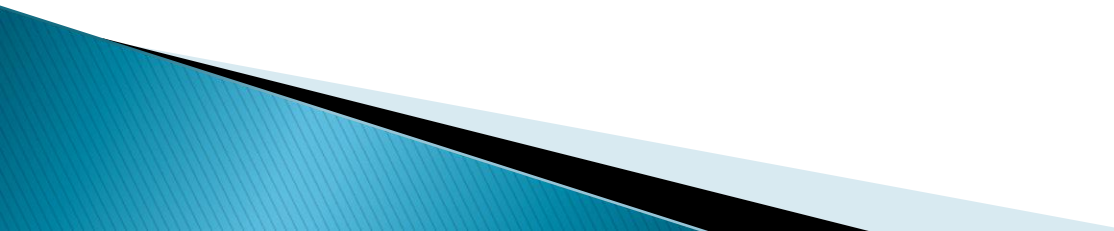


# Optoelectronică, structuri și tehnologii

Curs 10  
2014/2015

# Capitolul 11

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

# Lista subiecte

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

# LED

Dioda electroluminescenta  
Capitolul 8

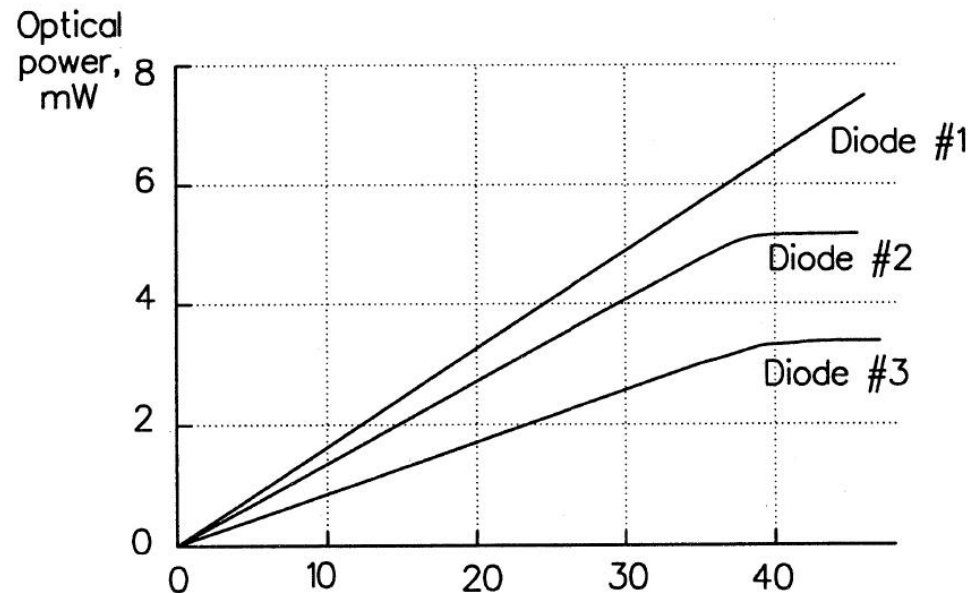
# Caracteristica de raspuns a LED-urilor

- ▶ 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  $r = 50 \mu\text{W}/\text{mA}$



# Dioda Laser

Capitolul 9

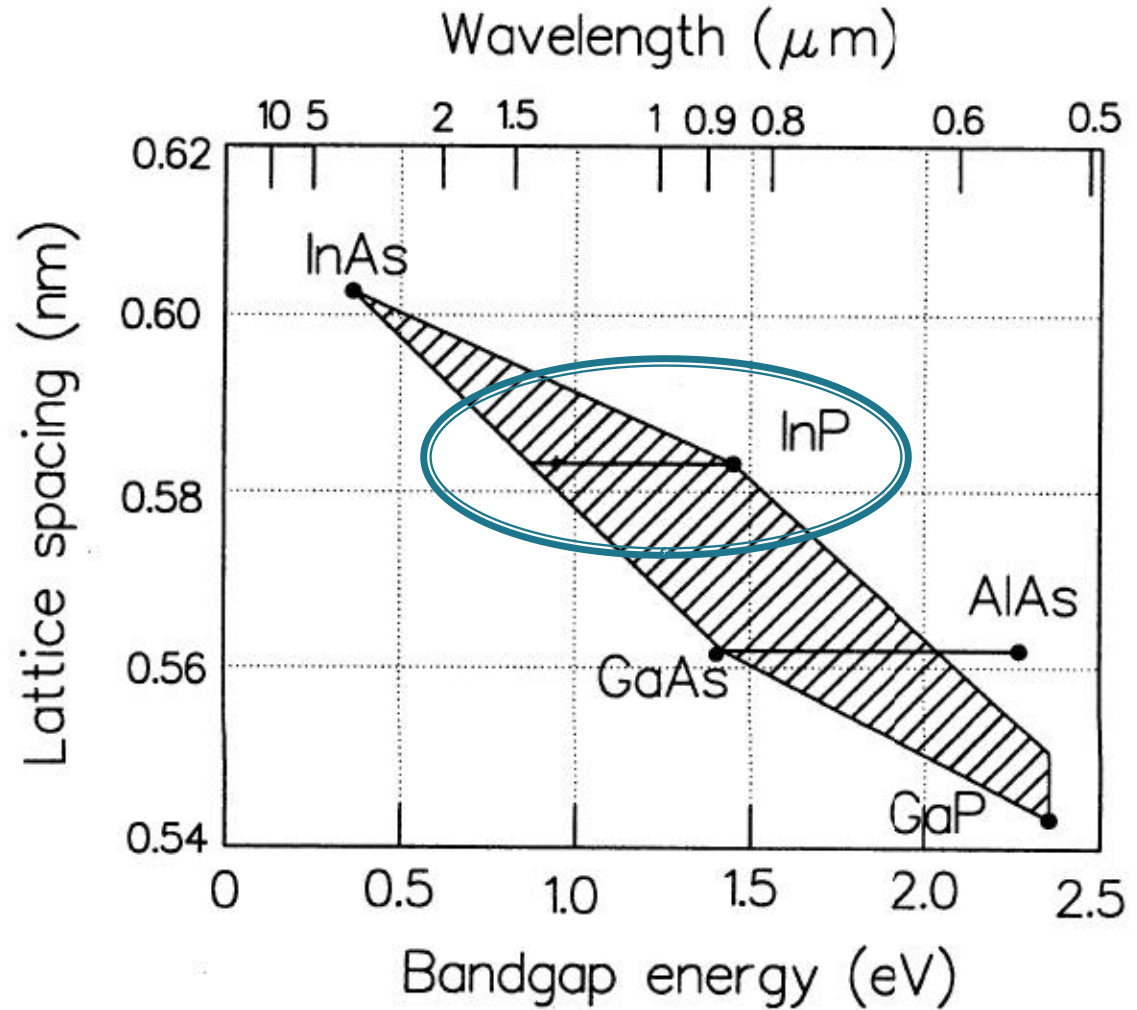
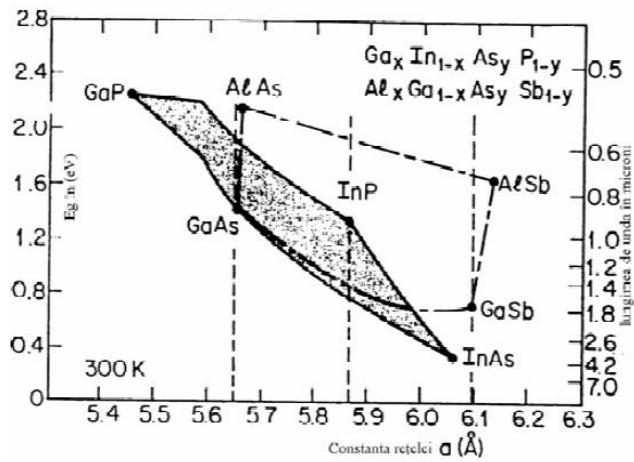
# Lățimea benzii interzise/lungime de undă pentru materialele uzuale

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

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

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

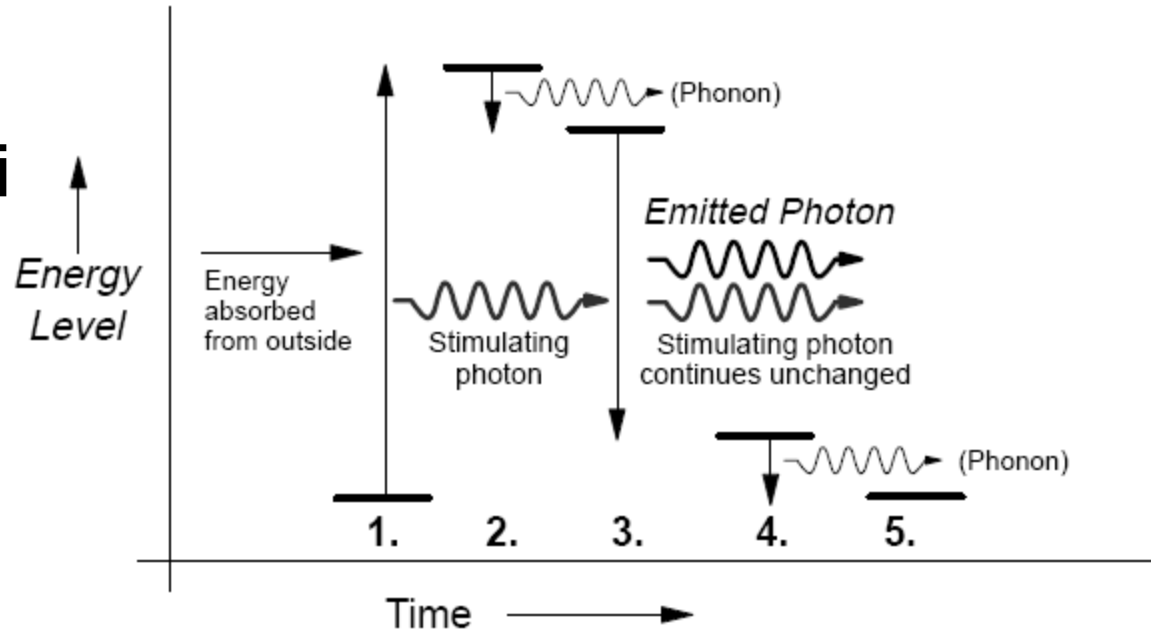
# Dependența benzii interzise de constanta rețelei



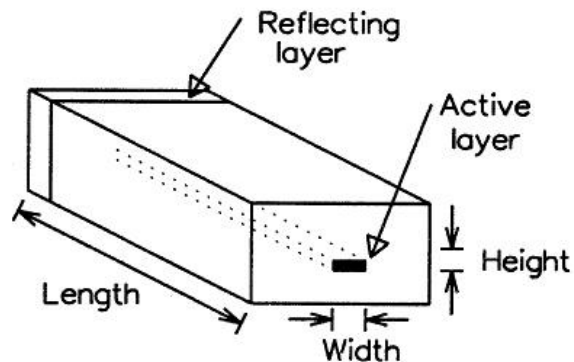
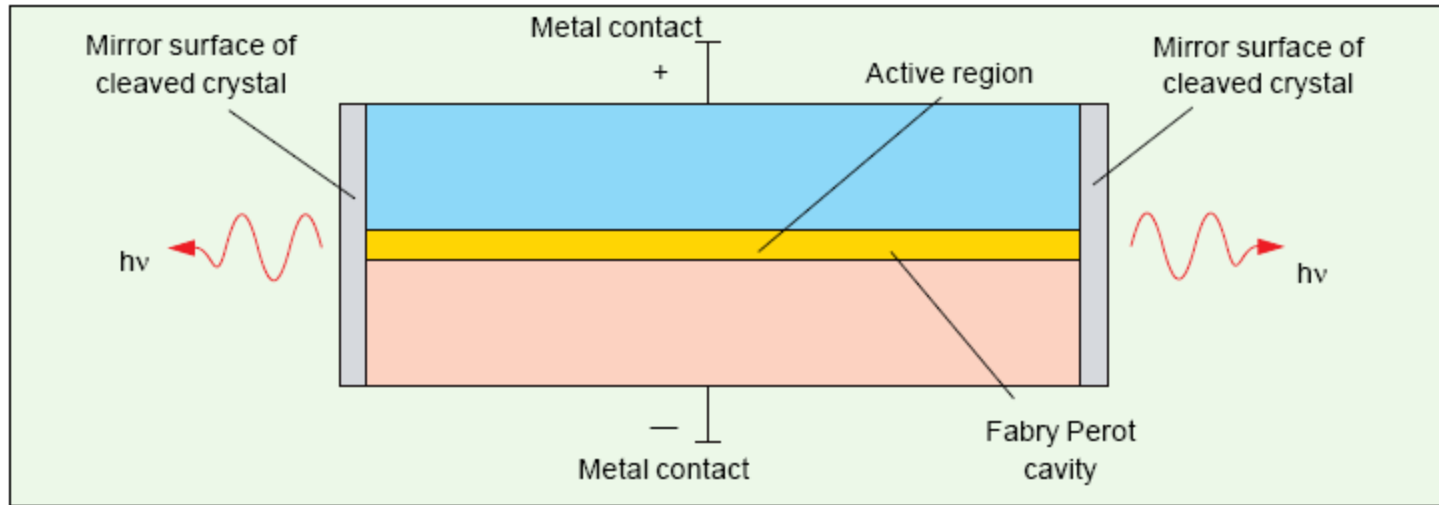


# Materialie cu 4 nivele energetice

- ▶ 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

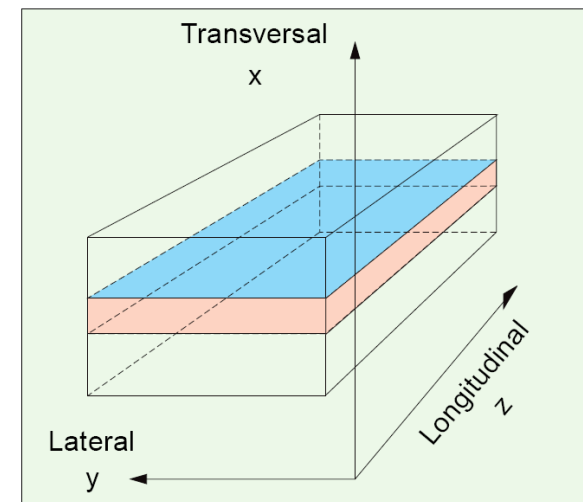


# Dioda LASER Fabry Perot

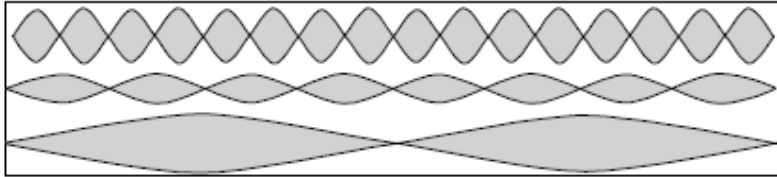


Height:  $0.1 - 0.2 \mu\text{m}$   
Length:  $250 - 500 \mu\text{m}$   
Width:  $5 - 15 \mu\text{m}$   
Sides: rough-cut  
Front: cleaved  
Back: 100% reflector

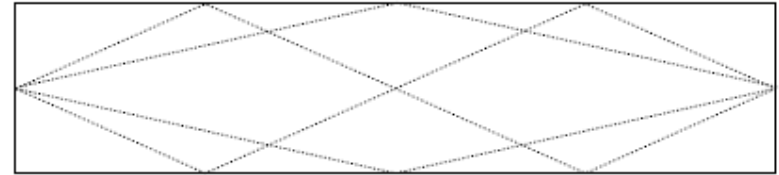
Definirea directiilor in dioda LASER



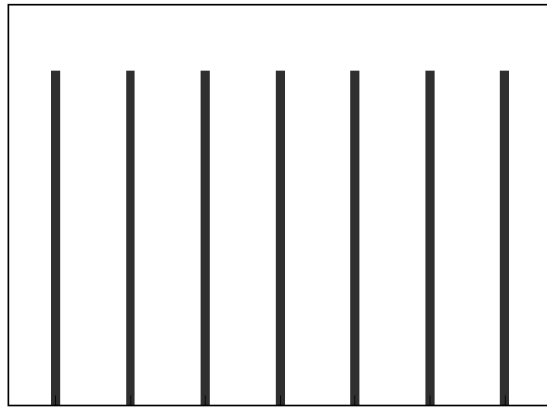
# Spectrul diodei LASER



Longitudinal Modes



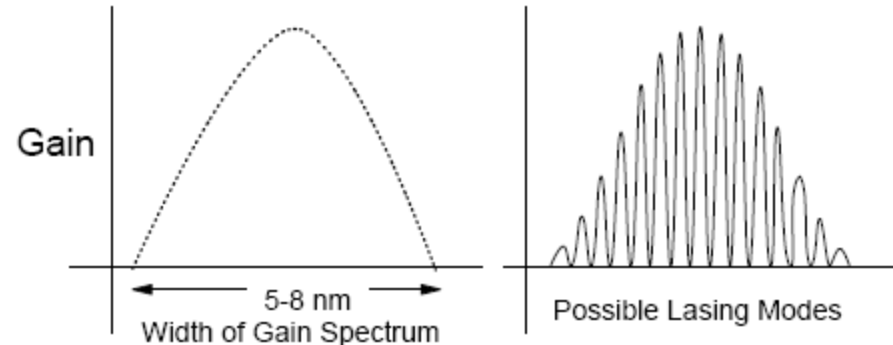
Lateral Modes



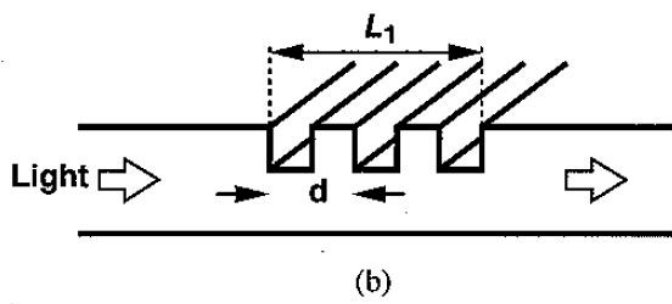
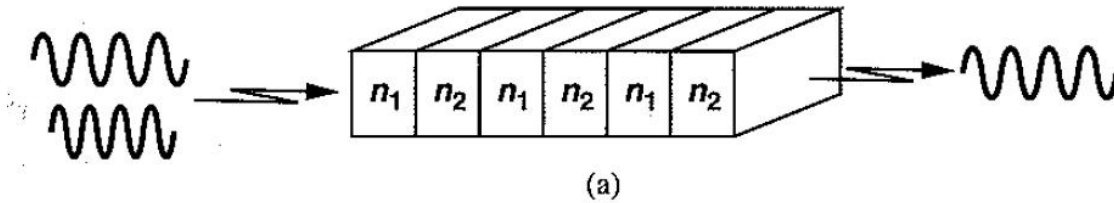
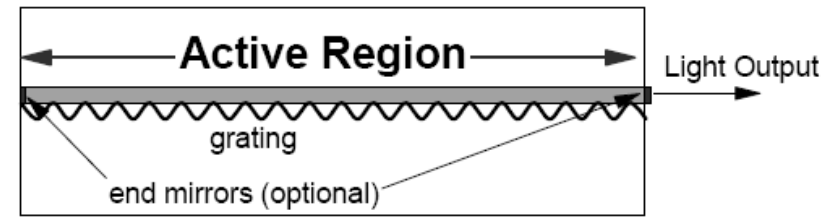
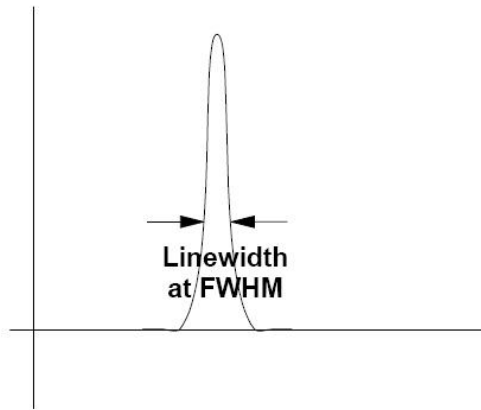
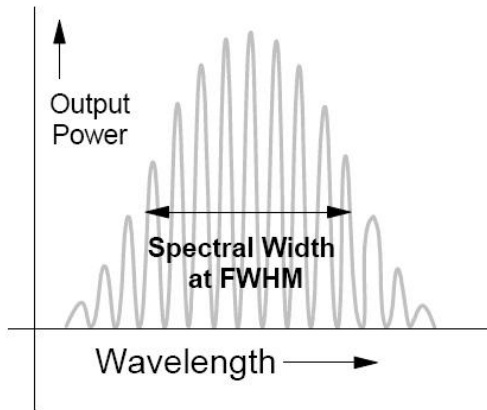
1.490 1.494 1.497 1.5 1.503 1.507 1.510  
Wavelength (nm)

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

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

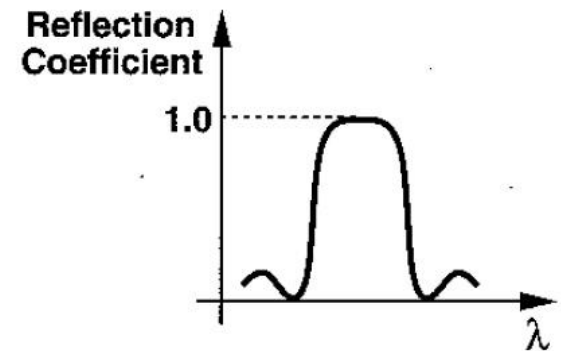
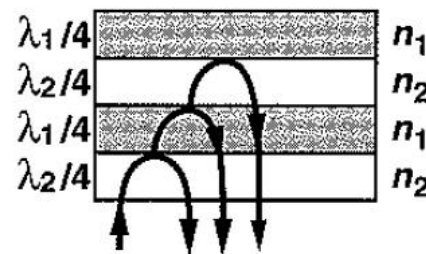
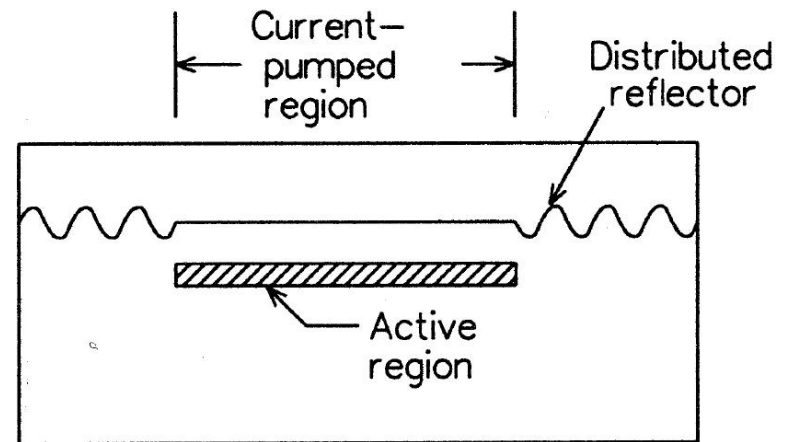


# Distributed Feedback (DFB) Lasers

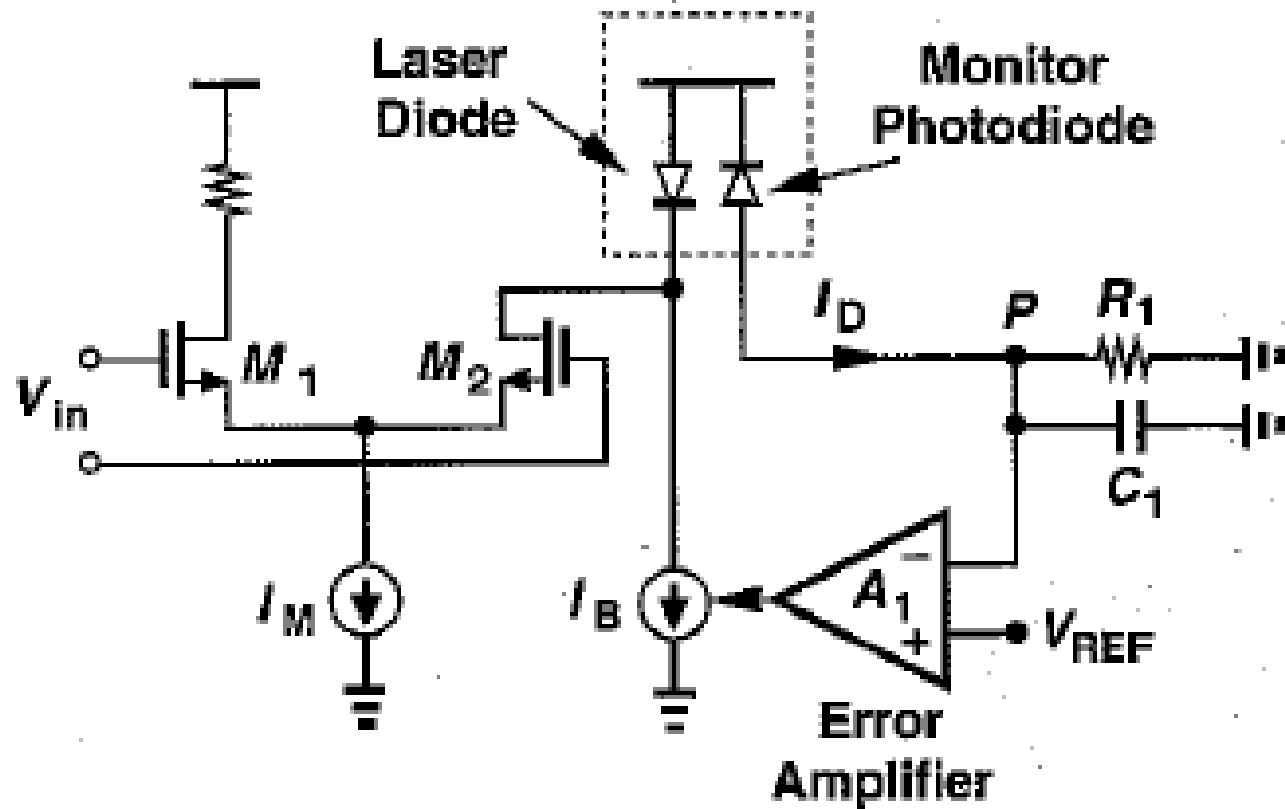


# Distributed Bragg Reflector (DBR) Lasers

- ▶ Se utilizeaza suprafete reflective selective pentru filtrare optica



# Monitorizarea radiației de spate



# Oscilatii de relaxare

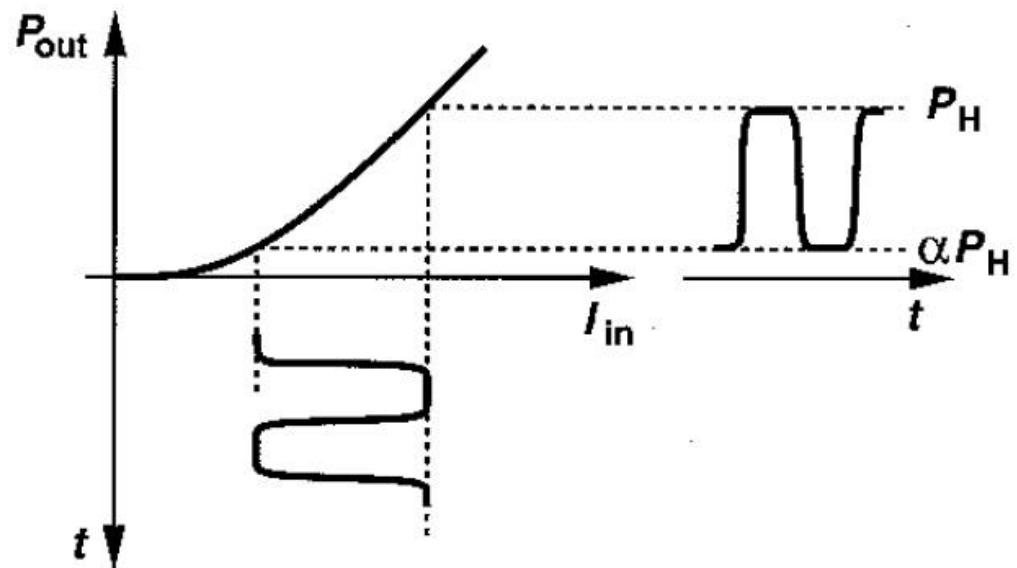
- ▶ Cresterea vitezei si minimizarea erorilor date de oscilatiile de relaxare si variatiile timpului de amorsare dioda este **partial** stinsa in timpul transmisiei unui nivel 0 logic

- ▶ Raport de stingere

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

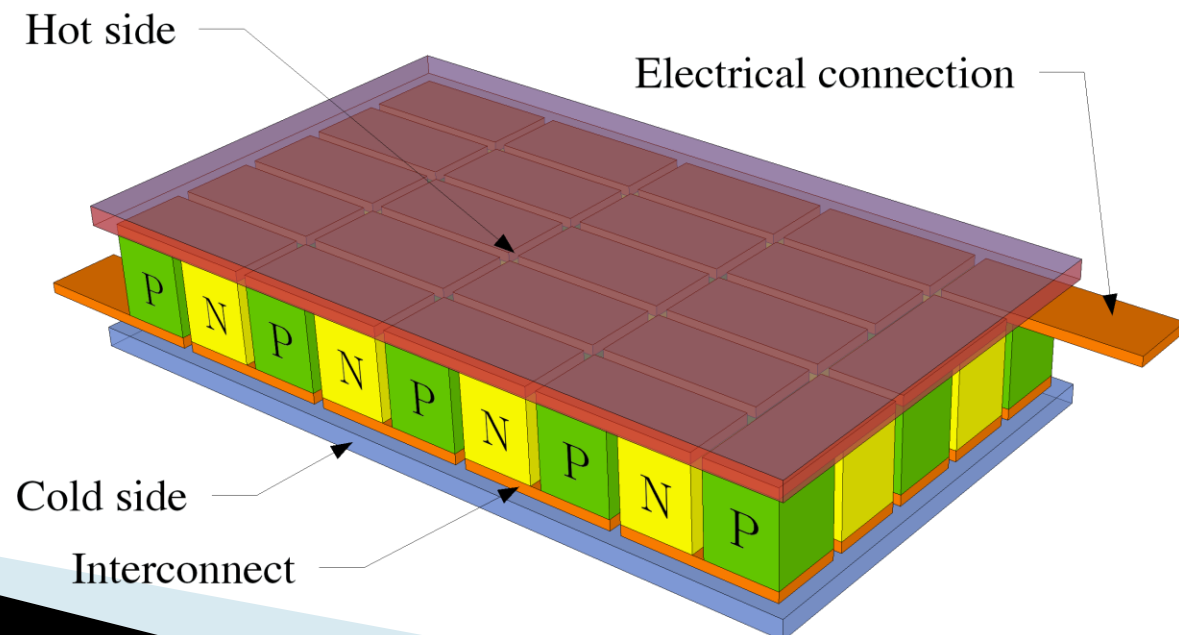
- ▶ Raportul semnal zgomot scade cu  $(1-\alpha)$

- ▶ Tipic  $ER = 10 \div 15 \text{dB}$



# Dispozitiv termoelectric (Peltier)

- ▶ Poate produce o diferenta maxima de temperatura de  $70^{\circ}\text{C}$
- ▶ 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

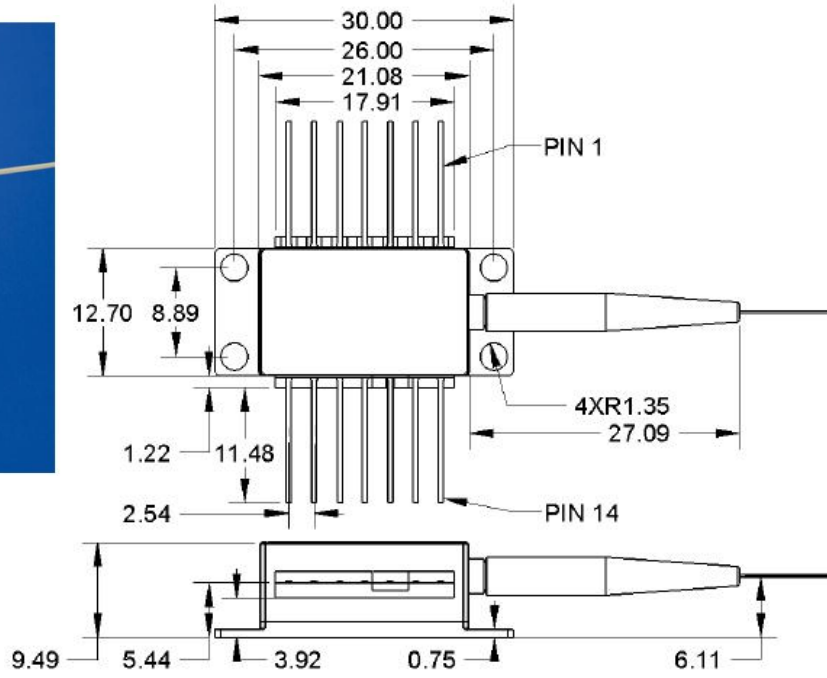




# 1550nm DFB Laser

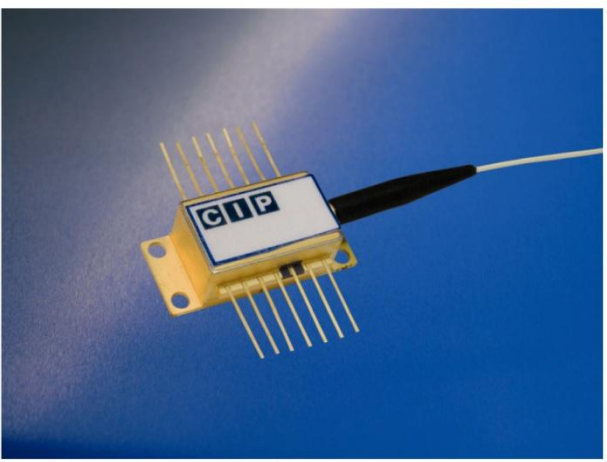
## Mechanical Drawing

All units in mm



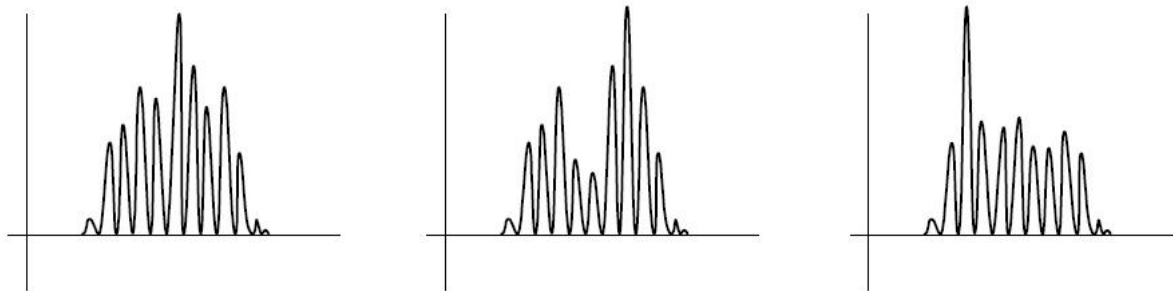
## Pin out

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



# Alte caracteristici DL

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

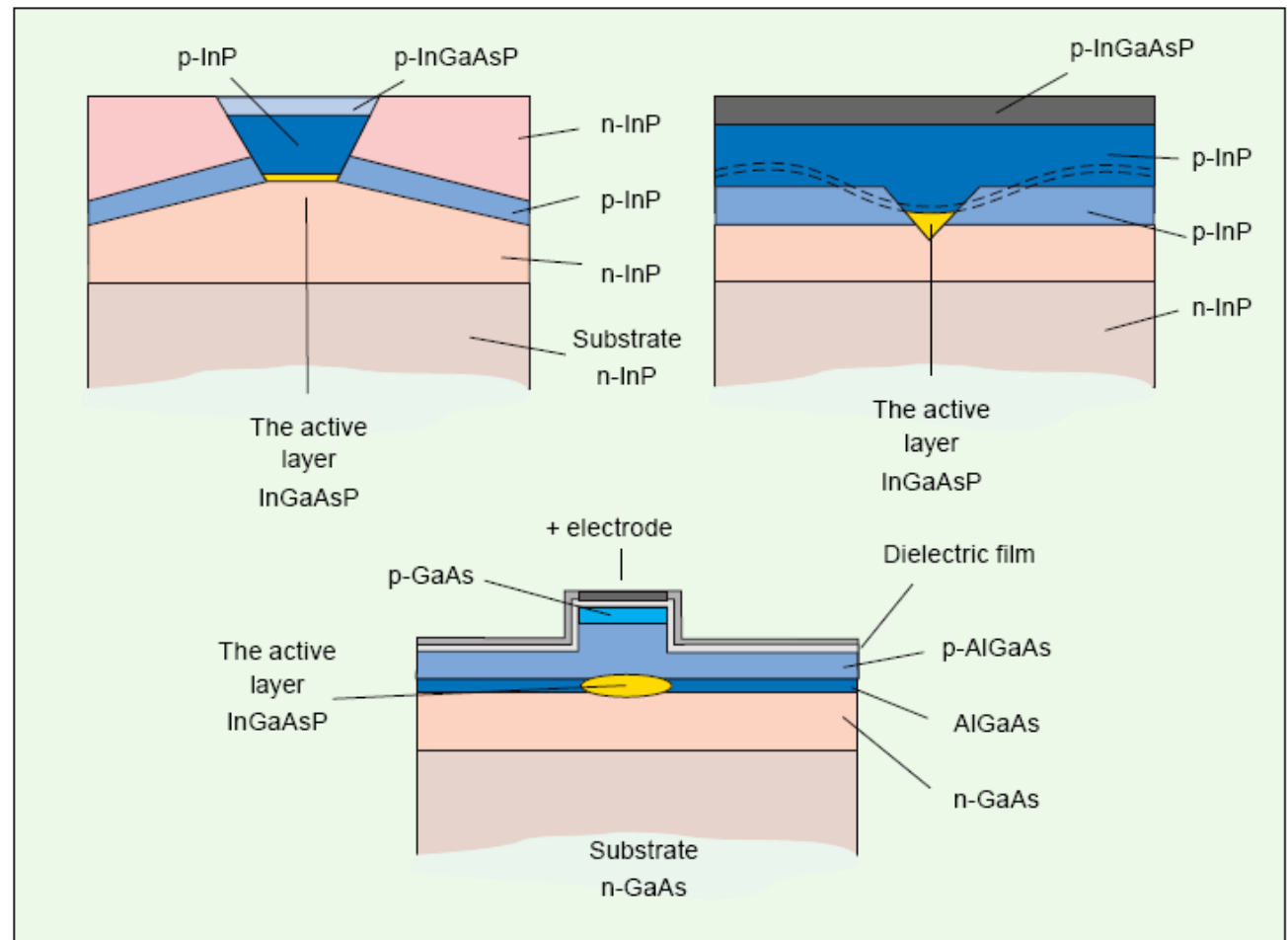


- ▶ RIN – Relative Intensity Noise (generat de emisia spontana)
- ▶ Zgomot de faza (idem) – necesitatea modulatiei in amplitudine
- ▶ Zgomot intercavitati (reflexiile din exterior in zona activa)
- ▶ Drift – variatia parametrilor cu varsta si temperatura (in special distanta intre oglinzi)

# Diode LASER cu heterojunctiune

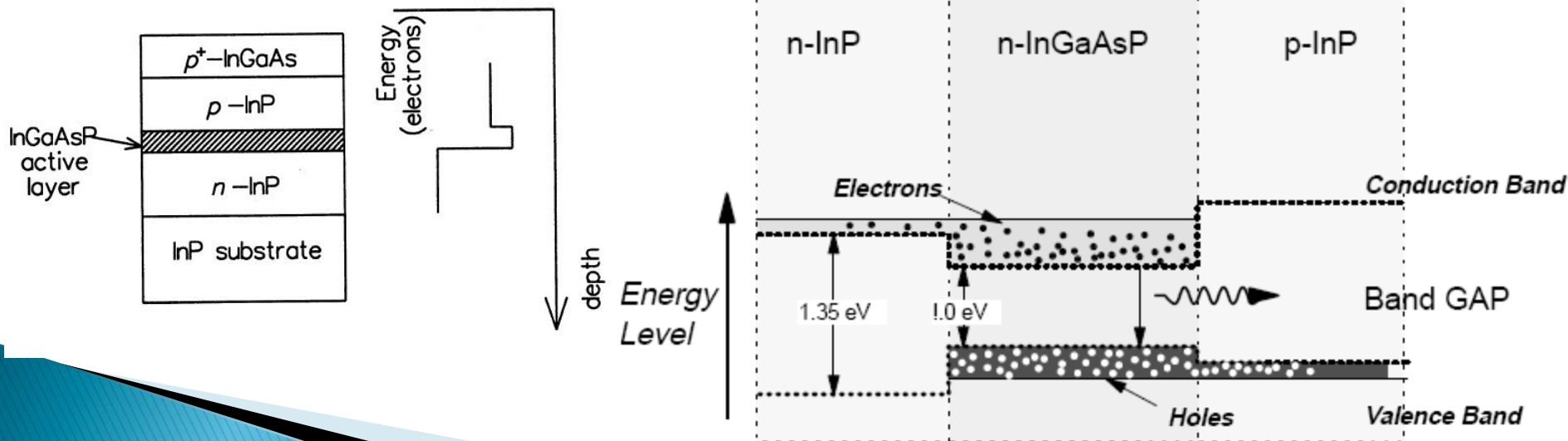
Heterojunctiune  
ingropata

Heterojunctiune  
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

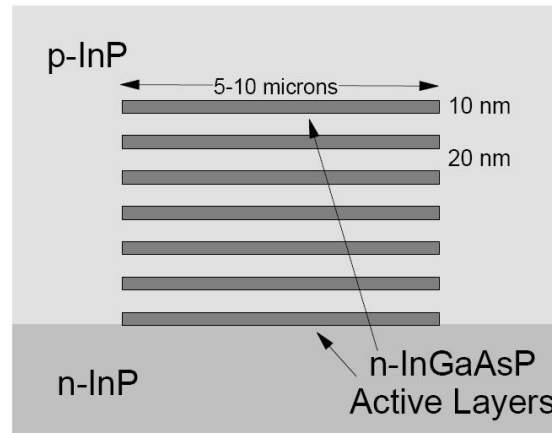


# Quantum Well Laser

- ▶ 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

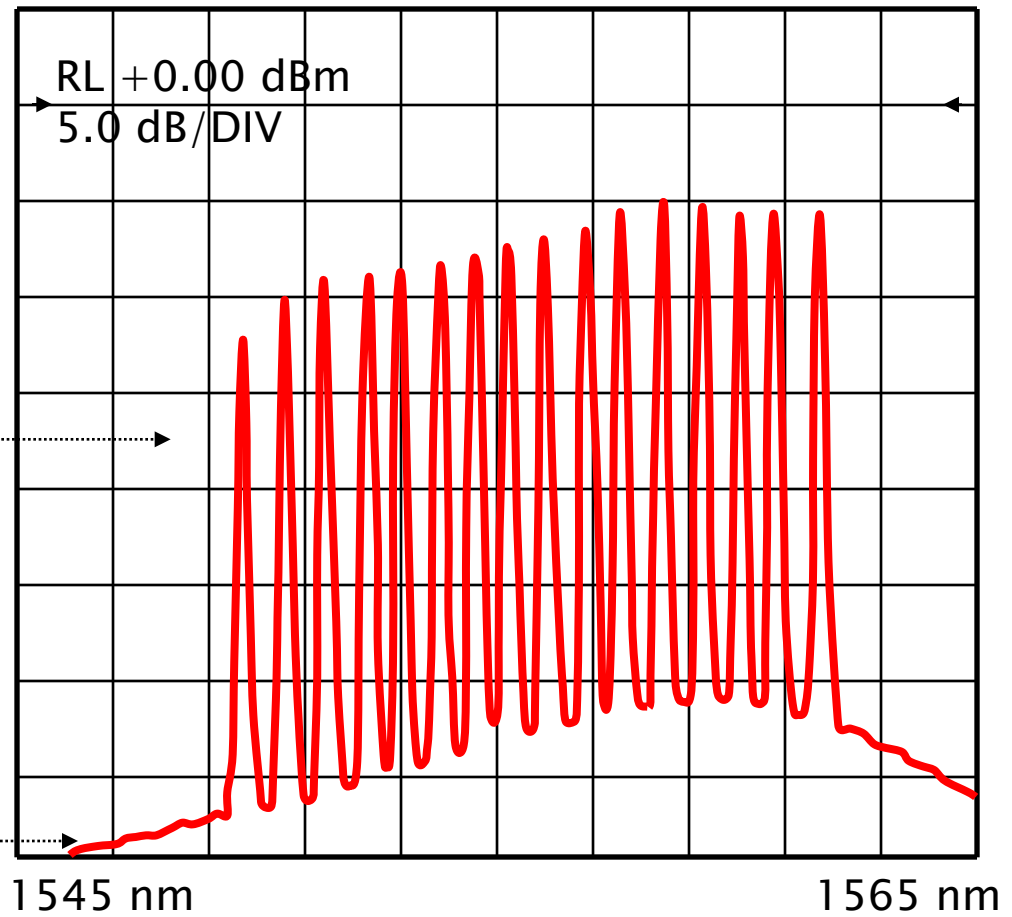
# Quantum Well Laser

- ▶ 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



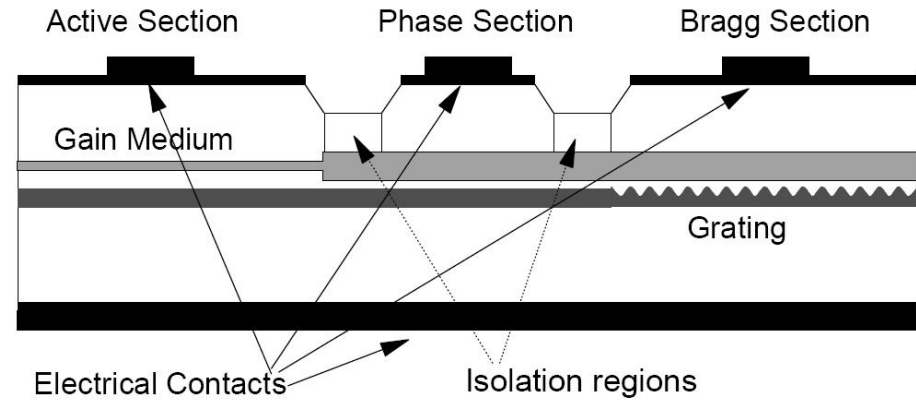
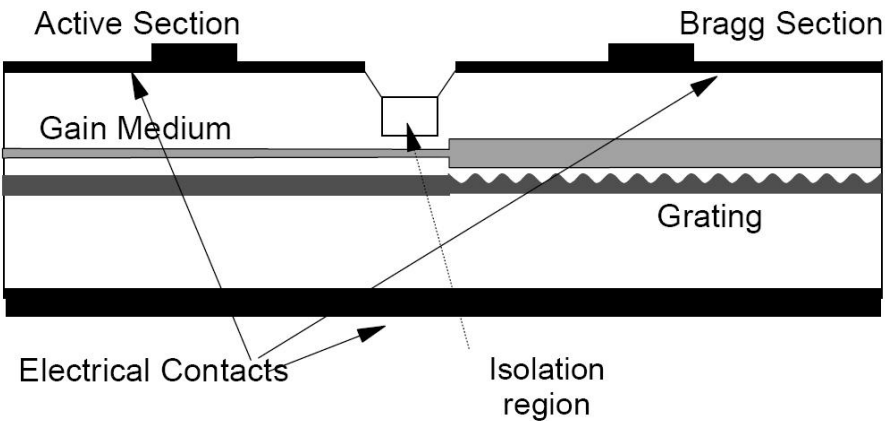
# Diode laser reglabile

## ▶ Necesitate

- In sistemele WDM exista necesitatea (in propuneri pentru arhitecturi viitoare de retele) pentru reglaj foarte rapid al lungimii de unda pe un anumit 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  $\mu$ s
- reglarea emitatorilor individuali in sistemele WDM
  - lipsa necesitatii controlului strict la productia diodelor
  - degradarea lungimii de unda in timp



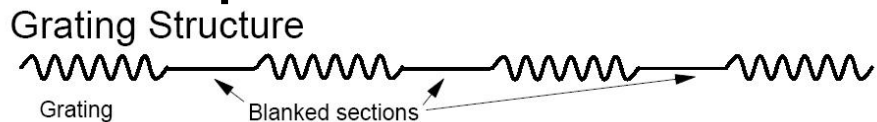
# Diode laser reglabile



- ▶ 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

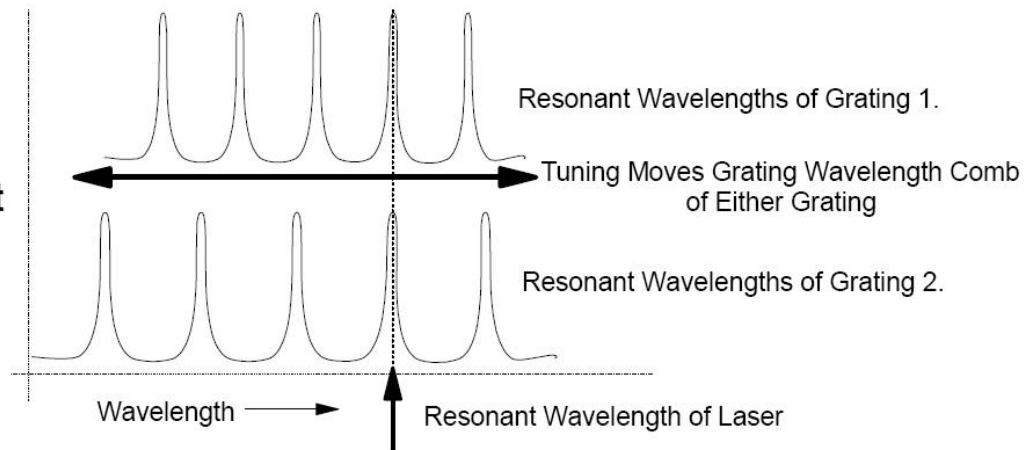
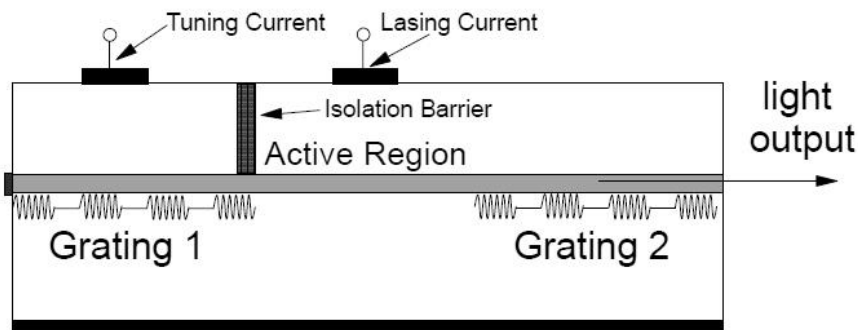
# Diode laser reglabile

- ▶ Dezavantajul metodelor anterioare e dat de limita redusa a reglajului ( $\sim 10\text{nm}$ )
- ▶ Reflectorul Bragg esantionat (periodic) produce spectru de filtrare discret

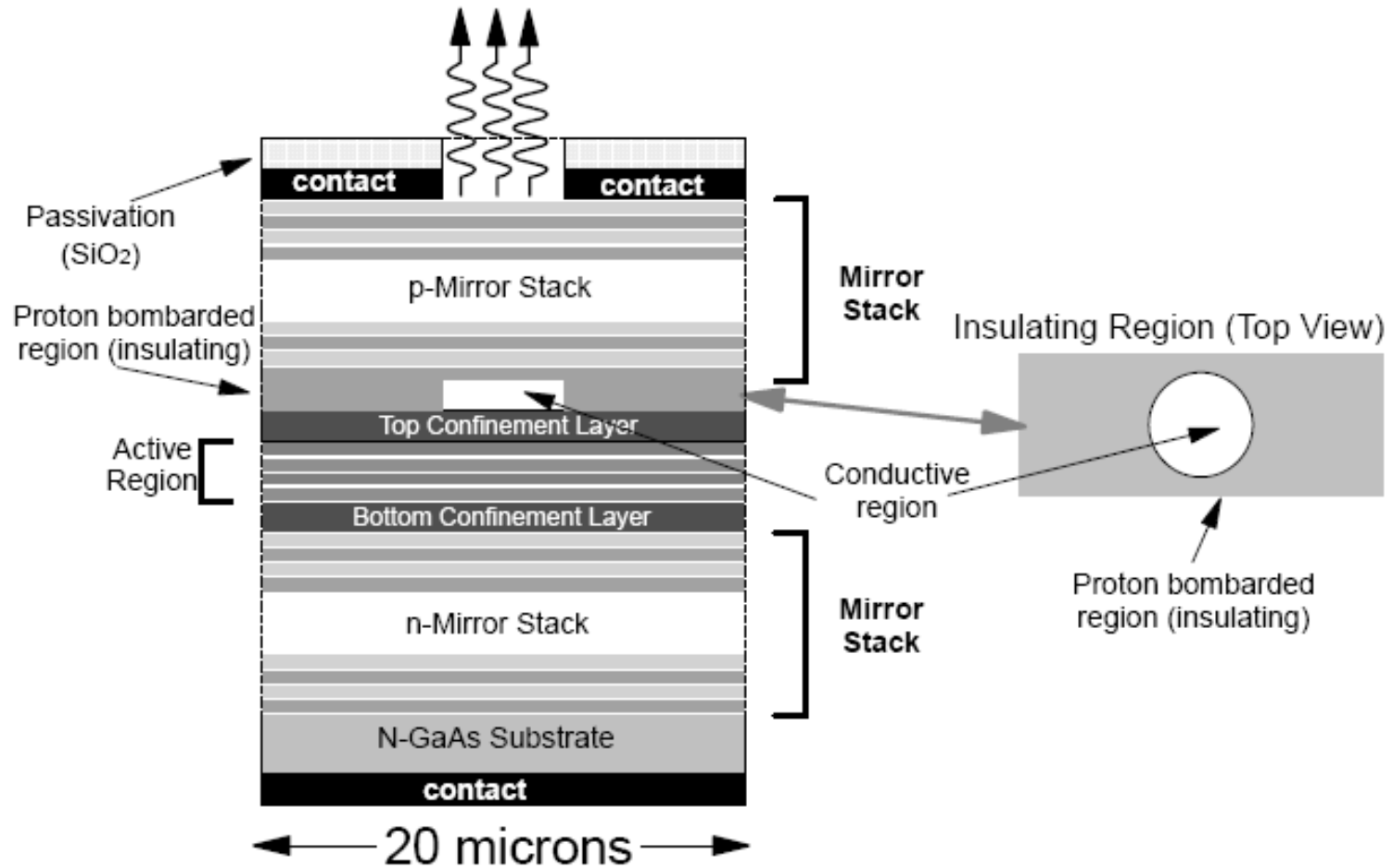


Dezavantaj :  
reglajul e discret

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

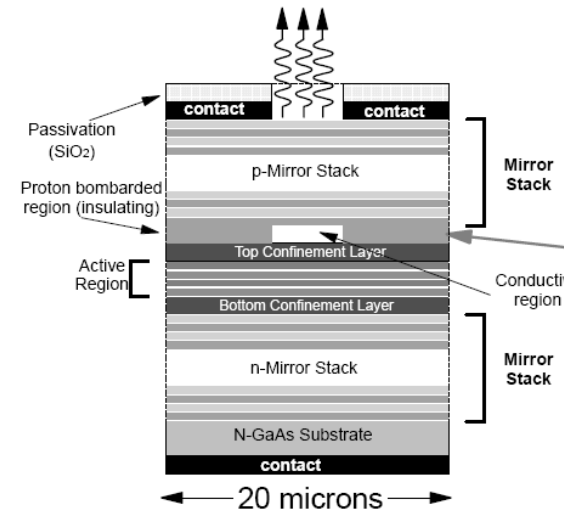


# Vertical Cavity Surface Emitting Lasers (VCSEL)



# 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



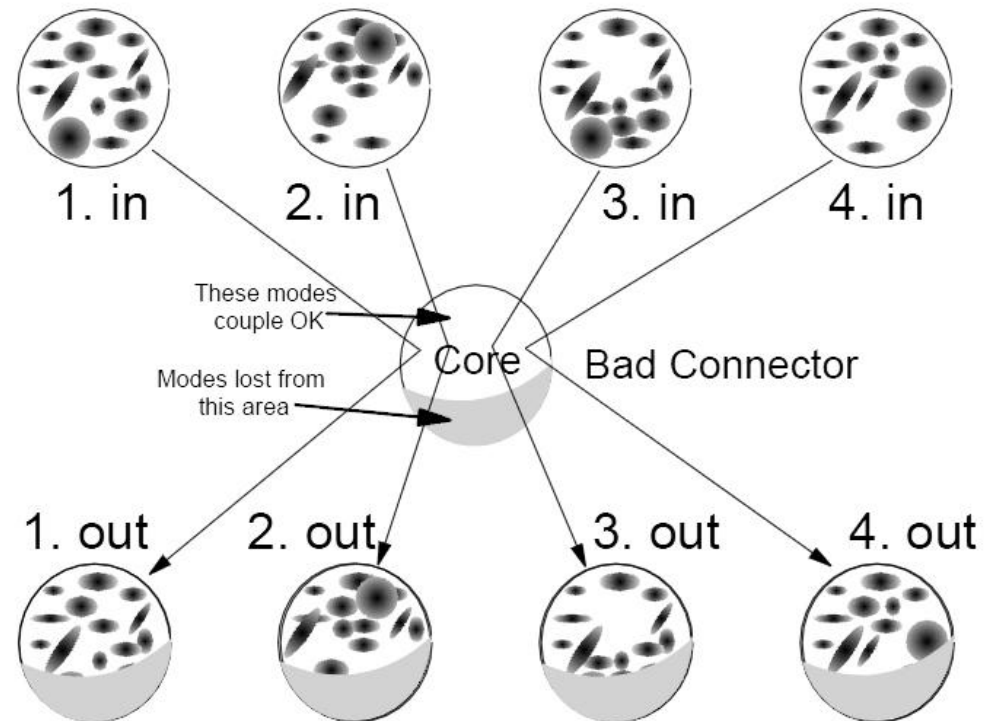
- ▶ Caracteristici

- ▶ 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

# Dependenta de temperatura

- ▶ Dependenta de temperatura a curentului de prag este exponentiala

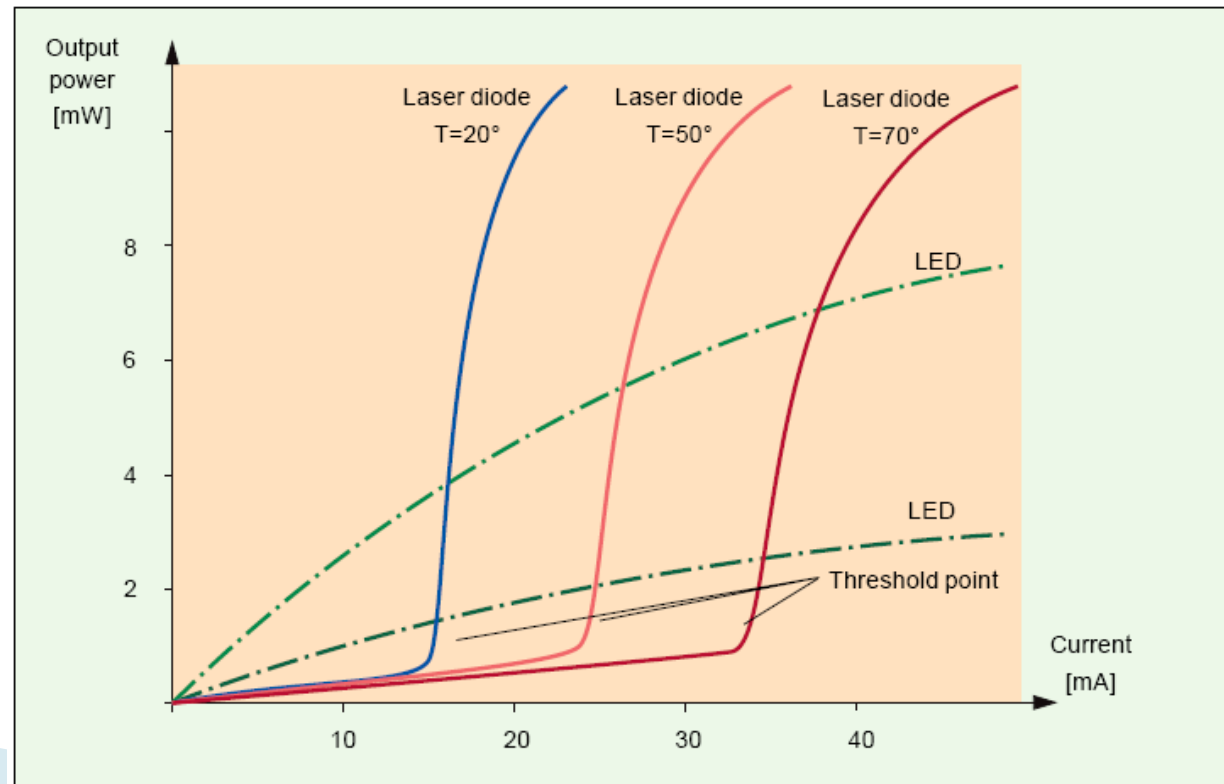
- ▶ 
$$I_{th} = I_0 \cdot e^{T/T_0}$$

- ▶  $I_0$  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





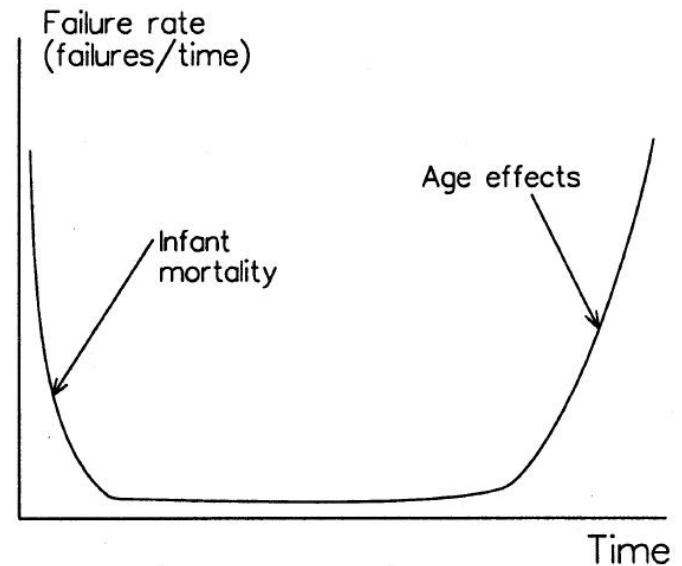
# Degradare in timp

- ▶ Puterea scade in timp exponential

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

- ▶  $\tau_m$  – 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

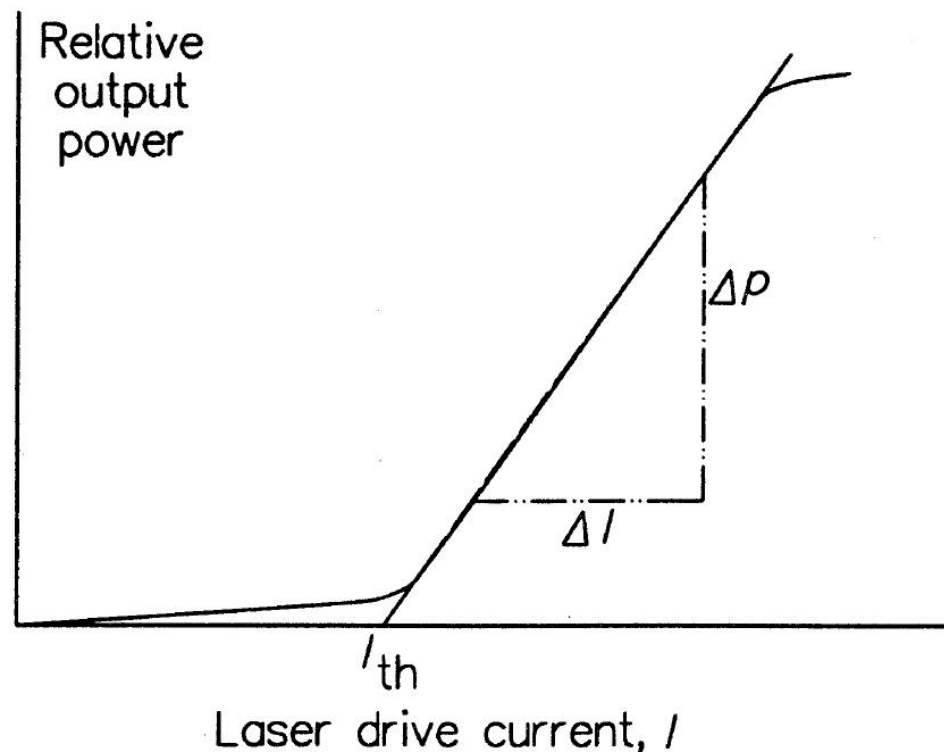
$I < I_{th}$  regim LED

ineficient!

$I > I_{th}$  regim LASER

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

Apare saturare la nivele mari de curent



# Eficienta

- ▶ eficienta de conversie electro-optic (randament)

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

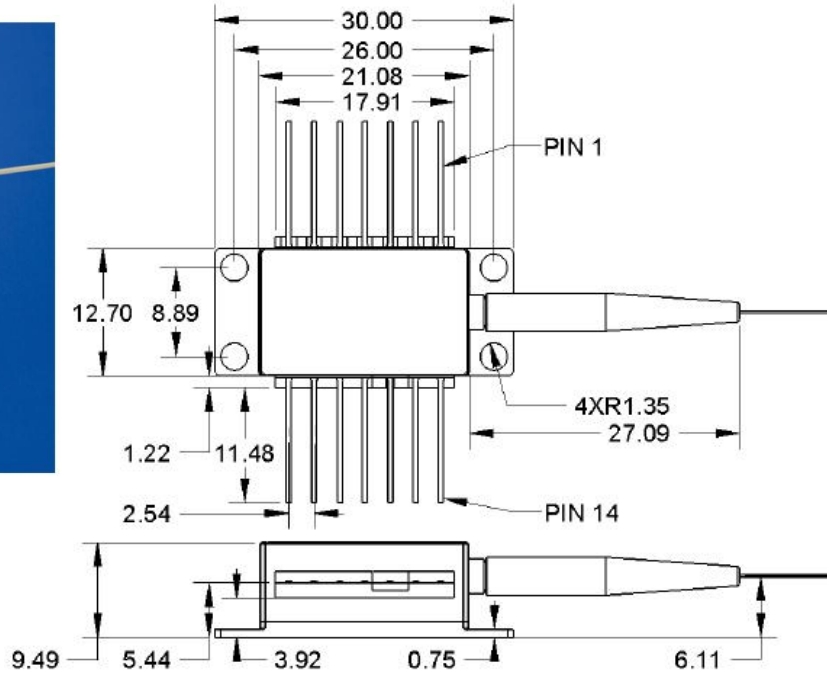
- ▶ tipic, randamente sub 10% sunt intalnite
- ▶ eficienta cuantica

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

# 1550nm DFB Laser

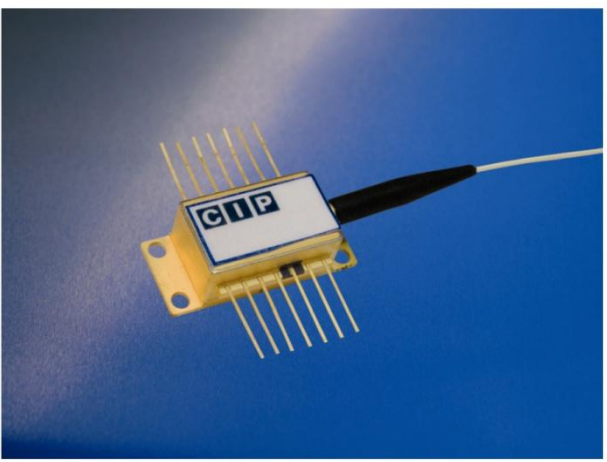
## Mechanical Drawing

All units in mm

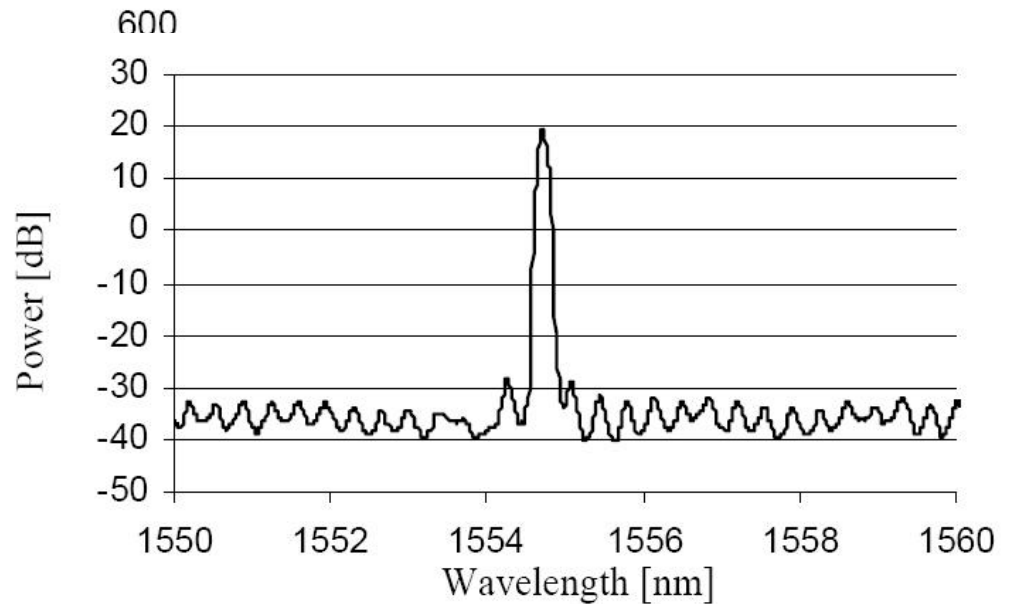
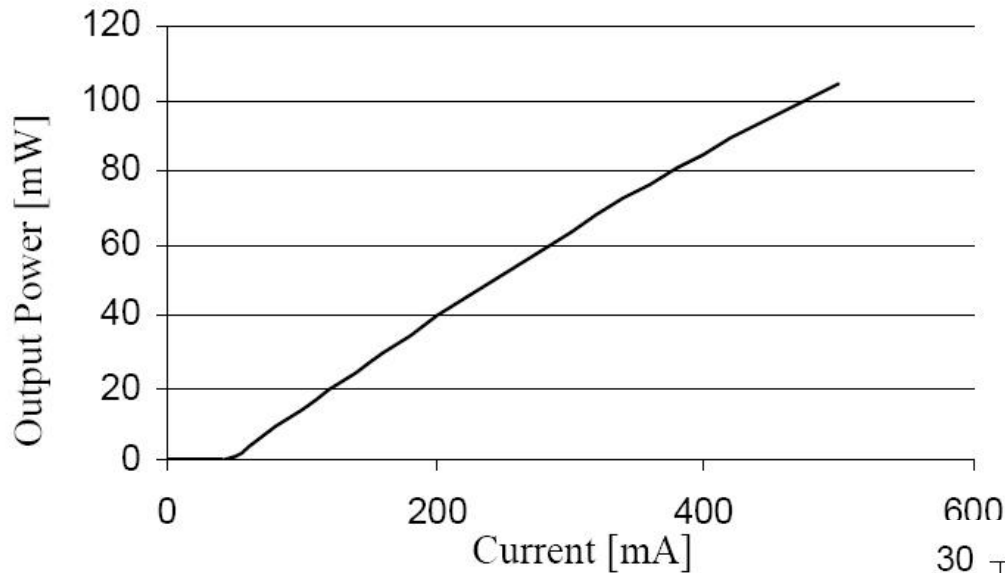


## Pin out

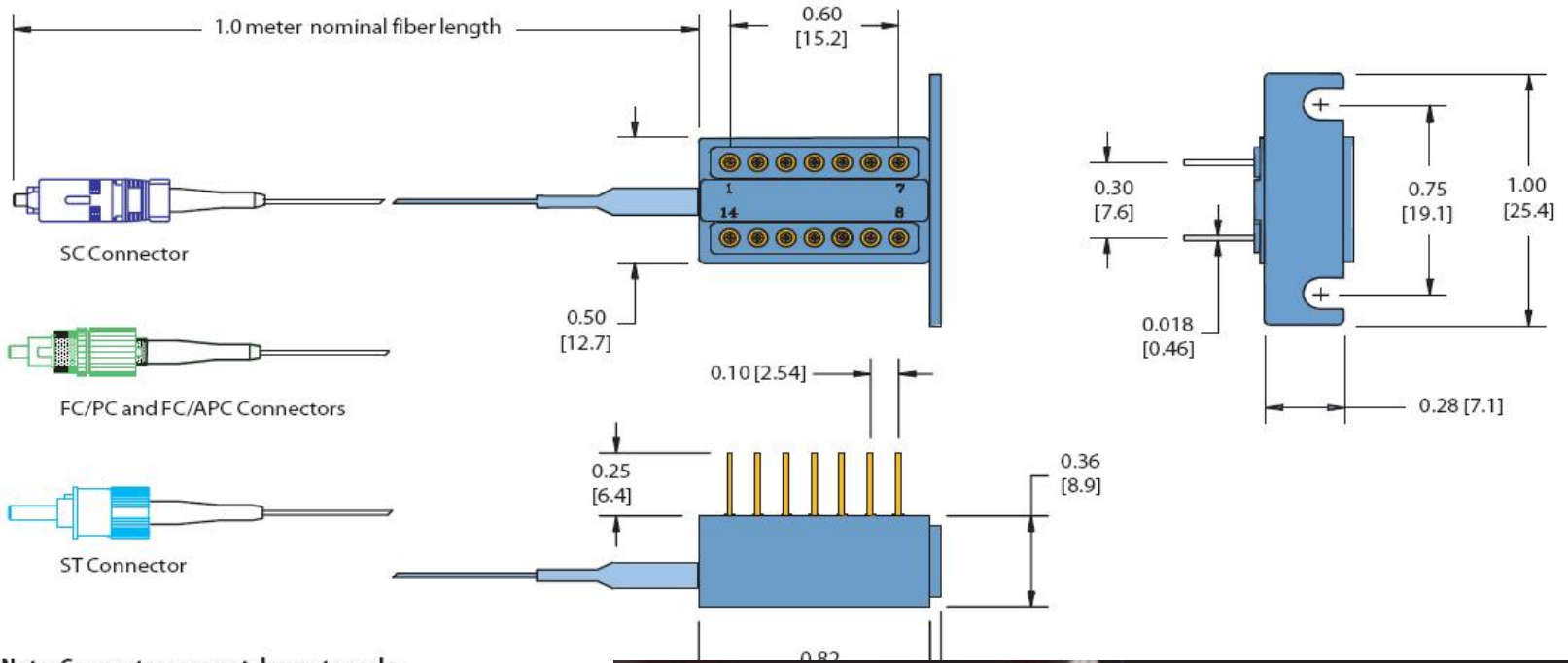
Pin	Description
1	Thermistor
2	Thermistor
3	Laser Cathode (Bias)
4	Monitor PD Anode
5	Monitor PD Cathode
6	TEC +
7	TEC -
8	Case GND, Laser Anode
9	Case GND, Laser Anode
10	Case GND, Laser Anode
11	Case GND, Laser Anode
12	Laser Cathode (modulation)
13	Case GND, Laser Anode
14	Case GND, Laser Anode



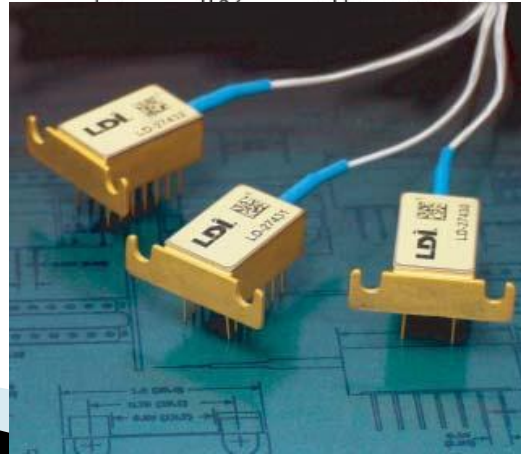
# 1550nm DFB Laser



# 1550nm MQW Laser

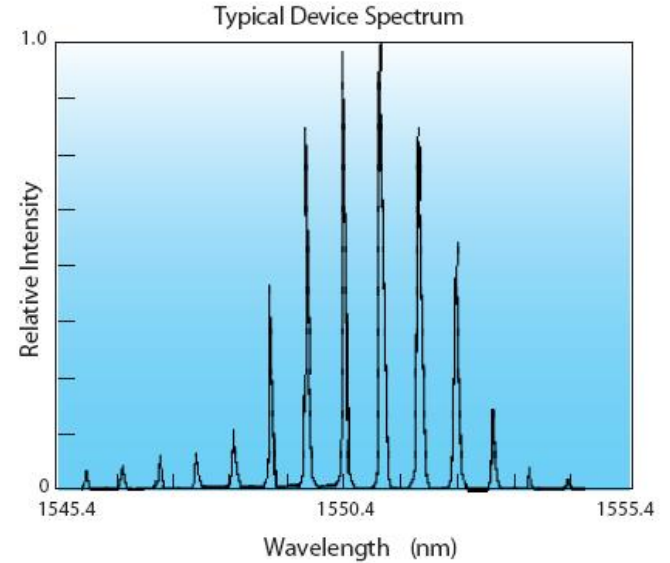
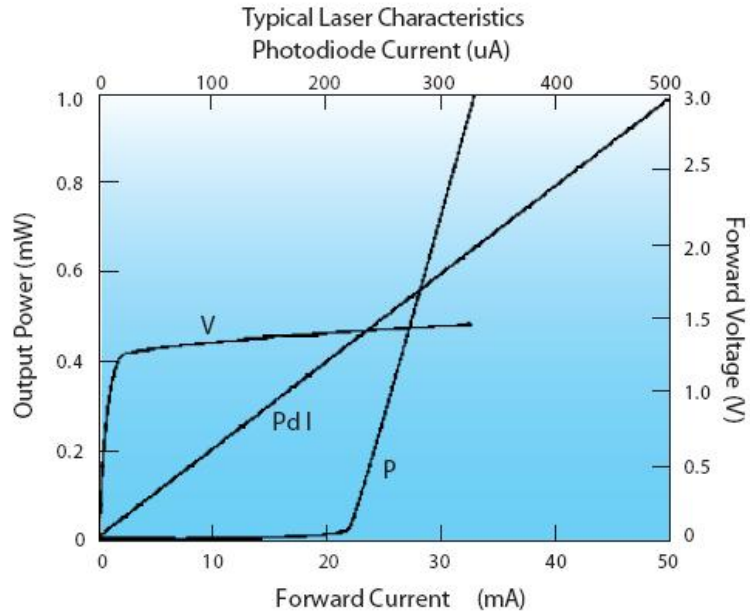


Note: Connectors are not drawn to scale.



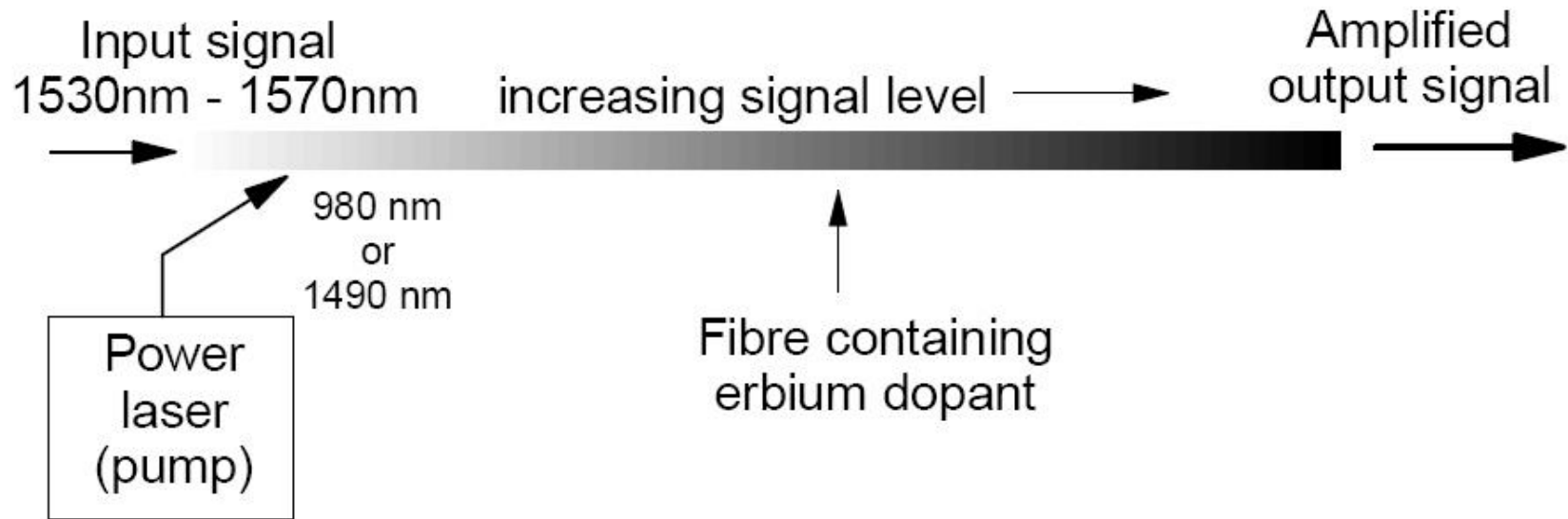


# 1550nm MQW Laser

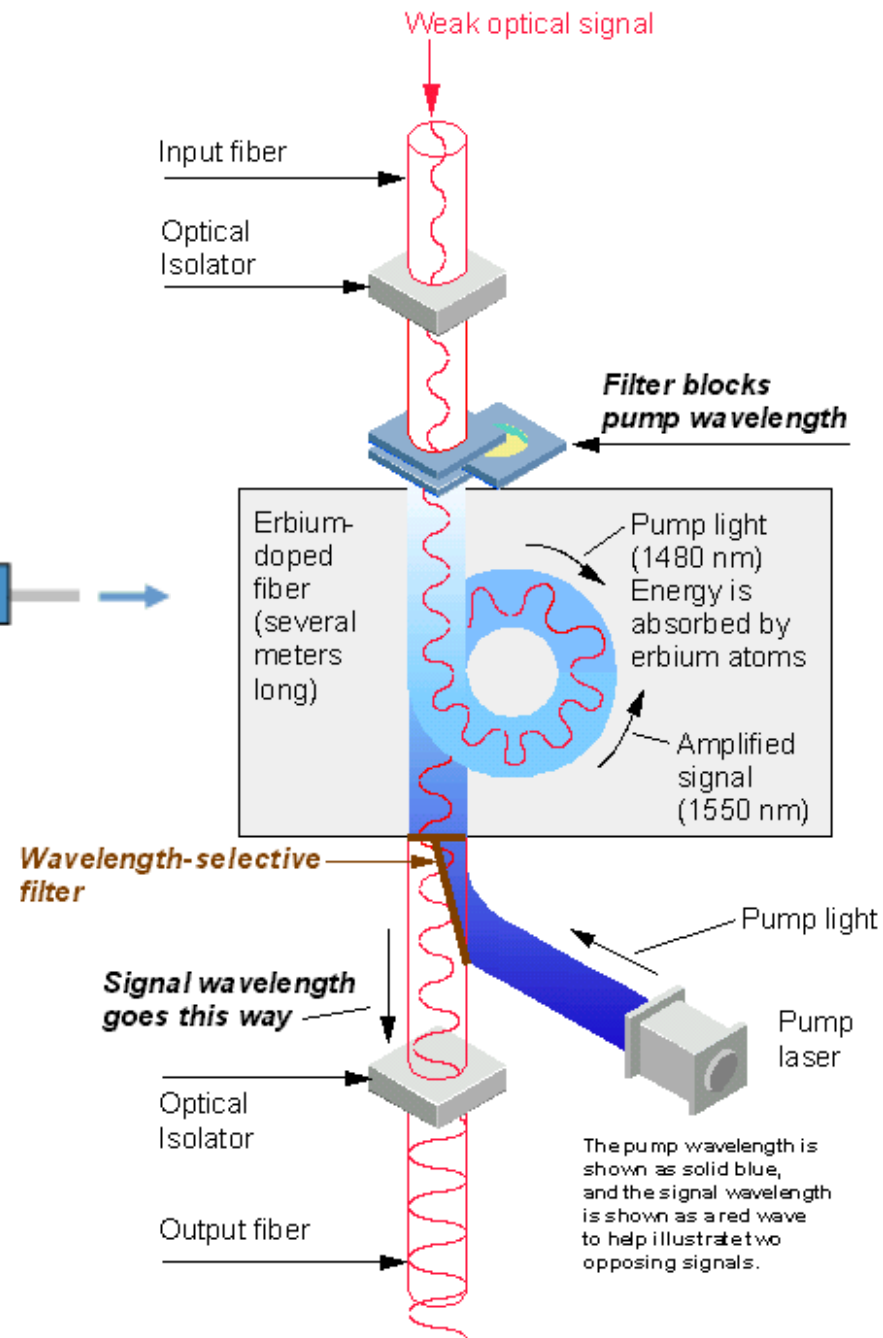
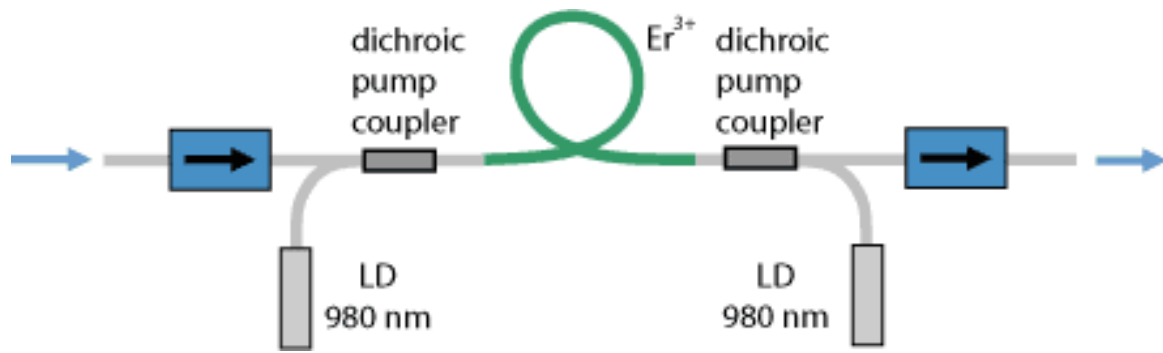


# EDFA

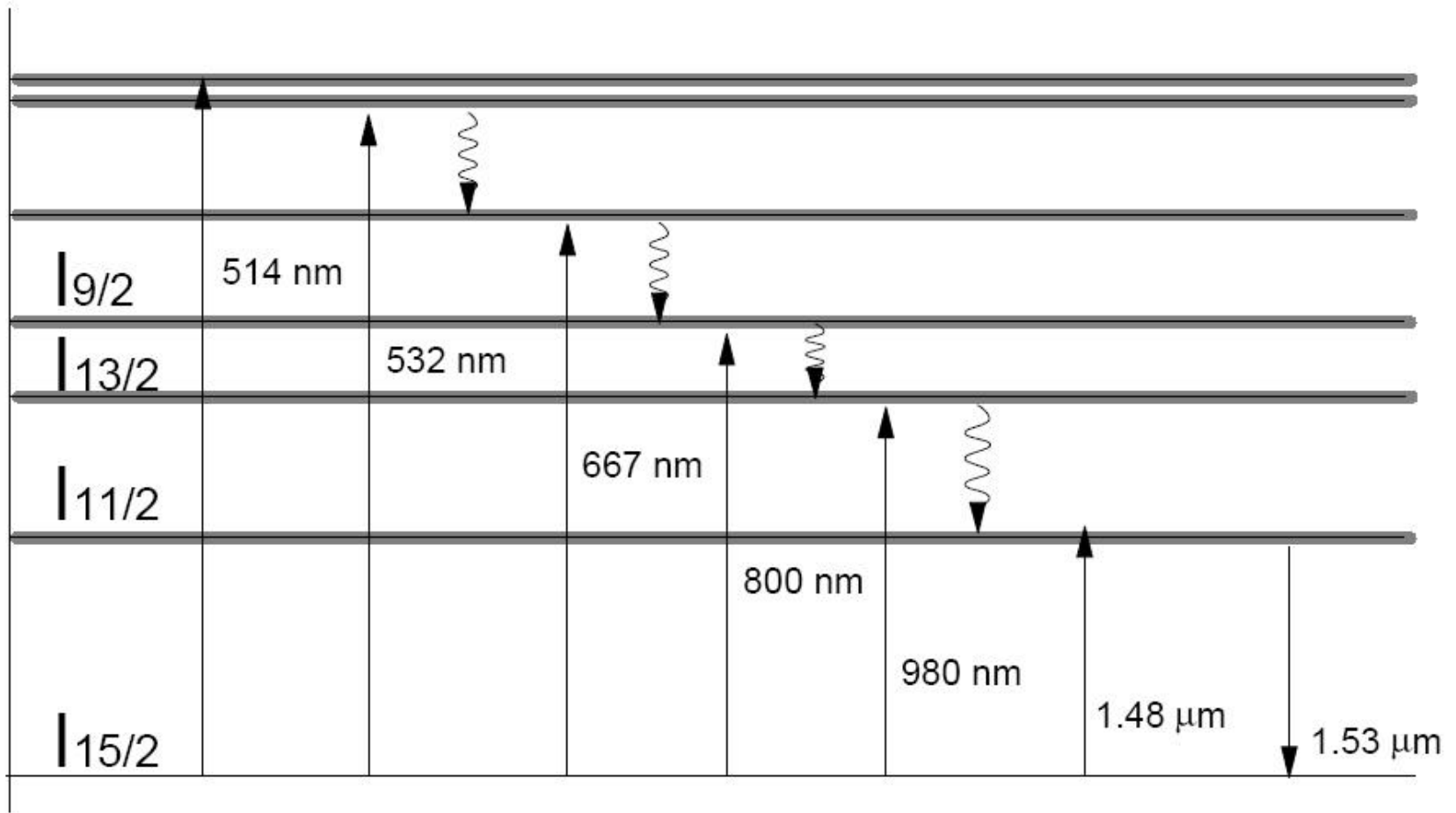
## ▶ Erbium Doped Fiber Amplifier



# EDFA

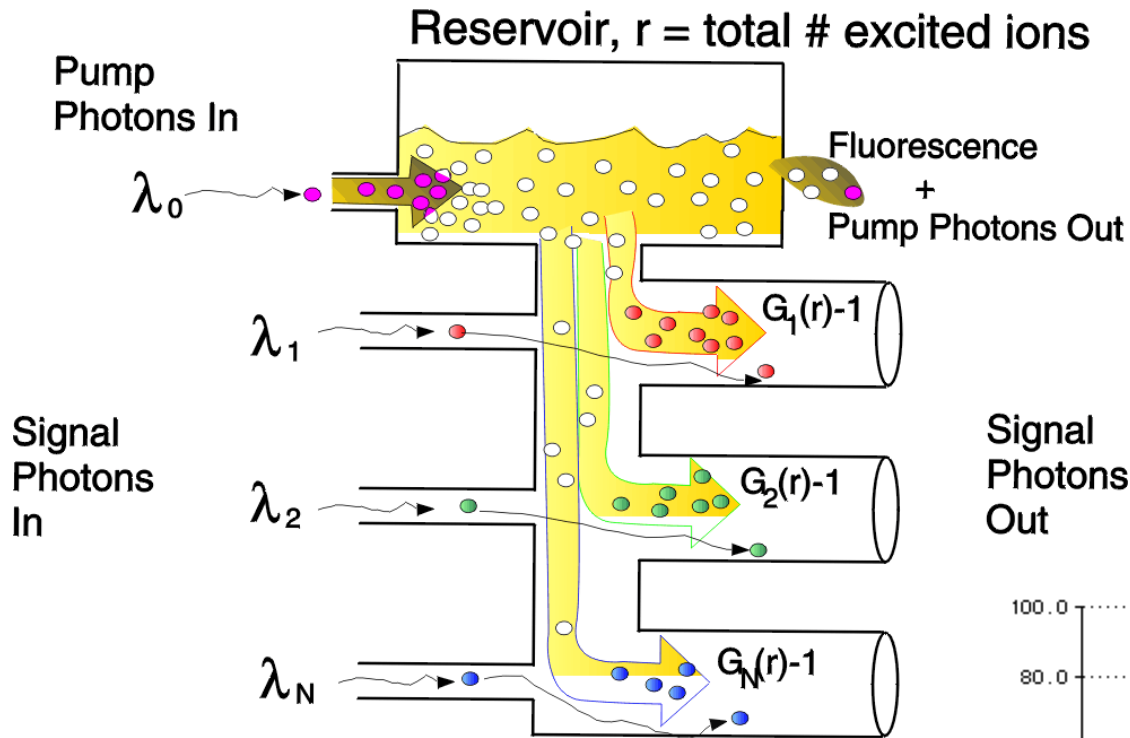


# EDFA

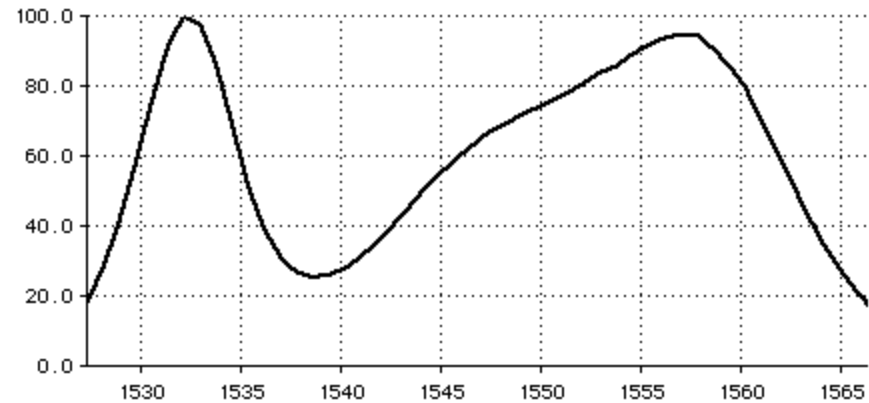


# EDFA

## How to think of an EDFA

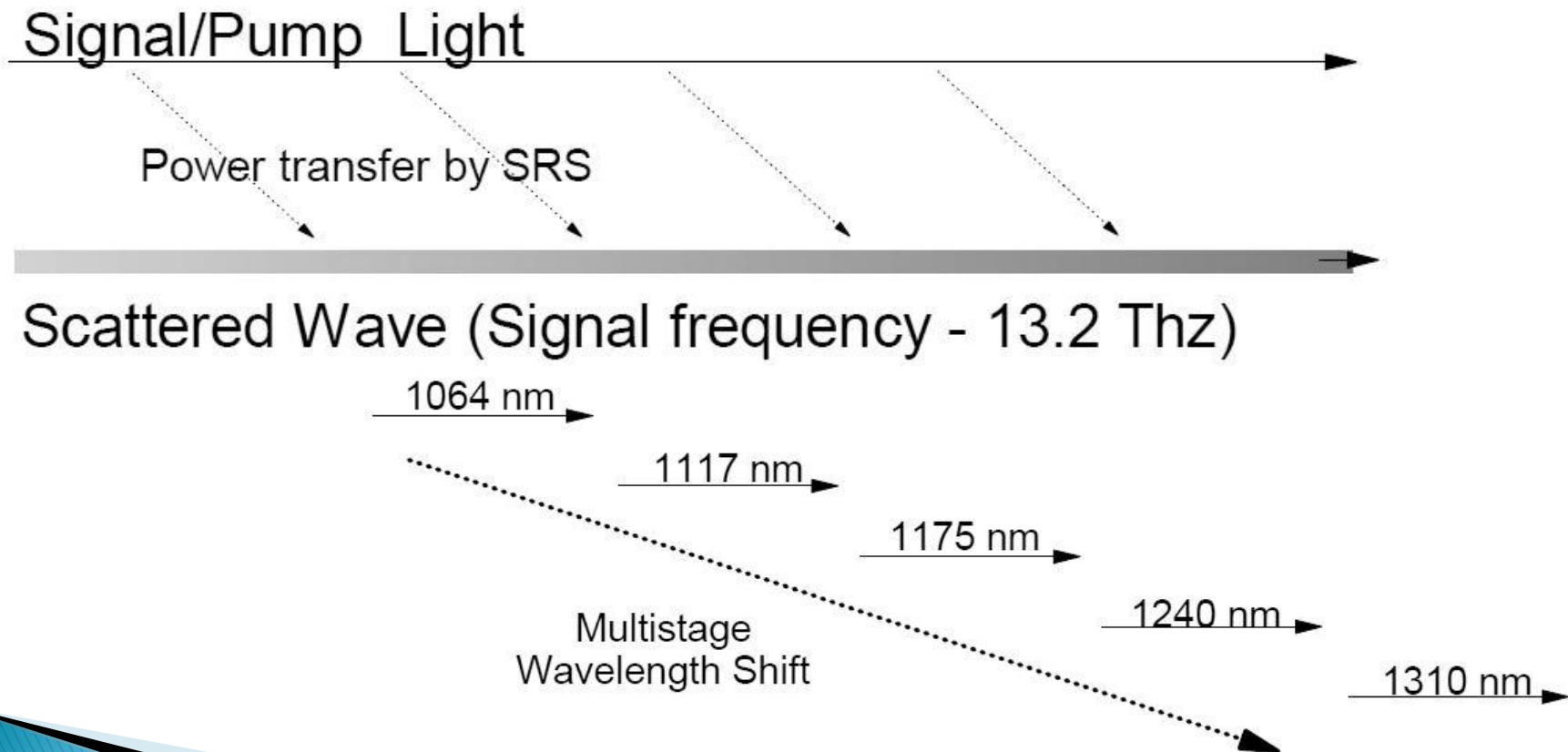


Signal Photons Out

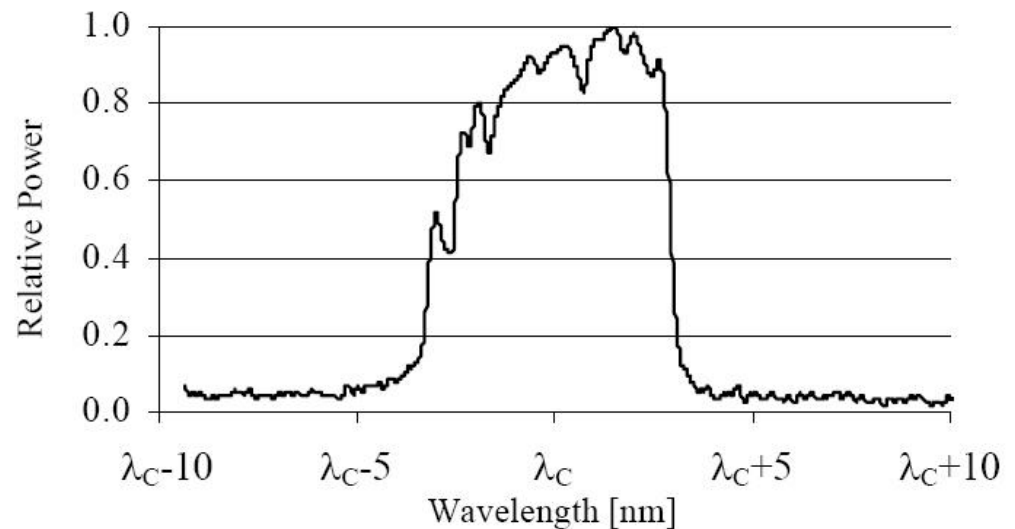
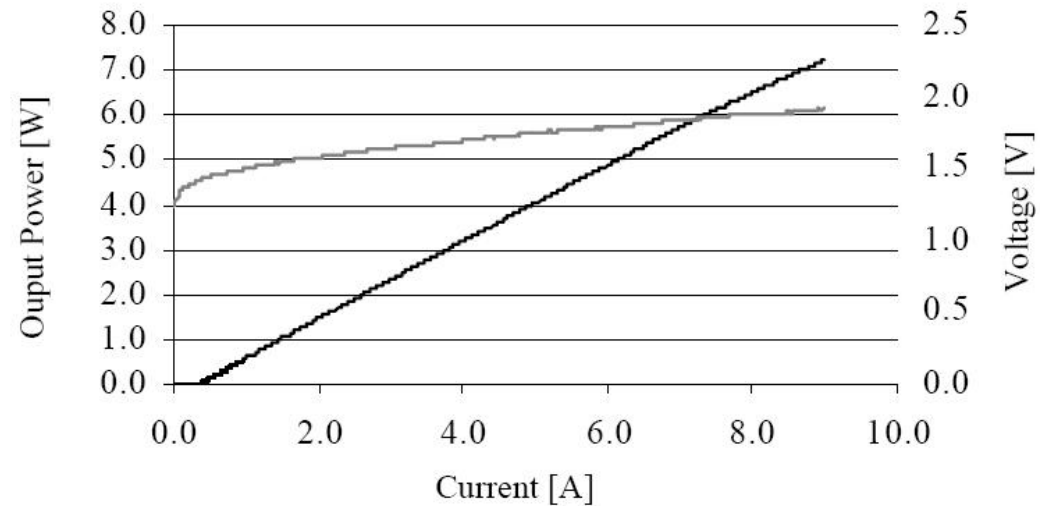
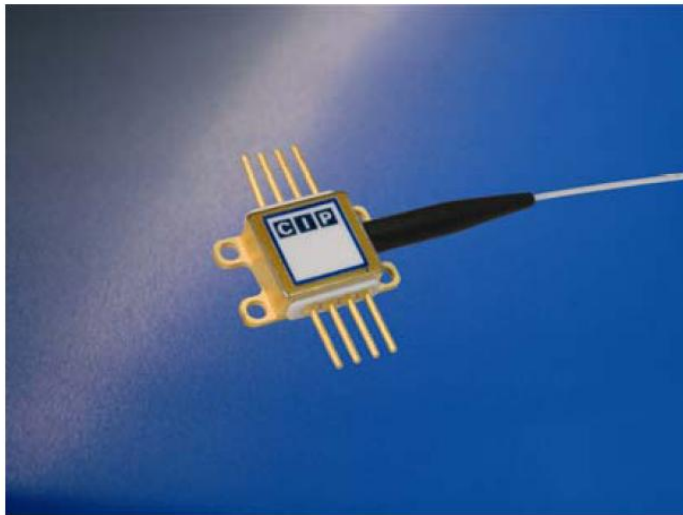


# Amplificator cu efect Raman

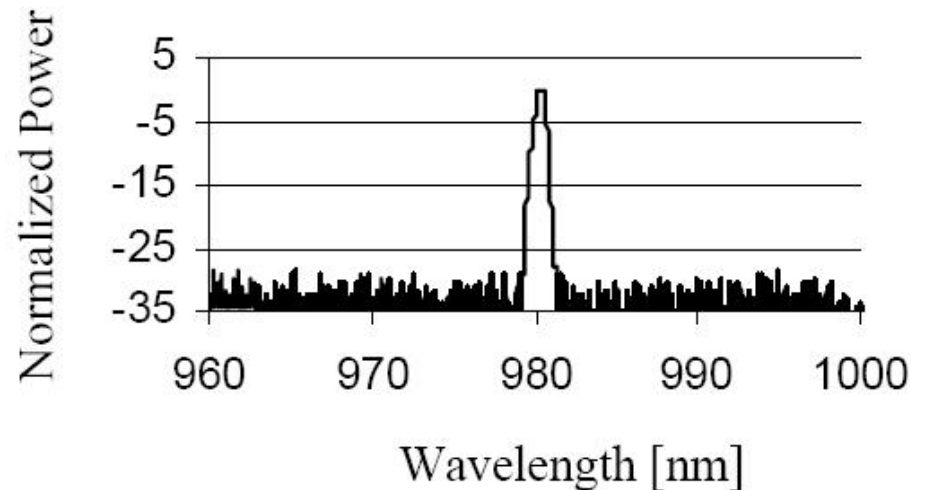
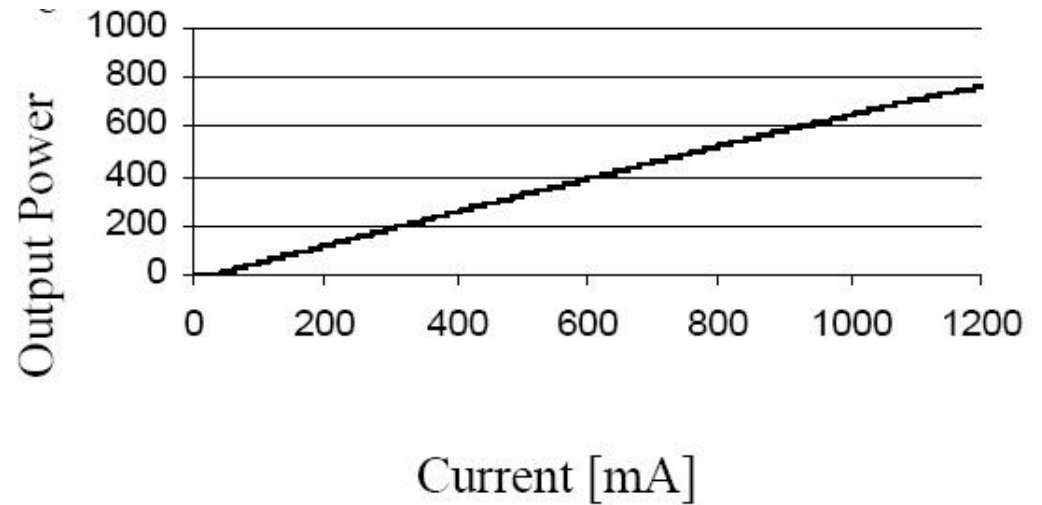
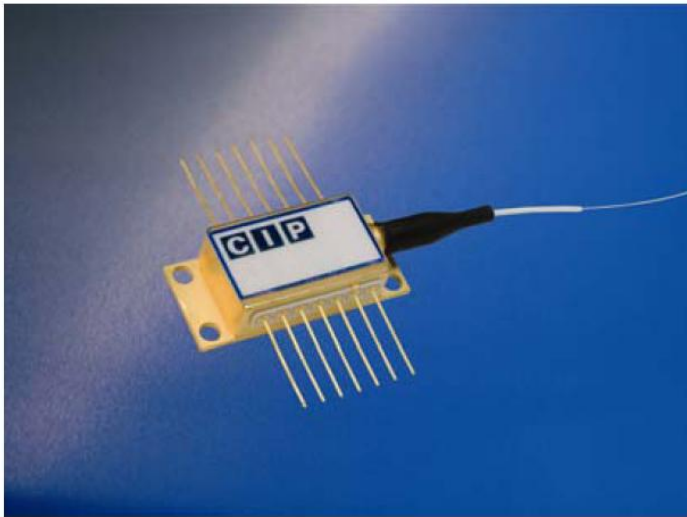
- ▶ Bazat pe efect Raman



# 7W 980 nm Multimode Pump Laser



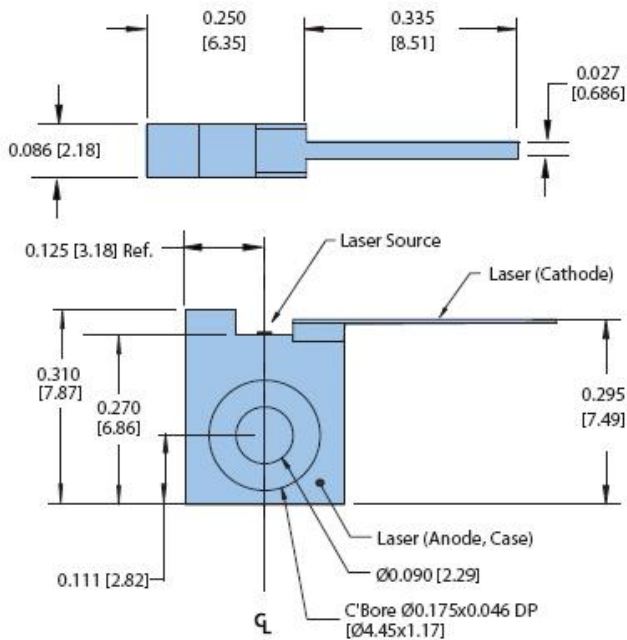
# 600mW 980 nm Singlemode Pump Laser



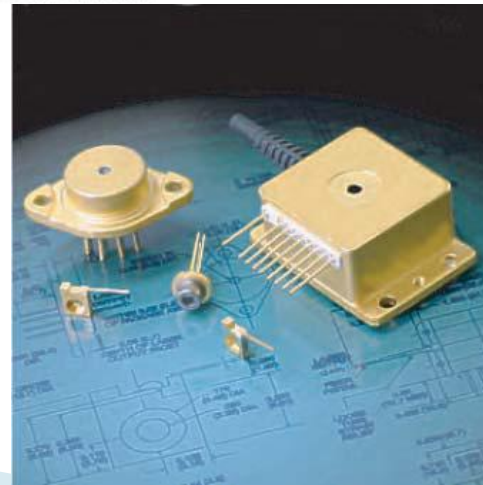
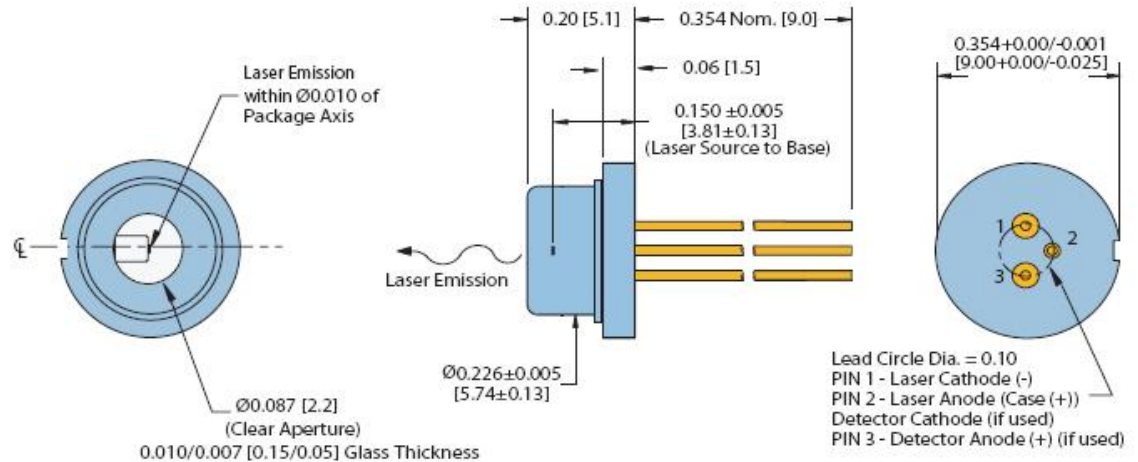


# 6 W, CW, 800nm

## C-Mount Package

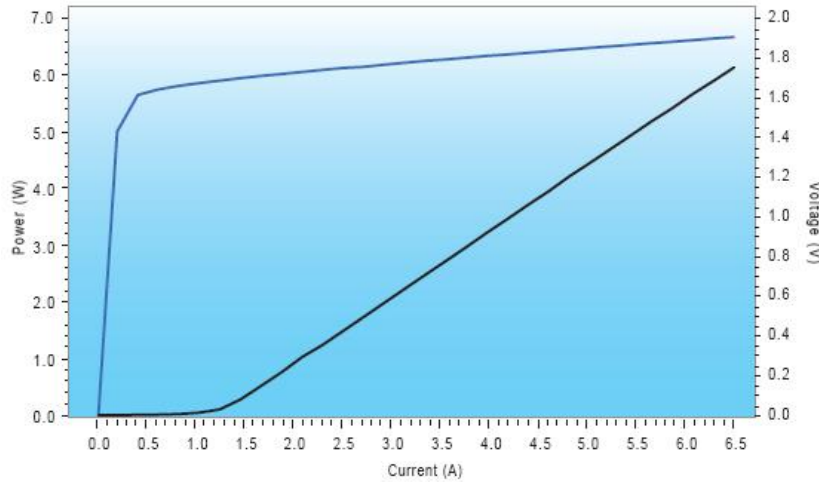


## 9mm Package

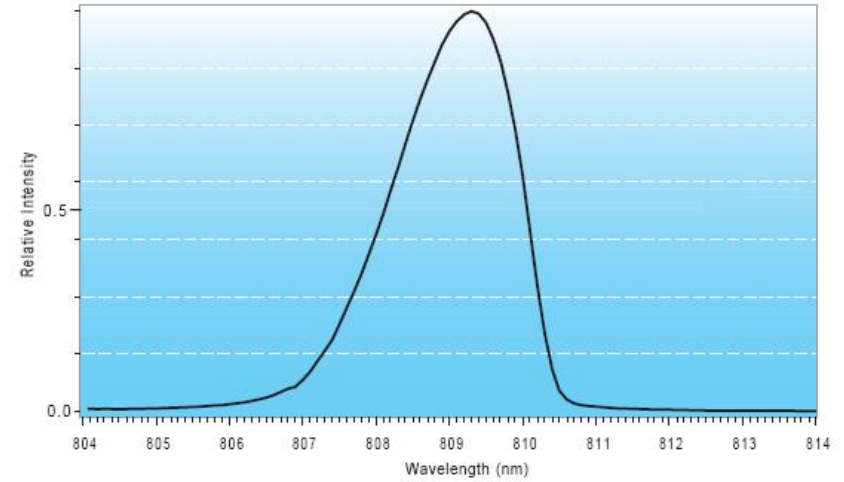


# 6 W, CW, 800nm

## Typical L/I, V/I Graph

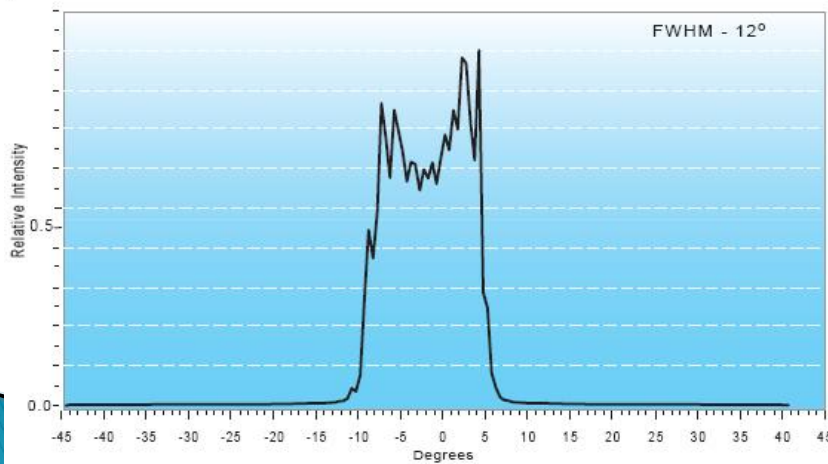


## Wavelength Distribution



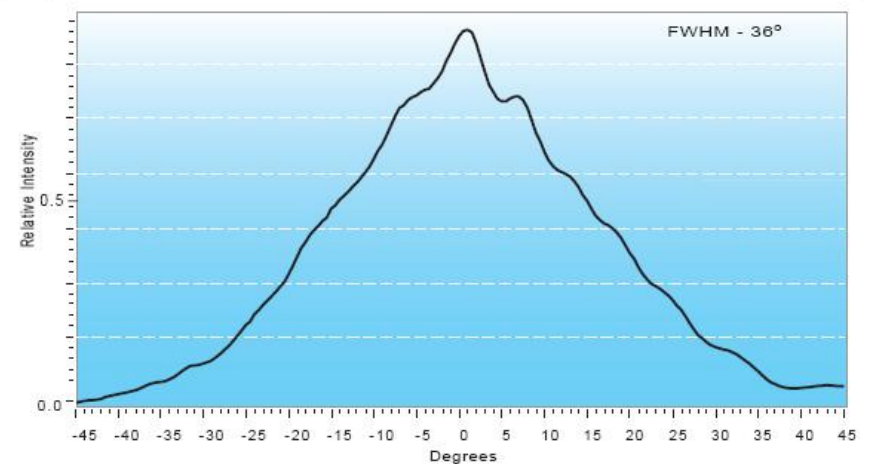
## Typical Beam Divergence

Parallel

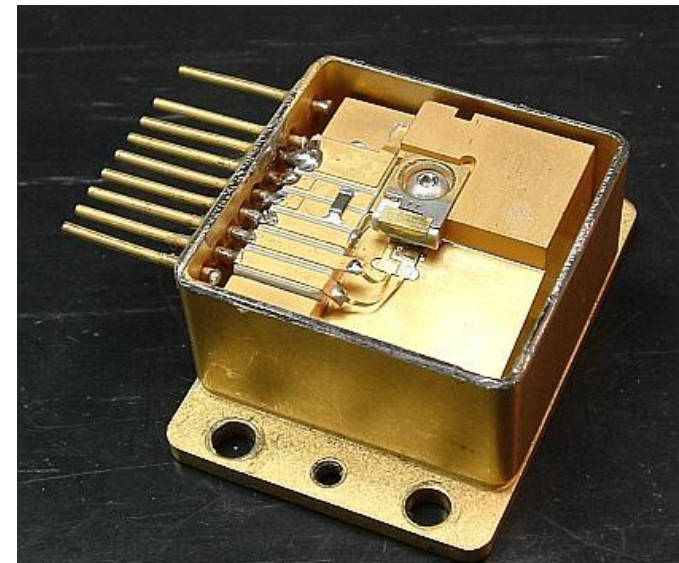
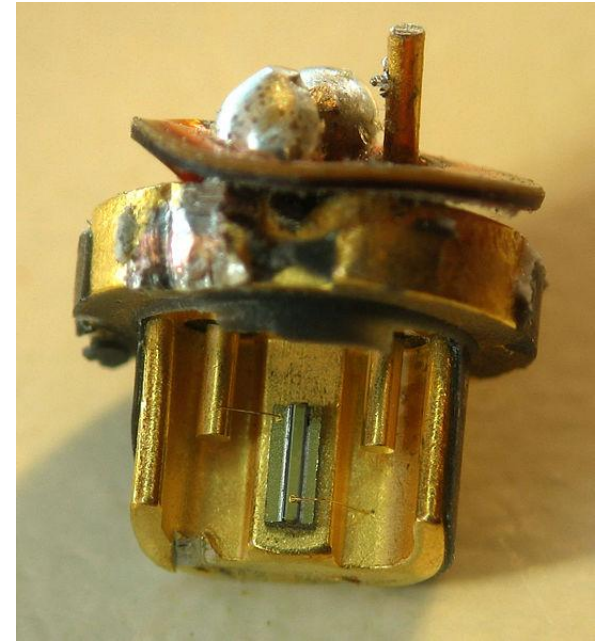
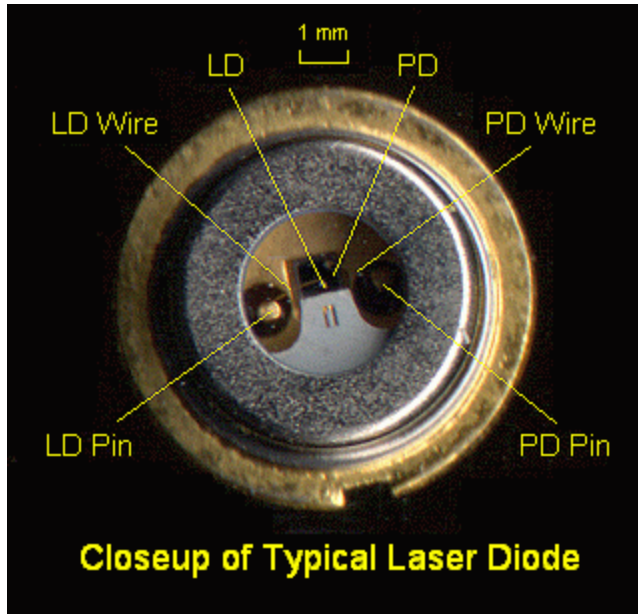


## Typical Beam Divergence

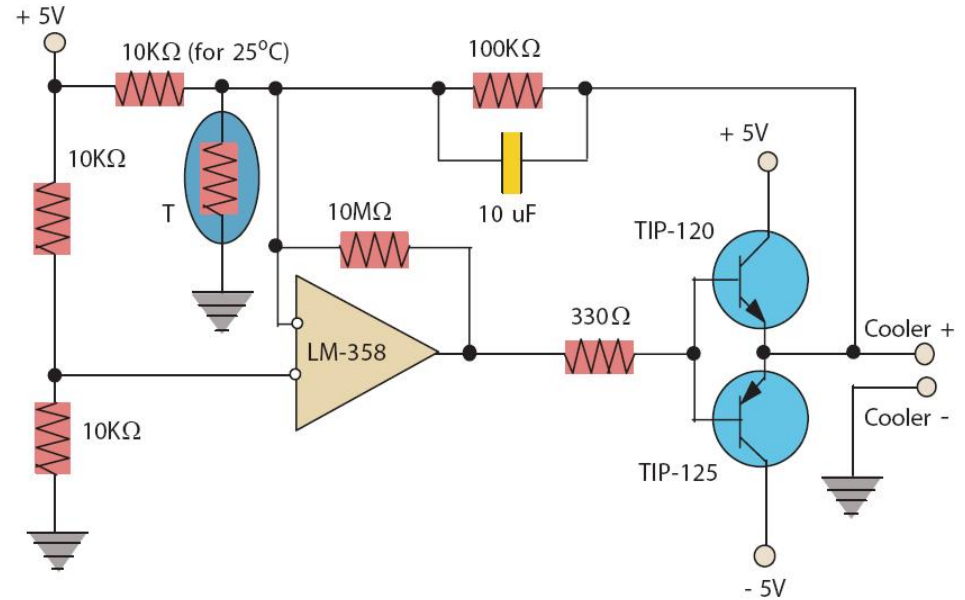
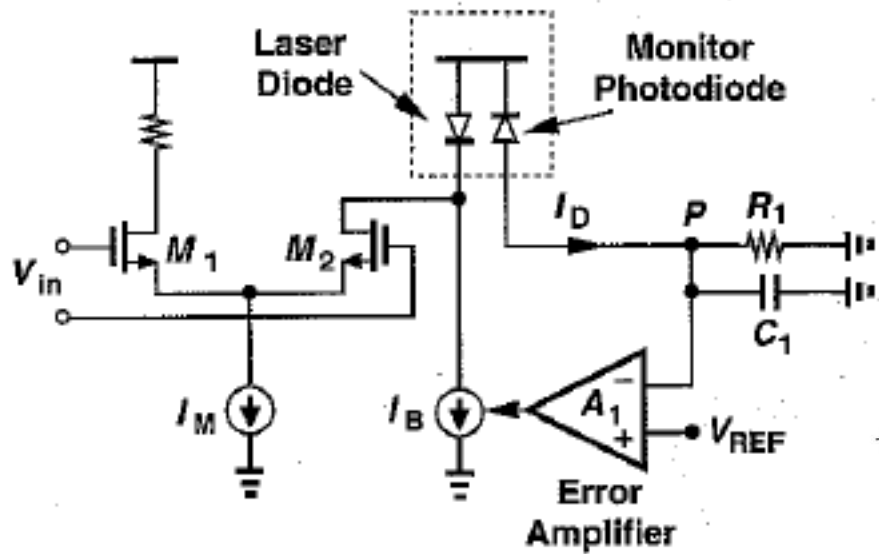
Perpendicular



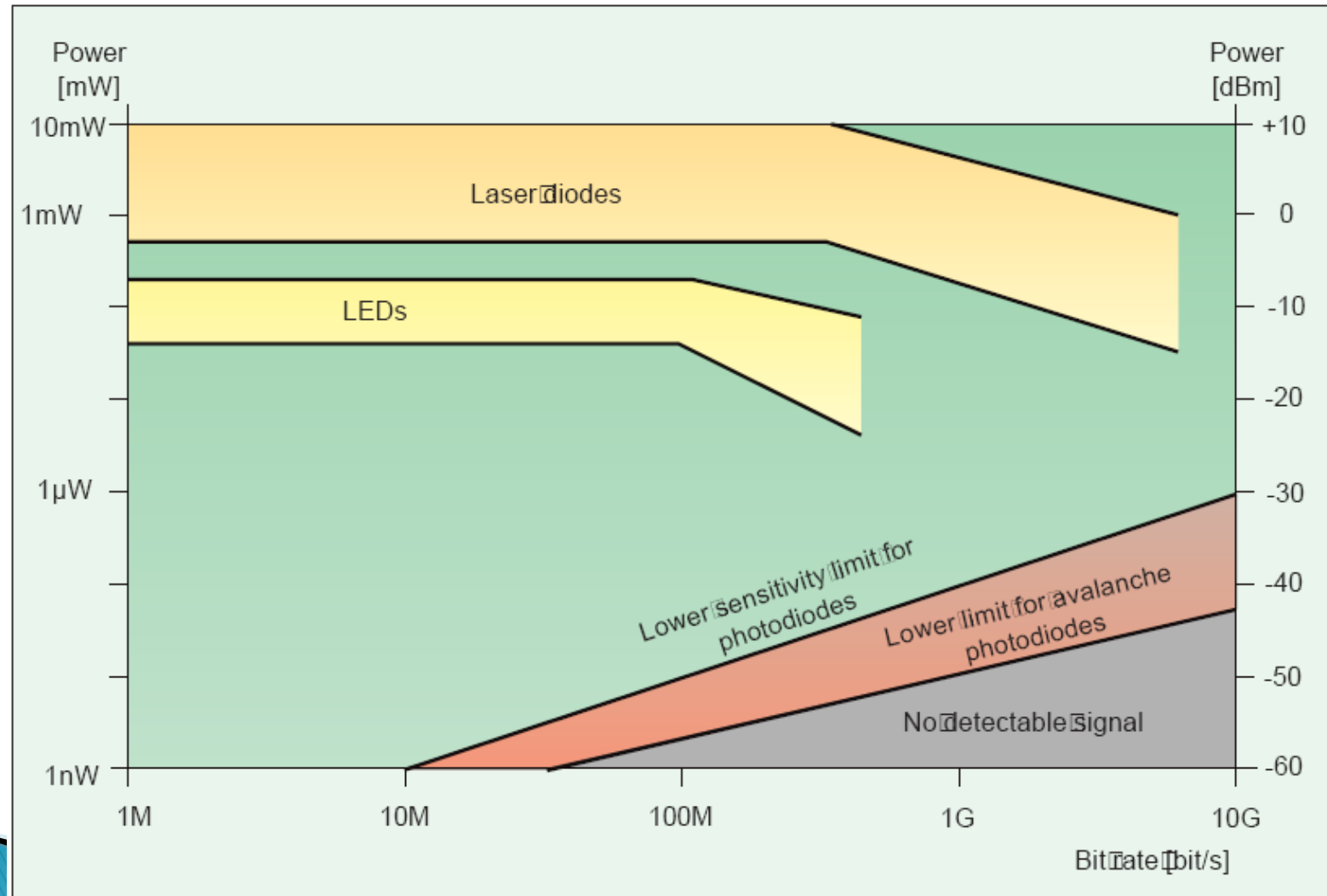
# CW Laser, 650 nm



# Control dioda LASER



# Limite putere/bandă a dispozitivelor optoelectronice



# Contact

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