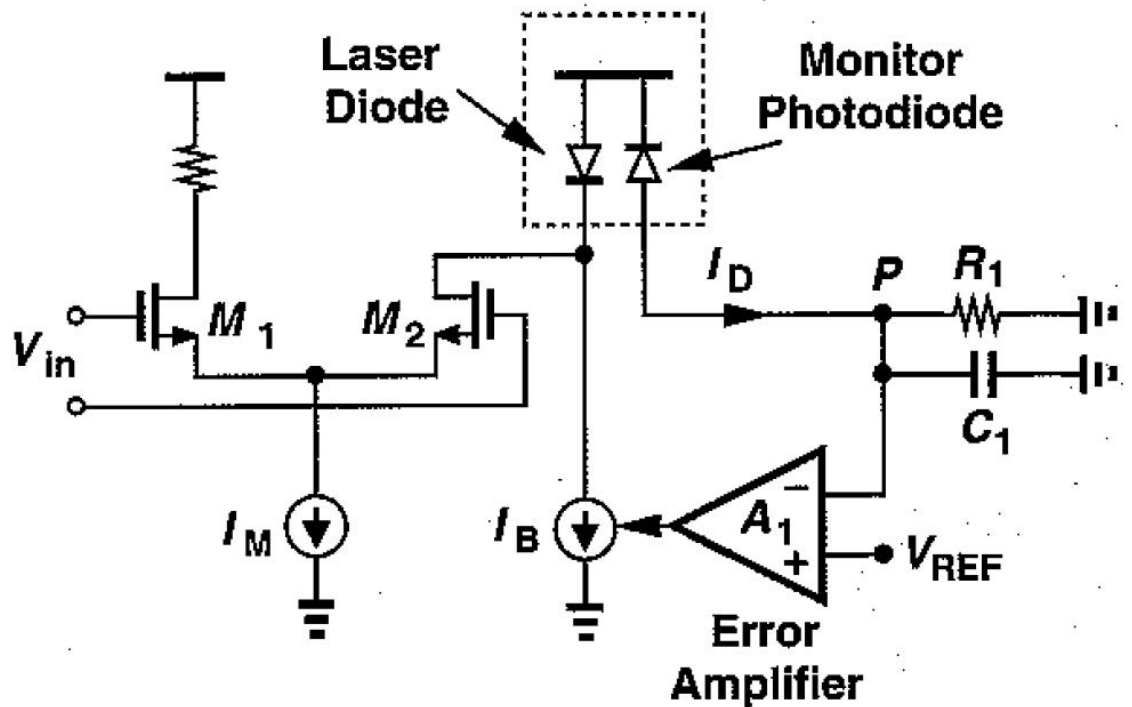
Controlul puterii in DL

- ▶ circuitul RC din schema de reglaj a curentului de polarizare realizeaza o filtrare trece sus a semnalului



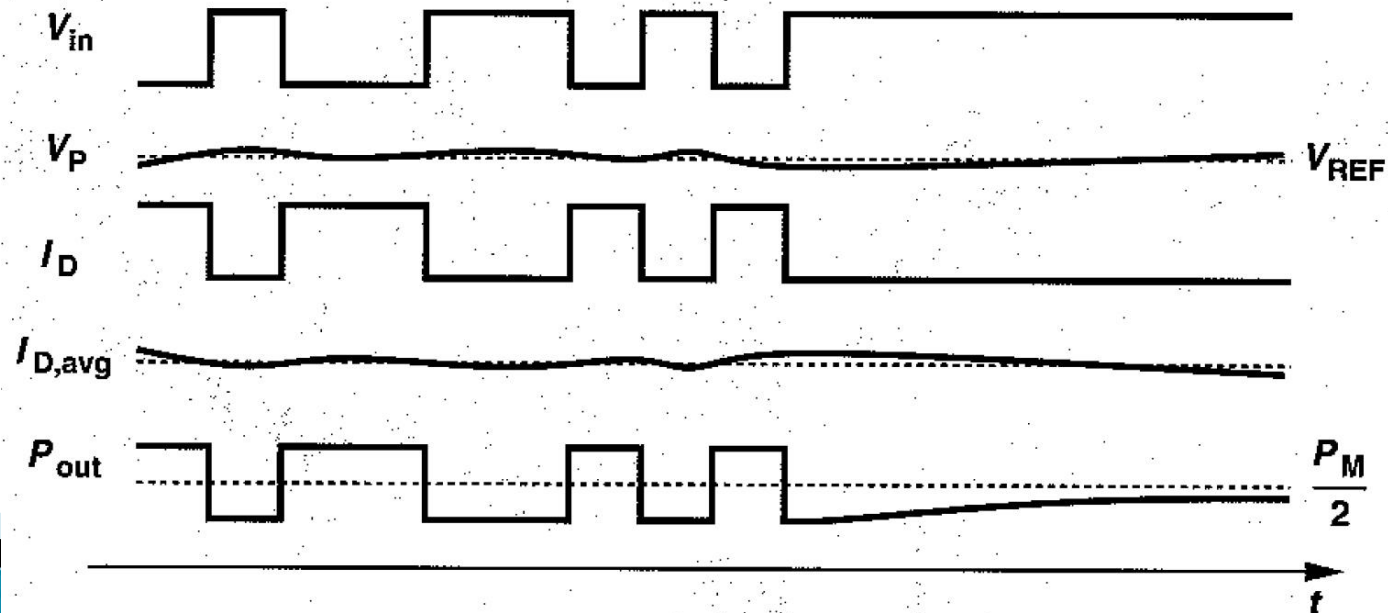
Controlul puterii in DL

- ▶ La frecvente prea mici de lucru bucla de reatie e suficient de rapida pentru a urmari si anula curentul de semnal



Controlul puterii in DL

- ▶ Bucla de reactie are efect si in cazul unei suite lungi de biti 1 transmisi
 - In acest caz, la limita curentul emis de dioda laser in starea OFF ajunge jumătate din curentul corespunzator starii ON
 - Capacitatea de filtrare din bucla trebuie aleasa mare pentru a minimiza acest efect
 - daca valoarea e prea ridicata e necesara o capacitate externa circuitului integrat



Fotodioda

Capitolul 9

Detectori optici

▶ Cerinte

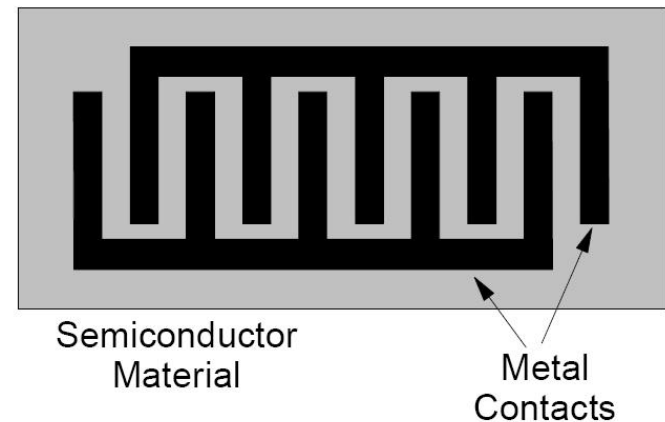
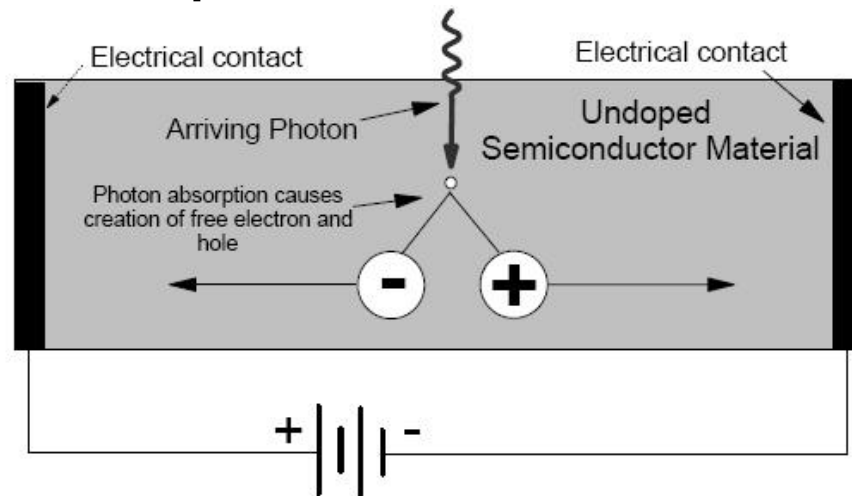
- eficienta crescuta a conversiei optic/electric
- zgomot redus
- raspuns uniform la diferite lungimi de unda
- viteza de raspuns ridicata
- liniaritate

▶ 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

Fotoconductor

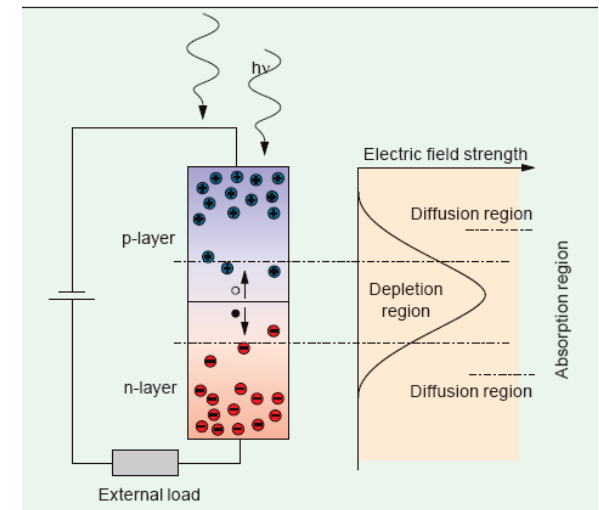
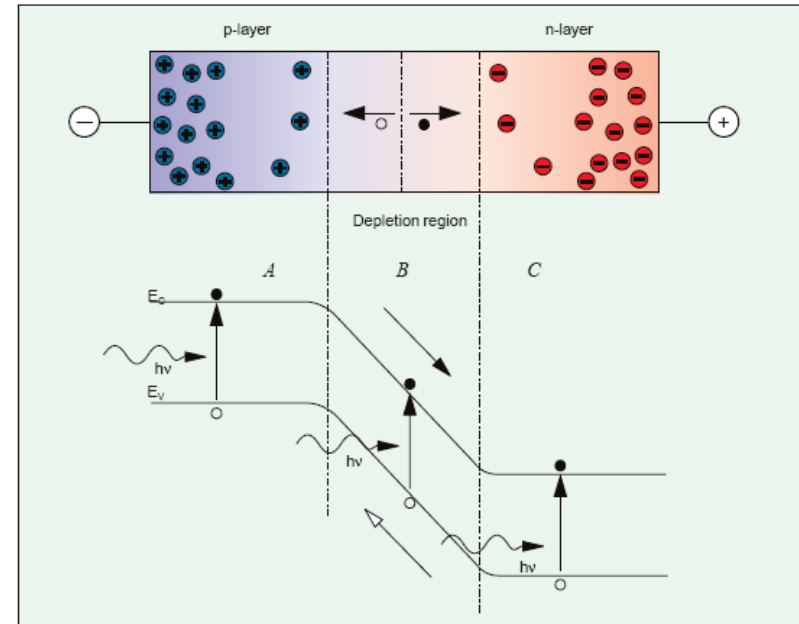
▶ Principiu



- ▶ 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

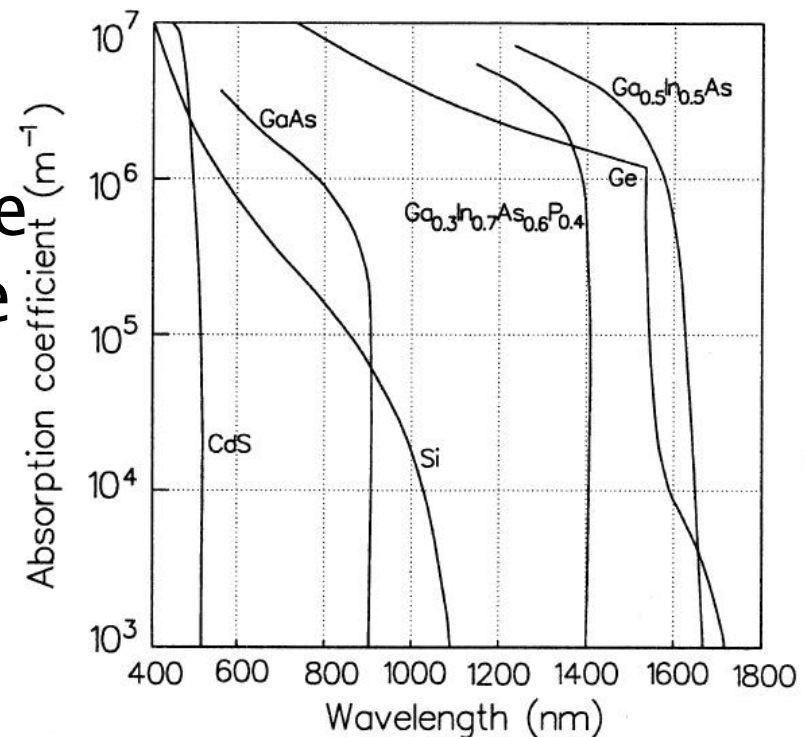
$$\lambda_{\max} = \frac{hc}{E_g}$$

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

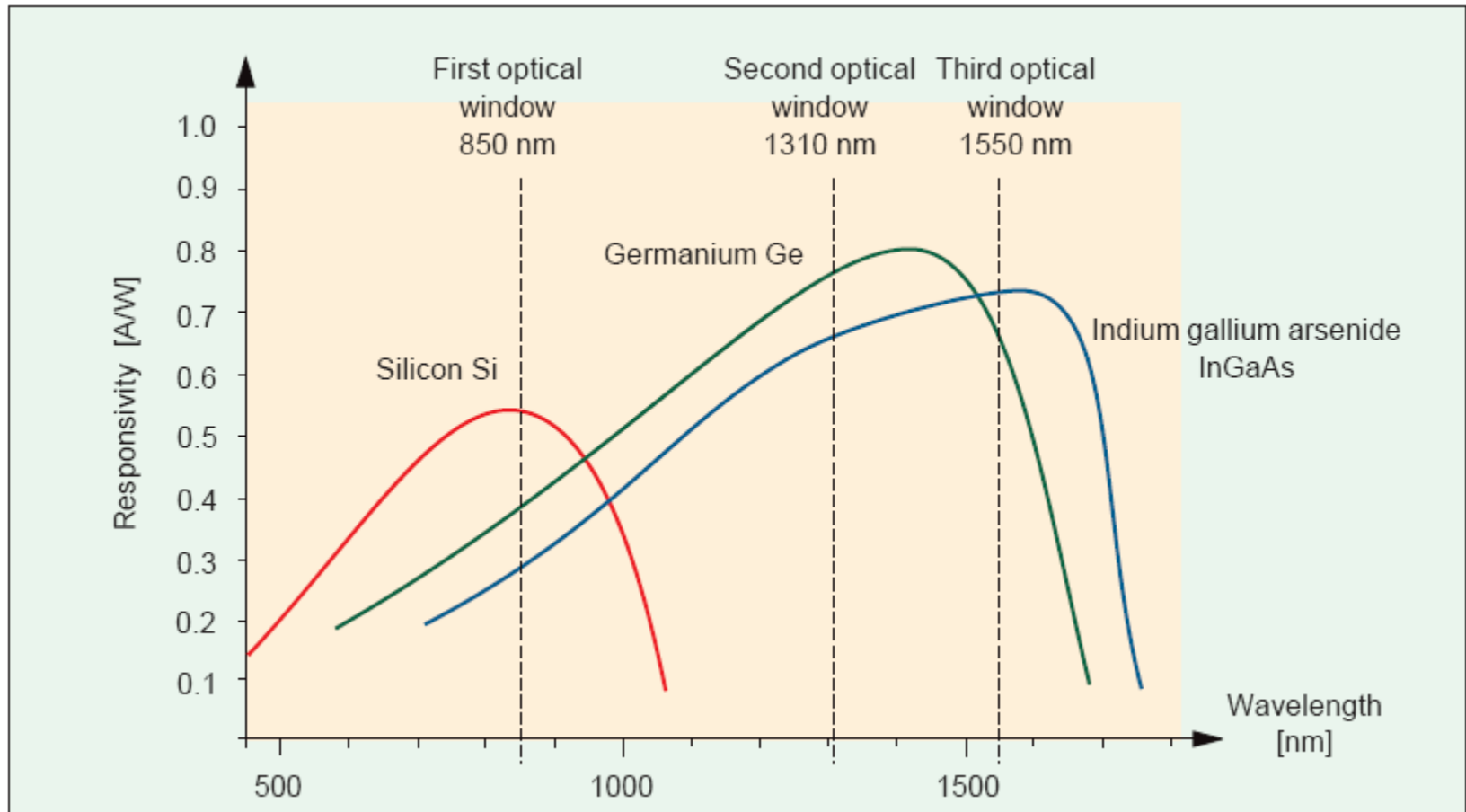
$$P(w) = P_i \cdot e^{-\alpha \cdot d} \cdot (1 - e^{-\alpha \cdot w}) \cdot (1 - R_f)$$

Fotodioda – Principiul de operare

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



Material utilizate pentru fotodiode



Fotodioda – Marimi caracteristice

- ▶ Eficienta cuantica – raportul dintre numărul de perechi electron–gol generate și numărul de fotoni incidenti

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

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

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

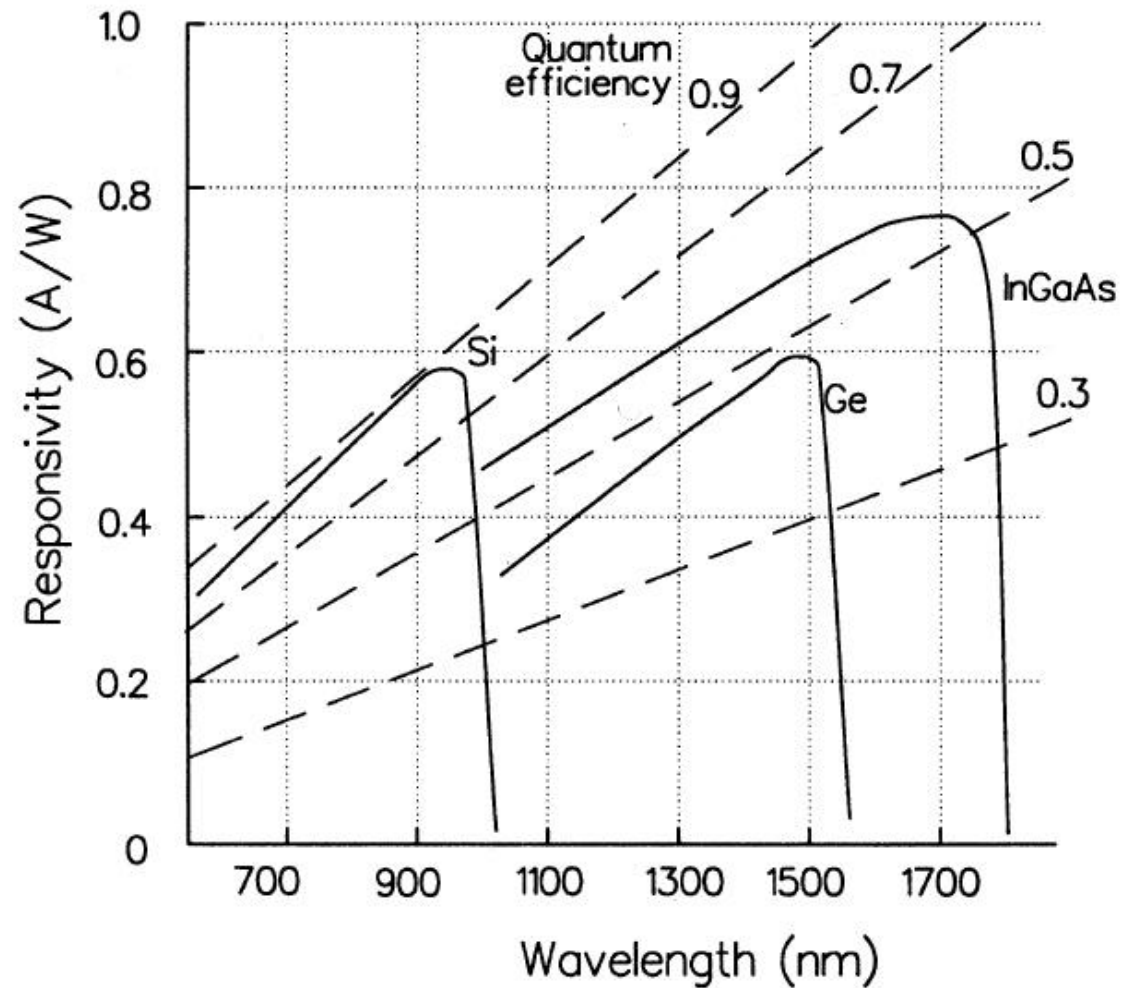
- ▶ Responzivitatea

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

$$R = 0.8 \cdot \eta \cdot \lambda [\mu m] \left[\frac{A}{W} \right]$$

Fotodiode - marimi karakteristik

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



Material 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	E_g (eV)
GaAs	1.43
GaSb	0.73
$\text{GaAs}_{0.88}\text{Sb}_{0.12}$	1.15
Ge	0.67
InAs	0.35
InP	1.35
$\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$	0.75
$\text{In}_{0.14}\text{Ga}_{0.86}\text{As}$	1.15
Si	1.14

Curent de intuneric

- ▶ Curentul invers al jonctiunii p-n, datorat agitatiei termice, prezent in absenta iluminarii
- ▶ Constitutie 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)

Contact

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